BOTTOM-UP CONNECTIVITY STRATEGIES:

Community-led small-scale telecommunication infrastructure networks in the global South

Research conducted by
Nicola J. Bidwell and Michael Jensen

"Connecting people in poverty is predominantly a matter of affordability, but the business-as-usual approach – setting prices to recover infrastructure investment – will never be affordable for the poorest in society."
Pathways for Prosperity Commission[1]

1. Pathways for Prosperity Commission on Technology and Inclusive Development. (2018). *Digital Lives: Meaningful Connections for the Next 3 Billion*. https://pathwayscommission.bsg.ox.ac.uk/sites/default/files/2018-10/digital-lives-report-180928-final-web.pdf

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Any errors or omissions remain, of course, the responsibility of the authors alone.

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SECTION 1. SUMMARY

Nicola J. Bidwell and Michael Jensen

INTRODUCTION

There is increasing concern over the worldwide slowdown in the growth of voice and internet users.[2] The networks being deployed by national operators are now only expected to connect 60% to 70% of the world's population by 2025. This indicates that the UN Sustainable Development Goals (SDGs),[3] which anticipate attaining universal connectivity by 2030, are unlikely to be achieved.

Despite decades of deployment, it appears increasingly likely that current strategies will not be able to address the needs of billions of people in developing countries who have ineffective communication services due to limited coverage or lack of affordable services. Fortunately, however, network equipment continues to become more affordable and easier to deploy, resulting in increasing numbers of networks emerging where community members build and operate their own telecommunication infrastructure, often managed on a cost-recovery basis, rather than for commercial gain.

Although there is no commonly accepted definition, these networks are usually called "community networks" because local communities are involved in some way in deploying, owning and operating the physical infrastructure that supports voice or internet connectivity. Many APC member organisations have recently become active in supporting these types of networks. This trend has strong parallels with APC's birth as an organisation almost 30 years ago, when it emerged in response to similar needs to build local internet infrastructure, prior to the development of the "commercial internet" that most people use today.

Nationwide commercial services owned by private operators have up until recently been seen as the only effective means of addressing needs for connectivity. However, although this strategy is now coming under scrutiny, most governments are not yet aware of the potential impact of independent small-scale community-based networks. As a result, these networks are still relatively scarce, or invisible, because regulatory environments are generally hostile to them and are not yet adapted to foster their growth and replication. Aside from the absence of enabling regulatory environments, community networks, particularly those in the rural global South, also face other difficulties. Financial resources for their initial deployment are often very limited and there are other factors such as lack of affordable or reliable energy supply, and high costs for backhaul connectivity.

Yet, despite these difficulties and their lack of visibility, community networks also appear to have many advantages over traditional large-scale commercial networks, including:

- More local control over how the network is used and the content that is provided over the network.
- Greater potential for attention to the needs of marginalised people and the specific populations of rural communities, including women and older people.
- Lower costs and retention of more funds within the community.

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2. World Wide Web Foundation. (2018, 23 October). Just released: A4AI 2018 Affordability Report. https://webfoundation.org/2018/10/a4ai-2018-affordability-report
3. https://www.undp.org/content/undp/en/home/sustainable-development-goals/goal-9-industry-innovation-and-infrastructure/targets.html

- Increased potential to foster a sense of agency and empowerment among users and those involved in the network.

To document the benefits of, and challenges facing, small-scale, community-based connectivity projects, APC researchers visited 12 rural community networks in the global South in 2018 and studied a number of others through desk research and interviews. The primary goal of the research is to provide information that can be used for evidence-based policy making that will contribute to creating a more enabling environment for small community-based local access networks. In addition, the research aimed to identify opportunities for these networks to be more effective and, hopefully, to encourage more organisations to support the development of these networks in future.

This report was part of the broader Local Access Networks[4] project that was carried out in partnership with Rhizomatica (an NGO supporting many community networks in Latin America) with financial support from the International Development Research Centre (IDRC).

RESEARCH METHODS

The research applied a multiple case methodology to scope community networks in the global South. The cases studied were selected based on criteria that aimed to provide insights about a variety of different connectivity technologies, services provided, institutional models and sustainability strategies, as well as a roughly even spread across countries in three regions of the global South – Latin America, Africa and Asia. In addition, the networks needed to have been established for a sufficient time to be able to derive useful learning from them.

The initial desk-based research identified 16 initiatives for further study, most of which had been in operation for more than two years. During 2018, in-country research visits took place, which provided a snapshot of the technical and operational aspects of cases in Argentina, Brazil, the Democratic Republic of Congo (DRC), India, Indonesia, Mexico, South Africa, Thailand and Uganda. This data was gathered by interviewing champions, managers and technicians in networks and examining documents they provided and equipment used at different sites. Three further networks, in Indonesia, Peru and the Philippines, were later examined via desk research and direct contact with individuals associated with the initiatives.

The social impact of six cases (in Argentina, India, Indonesia, Mexico, South Africa and Uganda) was studied in more detail. Over 300 people participated in interviews, observations, focus groups and other data gathering events, which accumulated over 200 hours of recorded data across 60 days. Some 90% of participants in interviews and focus groups were people who inhabit the rural areas in which community networks are deployed. Many of the interviews relied on translation from local languages which included Hindi, Marathi, Luo and Nilotic dialects, Mexican and Argentinian Spanish, isiXhosa, and central Javanese. In most countries participants lived in close proximity, in the same or nearby villages or very small rural towns; however, in Uganda and India, participants came

4. https://www.apc.org/en/project/local-access-networks-can-unconnected-connect-themselves

from villages that were farther apart. Participants' identities have been anonymised to the extent that is possible, and all data is stored securely. The social impact research sought to ensure a wide range of perspectives were represented, including many users of the networks as well as operators and managers, and additionally people in the community networks' footprint who did not use the network directly themselves. Women were actively recruited to participate in data gathering.

The social impact research produced mostly qualitative descriptions about how and why people coordinate, interact with and are affected by their local community networks. These descriptions are not statistically generalisable to entire populations of community network organisers, users and non-users. Nor should the cases be considered typical or atypical, since the cases studied are diverse, relatively few, and many are still at early stages of maturity and are rapidly evolving. Rather, the research provides portraits of some of the initiatives at the frontier in the communications revolution, situated in their specific contexts of management, access and use, and uncovers some common characteristics.

RESULTS AND CONCLUSIONS

General considerations

The cases covered in this study provide rich material on the value, motivations, potentials and constraints of rural community networks in the global South. However, it should be noted there were a number of restrictions in the scope of the research as outlined below. Some limitations were due to pragmatic issues – restricted time and resources available, or limited contact with or knowledge of some networks until after the research plan was made. There are many fertile potential areas for further research to gain more complete understandings of community networks in the global South; however, among the initial areas of most interest are likely to be:

- Mobile networks: Due to regulatory restrictions, community networks providing mobile services are still rare, although recent developments indicate that they are becoming more prevalent in some countries. The relatively high proportion of networks providing these services in the study is mainly due to the need to prioritise learning about voice services in rural areas in the global South. Also, most are quite recent deployments.
- Networks using licensed spectrum, TV white space (TVWS) and dynamic spectrum assignment technologies: Again, due to regulatory restrictions, the number of networks using these systems is few, and the potential of networks based on use of these technologies still remains largely unexplored.
- Small-scale fibre: Outside of a few urban areas, community networks deploying fibre are still virtually unknown in rural areas in the global South.
- Small-scale entrepreneur-based models: While there are many smaller commercial networks in the urban global South, our research was only able to study one example of a network operated by a local small business in a more rural area.
- Networks in more developed countries and other regions in the global South (such as Central America, North Asia, the Pacific or other island locations): These areas are not covered and may have different local conditions which need to be better

understood. Understanding of the experience of the more mature community networks in developed countries is likely to contribute to better understanding of those in southern regions.

- More recent deployments: The community networks studied were in part selected for their relative maturity. However, many more networks have emerged which may have different characteristics – for instance, taking advantage of more recent technologies, the experience of more mature networks, regulatory changes or other developments.
- Longitudinal studies: This study was originally conceived as a larger and longer research effort, but due to the limited funding available, the cases in this report were subsequently restricted to a study period of up to two weeks only. This precluded monitoring changes over time, or gathering more data about important factors. Such an abbreviated study cannot portray features of networks that are typified by highly emergent qualities that develop out of community life. The research analysis would be considerably strengthened by building on this initial work and conducting follow-up visits to examine how these networks develop over a longer period.

Short accounts of other community network initiatives can be found in the sister publication of this project – *Global Information Society Watch 2018: Community Networks*[5] – which covers networks in 43 countries.

The initiatives studied

The provision of connectivity infrastructure in the community networks we studied is little different from traditional commercial mobile networks and fixed wireless internet service providers (WISPs) operating in urban and rural areas in more developed countries. The community networks operate at a smaller scale, but the technical models are similar – wireless and wired routers or mobile phone base stations interconnect the members of the community, and backhaul links connect them to the rest of the internet or to other phone networks using fibre or copper cables, wireless or satellite links. However, in contrast to national voice operators, the community networks providing mobile voice services do not operate a centralised core network for switching and routing calls. Instead they take advantage of recent advances in technology which can provide for low-cost switching services at the site of the base station.

For community networks that build internet services, as with larger commercial networks, wireless routers are deployed as Wi-Fi hotspots in public areas, and/or in businesses, government offices or the residences of community members. They are either inter-connected in a star-topology, where a central point provides links to each Wi-FI hotspot, or they are deployed in a mesh topology, where Wi-Fi hotspots may obtain their connectivity via neighbouring devices. In contrast to most traditional large-scale internet providers, Wi-Fi hotspots in the community networks are often augmented with public access facilities, or in some cases, public access is the primary service, reflecting the low availability of access devices in some locations, most notably in the deep rural areas of the DRC and northern Uganda. Voice telephony gateways are also provided in some of the

5. https://www.giswatch.org/community-networks

Wi-Fi based networks, and similarly, the mobile networks often used internet links to carry their off-net voice traffic.

While they may be small relative to traditional national networks, the community networks still varied tremendously in coverage area and size – some service just a few dozen households in a settlement, while others provide connectivity for thousands of users spread across a dozen or more villages. Of note here is that a number of the larger and more mature community networks have developed specific organisational structures which act on behalf of the individual networks. These, sometimes called umbrella organisations, include TIC AC in Mexico, AlterMundi in Argentina and Zenzeleni NPC in South Africa. They support the operation of the community networks in a number of ways:

- Operating shared network infrastructure (such as high sites/backhaul links and voice gateways) on behalf of the individual networks.
- Centralising technical and administrative support, which reduces the need to replicate some of these often scarce resources in each local network.
- Acting on their behalf in relations with government and partners, and to support the development of community networks in the country more generally.

Deployment costs in community networks also varied considerably, depending on the nature of the network. While network equipment costs have continued to drop as the technologies advance, resulting in mobile base stations costing less than USD 5,000, and carrier grade wireless routers costing around USD 100, the solar power systems that are often needed substantially increased the cost of deployment. Similarly, towers can be costly items, especially when they need to be high enough to reach over trees, hills or distant locations, equipped with lightning protection or transported over difficult terrain from distant origins. However, in a few community networks there were opportunities to use existing telecom towers where regulations require operators to share passive infrastructure. Buildings for use as high sites and administrative premises were also often provided by the community at no cost.

Table 1 summarises the initiatives studied in the research, grouped by country. The networks examined either provide Wi-Fi-based internet connectivity or mobile voice and/or internet services. The relatively low number of small-scale mobile deployments worldwide is notable, particularly because in most rural unconnected contexts, mobile voice services are in higher demand than internet access. The rarity of mobile deployments is largely the result of lack of access to the licensed radio spectrum on which these services depend. Similarly, for non-line-of-sight situations, such as forested or hilly locations, lower frequencies are more effective, especially for backhaul, but are usually not made available at affordable rates, if at all. These problems are due to regulatory restrictions determined by national policy makers who are generally unaware of the need or the range of options for providing small-scale networks with affordable radio spectrum. As a result, because Wi-Fi uses licence-exempt frequencies, and can start at a very small scale, with a commodity wireless router for example, Wi-Fi hotspots connected to an upstream broadband connection are the most commonly found type of community network.

Table 1. The community network initiatives studied

Country	Initiative	Location(s)	Description
Argentina	AlterMundi/ QuintanaLibre	5 villages/small towns around José de la Quintana, Córdoba province	Households in multiple village-based informal groups install their own mesh Wi-Fi routers to connect with each other and to a shared mesh network operated by QuintanaLibre with a high site and low-cost long-distance backhaul, as a non-profit association.
Brazil	Associação Portal Sem Porteiras	Rural area near Monteiro Lobato in São Paulo state	Households manage their own mesh Wi-Fi infrastructure to connect to a shared mesh network, local content, public hotspots with usage fees, a high site and commercially provided backhaul operated as a non-profit association. Part of the Coolab collective supporting community networks.
Brazil	Quilombola Community Network	Barrio in Penalva town, Maranhão state	Semi-urban mesh Wi-Fi hotspots and public access facility connected by satellite in informal settlement operated by an agricultural producer association supported by university research group Nupef.
Democratic Republic of Congo (DRC)	Pamoja Net	Rural settlements across Idjwi Island in Lake Kivu	Public Wi-Fi hotspots and fixed links for NGOs and businesses provided by rural development NGO, Ensemble Pour la Différence. Has recently begun testing Open Cellular GSM base stations for voice and data.
India	Gram Marg	25 villages in Palghar/Thane districts, Maharashtra state	Public Wi-Fi hotspots and fixed wireless links for public institutions established by research organisation IIT Mumbai, in partnership with CSR programmes, local authorities and private ISP supporting village entrepreneurs.
India	Wireless for Communities (W4C)	Many locations in Rajasthan and Madhya Pradesh states	Public Wi-Fi hotspots, mobile public access facilities and fixed wireless links for public institutions supported by NGO Digital Empowerment Foundation (DEF).
Indonesia	Des Hotspot	Calang town, Banda Aceh	Residential and business Wi-Fi hotspots provided by a small informal business.
Indonesia	Puspindes/ RelawanTIK	Penggarit village, Pemalang, Central Java	Wi-Fi access provided by local authority with ICT technical support from NGO RelawanTIK.
Indonesia	RelawanTIK/ Common Room	Ciptagelar village, Sukabumi regency, West Java	Public access facility in an indigenous community supported by Bandung-based NGO Common Room and the local regency (local authority).
Indonesia	Ungu Community LTE	Bonkondini village, West Papua	4G/LTE data-only mobile service operated as an informal community-based network supported by University of Washington State research and Mission Aviation Services.
Mexico	Telecomunicaciones Indígenas Comunitarias (TIC AC)	16 villages and small towns in Oaxaca state	Mobile voice networks in multiple indigenous communities, operated as a non-profit civil association with a mobile licence, supported by local authorities, initiated by NGO Rhizomatica.
Peru	Mayutel/Red de Telemedicina del Río Napo	15 communities along the Napo River, Maynas province	Wi-Fi backbone linking clinics and mobile voice/data base stations established by Spanish NGO EHAS. Voice and data mobile network in partnership with a specialised rural operator providing access to the Telefónica network.

Philippines	VBTS Konekt Barangay	7 villages in Aurora province, Central Luzon region	2G voice networks operated as community cooperative infrastructure, established as a research partnership between the University of the Philippines, University of Washington and University of California, Berkeley, and supported by local authorities.
South Africa	Zenzeleni	Villages in Eastern Cape province	Public Wi-Fi hotspots and fixed links for businesses and public institutions operated as village cooperatives supported by Zenzeleni NPC (non-profit corporation). Initiated as a research project by the University of the Western Cape (UWC).
Thailand	Taknet/ Net2Home	Villages in Tak province, near border with Myanmar	Affordable mesh Wi-Fi hotspots operated as a partnership between local entrepreneurs, the Thai Network Information Center (THNIC) Foundation (the ccTLD operator) and intERLAB, Asian Institute of Technology (AIT).
Uganda	Battery Operated Systems for Community Outreach (BOSCO)	Villages, settlements and small town around Patonga districts near Gulu	Wi-Fi links for public access centres and schools. Focus on solar power, youth business training, refugee areas. Supported by a Catholic Church-based NGO.

Motivations for establishing community networks

Considering the limited body of knowledge about community networks, the small number of cases studied in this research and the abbreviated research period, generalisations about motivations and many other aspects of the networks studied need to be avoided. Seen as a group, their great diversity is readily apparent; however, the main motivation for building these networks is to help meet needs for better and more affordable communications infrastructure.

Not many of the networks were in areas without any other form of connectivity. In fact, satellite beams now blanket all but a few areas, and mobile operators were present in most of the sites. However, these large-scale commercial services are evidently too costly or unavailable. Despite their small size, improved affordability over national commercial networks is evident. For example, in the community network in South Africa, data fees are between 20 and 40 times cheaper than mobile data plans. In the Mexican mobile community networks, unlimited local calls cost about USD 2.50/month, while off-network calls cost about USD 0.02 a minute.

In addition, the per-minute or data traffic-based usage charges adopted by national mobile networks have a distinct chilling effect on the extent of use. In contrast, there is usually no charge associated with the traffic generated by the user of a community network for a particular communication session. There may be no monthly usage fees at all when costs are covered externally, although more usually, fees are based on a specific time period (e.g. one week or one month) over which unlimited use can occur, subject to bandwidth limitations or when the traffic is just within the community network.

While affordability and sometimes deficient connectivity in rural areas were usually cited as the primary reasons for community networks, a wide range of other benefits were often

reported – some were intentional by the network initiators, and others were revealed by users in the course of the research. Local economic development and community empowerment are common themes, while some of the community networks studied also had more specific focuses, such as addressing the communication needs of indigenous communities or other marginalised groups, or supporting aspirations for building the autonomy of their communities. Supporting the development of connectivity in this way is seen as an entry point to "building or preserving community". In some cases connectivity is used as one of many tools by integrated rural development organisations to assist in community upliftment, such as providing income generation or employment opportunities.

A substantial number of community networks have also emerged through support from academic and research institutions, which have set up community networking projects to study the potential of new technologies and alternative strategies for addressing connectivity gaps.

In total, about 50 different international and national organisations were identified that have been involved in supporting the 16 community networks, ranging from UN organisations and bilateral development agencies, to US and European foundations, NGOs, multinational technology companies, local authorities and academic/research organisations. The internet technical community, also known as the i* organisations[6] – in particular the Internet Society (ISOC) and the regional IP registries, LACNIC, AfriNIC and APNIC – have also supported many of the networks.

Technical and operational strategies in community networks

The technical strategies or institutional models adopted by the networks reflect the different conditions present at each location, which mainly result from variations in the following factors:

- Regulatory environments
- Income levels, literacy, and other "development" indicators
- Availability of supporting infrastructure – backhaul capacity, energy
- Awareness of technical options and access to technical/management skills
- Sense of community agency, local culture and traditions
- Support from local authorities and/or external organisations.

As indicated above, the regulatory environment has the most far-reaching impact as a "threshold factor" which affects the technology strategy of the network, the institutional model and also its longer-term impact. Most of the initiatives studied have been at a disadvantage in providing connectivity because the national policy environments have not been conducive to these networks. This is especially the case for providing mobile voice services. Access to radio spectrum is insufficient, while licensing or interconnection requirements and government fees/taxes are not adjusted for small networks, which creates relatively much higher burdens on them. For example, in Brazil, government taxes and levies on the satellite service doubles the cost of the bandwidth used by one of the community networks for the backhaul connection to the internet, the largest cost component of running the network.

6. https://www.apnic.net/community/ecosystem/iorgs

Also, community networks have usually not been given the same government support that is given to national operators for extending their services into underserved areas. Of relevance, here is the fact that the community networks actually generate additional traffic (and revenues) for the existing commercial networks. For example, analysis of calling patterns in the community mobile networks deployed in Mexico and the Philippines shows incoming call traffic is four to 10 times higher than the outbound traffic originating from the community networks.

As a result of inhospitable regulatory environments, most of the community networks have been confined to using unlicensed spectrum and are dependent on limited sources of funding in the start-up phase, or for expansion. The networks are thus slower to grow or replicate and few provide voice services.

The networks studied provide many examples of the innovative strategies that have been adopted to address the need for connectivity in the face of these difficult conditions. The proverb "Necessity is the mother of invention" is particularly apt here. Some of the noteworthy innovations and strategies that were found in the community networks are listed in Table 2.

Table 2. Notable strategies of the community network initiatives studied

Country	Initiative	Special strategies
Argentina	AlterMundi	Partnership with local university for free off-peak backhaul capacity. Locally manufactured parabolic antennas to reduce costs. Design/manufacture of LibreRouter wireless router for community networks, with LibreMesh operating system software which can also replace software on off-the-shelf commercial routers. All members/users attend technical workshops, can provide in-kind contributions.
Brazil	Associação Portal Sem Porteiras	A non-profit association using a Sociocratic decision-making methodology. Member of a collective of technical support for community networks in Brazil. Provides public hotspots, technical development, support and content-sharing platform.
Brazil	Quilombola Community Network	Indigenous women's association of traditional palm harvesters providing livelihood support and managing conflict with large land owners/cattle ranchers. Usage fees more than cover satellite costs, surplus used for printing. Participatory mapping used to identify the communities.
Democratic Republic of Congo (DRC)	Pamoja Net	Youth upliftment and integrated development focus, free off-peak Wi-Fi access is cross-subsidised by income generated from business and NGO users. Network is a response to a request by the traditional leader. Community radio station support.
India	Gram Marg	Testing different institutional models – public-private partnership with local authorities and village entrepreneur model. Locally developed TVWS equipment. Subsequent regulatory restrictions on use of TVWS required backhaul links to be replaced with 5.8 GHz Wi-Fi, resulting in blackspots (no coverage) and greater costs for the higher towers needed for line-of-sight Wi-Fi.
India	Wireless for Communities (W4C)	Roving public access vehicle for nomadic groups, e-commerce/entrepreneurship support for women, connectivity and distance education for local authorities and schools, connectivity and telemedicine for clinics, community radio station connectivity, "network in a box" developed for quick and easy deployment.
Indonesia	Des Hotspot	Electronics hardware repair/copy service adds small-scale WISP service to repackage retail fibre broadband into lower bandwidth, more affordable services for residences and small businesses.

Indonesia	Puspindes/ RelawanTIK	Provision of access is part of a broader ICT adoption programme and mandate for local authorities, including government-mandated requirements for local authority websites and content development. Supported through a nationwide group of "ICT evangelist" volunteers.
Indonesia	RelawanTIK/ Common Room	Public access provision is part of a civic rural/urban digital development collaboration and support programme using art, culture and multimedia supported by the regency (local authority).
Indonesia	Ungu Community LTE	Test bed for a new open source low-cost LTE-based mobile network. No voice services are provided in order to avoid competition with licensed voice provider.
Mexico	Telecomunicaciones Indígenas Comunitarias (TIC AC)	Legislated access to small quantities of licensed mobile spectrum for indigenous populations. Close support from indigenous assemblies and strong community-based decision making. Low-cost software-defined radios used for mobile base stations. Interconnection, backhaul, technical and administrative support and licence management is operated as a shared facility for all the village networks. Indigenous local assemblies were involved in the legal test cases to help change legislation.
Peru	Mayutel/Red de Telemedicina del Río Napo	Mobile network supported by Peru's universal service fund (FITEL) with specialised rural mobile operator. Ninety-metre-high towers constructed to reach isolated locations with effective lightning protection systems. Close links between NGO activities in the field and support from academic and research institutions in Spain and Peru.
Philippines	VBTS Konekt Barangay	Leverages a partnership with one of the two national mobile operators (Globe) for access to their spectrum and interconnection. Voice and SMS services only currently. Randomised control trials taking place to compare impacts with unconnected villages.
South Africa	Zenzeleni	Network supported by the local tribal authority. Regulator provided exemption from licence requirement. Business development embedded in the model with the communities learning how to start and manage their own businesses.
Thailand	Taknet/ Net2Home	Repackaging of retail fibre broadband into smaller, more affordable services. Weather and environmental/air pollution sensor network adds additional value by detecting patterns of smoke pollution from burning rice fields.

Institutional models

The institutional models exhibited by community networks vary considerably. These range from networks run and/or supported by non-profit member associations, cooperatives and small businesses, to NGO projects and partnerships between government and academic institutions. Local authorities have a significant role in many of the networks, although these institutions vary in terms of their involvement and relationship with the "grassroots" community that may own and operate the network.

It should also be noted that five of the community networks have close relationships with, or even emerged from, initiatives to operate community radio stations: AlterMundi/ QuintanaLibre (Argentina), BOSCO (Uganda), Pamoja Net (DRC), TIC AC (Mexico) and W4C (India). This is perhaps not surprising given the similar objectives that community radio stations usually have around improving access to communications and information, along with their infrastructure resources such as high towers and power.

Figure 1 is a simplification of the situation, but illustrates how networks can be roughly divided into five groups spread across a spectrum of levels of community involvement.

These groups are also associated to a greater or lesser extent with different institutional models.

Figure 1. Networks divided into five groups in relation to community involvement

Different levels of community involvement and related institutional models reflect local and national cultures and socioeconomic contexts. In particular, strategies largely result from different approaches to coping with the hostile or non-existent policy and regulatory environments which exist for community networks.

Depending on the legal environment for cooperatives vs. non-profit associations and clubs, the cooperative or non-profit membership association models appear particularly well suited to these community network endeavours. Rural cooperatives in telecommunication, energy production, savings, agriculture and food distribution have already existed for decades in both developed and developing countries. So it appears these models may become more widely adopted among community networks, given the objective of providing affordable communications combined with the cultures of resilience, community involvement and resource sharing present in rural areas, or provoked by community networks. These models also fit well with network topologies comprised of wireless links between neighbouring homes which share the available capacity.

Local and global benefits offered by community networks

Aside from the well-documented benefits of access to voice and internet services that connectivity offers to rural populations in the global South, as well as the commercial benefits to existing national networks from the traffic generated by the communities, the social impact research showed that community networks have many other benefits. Some 77 different benefits were articulated in studying just six cases (in Argentina, India, Indonesia, Mexico, South Africa and Uganda) and many of the positive contributions to the telecommunications ecosystem and to local social and economic development are specific to community networks.

Wider affordability of communications, direct savings made on the cost of existing communications, and the roles of community networks in the local circulation of money are the benefits that tend to attract policy makers and development agency attention. However, it is important to observe that while financial benefits are important to people in low-income community networks, these are by no means the aspects they value the most. It is equally important to appreciate that beyond the benefits to the social and economic

development of rural populations, community networks also provide insights into factors within, or acting upon, the telecommunications sector that hinder access for all, whatever telecommunications model is applied. Moreover, the community networks paradigm offers unique practical ways to compensate for the effects of these factors on their populations and, thus, provide valuable lessons for stakeholders seeking to connect the unconnected.

Direct and indirect economic benefits

Key benefits to local economies are accrued from wider affordability of communications, direct savings made on the cost of existing communications, and community networks' various roles in facilitating the local circulation of money. In the rural areas studied, where the only other means of internet access is through mobile operators, many people spoke of the importance of low-cost communications. For example, many of the frequent users of Zenzeleni in South Africa interviewed indicated spending between 10% to 40% of what they had previously spent on mobile data; and users in Mexico indicated the affordability of their community network's GSM provision, where alternative communications involve costly landline, satellite and radio phones, Wi-Fi services, and the expense of transport involved in travelling to the locations where they are available.

In addition to cost savings and affordability, cheaper services enable people to use the internet more effectively, with direct impact on income-generating activities, extending beyond retaining money within communities through cash payments to the community network, instead of to non-local telecommunications companies or financial intermediaries such as banks or credit cards. These benefits include:

- Fairer trade, by accessing market information to enable people to negotiate prices.
- Increased turnover in selling via e-market places.
- Better informed consumer decisions.

Community networks also make important contributions to the local circulation of money via the social links and spin-off services they support. These include:

- New local trade within rural communities based on relationships forged through community networks.
- Direct income generation by people on-selling their connectivity in some cases.
- Ad hoc, small cost-saving arrangements between local people facilitated by the community network.
- Improved performance of local businesses, e.g. local transport services.
- Increased business for other local service providers, e.g. local printing services.
- Fostering community-oriented business attitudes locally.
- Introducing people to each other and creating new relationships.

Thus, along with cost savings and wider affordability, community networks have many other intrinsic benefits for the local circulation of money.

Other benefits from unrestricted access and better access to information

Affordability is vital for people in low-income communities in order to benefit from the wider economic and social value of national networks in enabling links beyond the local communities, such as for personal contact, education and business activities. However,

the traffic-based usage charges of national mobile networks, especially as these charges occur irrespective of whether the traffic is local or not, can have a chilling effect on the extent of use. In contrast, the lack of charges associated with the traffic generated by the user of a community network means that community networks are more likely to encourage greater use generally, and enable activities that were not economically justifiable (affordable) with a traditional mobile network. Participants, for instance, not only referred to using the internet in informal and formal education, but also how they learned better using resources when they did not have to worry about the cost of their data consumption, for instance to learn using bandwidth-consuming video.

The research data illustrates many different benefits to individuals and public institutions, particularly local authorities, of using a community network to access information frequently, for extended periods, in a timely manner and/or in social situations. These encompass benefits in formal and livelihood-relevant contexts including, for instance, access to up-to-date healthcare and agriculture information; support for teachers and students at all educational levels, for classes, assignments and research projects; opportunities to search for employment; research about professional or higher education opportunities; and informal remote peer exchange of information across social media platforms. These benefits are further extended by increased numbers of communication channels to disseminate information locally, most frequently through WhatsApp groups.

The affordability of community networks not only offers the many benefits of frequent, extended or timely communication with people and institutions who would not otherwise enjoy them, but in doing so greatly enriches the local communication ecology. The data gathered shows benefits such as sending applications for jobs and tertiary education, working from home, providing proof of remote work to employers, coordination for administration and governance, online financial transactions and reducing travel costs for employment and local administration. These benefits combine with the particular social qualities of community networks. Thus, the data also illustrates that community networks significantly contribute to:

- Disseminating information using broadcast SMS over GSM.
- Linking local information channels, such as local radio, drama groups and printing services.
- Information sharing and intermediating communication for people with accessibility constraints.

Rural community empowerment

Rural communities in the global South are particularly vulnerable to outmigration, especially of young men and skilled workers, a sense of disempowerment, and helplessness about their ability to improve their lives. Community networks can help empower rural people in using, deploying and innovating technologies. All six of the cases studied for social impact illustrate considerable capacity building, including women, children and older people. For instance, people with little prior exposure learned about technology by relating it to their everyday experience because the community network emerged in their own local environments.

While there are many barriers to women's technical involvement in technology projects in general, some of the cases studied are starting to specifically support women's

involvement in set-up and operations. Women in these networks explained that they had gained confidence by learning about technology together, being inspired by women role models, and had new opportunities for meeting other women beyond their own villages.

Also, for some participants, gaining skills in building and operating their networks enabled them, or people they know, to establish their own small businesses or gain employment. Some of the cases also illustrate that community networks afford opportunities for local creative industries that innovate software or hardware solutions suited to particular rural contexts.

Because building, operating and using a community network involve more than just the technical aspects of telecommunications, benefits extend deep into the fabric of local society. Like traditional networks, community networks provide communication channels that people can use to, say, help avert loneliness. Additionally, most of the cases studied also showed that community networks offer avenues to address the social fragmentation that can accompany increased use of digital communications. For instance, community networks have acted to bridge different parts of society, such as between newcomers and migrants; supported people's cultural identity; improved local security and safety; provoked and informed local discussion about privacy; and supported intergenerational cooperation.

Strikingly, the research data on the social impact in just six cases shows that the success of community networks has also amplified people's sense of their individual and collective capability and their confidence to set new objectives for themselves and/or their communities. Local coordinators, and often users, spoke of considerable pride and satisfaction in their achievements in establishing their own network. Their descriptions of their endeavours showed that local networks contribute to, and can extend, self and collective efficacy and agency. People expressed a sense of empowerment and self-sufficiency in being able to make decisions about telecommunications and undertaking operations.

Addressing exclusion

The research data for most cases shows that the community networks paradigm fosters local commitments to ongoing learning, continuous improvement and readiness to change their operations. While community networks provide more affordable access than traditional telecommunications networks, at this early stage in their evolution there also remain barriers to access for some people. However, three unique benefits of community networks suggest they will resolve this situation in the months and years to come:

- Unlike commercial telecommunications, the local nature of community networks makes the specific factors that contribute to exclusion easier to identify.
- The incentive to address the factors is far greater than for commercial telecommunications that operate at a distance from their users and value-price their services only for populations that can afford them.
- The collaborative, rather than competitive, approach between different community networks around the world, and the dramatic recent increase in channels of communication between them, promotes sharing experiences and co-creating practical ways to address factors contributing to exclusion.

Indeed, our research shows that these unique characteristics of community networks will provide valuable lessons for many different stakeholders seeking to better serve rural populations, including commercial providers.

Impediments to the benefits of community networks

The detailed research on social impact shows unequivocally that community networks provide specific social and economic benefits along with the broader benefits of connectivity to people whose needs are unmet by national networks. However, community networks also encounter problems in achieving their goals to provide access to connectivity to the most excluded people in society. These problems are caused by an absence of wider recognition of the special benefits of community networks, and lack of enabling policy, regulatory and investment environments, along with different types of discrimination embedded in the global culture of the telecommunications ecosystem.

The research illustrated that community networks can provide affordable access to many people who are excluded by national telecommunications networks; however, in the cases studied, not everyone in the community networks' constituencies had access. Most barriers to people's access are also included in the much larger set of barriers presented by traditional telecommunications networks, rather than being intrinsic to the community network paradigm. Nevertheless, these encompass exclusion because potential users cannot afford phone handsets or other devices to use the network, do not have written and/or technological literacies, or have needs and interests that are not targeted when designing services, for instance, because of their age.

All telecommunications systems amplify existing gaps between people and, because community networks provide benefits to people in their rural constituencies, they also advantage those that have access in varied ways. For instance, people who already have basic technological literacy are more able to gain skills in operating community networks and consequently to participate in decision making about community networks and/or generating income by applying the skills they gained.

The research data shows that challenges to inclusive decision making that were evident in some cases studied result from broader problems in technology. For instance, technical manuals and interfaces focus on certain languages which exclude many people from understanding networks. This exclusion, of course, characterises telecommunications networks as a whole, but the problem becomes more visible in community networks precisely because they are situated within communities that are residential, rather than specifically technical, and involve the skills of local residents.

Other examples of the ways that community networks reveal conventions and practices in telecommunications that exclude diverse people relate to age and gender. For instance, the research data shows that prioritising the technical skills of younger people can be incompatible with the age profile of rural populations, where people tend to be older. Further, the global culture of telecommunications only ascribes higher value to certain sorts of work, and associates this work with men, not women. This contributes to situations where the work of social coordination, which is fundamental and vital to community networks and often undertaken by women, is not valued as much as the work of software and network engineering; thus, women are under-remunerated. In contrast to

commercial telecommunications providers, however, community networks are often highly motivated to include diverse people in operations.

Unfortunately, despite their motivation and capacity to identify and address exclusion, community networks are impeded by factors related to enabling policy, regulatory and investment environments. Some challenges that community networks face in achieving inclusivity are the direct result of the current absence of enabling policy and regulations, others are more indirect. For example, exclusions relating to geographic dispersion of people occur less frequently for mobile networks than for the Wi-Fi networks that most community networks are forced to use.

The limited spatial coverage of a particular Wi-Fi hotspot can restrict connectivity to certain places, and these places may not be accessible to some people with social, cultural or bodily constraints. Sometimes this means that community networks reinforce local power structures because access points are located at authority premises, where only privileged people are permitted to use their modest amounts of bandwidth. Further, if the location of public Wi-Fi hotspots in a network is not gender-sensitive, then girls and women encounter specific barriers to access.

It is imperative to appreciate, however, that at the root of this problem are national policies and regulatory frameworks that preclude community networks from using technologies that have greater spatial coverage or lower costs. The relationship between policy, regulation and the exclusion of women and girls from access, which in turn amplifies gender differentials in freedom to access information, is a clear example of the way that community networks expose issues that are hidden, and in fact caused by, established telecommunications infrastructures.

Other challenges arise because community networks that are situated in economically deprived, remote rural areas and are also based on less familiar telecommunications paradigms are unable to access capital from traditional investors or lenders. All the cases studied show that community networks emerge from small beginnings and operate with meagre resources, including limited access to training, vehicles and printed material, and this, in turn, constrains their ability to maintain their networks and publicise their services as well as they would like. Thus, although many of the community networks in the study respond conceptually and organisationally to the needs of their constituencies, financial limits on their operations mean their growth and changes emerge slowly.

Lack of access to capital results from a combination of factors that are all, ultimately, attributable to comparing community networks with the traditional telecommunications model and discounting their unique value:

- Compared with traditional telecommunications, community networks are seen as having higher actual or perceived levels of risk. This is because their distant rural locations are unfamiliar, they involve new technologies in apparently alien social contexts with novel sustainability strategies, and they may be run by people with limited management experience. The community network initiatives may also lack land or other assets to provide collateral as guarantees for loans. Even if collateral is available, the cost of commercial bank finance is usually too expensive as it is priced at levels which reflect high perceived risk.
- When it comes to investment, community networks are judged according to specific measures of potential, specifically scale and replicability. Small

networks are less attractive to traditional sources of finance or development assistance because the overheads for administering projects and funds disbursements are much the same, regardless of the size of the project. Thus, the proportion of overheads in the project is higher than for larger-scale projects, resulting in a relatively high cost of support. Also, many of the networks focus on providing connectivity in a particular location, with little or no interest in growing and replicating in ways that would create the larger projects that attract traditional funders seeking scale.

- Community networks offer low surplus revenue. This is a disincentive for lenders and investors looking for higher returns in the telecommunications sector and limits community networks' ability to service loans. The members and customers of community networks in rural areas of developing countries have very low incomes, and operating costs can be substantially higher compared with urban areas. This is commercial telecommunications providers' key justification for not covering these areas. Further, unlike traditional telecommunications that value-price services for wealthier markets, many of the networks a) do not aim to make a profit and/or b) try to ensure that any fees for service are as low as possible.
- Community networks often need to obtain soft finance and grant funding from development agencies and national governments, because of their difficulties in gaining start-up financial support. Again, however, they can encounter problems. Firstly, until recently there were very few specific global development funding streams for community networks, and to our knowledge no national ones. Now, while there are more funding streams, there are also more community networks competing for those streams. Secondly, project proposals are evaluated and monitored against the better-known connectivity strategies of commercial telecommunications provision. These tend to emphasise the technical aspects of implementation, which do not account for community networks' inherent social qualities. Thirdly, outcomes are also evaluated against the connectivity strategies of commercial telecommunications provision, which do not account for the wide array of unique benefits offered by community networks.

FINAL REMARKS AND RECOMMENDATIONS

Our research visits allowed us to witness at first hand the issues faced by some of the more mature members of the community network movement. These struggling breaths may be different to those of the community networks that are now emerging, which may not face the same level of difficulties. In interviews, several people in community networks explained that in the face of the considerable odds, community networks are only recently beginning to demonstrate their potential and our research may have been too early. Yet, the vast number and array of benefits we analysed, along with opportunities to improve operations, suggest that undertaking research relatively early in their journey was precisely the right time to inform stakeholders and wider audiences in order to amplify and accelerate the realisation of community networks' full potential.

The situation for community networks is already changing. Since the research started at the end of 2017, community networks have emerged in ever greater numbers across the

world, and their potential for meeting connectivity gaps has become better recognised in international forums discussing ways to address digital divides. As a result, some countries have begun to adjust their policy and regulatory environments to be more conducive to community networks. Nevertheless, there are many areas that must still be addressed before community networks will reach their full potential. Below are listed the most important recommendations emerging across the entire research.

Recommendations for policy and regulation

Policies and regulations need to be modified to eliminate barriers to entry for small networks and to provide them with more opportunities to emerge and flourish. This includes recognising that technology-specific regulations cause exclusion. For instance, regulations which restrict community networks to only the use of Wi-Fi can limit accessibility to the segments of the population who have either personal access to routers or socially, culturally and physically unconstrained movement.

Enabling policy and regulatory environment improvements, therefore, primarily involve changes that:

- Make licensed and secondary-use spectrum available and affordable to small networks, and make additional frequencies available, either on an unlicensed basis, or on affordable and flexible authorisation schemes. As indicated repeatedly above, lack of spectrum access for small networks precludes their abilities both to provide mobile voice services and to use lower-cost or more effective systems based on frequencies for backhaul that do not require line-of-sight.
- Make backhaul/backbone infrastructure and capacity more widely available (greater coverage), such as through infrastructure sharing and ensuring access to international fibre capacity. The main operating expense of most community networks is the cost of backhaul, which is ultimately reflected in cost recovery from the end-user, and can also limit the number of upstream links that networks depend on to only one path out of the local network, which makes them more vulnerable to upstream network outages. So, reducing backhaul costs significantly impacts both affordability and reliability.
- Ensure small-scale operators can interconnect with other operators in the country on an equal cost basis. Small networks have severe financial and other barriers to entry in gaining equal access to national voice network interconnection and numbering resources, national/international wholesale capacity and dark fibre where available.
- Ensure universal service funds are available to support community networks. National governments usually have universal service funds to support the provision of connectivity in rural and under-served areas. Many governments have already accumulated large amounts of unspent funds, partly because of the limited capacity to evaluate and disburse funds, and also because of the paucity of effective projects to support. It is likely that this avenue of support will become increasingly fertile for community networks in future, given the recent response of regulators and policy makers and their sensitisation to the potential of community networks.

Of these above actions, the freeing up of radio spectrum is the most urgent and pressing issue that needs to be addressed as soon as possible.

Recommendations for investment and funding

Investment in, and support for, the development of community networks must respond to the wide array of unique benefits offered by community networks and the particular contexts in which these benefits arise. Remote rural contexts in the global South are poorly served not only by affordable and reliable traditional telecommunications but also by many other infrastructures, thus additional resources and longer-term approaches are often necessary. This response primarily involves changes that:

- Recognise the varied, and often indirect, nuanced or intangible benefits of small-scale, bottom-up infrastructure building in evaluating impacts and success. Traditional measures associated with voice and internet access provision, such as number of subscribers or traffic volume, do not account for the many benefits that community networks offer that national commercial telecommunications models may not.
- Extend timescales for project implementation and adapt expectations for outputs to reflect the social realities of community networks in developing countries. Timescales, project plans and milestones need to reflect local human resource constraints and cultural contexts in rural areas, and the additional time involved in the social relationships that constitute community networks.
- Ensure teaching and learning materials, network management tools and local applications are in the languages that community members usually speak and read in everyday life. If basic literacy is an issue, audiovisual materials will be a priority.

Recommendations about inclusivity

Rural populations in the global South tend to be older and comprise a higher proportion of women, in stark contrast with urban areas and global populations of technologists and regulators. Thus community network projects often need to make special efforts to take into account the needs of women and other marginalised groups. Responses are required at all levels that:

- Ensure women and people with disabilities are represented and visible in international, national and regional policy and movement-building forums. Mentoring opportunities can enable more experienced women, of all ages, to share their experiences with women with less experience, of all ages, in all aspects of community networks from technical work to policy and advocacy.
- Create programmes targeted at older people and women-only spaces to learn about technology use and network deployment within community networks. Where appropriate, opportunities for technically skilled women to directly support women-led networks should also be promoted.
- Schedule decision making, training, network access and all other operations so that women are always included and plan activities to account for the split-focus that accompanies women’s, and other carers’, responsibilities.

- Account for the labour involved in the many social aspects of community networks when remunerating work.
- Situate network access points and administrative operations in places that are accessible to people of diverse genders, physical abilities, ethnicities, classes, castes, etc. It may also be important to explore with women's organisations ways to ensure women's safety and comfort in all work contexts within the community network.

Recommendations for future research

While this study has made some first steps in building a body of knowledge and understanding of community networks, it is clear that further research is necessary. Future research should include:

- Broadening the range of types of networks studied.
- Tracking the evolution, communication ecosystem and impact of networks over time.
- Deepening insights about local innovations and businesses that emerge within networks.
- Analysing responses to changing regulatory conditions, and investment and support opportunities.
- Assessing opportunities for building local knowledge exchanges and associated content.
- Designing and evaluating application services that can be built on the community network infrastructure.

SECTION 2. COMMUNITY NETWORKS: OPERATIONAL AND TECHNICAL RESEARCH

Michael Jensen

BACKGROUND

Slowing global connectivity growth indicates that by 2025 only about 60% of the world's population will have internet access, and just 70% will have voice access.[7] If this situation persists, the target of attaining universal connectivity by 2030 set by the UN Sustainable Development Goals (SDGs) will not be achieved. It has become increasingly apparent that in low-income countries, the currently prevailing market model based on nationwide deployments of communications infrastructure by large operators is reaching its limits, as shown in the graph in Figure 1.

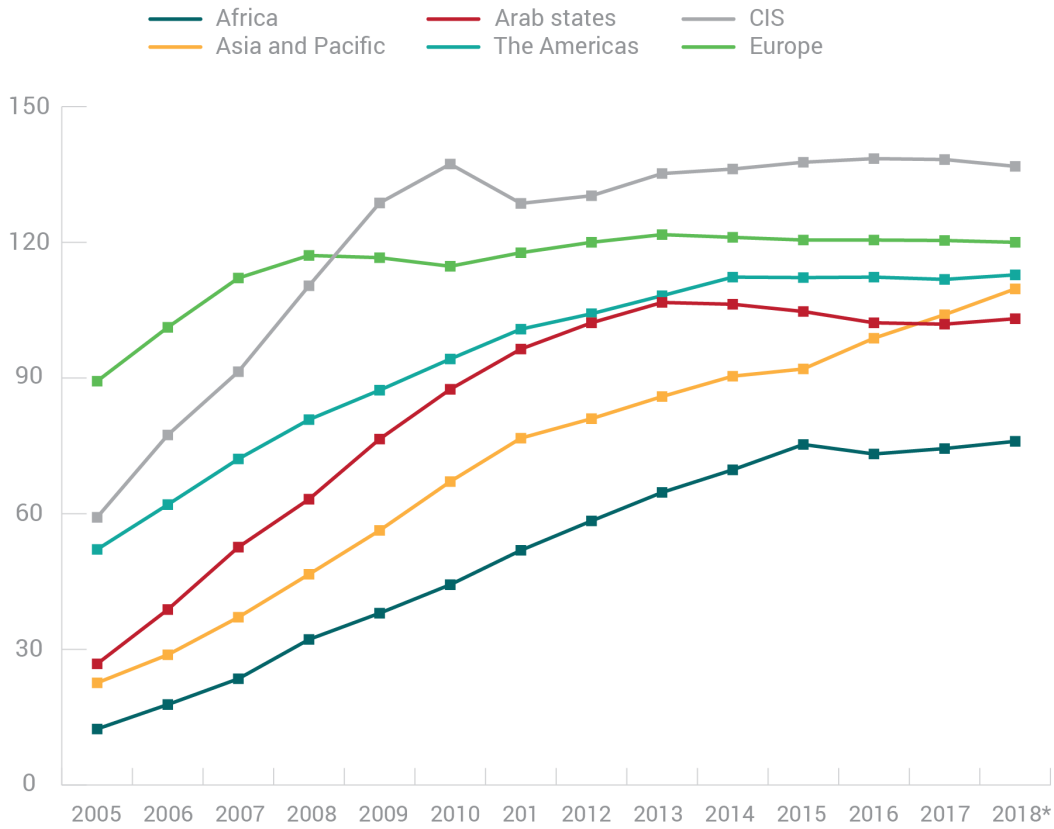

Figure 1. Mobile subscription penetration trends (percent of population with a mobile account)
*Estimate | Source of data: ITU

The affordability of existing services for the bottom of the pyramid is already an acute issue, and recent estimates indicate that mobile data charges are becoming even less affordable in Africa.[8] Revenues for operators from people in sparsely inhabited rural areas are simply insufficient to cover the costs of extending connectivity at an affordable price. The problem is typified by a recent statement from mobile operator MTN Nigeria's senior manager of Access Transmission Planning, Tolulope Williams:

7. GSMA. (2019). *The Mobile Economy 2019*. https://www.gsma.com/r/mobileeconomy
8. Alliance for Affordable Internet. (2018). *2018 Affordability Report.* https://webfoundation.org/2018/10/a4ai-2018-affordability-report

> Compared to our physical sites, of which we have over 13,000, our rural telephony network is less than 300 sites. In a lot of countries, it's actually the government that drives the broadband initiative to rural areas; operators need a lot of incentives in order to begin offering services. If you're going into a rural area, you're not going to make money.[9]

Government subsidies and international development support for national operators to encourage them to extend services into rural areas has been tried in many countries. But insufficient resources are available to do this effectively, as is evident from the continued lack of affordable services, the plateau in global uptake of mobile subscriptions, and the low or non-existent levels of access in rural areas in most developing countries (and even in many developed ones), despite more than 20 years of mobile network deployment. Rural roll-outs have in fact recently slowed, or even ceased, as operators focus on more profitable 4G/LTE and now 5G installations in competitive urban markets.

As a result of lowering expectations that large-scale commercial mobile deployments will be able meet universal needs for connectivity, there is increased interest in other strategies to address the gap between the connected and the unconnected. Grabbing most attention have been projects such as constellations of thousands of low earth orbit satellites or stratospheric balloons, and wholesale rural wireless mobile networks. While these large-scale initiatives have so far gained little traction, bottom-up approaches to better and more affordable connectivity have so far not been seen as credible alternatives.

Meanwhile, the cost of network equipment has continued to drop, and it is far easier to deploy, which has resulted in a growing number of small-scale networks where community members build and operate their own telecommunication infrastructure. This began with the emergence of low cost Wi-Fi routers in the early 2000s, where small-scale networks were pioneered by technical communities in urban areas in developed countries. People clubbed together to share the cost of broadband connections, or to improve network performance and to provide independent access to local online information resources. This approach resulted in extensive networks which now connect hundreds of thousands of people; the most well known of these are centred in Barcelona (guifi.net), Berlin (Freifunk), and New York (NYC Mesh). There are also many more unrecorded informal networks that use these technologies, as well as "offline networks" which exist without a link to the internet, to share content and applications in local "intranets" using Wi-Fi or cables.

Although there is no widely accepted definition, initiatives that in some way involve local community members in deploying, owning and operating the physical infrastructure that supports voice or internet connectivity are usually called "community networks". These types of networks have emerged in most developed countries, and now also include rural villagers who dig their own optic fibre networks and local authorities operating their own broadband services for their constituencies. Such initiatives are also happening in the global South.

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9. Developing Telecoms. (2016). *Last Mile Connectivity in Emerging Markets*. https://www.developingtelecoms.com/images/reports/last-mile-connectivity-dt-report-final.pdf

Although diverse in nature, many community networks also appear to offer a number of other advantages over traditional large-scale commercial deployments and not just better or more affordable connectivity. As the detailed insights described in Section 3 illustrate, these benefits also potentially include:

- More control over how the network is deployed and used, encouraged by the close relationship between the network operators and the members of the local community.
- Opportunities to better attend to the needs of women and other marginalised groups in network deployment and use, especially in rural areas where women and older people constitute higher proportions of populations. Compared with commercial telecommunications, barriers to their involvement and use are more visible, and the individuals and organisations behind many of the networks may aspire to greater inclusivity.
- Opportunities to retain more funds within the community because a) the network access fees are usually based on cost recovery rather than maximising profit, b) a higher proportion of the payments for use of the network are made to people resident in the locality, c) community members can make in-kind contributions in return for access (labour, etc.), and d) the social aspect of the network promotes local business relationships.
- Fostering a sense of agency and empowerment among community members through the success of their collaborative project that can then generate other joint efforts to improve local livelihoods. In this way the success of the community network project could help to amplify people's sense of capability and their confidence to set new objectives.

However, small networks, and particularly those in rural areas in the global South, face many serious difficulties. The main constraints are the regulatory barriers resulting from inhospitable government policy environments and radio spectrum management strategies that are not designed to accommodate small or non-commercial networks. In addition, financial resources are often very limited in these areas, and people residing there may not have knowledge of the possibilities to deploy them. This can be exacerbated by factors such as lack of affordable energy sources, high costs for upstream connectivity, and low economies of scale.

While there are a variety of ways to address these impediments, wider understanding of community networks and their specific needs is limited, and the means to support their replication and long-term viability may not be evident, especially in the predominantly market-based commercial environment in which they inevitably operate. In particular, there is limited awareness among most policy makers of the regulatory constraints faced by these networks, or how they might be addressed. There have also been few concerted efforts by the development community to support these types of initiatives. Furthermore, levels of strategic and technical knowledge among many of the community networks themselves are often limited, and there have been few opportunities to learn from the experience of other networks facing similar problems.

To help address these knowledge gaps, this section of the report describes an analysis of community networks based on field research and desk-based investigations into 16 selected community-based networks spread across developing countries in Latin America, Africa and Asia over 2018. The primary objectives of this research have been to describe

their nature, strategies and dynamics; to learn more about their opportunities for replication; and to better understand their potential benefits compared to more traditional national commercial networks.

Note on terminology

At the technical level, the term "network" is used in this report for specific physical (tele)communications infrastructure (for internet or voice services) that can operate largely independently of other networks that may be part of the same initiative. Thus an "initiative" may be a project to establish a single network, although it can also comprise support for multiple independent geographically separated networks, or it may comprise a number of networks which are linked together in an organisational structure which supports the operation of the individual networks.

RESEARCH STRATEGY

From 40 community networking initiatives identified in the global South that have been active for a sufficient period from which to derive useful insights (see Annex 1 for a list), a total of 16 in 12 countries were analysed from the perspective of technical and business models. The primary selection criteria were to ensure there was a spread of different connectivity technologies adopted and services provided, a variety of institutional models, governance structures and sustainability strategies, as well as a roughly even spread across the three regions.

Field visits took place over the course of 2018 to networks in Argentina, Brazil, India, Indonesia, Democratic Republic of Congo (DRC), Mexico, South Africa, Thailand and Uganda. Of the initiatives in these countries, six were the subject of more extensive and detailed social and gender impact research (see Section 3 and Annex 2). After analysis of the information gathered during the field visits, to improve on the range of cases being examined, additional initiatives, located in Indonesia, Peru and the Philippines, were the subject of additional desk research and personal interviews and email exchanges with the people working on these projects.

Considering the relatively small number and diversity of networks studied, this research is primarily descriptive in nature, and should not be seen as using a sampling methodology from which conclusions are derived about the general nature of community networks. Being at early stages of maturity not only means that few have systematically documented network operations and use, but also it is important to appreciate that they are still rapidly evolving. In addition, many more community networks have only recently been established, and these may have fewer similarities to the networks described here, which were selected primarily because they had been in existence for some time.

The cases studied provide rich material on the technical and business operations, and the potentials and constraints, of rural community networks in the global South. Yet, it should also be noted here that the scope of the research was subject to a number of important limitations in the following areas:

- Mobile networks: Although recent developments indicate that small-scale mobile networks could become more prevalent, due to current regulatory restrictions, community networks providing mobile services are still rare, and so information about them is limited. Those covered in the study are among the few that exist and most are quite recent deployments. However, they are prioritised in order to learn more about mobile services in rural areas in the global South.
- Networks using licensed spectrum, TV white space (TVWS) or dynamic spectrum assignment technologies: Again, due to regulatory restrictions, the number of networks using these systems is very limited, and the considerable potential of these technologies for use by community networks still remains largely unexplored.
- Community fibre: Fibre optic systems are also being deployed by collaborating members of local communities in rural areas in developed countries, and have the advantage of not being subject to restrictive spectrum regulations. However, although there are perhaps a few urban deployments in the global South, rural community networks deploying fibre still appear to be unknown as yet.
- Entrepreneur-based models: While there are many small commercial Wi-Fi networks operating in some countries of the global South in urbanised areas and in some of the more affluent rural areas, the research encountered fewer examples of these in rural areas with low incomes.
- Networks in other regions or countries: The research did not cover community networks in more developed countries and other regions in the global South (such as Central America, North Asia, the Pacific or other island locations). Linking the knowledge gathered here with that of more mature community networks in developed countries is likely to contribute to better understanding of the potential development of those in Southern regions. In addition, other countries in the global South that were not covered in the research may have significantly different local conditions which need to be better understood.
- Recent deployments: The community networks studied were in part selected for their relative maturity. However, many more networks have emerged which may have different characteristics – for instance, taking advantage of more recent technologies, the experience of more mature networks, regulatory changes or other developments.
- Longitudinal studies: This project was originally conceived as a larger and longer research effort but, due to funding constraints, the cases in this report were subsequently restricted to a single study period. This provided a snapshot of the network, but limited the monitoring of quantitative changes over time which is necessary to have a fuller understanding of how networks evolve and the scaling dynamics related to network growth. As a result, the goals were modified accordingly, and this research was seen as a learning process for devising a more complete research framework for the future.

While the research describes a number of important trends and shared characteristics among the networks that were studied, as well as uncovering individual experiences that have broader relevance, it is important for the reader to bear in mind the above considerations in the analysis where the features of the different networks are summarised and grouped together.

THE INITIATIVES STUDIED

Table 1 provides basic details on the 16 initiatives in the research, grouped by country. The national setting of the locations of the networks varied from higher-income countries such as Argentina, Brazil, Mexico and Thailand, which had annual GDPs per capita in 2017 of between USD 14,400 and USD 6,500, to lower-income countries, in particular the DRC, India, Indonesia and Uganda, with GDPs per capita of between USD 500 and USD 3,800. These income figures, however, mean less in the remote and rural areas in which the networks are located, as incomes are generally much lower than these averages, although they do give some indication of levels of access to some resources such as education and basic infrastructure.

While they may be small relative to traditional national networks, the community networks still varied tremendously in coverage area and size – some service just a few dozen households in a settlement, while others provide connectivity for thousands of users spread across a dozen or more villages.

The setting of the community networks visited also varied to some extent in terms of levels of urbanisation and access to other infrastructure. While most initiatives were in "deep rural" areas with small, largely agrarian or subsistence farming communities and villages, some were located in more urbanised areas, notably Des Hotspot in Banda Aceh, Puspindes in Indonesia, the Quilombola Network in Brazil, and some of the networks in Thailand and Mexico. Most of the sites had some mobile voice and data services, and commercial cable or wireless internet providers were also present in almost half the sites, while about a third had no access to grid power.

Additional details about each of the community networks are presented at the end of this section.

Table 1. Summary of the community network initiatives studied

Name/organisation Date started	Country	Location(s)	Initiative description
AlterMundi/*Libre **2009**	Argentina	5 networks in villages around José de la Quintana, Córdoba province. Rural low-density settlements with some tourists, two WISPs and 3G mobile operator present.	Non-profit association supports a group of 5 independent village-based networks to install their own mesh Wi-Fi routers and connect with a shared mesh network with local content, a high site and low-cost long-distance university-provided internet link.
Associação Portal Sem Porteiras/Coolab **2016**	Brazil	1 network in a rural area near Monteiro Lobato in São Paulo state. Rural low-density village, other WISPs and variable mobile 3G coverage.	Non-profit association supports households to manage their own mesh Wi-Fi infrastructure to connect to a shared mesh network, with local content, public hotspots, a high site and commercially provided internet link.

Battery Operated Systems for Community Outreach (BOSCO) **2006**	Uganda	28 sites across widespread settlements of internally and internationally displaced people living among the local population in villages, camps and small towns near South Sudan border. Some mobile coverage, mainly 2G. Most areas with no grid power.	Church-based NGO operates Wi-Fi links for public access centres and schools in an area affected by refugees, with a focus on solar power provision, enterprise development, youth business training.
Des Hotspot **2011**	Indonesia	1 network in Calang town, Banda Aceh. Remote small town, 3/4G coverage.	Small wireless ISP business providing Wi-Fi hotspots for residential and business customers.
Gram Marg/IIT Bombay **2012**	India	25 networks in rural agricultural villages in Palghar/Thane districts, Maharashtra state. Scattered low density communities with mobile 3/4G coverage in some areas near highways. 84% of households eligible for food subsidies, 77% have electricity. Population of about 12,000 adults, 23% have a mobile phone, 13% use the internet.	Mumbai-based national research organisation-initiated public Wi-Fi hotspots with connections to local authorities, schools, primary health care and rural child care centres as test bed for wireless technologies and business models.
Mayutel/Red de Telemedicina del Río Napo/TUCAN3G/ **EHAS** **2006**	Peru	15 communities along the Napo River, Maynas province. Forested areas on the banks of large river, small communities, no other mobile coverage except Mayutel.	NGO/academic partnership deployed a Wi-Fi backbone linking clinics which now supports a 3G voice and data mobile network operated by specialised rural operator providing access to the Telefónica national mobile network.
Pamoja Net/ Ensemble Pour la Différence **2017**	Democratic Republic of Congo (DRC)	1 network spread across rural settlements on Idjwi Island in Lake Kivu. Relatively densely populated, extreme poverty, average life expectancy of 27 years, average 8.5 children per family, subsistence farming, some coffee co-ops, fishing and informal mineral mining, some 2G coverage, no grid power.	NGO-operated public Wi-Fi hotspots and fixed links for organisations, kiosk for phone charging, news/info. Recently (2019) began testing Open Cellular GSM base stations for voice and data.
Puspindes/RelawanTIK **2008**	Indonesia	1 network in a village near Pemalang, Central Java. Rural village with agriculture and tourism, some 3G mobile connectivity and WISPs.	NGO and local authority operate pay-to-use public and residential Wi-Fi hotspots.
Quilombola Community Network **2017**	Brazil	1 network in a barrio in Penalva town, Maranhão state. Informal urban settlement of about 1,000 people with 2G coverage and recently some WISPs.	Indigenous women's association owns/operates public and residential mesh Wi-Fi hotspots and public access facility with satellite link in a semi-urban informal settlement.

RelawanTIK/Common Room **2008**	Indonesia	1 site in Ciptagelar village, Sukabumi regency, West Java. Rural agricultural community with no coverage.	NGO-supported public access facility and digital media training in an indigenous community.
Taknet/Net2Home/ intERLab-AIT/THNIC **2013**	Thailand	17 villages near Mae Sot in Tak province, on border with Myanmar. Rural and semi-urban agricultural villages with 3/4G coverage and fixed internet services.	Research organisation-initiated residential Wi-Fi hotspots provided in a franchise model in partnership with local entrepreneurs and tech foundation supported by provincial non-formal (adult) education/community college.
Telecomunicaciones Indígenas Comunitarias (TIC AC) / Rhizomatica **2009**	Mexico	16 2G networks covering 70 localities in Oaxaca state in a mountainous region. Some villages with 2G coverage, all with WISPs (previously needed to provide backhaul but recent agreement on satellite access changes this).	Federated group of independent mobile 2G voice/SMS networks operated by indigenous communities, supported by non-profit civil association with social purpose mobile licence (TIC AC).
Ungu Community LTE/Mission Aviation Services **2018**	Indonesia	1 site in Bokondini village, West Papua. Small village of about 1,500 people in mountainous Baliem Valley in the West Papuan Highlands. Some 2G coverage. No grid power, some solar and hydro power during the day.	International research group-initiated 4G/LTE data-only mobile service operated as an informal community-based network supported by a local small business.
VBTS Konekt Barangay/University of Philippines **2017**	Philippines	7 villages in Aurora province, Central Luzon region. Small rural and isolated villages with no other mobile coverage, no grid power.	Local and international research organisation partnership implementing 2G voice/SMS networks operated as community cooperative and supported by local authorities.
Wireless for Communities (W4C)/Digital Empowerment Foundation **2010**	India	20 locations in rural and semi-urban locations in Rajasthan and Madhya Pradesh states. Mobile 3/4G coverage in areas near highways.	NGO-initiated public Wi-Fi hotspots, public access facilities, and fixed wireless links for public institutions (schools, clinics, etc.), also roving vehicle for nomadic groups and portable wireless “network in a box”.
Zenzeleni Co-op/ Zenzeleni NPC **2013**	South Africa	Scattered settlements in large area in Eastern Cape. Poorest area in the country, 90% unemployed, 70% female, many migrant workers. Average income USD 1-2/day. 2% have grid electricity. 3G mobile data coverage.	Cooperatives supported by umbrella organisation providing public Wi-Fi hotspots and fixed links for local businesses and public institutions.

Types of connectivity provided

The range of services provided by the initiatives studied can be grouped into four types, as listed below. In some cases a single service may be provided, but often multiple service types are provided within the same initiative.

- **Public Wi-Fi hotspots:** Community members can access the internet in public locations using their portable devices. Some members of the community may be in close enough proximity to the hotspot to access the service inside their residence, while others may have to travel some distance to gain access. Access may be provided for free, as part of a monthly subscription or on a pay-as-you go basis, depending on the cost-recovery strategy adopted by the initiative.
- **Private Wi-Fi hotspots:** Closely related to the above service, and often provided along with public hotspots, is the provision of Wi-Fi routers/hotspots within the community members' premises – most usually in their homes, but also in businesses or NGO offices. In some networks, community members using the network are expected to install a router at their premises, while in other networks, it was decided that provision of an in-premises hotspot is not an economically feasible option to maintain. These two policies reflect different approaches to community involvement – in the former, every household is encouraged to participate in the operations and decision making of the network, while the latter strategy is in a larger, lower-income community, where the aim is to minimise inequalities and technical support requirements.
- **Public access centres:** Computers/laptops in a public space, usually augmented with printers/scanners and access to advice or training. In the case of BOSCO (Uganda), some sites consist of computers that are offline but are connected to a local server or set up to access data on the computer's hard drive. In some cases the community network may provide public access facilities as well as Wi-Fi hotspots, in others, public access is the primary service, often reflecting the low availability of personal access devices in some locations. Where the available time on the computer is a limited resource relative to demand, access is rationed through a roster system which gives people an opportunity to book time at a certain hour. In some cases rationing is achieved using a time-based usage model, with varying availability periods for different types of users also being observed. For example, in one of the networks, students receive 15 minutes on the computers while other types of users have 30 minutes.
- **Mobile connectivity:** The basis of the community networks in four of the initiatives studied. This varied from voice and SMS services (in the cases of Mexico and the Philippines), to no voice or SMS, just data/internet (in the case of Indonesia), while in Peru, voice, SMS and data/internet services were provided.

Prevalence of Wi-Fi

Reflecting similar patterns worldwide, Wi-Fi-based services are the most common technology among the community networks studied. The predominance of initiatives based on Wi-Fi is mainly the result of three factors: 1) the demand for internet access in rural areas, where mobile voice services may already be present (and often with less affordable mobile data services), 2) the lack of need for a spectrum licence to operate equipment in the licence-exempt (ISM) bands on which Wi-Fi equipment is based, and 3) the relatively low cost of Wi-Fi equipment, which also means that these networks can start at a very small scale, with a wireless router costing less than USD 50, for example. As a result, Wi-Fi hotspots directly connected to an upstream broadband connection are among the most frequently encountered type of community network.

Limited instances of mobile (GSM/3GPP) networks

Considering that mobile voice services are usually in higher demand than internet access in rural low-income and unconnected contexts, the very small number of community networks operating these voice services is notable worldwide. Although the start-up costs may be higher and low-cost mobile technologies are not as well known,[10] the small number of mobile services is mainly the result of lack of access to the licensed radio spectrum on which these services depend.

These restrictions are due to the regulations set by national policy makers who are unaware of the need or the range of options for providing small-scale networks with radio spectrum, as discussed further below and in associated reports.[11] Voice services provided directly over the internet (VoIP) may appear to be a viable option, but this has not really been widely adopted as a stand-alone alternative due to the limited range of Wi-Fi signal compared to mobile, as well as the lack of low-cost handsets.

UNDERLYING MOTIVATIONS AND SUPPORT FOR SETTING UP COMMUNITY NETWORKS

Motivations for establishing community networks

Considering the limited body of knowledge about community networks, the small number and diversity of cases studied in this research and the abbreviated research period, generalisations about many aspects of the networks studied should be avoided. Nevertheless, it is readily apparent that the main motivation for building these networks is

10. In contrast to free/libre and open source operating system software for Wi-Fi equipment, which is now relatively mature, low-cost hardware and software has only more recently become available for mobile equipment.
11. Song, S., Rey-Moreno, C., & Jensen, M. (2019). *Innovations in Spectrum Management: Enabling community networks and small operators to connect the unconnected.* Internet Society. https://www.internetsociety.org/resources/doc/2019/innovations-in-spectrum-management

to address needs for better communications infrastructure. As noted above, few of the networks were located in areas without any other form of connectivity. Mobile operators and WISPs were present at most sites; however, these services are evidently too costly or unavailable.

Despite their small size, improved affordability over national commercial networks is evident in the networks examined. In addition, an important aspect of the incentive for establishing a community network is that because of the way the national mobile operators sell access, their per-minute or data-traffic-based usage charges can have a distinct chilling effect on the extent of use, especially in low-income communities, and also because internet use results in consumption of an intangible resource. National commercial mobile networks also usually have expiration dates on their prepaid data packages and charge more per megabyte for the smaller data bundles that low-income communities can only afford.

The effect of this pricing was recently the subject of a report from the Competition Commission of South Africa, which stated: "This finding indicates a potential structural problem with retail prices in South Africa, whereby poorer, prepaid consumers are exploited with relatively higher prices than the wealthier post-paid consumers." The Commission went on to state: "The sample shows that subscribers consuming between 100-500MB per month can pay more than twice per MB compared to consumers of 1-2GB per month. This is far worse for even poorer consumers, with those consuming between 50-100MB per month paying up to three times more and 20-50MB around four times more."[12]

In contrast to national commercial networks which charge per minute or per megabyte of data consumed, there are usually no usage charges associated with the traffic generated by the user of a community network, except for long-distance calls. In some cases, there were no monthly usage fees at all, when costs were covered externally. However, more often, fees are based on a specific time period (e.g. one week or one month) over which unlimited use can occur, subject to bandwidth limitations.

In the community network in South Africa, for example, data fees are between 20 and 40 times cheaper than the "pay-as-you-go" mobile data bundles available to the people there. Prior to the widespread deployment of the network, local people spent more than 20% of their income on communications,[13] and as described in Section 3, many now spend under 5% of their income. Similarly, in the Mexican mobile community networks, unlimited local calls cost about USD 2.50 a month, while off-network calls cost about USD 0.02 a minute. Even when the network depends on expensive satellite internet links, such as one of the networks in Brazil, monthly access fees are only about USD 5 a month per user, which is shared among an average of 40 devices.

While affordability and limited connectivity in rural areas were cited as the primary reasons for establishing the community networks, a wide range of other benefits were often

12. Competition Commission of South Africa. (2019). *Data Services Market Inquiry*. http://www.compcom.co.za/wp-content/uploads/2019/04/Data-Services-Inquiry-Summary.pdf
13. Rey-Moreno, C., Blignaut, R., Tucker, W. D., & May, J. (2016). An in-depth study of the ICT ecosystem in a South African rural community: Unveiling expenditure and communication patterns. *Information Technology for Development*, 22(1), 101-120. https://www.tandfonline.com/doi/full/10.1080/02681102.2016.1155145

reported – some were intentional by the network initiators, and others were revealed by users in the course of the research, as described in more detail in Section 3 below.

The initial triggers for starting the network were observed to be closely related to the goals of the network, the level of community involvement and the types of services provided. In this respect four main groups of motivations were identified, some of which are likely to overlap within any particular initiative:

- **Provision of voice or internet services** where there were none, or faster/more affordable services than are already present through traditional commercial networks. As indicated above, the key motivation for community networks is to address the lack of coverage and affordable services that is so widespread in the rural global South. Some of the community networks also had a more specific focus, such as addressing the communication needs of indigenous communities or other marginalised groups.
- **Supporting rural development and/or community empowerment.** Provision of connectivity is often seen as an important means or entry point to "building community", or it can be part of one or more of a number of different rural development efforts being used for community upliftment aiming to leverage the benefits associated with better connectivity, such as improved education/training and business or employment opportunities. In some cases, support for connectivity is built on the provision of solar energy because of the absence of grid power in many rural areas.
- **Income generation/employment by small businesses.** Where connectivity is limited and local entrepreneurs or small businesses based in the community have awareness of the opportunities, as well as the required skills, connectivity services based on traditional commercial models of selling access to the end-user are visible. These types of networks appear more common where commercial fixed internet providers are present in the community but are selling broadband services that are unaffordable to the majority of the community members.
- **Research** into the use of different connectivity technologies and institutional sustainability models. Given the role of academic and research institutions in the genesis of the internet, along with their foresight and innovation facilitation roles, it is not surprising that a substantial number of the community networks have been initially established with their support. In most cases, this has been as a test bed for investigating the potential of new technologies and alternative strategies for addressing connectivity gaps; in other cases, academic and research institutions have provided technical support or internet capacity.

The individual motivations behind the establishment of the 16 community networks are outlined in Table 2. As shown in the third column of the table, there is also often a specific initial "inspiration" which triggers the establishment of the initiative. This starting point may not necessarily be directly related to the current objectives, but following the initial inspiration, wider goals for provision of connectivity in the communities have usually emerged, and this is also often intertwined with the sustainability strategy.

It can also be observed that at least four of the community networks studied have some kind of relationship with community or hyperlocal radio stations: AlterMundi/QuintanaLibre (Argentina), BOSCO (Uganda), Pamoja Net (DRC) and W4C (India). In addition, the first mobile network in Mexico emerged from a community radio initiative. These relationships with community radio are not surprising given the similar objectives that they usually have around improving access to communications and information. Many community radio stations also have physical infrastructure that could be leveraged for a community network, in particular high towers and electric power.

Table 2. Community networks: Primary goals and initial inspirations

Initiative and country	Primary goal(s)	Initial inspiration
AlterMundi/QuintanaLibre, Argentina	Affordable wireless internet and community empowerment through collaborative activities.	Self-provisioning of better/cheaper internet access, and improved community cohesion.
Associação Portal Sem Porteiras, Brazil	Affordable wireless internet and community empowerment through collaborative activities.	Self-provisioning of better/cheaper internet access, and improved community cohesion.
BOSCO, Uganda	Economic development for communities in refugee area through public access facilities.	Address isolation through solar power for youth upliftment/business development – job opportunities, training, and access to information.
Des Hotspot, Indonesia	Take advantage of business opportunities for addressing lack of affordable access.	High cost of local fixed-line internet services, income generation.
Gram Marg, India	Identify new options for addressing connectivity gaps in rural India.	Research and demonstrate locally developed TVWS radio system for internet links, plus test PPP and entrepreneur models for connecting the unconnected in rural areas.
Mayutel/Red de Telemedicina del Río Napo/TUCAN3G, Peru	Connectivity for health clinics, later combined with technology research for more affordable mobile voice and data access.	Telemedicine and access to information for health centres for malaria control and improving maternal/child health.
Pamoja Net, DRC	Connectivity provision to support economic development and reduce isolation on a large remote island.	Response to request from King (Mwami) of Idjwi North Island, Gervais Rubenga, to help create opportunities for youth.
Puspindes Centre for Information and Rural Empowerment/RelawanTIK, Indonesia	Support digitalisation of local authority procedures, develop village online presence and local populations' use of ICTs in rural communities.	Improved economic and social development through better access to and use of ICTs.
Quilombola Community Network, Brazil	Indigenous community strengthening through better access to communications, and government services.	Provide communication tools to mitigate threats to rural livelihoods created by conflicts with cattle ranchers over access to land.
RelawanTIK/Common Room, Indonesia	Leverage urban/rural collaboration for better access to communications and accelerated adoption of ICT use.	Urban/rural collaboration to improve economic, social and cultural development through better access to digital media.

Taknet/Net2Home, Thailand	Improve rural internet connectivity and test new technologies.	Mesh networking research project for better community resilience.
Telecomunicaciones Indígenas Comunitarias (TIC AC), Mexico	Indigenous rural community strengthening through better access to communications.	Address lack of access to communications in indigenous communities.
Ungu Community LTE, Bokondini, West Papua, Indonesia	Improved rural connectivity.	Pilot using new mobile technologies for community-based mobile data services.
VBTS Konekt Barangay, Philippines	Technology and institutional model research for improved rural connectivity.	Assess impact of connectivity provision through the use of new low-cost mobile base stations.
Wireless for Communities (W4C), Digital Empowerment Foundation, India	Empowerment of rural communities through support for better use of ICTs through connectivity provision.	Rural empowerment through the use of digital tools.
Zenzeleni, South Africa	Better connectivity to support rural economic development through cooperative ownership and operation of telecom resources.	University research to test if rural self-provision could address the high voice and data costs in South Africa.

Organisations with supporting roles in community networks

As listed in Table 3, material support for the networks has been received from over 50 different international and national organisations, ranging from UN institutions and bilateral development agencies, to US and European foundations, national and international NGOs, technology companies, local authorities and academic/research organisations. The internet technical community, also known as the i* organisations[14] – in particular the Internet Society (ISOC) and the regional IP registries, LACNIC, AfriNIC and APNIC – have been particularly active in supporting a number of the community networks through their grant programmes, providing financial support as well as training, convening groups of community network representatives, and commissioning research.

It was also observed that local authorities (municipalities) or their equivalents – traditional authorities and indigenous people's assemblies – had a significant role in virtually all of the community networks studied. This ranged from material support such as rent-free provision of premises for the network, meeting spaces, tower or hotspot space and electricity, to support at a more strategic level where the local authority is involved in the governance and promotion of the network.

Of special interest for replication of community networks in future is the key role in some of the community networks played by organised groups of volunteer information and communications technology (ICT) technicians in addressing needs for technical skills and training. These were found in Thailand and Indonesia, where the networks benefited from

14. https://www.apnic.net/community/ecosystem/iorgs

assistance provided by these volunteers, who are usually students and graduates from ICT programmes of tertiary and vocational training institutions.

In the case of Thailand, the THNIC Foundation, established by the administrator of the .th ccTLD – the Thai Network Information Centre (THNIC) – supports annual "camps" of the Thai Networking Group (THNG)[15] on the theme "Internet Technology for Society". Volunteers from this group have assisted in the initial deployment of the TakNet/ Net2Home networks and trained the local entrepreneurs in network technologies.

In Indonesia, the volunteers are members of an NGO specifically registered to support and encourage them – RelawanTIK[16] – which was founded in 2011 by well-known exponents of ICTs in Indonesia who had grasped the potential of wireless network technologies for bottom-up connectivity approaches in the early 2000s. RelawanTIK (which means ICT Volunteer in Bahasa Indonesian) now has about 8,000 member volunteers across the country, who are present in virtually every district, working to assist in the adoption of ICTs in society. They help individuals, local authorities, public institutions such as schools and clinics, as well as small businesses to use the internet more effectively and develop an online presence. Through instant messaging channels, RelawanTIK volunteers make themselves available for technical support, and they often hold monthly talks and training sessions on specific topics. RelawanTIK also has an annual nationwide meeting supported by government and corporate social responsibility (CSR) programmes. A branding strategy with a uniform has been produced for them as well.

In Pemalang, Central Java, the local RelawanTIK group, called Puspindes Centre for Information and Rural Empowerment, has been provided with premises by the governor of the district to carry out training and to house and manage the servers, wireless networking equipment and tower needed to provide connectivity and hosting for some of the village authorities. Even in the remote province of Banda Aceh there are an estimated 1,000 RelawanTIK members, of which about 30% are thought to be women. The members there meet regularly in 34 special interest groups, ranging from promoting culture online and network security, to using drones, printing on t-shirts and digital photography. In Bandung, the RelawanTIK group has a strong focus on supporting the use of educational tools based on digital technologies for schools and vocational training.

In Indonesia in 2017, an umbrella group for all the community-based and grassroots movement on digital literacy called Siberkreasi[17] was formed, comprising government, CSOs, academics and the private sector. At the end of 2018, about 100 organisations had joined the group, which aims to set up free digital literacy hubs in 100 cities and provide intensive digital literacy training for 4.6 million people.

15. www.thng.in.th, www.thng.in.th/#thng-camps
16. https://relawantik.or.id
17. www.siberkerasi.id, www.literasidigital.id

Table 3. Organisations supporting the community networks

Initiative and country	Supporting organisations
AlterMundi/*Libre, Argentina	Universidad Nacional de Córdoba (Argentina), ISOC, FRIDA (LACNIC)
Associação Portal Sem Porteiras, Coolab, Brazil	Coolab/Fundação Rosa Luxemburgo (Brazil), Ford Foundation (US), Mozilla Foundation (US)
Battery Operated Systems for Community Outreach (BOSCO), Uganda	Roman Catholic Church, Caritas (Italy), Ocer Campion Jesuit College, UNHCR, UNICEF, War Child (UK), University of Notre Dame (US), Accenture Foundation (US), HorizonT3000 (Austrian NGO implementing Austrian government development projects), Hewlett Packard, NetHope, AfriNIC/FIRE, local authorities
Des Hotspot, Indonesia	RelawanTIK
Gram Marg, India	Indian Institute of Technology (IIT) Bombay, Tata Trusts (India), gram panchayats (local authorities), Ford Foundation (US), Mozilla Foundation (US), Common Service Centres (Indian government)
Mayutel/Red de Telemedicina del Río Napo/TUCAN3G, Peru	Universidad Rey Juan Carlos (Spain), GTR-PUCP (Group for Rural Telecommunications, Pontificia Universidad Catolica del Peru), Agencia Española de Cooperación Internacional para el Desarrollo (AECID), City Council of Madrid, ORAS (Andean health NGO), European Commission, FITEL (Universal Service Fund of Peru)
Pamoja Net, DRC	Fjord[18] UK (Accenture Interactive), Altech (DRC), Falling Whistles (UK), Facebook (US), Open Mobile Alliance
Puspindes/RelawanTIK Indonesia	RelawanTIK, local authority
Quilombola Community Network, Brazil	Instituto Nupef (Brazil), Coolab (Brazil), Ford Foundation (US), APC, Google (US), NIC.br, ISOC, IDRC (Canada)
RelawanTIK/Common Room, Indonesia	RelawanTIK, regency (local authority), GIZ (Germany), Astra International
Taknet/Net2Home, Thailand	Internet Education and Research Laboratory (intERLab), Asian Institute of Technology (AIT), Thai Network Information Centre Foundation (THNICF), Tak Community College (adult/community learning centre), National Broadcasting and Telecommunication Commission (NBTC), Microsoft Research, ICTP, University of Cambridge
Telecomunicaciones Indígenas Comunitarias (TIC AC) Mexico	Rhizomatica, Redes por la Diversidad Equidad y Sustentabilidad AC, Shuttleworth Foundation, IDRC (Canada), ISOC, Mozilla Foundation (US), UBS/Google Prizes, local indigenous authorities
Ungu Community LTE, Indonesia	University of Washington & Airwaves Mission, Amazon Catalyst, APNIC/ISIF
VBTS Konekt Barangay, Philippines	University of the Philippines, University of Washington, University of California Berkeley, Aurora State College of Technology (ASCOT), Philippines Commission on Higher Education (Philippine government), Globe (mobile operator), APNIC/ISIF, USAID
Wireless for Communities (W4C), Digital Empowerment Foundation (DEF), India	ISOC, APC, Cap Gemini, Ford Foundation (US), Goldman Sachs (US), Ericsson, IEEE, Indus Towers, Microsoft, Media Lab Asia, Ministry of Communications and IT, Mphasis, Nokia, Railtel, Tata Trusts (India), Vodafone Foundation, gram panchayats (local authorities)
Zenzeleni, South Africa	University of the Western Cape, APC, ISOC, AfriNIC/FIRE, Mozilla Foundation (US), Ellipsis Regulatory Solutions, Technology Innovation Agency (TIA), European Commission CONFINE programme, traditional authority

18. https://firstlight.fjordnet.com

INSTITUTIONAL MODELS AND SUSTAINABILITY STRATEGIES

The institutional models of the community networks studied varied considerably, ranging from networks run by non-profit member associations, cooperatives and small business franchises, to NGO projects and partnerships between government and academic institutions. The institutional models not only reflect the origins of the networks but also the varied sustainability strategies adopted.

Ensuring effective sustainability strategies is often seen as a concern for the long-term viability of rural networks because they operate in remote, sparsely populated areas which are inherently more expensive to cover than more densely populated areas, while income levels of the potential users are much lower. Costs for backhaul, energy and transport are also often higher than in urban areas, and due to the generally small size of community networks, there may be limited economies of scale. This can mean higher per-user overhead costs than in larger networks, although on the other hand, operational expenses in community networks can be considerably lower considering they do not have other expenses that national operators incur, such as advertising, retail stores, R&D, etc.

In addition, because of their localised nature and the community involvement in the initiative, the networks often receive pro-bono services from community members, local authorities and local businesses, and marketing and public relations budgets are generally not a high priority. Being able to start at a small scale, their start-up costs are low, and operating expenses are often minimised by drawing on volunteer labour, rent-free provision of premises and high sites to erect towers, as well as grants providing donations of equipment, or CSR programmes providing discounted backhaul capacity. Volunteer labour ranges from basic administrative and coordination tasks to more innovative local production of equipment, such as antennas and masts.

There are also many important social and indirect economic benefits that can be derived from the community networks, as described in Section 3. However, it is still necessary for them to operate within the market economy and have the financial means to pay for the network and its operations. Some of the networks have similar strategies to traditional commercial networks, where users pay a monthly fee to cover all costs, although many community networks have a more diverse range of alternative models and strategies which help them achieve financial sustainability. The variety of these strategies also illustrates how, despite the homogenising effect of the market economy, community networks address the unequal distribution of resources by drawing on a more diverse set of mechanisms in order to achieve sustainability.

In this respect, “sustainability” has a variety of other faces than simply “financial sustainability”. However, frameworks for including these are generally absent in the current market-driven environment. As a result, sustainability strategies generally cannot take into account the many indirect benefits and positive externalities created by the community networks described in Section 3. This is also because of the difficulty in quantifying the multiple, diverse and small/micro economic benefits that community networks offer, and this is heightened because their cumulative positive effects occur incrementally over time, and most networks are still relatively young.

Underscoring the variety of approaches taken, the noteworthy elements of the institutional models and sustainability strategies are summarised in Table 4. See the end of this section for additional details on each network.

Table 4. Institutional models and sustainability strategies in community networks

Initiative and country	Institutional models and sustainability strategies
AlterMundi/*Libre, Argentina	• Independently governed village networks supported by a non-profit umbrella organisation. • Agreement with a university for free internet capacity. • Users make small monthly contributions to cover equipment replacement costs. • Locally manufactured parabolic antennas to reduce costs. • All members/users attend technical workshops, and can provide in-kind contributions. • Partnership with company to manufacture low-cost mesh wireless LibreRouter to address deficiencies in existing commercial equipment, partially supported by a grant from the tech community.
Associação Portal Sem Porteiras, Coolab, Brazil	• Non-profit membership association providing free guest access public hotspots, with content-sharing platform. • Members make small monthly payments and in-kind payment to cover bandwidth and equipment. • Some loan funds from the Coolab collective, which supports development of community networks in Brazil. • Uses the "sociocracy" decision-making methodology.

Battery Operated Systems for Community Outreach (BOSCO), Uganda	• NGO BOSCO sets up public access centres in partnership with premises owners, and centres are managed by local youth groups.
	• BOSCO provides free Wi-Fi links to the centres and also to schools and other charitable organisations; cost recovery from organisations in planning.
	• Free access given through external donor funding which supports:
	  ○ Digital literacy and entrepreneurship capacity building
	  ○ Content for community radio station.
	• Support provided for premises from some local authorities.
	• Initially donated microgrid solar electricity generation systems – sale of energy managed as a business by youth group to repay cost or by local schools paid through savings on grid electricity payments.

Des Hotspot, Indonesia	• Existing electronics hardware repair/copy service. • Adds small-scale WISP service to repackage unaffordable retail fibre broadband into lower bandwidth, more affordable services for residences and small businesses.

Gram Marg, India	• Research organisation initiated partnership with large telecom operator CSR programmes, local authorities, and later the national e-government implementation SPV-CSC.
	• Testing of different institutional models for public access Wi-Fi:
	  ○ Public-private partnership with local authorities and CSR digital education support
	  ○ Commercial WISP dedicated to supporting village-level entrepreneurs (VLEs)
	  ○ Sale of Wi-Fi airtime vouchers and provision of support for users making online transactions/e-government and bill payments provides commission income for VLEs.

Mayutel/Red de Telemedicina del Río Napo/ TUCAN3G, Peru	• NGO/university partnership develops Wi-Fi backbone for connecting clinics. • Now used by specialised rural 3G mobile operator supported by Peru's universal service fund (FITEL). • Commercial operator partnership provides for sustainability and scaling/replication. • Close links between NGO activities in the field and academic and research institutions in Spain and Peru.
Pamoja Net, DRC	• NGO-operated network as response to request for youth upliftment from the traditional leader of Idjwi Island to the organisation supporting integrated rural development. • Free off-peak Wi-Fi access cross-subsidised by income generated from business and NGOs.

Puspindes/RelawanTIK, Indonesia	• Nationwide tech volunteer NGO assists in provision of paid Wi-Fi hotspots as part of a broader government-supported ICT adoption programme for local authorities. • Includes government-mandated requirements for local authority websites and content development.
Quilombola Community Network, Brazil	• Non-profit livelihoods association provides mixed domestic/public Wi-Fi hotspots with monthly subscription to cover the cost of the satellite link, and a mixed free/pay-to-use public access facility. • Public access service used for e-government registrations which are vital to legitimise the traditional livelihoods of palm nut harvesters that are in conflict with large landowners/cattle ranchers. • Participatory mapping programme used to identify the communities in need. • Initial grant and ongoing tech support from research institution.
RelawanTIK/Common Room, Indonesia	• NGO-supported public access facility as part of a larger digital media, arts and culture-based rural/urban development collaboration support programme with support from the regency (local authority).
Taknet/Net2Home, Thailand	• Partnership between technology research agency and internet domain name administrator. • Uses a local franchise model to repackage unaffordable retail fibre broadband into lower bandwidth, more affordable services for residences and small businesses. • Community decision making on locations for placement of broadband gateways. • Weather and environmental/air pollution sensor network adds additional value by detecting patterns of smoke pollution from burning rice fields.
Telecomunicaciones Indígenas Comunitarias (TIC AC), Mexico	• Non-profit association provides interconnection, backhaul, technical and administrative support and licence management as a shared facility for independent village-level mobile networks. • Local networks managed by local authorities with strong community-based decision making. • Low-cost software-defined radios used for mobile base stations. • Indigenous local assemblies involved in the legal test cases to help change legislation. • Tower exchanges and commercial relationships with WISPs for backhaul. • Interconnection with other local voice networks via international VoIP/SIP gateways.
Ungu Community LTE, Indonesia	• Test bed/pilot for new open source low-cost LTE-based mobile broadband network. • Prepaid airtime top-up for data. • Data only – no voice services provided to avoid competition with licensed voice provider.
VBTS Konekt Barangay, Philippines	• Academic- and government-supported research project leveraging a partnership with one of the two national mobile operators (Globe) for access to their spectrum and interconnection. • Local networks are owned by community cooperatives supported by local authorities. • Voice and SMS-only service currently. • Randomised control trials taking place to compare impacts of the networks with unconnected villages.

Wireless for Communities (W4C), Digital Empowerment Foundation (DEF), India	• NGO uses local and international grant funds combined with revenues from sale of access to support a wide range of charitable rural access initiatives:
	  ○ Provision of roving public access vehicle for nomadic salt-harvesting community groups.
	  ○ E-commerce/entrepreneurship support for women.
	  ○ Provision of digital literacy, information services and digital services by local entrepreneurs running wireless networks.
	  ○ Connectivity and distance education for local authorities and schools.
	  ○ Connectivity and telemedicine for clinics.
	  ○ Community radio station connectivity.
	• "Network in a box" developed for quick and easy deployments.

Zenzeleni, South Africa	• Non-profit company acts as an umbrella group to support village-level cooperatively owned prepaid public Wi-Fi hotspots, supported by local traditional authority. • Additional revenue generation from wireless links to businesses and public institutions. • Has access to low-cost backhaul via partnership with wholesale operator. • Business development included in the strategy with the communities learning how to start and manage their own businesses.

Provisioning models

More detail on each network is provided further below, but as can be observed from Table 4, the initiatives examined can be grouped into three models which reflect their institutional strategies: a) **self-provisioning** of connectivity, b) **entrepreneurial provision** of connectivity, and c) **externally supported provision** of connectivity. These may be called "business models", but the term is avoided here because so many of these networks do not operate as a business in the traditional sense.

In the **self-provisioning** group, members of the community have established and operate the network mainly on a cost-recovery basis and largely with their own resources. Some of these networks started informally and grew relatively slowly, but are largely independent of outside support, and their governance models are usually based on participatory structures such as a non-profit association, traditional assemblies or a consumer cooperative.

In the **entrepreneurial provision** group, a local business or informal commercial enterprise sells connectivity services to end-users, usually as an addition to other existing business activities and in most cases supported by an umbrella organisation. Similarly to the self-provisioning model, some have established their community network without external resources and grew organically. However, some operate as part of a more complex and mixed model structure, where, for example, the infrastructure is established and maintained as a non-profit by one entity and businesses simply sell air-time or access vouchers. Although the pure entrepreneurial approach may be focused on the jobs or income potential that can be derived from a market opportunity, where they have low overheads and operational proximity to the end-users, these networks can be more affordable and potentially more responsive to community needs than larger commercial operators.

The **externally supported** group is the largest and most diverse among the network groups examined. There are essentially two sub-groups here: a) development organisations providing connectivity as part of broader rural upliftment activities, and b) research organisations setting up pilot projects to test technologies and institutional models. It can be observed that a number of initiatives in this group also contain elements of the other two groups, or are transitioning to the **entrepreneurial provision** model or to the **self-provisioning** model. In this respect, it should be noted here that while the strategies and sustainability models are stable in some of the networks, in others they are still emerging.

There may also be a regional pattern to the distribution of these models. Among the cases studied, the self-provisioning model is more common in Latin America, while the external provisioning model is more common in Africa, and the small-scale entrepreneurial model is more common in Asia. Given the small number of cases studied, and an inability to assess their degree of typicality, further research on a larger spread of community networks is necessary to explore this rather crude generalisation. Nevertheless, this pattern may fit

with general observations in these regions which indicate that rural communities in some countries in Latin America are more politicised and have a strong sense of their capabilities and a culture of self-reliance, in addition to their higher wealth and education levels. At the other extreme, rural communities in many African countries may have less capability to take advantage of new technologies and institutional models, partly because they have fewer financial resources, basic infrastructure is more scarce, and people are generally much less well educated.

These observations are not meant to suggest that the distribution of these models reflects the most appropriate matches for each region. Rather, they aim to improve overall understanding so that future initiatives can take advantage of having better knowledge of the contexts in which the most effective models and strategies can be adopted.

Umbrella and support organisations

One particularly important observation emerging from the research is that most of the initiatives studied have an additional institutional layer – an "umbrella" or support organisation – that provides the individual community networks with various resources. This is to be expected in the externally supported networks, but is also evident in the other models, with their supporting organisations based in towns or cities at some distance from the operating networks in the rural villages. The three main ways that support to individual networks is provided by these umbrella organisations are by:

- **Operating shared network infrastructure** as resources which are used by the individual networks, such as high sites/backhaul links and voice gateways. This also has parallels with some of the developed country community networks, such as guifi.net, where shared network resources are treated as a "commons" and are managed as common-pool infrastructure.
- **Centralising technical and administrative support**. This can be related to the design and operation of shared infrastructure, which often requires experienced technicians to configure mobile base stations, for example, or scaling Wi-Fi networks to share bandwidth and calculate link budgets to optimise long-distance links. In addition, centralised technical support can reduce the need for each local network to replicate all of the often scarce human resources required to operate and maintain the network.
- **Acting/negotiating on behalf of individual networks** in relations with government, suppliers and partners, such as in licensing, obtaining internet links and fundraising. This usually also includes support for the development of community networks in the country more generally, such as by raising awareness of the potential of community networks and lobbying for their support by policy makers and regulators.

Overall, it is apparent that the presence of the umbrella organisations helps to avoid unnecessary replication of network resources at each location, and is also a response to the difficulties of supporting widely scattered rural networks with limited local availability of skills, helping to address the need for scale in these environments. Since these umbrella organisations are usually located in a city, this also allows them to be closer to upstream capacity providers, equipment vendors, donors, spheres of political influence and offices where paperwork is required.

This stratified structure of many of the community network initiatives thus appears to be a particularly important component for helping to ensure effective and sustainable community networks. As Section 3 explains, the physical, educational and cultural distance between far-flung parts of the organisations also brings challenges. Technical staff working at these support organisations often work extremely long hours, and may need to travel long distances when they need to be physically on-site at the network. Although they are motivated by a strong sense of responsibility to the local networks they serve, there may be a need for more resources being allocated to building and maintaining network administration skills in each local network. However, further research across a wider range of community networks over longer time periods is needed to better understand these relationships, and the advantages and challenges of these organisational structures.

Levels of community involvement

In terms of community involvement, Figure 2 is a crude simplification of the situation, but illustrates how the networks can be roughly divided into five different categories. These are spread across a spectrum of levels of community involvement, and associated to a greater or lesser extent with the different institutional models and sustainability strategies.

Figure 2. Networks divided into five groups in relation to community involvement

Related to the level of community involvement, the goals of the cooperative model and the non-profit membership association can be closely aligned with community network endeavours, especially as these structures can help to reinforce the broader social benefits described in Section 3. Also, although not present in the group of community networks studied, the user-group club may offer similar potential. Furthermore, there is often a high level of community-wide resource sharing already present in many rural communities, which can be specifically encouraged, or leveraged, by community networking initiatives, such as in agreeing to share the cost of a base station, a VSAT link, a fibre cable or a high site, or being part of a mesh network. Cooperative institutional models would appear particularly well suited to these types of network architectures.

The rich history of rural cooperatives suggests that there is a strong precedent for these types of models. In both developed and developing countries, rural cooperatives are widespread and many have existed for over a century, working in the areas of telecoms, energy production, savings/finance, agriculture and food distribution.

INDIRECT OUTCOMES: IMPACTS ON THE CONNECTIVITY ECOSYSTEM

The study shows that the emergence of some of the community network initiatives has resulted in a number of changes to the general connectivity ecosystem in the area.

In some cases, this has been in the form of a response from larger commercial providers that are active in the same location, such as in Argentina and Brazil, where they have reduced their fees or extended their coverage in an effort to "compete" with the community networks. This took some time because initially the commercial providers were doubtful that a community-based self-provisioning initiative would be able to get off the ground or have staying power.

In a number of locations, community networks and commercial providers co-exist, which gives the user more choice, and may potentially incentivise the community network to provide a higher quality service. This also means that community members can choose the type of service that meets their needs best – some may choose to use the large commercial services, while others may choose to be part of the community network. Frequently, people use both the local network and one or several commercial providers. In particular, users of the community network often also keep SIM cards of the commercial operators for calls or internet access when travelling to other areas, or for when the local network is down.

Traditional commercial operators with a footprint in the area have in some cases supported or collaborated with the community networks, such as by providing discounted internet links, or providing other resources such as sharing access to towers or spectrum. In a number of cases, the large commercial providers benefit directly by having their service "re-sold" in smaller units, growing their market without requiring their effort. In a sense, these community networks are basically low-cost agents for larger commercial networks, selling access vouchers or collecting fees to pay the operators. This can be observed with the community Wi-Fi networks in Thailand and Indonesia, for example, as well as the mobile networks in the Philippines.

In the case of mobile/voice networks, many of the community networks make extensive use of local internet providers to provide backhaul connections for the base stations, or to link to other voice networks in other countries or regions. This type of synergy may change once the community voice networks gain data capabilities.

Similarly, the community voice networks also provide benefits for commercial networks because the community networks generate additional traffic (and thus revenues) for the commercial networks. For example, analysis of calling patterns in the community mobile networks deployed in Mexico and the Philippines shows incoming call traffic is four to 10 times higher than the outbound traffic originating from the community networks.

It is also evident that the experience gained by the presence of the community network has encouraged some members of the local communities to build on the services offered or develop their own communications services. This can range from providing additional public access facilities (Uganda), to restaurants and shops selling Wi-Fi access vouchers

(Indonesia), or using the community network's mobile base station towers to establish Wi-Fi services (Mexico). See Section 3 for further details on some of these.

Some community networks have also helped larger commercial operators to make a business case for provision of services in otherwise "unprofitable" areas (intentionally or unintentionally). For example, the Wi-Fi backbone built by EHAS for the clinics along the Napo River in Peru helped encourage rural mobile operator Mayutel to roll out voice and data services. More generally, it is likely that the presence of an active community network has pointed to potential markets, or built demand for services that make it sufficiently attractive for the traditional operators to deploy services there.

In conclusion, it appears that community networks may not be the only option for a particular area. They are likely to exist in a more heterogeneous environment where there are a variety of operators and different types of services present. They are also likely to have a positive indirect impact on the general communications ecosystem in which they operate, although further research is required to better understand how these dynamics play out and the opportunities they bring.

Table 5. Summary of institutional models and financial sustainability strategies

Initiative and country	Institutional model	Primary financial sustainability strategies
AlterMundi, Argentina	Non-profit association	Cost recovery from users, in-kind contributions from community members and university
Associação Portal Sem Porteiras, Coolab, Brazil	Non-profit company	Cost recovery from users, in-kind contributions from community members
BOSCO, Uganda	NGO with partnerships with municipalities and refugee support agencies	External support from grants, partnerships and in-kind support
Des Hotspot, Indonesia	Semi-informal small business	Revenue generation from end-users
Gram Marg, India	Research organisation in partnership with government and private sector	Cost recovery from selling access to users
Mayutel/Red de Telemedicina del Río Napo/TUCAN3G, Peru	Commercial operator supported by NGO	Revenue generation from end-users combined with low-cost wireless backbone/backhaul
Pamoja Net, DRC	NGO supported by traditional leader	Cost recovery via cross-subsidy from leasing fixed links which covers free off-peak public Wi-Fi access
Puspindes/RelawanTIK, Indonesia	NGO in partnership with local authority and private sector	Volunteers, national and local government partnership
Quilombola Community Network, Brazil	Non-profit company	Cost recovery from Wi-Fi users, revenue generation from public access facility
RelawanTIK/Common Room, Indonesia	NGO supported by indigenous community leadership	Volunteers, grant funding and local authority partnership
Taknet/Net2Home, Thailand	Research organisation partnership with foundation operating a franchise with small business franchisees	Mixed cost recovery for shared network operated by the foundation, with revenue generation for local entrepreneurs from fees charged to end-users

Telecomunicaciones Indígenas Comunitarias (TIC AC), Mexico	Civil association ("Asociación Civil" – an association of actors with common objectives)	Cost recovery and revenue generation from end-users to support the projects of the indigenous assemblies that own/operate the networks
Ungu Community LTE, Bokondini, West Papua, Indonesia	Informal structure supported by international research organisation and local small business	Cost recovery from end-users
VBTS Konekt Barangay, Philippines	University, government and private sector partnership with cooperatives at the village level	Revenue generation from end-users
Wireless for Communities (W4C), Digital Empowerment Foundation, India	NGO in partnership with local authorities	Grant-funded free services with some cost recovery from end-users, combined with partnerships and in-kind support from local authorities
Zenzeleni, South Africa	Cooperatives supported by non-profit company	Cost recovery from end-users

A conceptual framework for financial sustainability

The financial sustainability of the network is mainly affected by four factors: the density of users, their income levels, usage-dependent costs (primarily upstream connectivity and to some extent energy), and fixed operating costs. Fixed operating costs are at least relatively usage-independent, such as tower/premises rental, staff, depreciation and licence fees. Each of these factors can vary by a factor of 10 or more, depending on the location, government policies and the scale of the network, so drawing generic conclusions about the start-up or operating costs for sustaining or dimensioning community networks can be somewhat meaningless. However, there are some broad underlying principles that help to provide a picture of how these networks can be financially sustained.

The smallest, and probably most prevalent, community network sustainability model worldwide is simply the shared broadband connection. This is how virtually every household or business with a fixed broadband internet connection functions today – a wireless router is used to share the connection between the occupants, usually informally, paid for by the household or by the company. Where there is more than one family, or another grouping within the household or business, they may jointly pay for the connection. In developing countries, many may also share it with their neighbours in order to reduce the cost further.

The shared broadband connection is not only the essence of the self-provisioning model, but is also basically how the entrepreneurially supported community networks function, where small local businesses resell a local broadband connection to their neighbours and further afield using low-cost Wi-Fi routers. Both these models can also be sustained by the economies of scale in internet capacity provision, where cost of bandwidth on a per Mbps basis becomes significantly cheaper as more capacity is purchased. The village-level entrepreneurs that are part of the ecosystem of many of the community networks are based on the opportunity this creates, which in essence is simply an extension of the tiered architecture of the internet's wholesale/retail market-based access provision, with further downstream "micro-tiers".

For both small entrepreneurs and self-provisioning communities, the presence of fibre broadband down to the village level makes it relatively easy to start these initiatives with minimal resources. However, significantly more funds and a much larger organising process are required to establish relationships with distant suppliers, to build expensive towers and to set up the long-distance links that are needed when backbone infrastructure is more remote. This helps to explain the presence of umbrella organisations, as well as the externally provisioned model, especially where the local population may not have the initial awareness of the possibilities and/or the technical capabilities and financial resources. This is particularly the case where deficient policy and regulatory environments result in expensive and burdensome licensing requirements, lack of infrastructure sharing, and distant or costly upstream connectivity.

For community-based mobile GSM/LTE networks, the basic frameworks for financial sustainability are similar to Wi-Fi, although there are additional issues around licensed spectrum access, initial start-up costs, and the geographic restrictions or other conditions that are imposed as part of the licence obligations. Assuming the conditions allow both fixed and mobile wireless technologies, then there is potential for cost savings by combining the deployment of both mobile and Wi-Fi infrastructure, as is taking place, for example, in Colombia's Cauca district community networks, which are currently being set up with support from Colnodo.

Sustainability challenges

The key sustainability challenges of the community networks studied were largely related to the policy and regulatory environment. Challenges were also related to factors such as remote locations, sparsely distributed low-income populations, and hilly or mountainous topography, which inherently make the establishment of network infrastructure more difficult or more costly to set up and operate. However, those factors cannot be changed, and the networks demonstrated that the challenges relating to them can be surmounted, especially if they are mitigated by enabling government policies on the telecom sector. By the same token, the challenges can be exacerbated by the lack of policies and regulations that could support community networks. In some cases, policies and regulations were partially in place but not defined sufficiently or enforced to the benefit of community networks.

Technology choices

In terms of technology choices, as indicated earlier, the regulatory environment generally excludes community networks in most countries from providing mobile 2/3/4G voice or mobile data services. This is despite the fact that GSM spectrum is largely unused in rural areas.

Although TIC AC in Mexico was the recipient of the world's first indigenous 2G GSM concession, its licence has a cap on the size of the community that can participate of 2,500 people. The licence also restricts it to operating in five states – mostly those with the lowest incomes and highest proportion of indigenous people. In addition, the amount of 2G

spectrum provided to TIC AC is very limited – to only two (2+2 MHz)[19] channels – which significantly restricts the number of people that can be served in the same location. Moreover, while TIC AC is also keen to deploy 4G systems to provide internet services, more spectrum in a band suitable for rural coverage would be needed, and so far that has not been made available.

In the case of VBTS in the Philippines, to gain access to spectrum and avoid the substantial regulatory burdens attached to mobile networks in the country, the University of Philippines established a partnership with Globe, one of the two dominant operators. Globe provides access to its 2G spectrum and its core network for the community networks, which are institutionally independent organisations (existing village cooperatives). The community networks need to purchase their own satellite capacity to connect to Globe's infrastructure, and only voice and SMS services are currently supported.

The case of Peru's Mayutel is similar. This is a larger commercial initiative which has a rural provider licence and is now present in 150 locations. In the Napo River area it uses Telefónica's spectrum, essentially acting as a reseller of Telefónica's mobile voice and data services, while renting capacity and tower space on the Wi-Fi backbone originally deployed for clinics along the river.

In Indonesia, Ungu is able to operate a mobile 4G/LTE network which does not compete with existing licensed service providers. The national operator has recently begun providing 2G services in the area, and so Ungu operates a pure data (internet) mobile service, which uses a satellite link for upstream connectivity.

Regarding mobile services among other community networks, in December 2018 AlterMundi in Argentina received a licence from the national regulator for provision of non-profit ICT services, limited to population centres of less than 5,000 inhabitants.[20] As such, self-provision of any type of communication technology by its membership, or the provision of free services, is permitted; however, access to mobile spectrum is not covered by the dispensation.

Similarly, subject to gaining access to mobile spectrum, Zenzeleni in South Africa has obtained a licence exemption, while Pamoja Net in DRC hopes to obtain a licence for 4G/LTE service under the dispensation of the king of the island. Also of note is that in early 2019, APC member Colnodo gained permission to assist local communities to set up mobile networks in the Cauca district in Colombia, but it is restricted to areas outside those covered by existing operators.

The remaining community networks in the study are limited to using technologies based on the licence-exempt 2.4/5.8 GHz Wi-Fi spectrum bands – also often called the Industrial, Scientific and Medical (ISM) bands – to serve their users, although operating licences may still be required. Some of the networks, such as BOSCO in Uganda, operate as private networks which do not sell services, and therefore they do not require an operating licence, provided they are fixed networks which use licence-exempt spectrum. In Brazil, the community networks are taking advantage of the ruling of ANATEL, the Brazilian regulator, which has exempted small providers with less than 5,000 users from the obligation to

19. 2 MHz on the downlink and 2 MHz on the uplink.
20. blog.altermundi.net/media/uploads/licenciaaltermundi-1895-18_resol.pdf

obtain a licence based on the principle of "insignificance". Instead they are only required to submit a notification and annually update the information in their records. In Thailand, Net2Home has a social enterprise licence which allows it to function as an ISP.

In contrast to the lower frequency bands such as those used by mobile networks, which make it possible for devices to connect to a base station over distances greater than a kilometre, the licence-exempt 2.4/5.8 GHz bands need a line-of-sight link when connecting over distances greater than a few dozen metres. However, regulators impose limitations on the power output of the radio transmitters used, which affects the distance over which there is a usable signal, which in turn has an influence on the density (number) of hotspots required to cover a particular area. As a result, start-up costs are higher when low power devices are required by regulations.

The power output limitations can vary significantly from one country to another. For example, in Brazil and the Philippines, the maximum outdoor output power (EIRP) is 1,000 mW, while in India it is 4,000 mW, and in Indonesia and Thailand it is only 100 mW. South Africa also offers a licensing exemption with regards to Wi-Fi, allowing for higher radiated power than in many other countries. In the event that a community network runs out of channels in its licence-exempt spectrum, the South African regulator also allows a flexible and low-cost fee structure in other bands that could be used in backhaul links by community networks.

The lower frequency 900 MHz ISM band, which could be used in non-line-of-sight situations, such as through hills and the forest vegetation present at many of the community network sites, is only defined as licence-exempt in North America and a handful of other developed countries, including China, but is not available elsewhere. Similarly, the lower frequency UHF bands traditionally occupied by analogue broadcasting between 450 MHz and 800 MHz are largely unoccupied in rural areas in the global South.

These bands can also be shared with other licensed users by using software-defined radios with dynamic spectrum assignment, often known as TV white space (TVWS) technologies. These offer great promise for community networks, as was experienced in Gram Marg's pilot, prior to the non-renewal by the regulator of its test licence (see below for details). Speaking on the potential value of TVWS in the United States following the opening of regulations there, Rise Broadband's Jeff Kohler recently stated:

> All of the testing that we've done in the field and that we've done in the lab shows that we're going to be able to deliver well in excess of the FCC-mandated broadband speed of 25Mbit/s [downlink]/3Mbit/s [uplink]. We'll be able to do it at good distances and with much better propagation than any other spectrum tool that we have in the bag right now being installed in low band.[21]

However, despite these advantages, regulators in the global South, except for South Africa, have so far not been willing to make these frequencies available for networks operating TVWS-based links.

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21. Dano, M. (2019, 21 March). TV White Space Supporters Have New Reasons to Cheer. *Light Reading*. https://www.lightreading.com/mobile/white-spaces/tv-white-space-supporters-have-new-reasons-to-cheer/d/d-id/750348

Network links and interconnection

As indicated earlier, due to the low cost of the equipment, in-kind contributions, and shared institutional resources, start-up and operating costs for community networks are relatively small compared to commercial networks. However, the cost of the links to connect the community networks to the rest of the world are usually much greater than for commercial networks. Upstream costs in the community networks varied considerably, depending on the location and the nature of the capacity provided, but the most frequently observed costs for terrestrial links were USD 40-80 per Mbps per month, while satellite links. For comparative purposes, large commercial operators normally pay less than USD 2 per Mbps per month for internet transit capacity.

One of the chief reasons for the higher costs of capacity experienced by community networks is that the relatively low quantities of capacity they require means that it is often purchased at retail prices, and is consequently much more expensive per Mbps than the higher capacities and wholesale pricing obtained by large commercial operators. Many of the large operators actually do not have to purchase upstream capacity at all. They are part of multinational telecom groups that are vertically integrated – not only do they sell in the retail market, but they often have their own fixed-cost fibre backbones and submarine cables, resulting in virtually zero incremental costs for their own capacity use. Most of the community networks were located in countries which also have state-owned backbones, but pricing of capacity on this public infrastructure has not been any cheaper.

A few of the community networks have been able to negotiate discounted or free capacity, but this is unlikely to be available indefinitely, and for the remainder, bandwidth costs are usually the single largest operating expense, which is a significant burden on sustainability and limits its use by community members. In the majority of the networks where cost recovery takes place from the end-users, the high cost of capacity creates a disincentive to more extensive use, or the expansion of the network. This takes place in two ways: a) by reducing the number of people who can afford to use the network because the high costs of capacity need to be recovered through the higher fees charged to the end-users, and b) to save costs, the amount of upstream capacity purchased is limited, resulting in demand exceeding supply, which creates congestion, resulting in poor performance.

Some of the networks, such as BOSCO in Uganda, have had to address these constraints by limiting the use of high bandwidth applications (such as video) during the day, but this can be counterproductive, for example, when so many valuable educational materials are in multimedia format. There are also software tools used by the networks which can help optimise the use of congested and expensive upstream links, such as web caching servers and ad-blockers, but these only mitigate the problem to some extent.

Aside from the high operating costs resulting from the community networks' upstream capacity needs, high set-up costs were also evident, resulting from the high towers needed in many cases to reach fibre points of presence, which were up to 50 km distant in nearby towns. This was the case in most of the networks studied, except for those in Asia, which are located in relatively populous rural areas, where government policies and investment have resulted in more extensive capillarity of fibre infrastructure down to the village level. In a few instances in the other regions, the fibre backbones of large commercial operators pass near to some of the community networks. But even in the rare instances where regulations require the owners to make spare capacity available to others, it is usually not

economically feasible for the communities to use them due to the high minimum charges levied.

For example, in Mexico, Telmex fibre is present near some of the community networks in Oaxaca and the company is required by law to provide its network to third parties. However, it is not affordable for the TIC AC community networks to use it, because the fees and requirements of the offers are designed for large commercial operators and cannot be met by the community-owned networks with much smaller economies of scale.

High tower costs

Similarly to the constraints the community networks experienced in cost-effective access to fibre, there is also lack of access to the existing towers of the large commercial operators. While infrastructure-sharing regulations are more common for towers than for fibre cables, the fees charged by the operators usually make it prohibitively expensive to use them.

For example, Pamoja Net on Idjwi Island in the DRC needs to obtain a backup link and access the cheaper upstream internet capacity available across the lake in nearby Rwanda. But this is not economically feasible, because Airtel Rwanda would charge the ISP in Rwanda USD 1,600 a month just to rent space for the radio on the Airtel tower (Airtel already uses the tower to connect to its sister network, Airtel DRC). This high fee is most probably levied to deter competition, which Airtel is free to do because the Rwandan authorities (as with most regulators) do not have price controls in their infrastructure-sharing regulations.

As a result of these regulatory deficiencies, setting up links to the rest of the world (or even to extend local coverage) has required the community networks to construct their own high towers. Aside from the waste and added visual pollution resulting from the duplication of towers, in many of the locations they usually constituted the largest single cost for setting up the network. In Uganda, for example, the cost of BOSCO's standard 25- to 30-metre-high towers is about USD 9,000 to 10,000. BOSCO operates 14 towers and one of them is as high as 80 metres. Transport costs, installation and lightning protection all add to these costs. As an indication, some of the 90-metre-high towers with extensive lightning protection set up in the remote areas of the Amazon jungle in Peru by EHAS cost up to USD 50,000. In some countries, there are also additional licensing fees and onerous environmental impact assessments required for towers.

Tower costs could be minimised by using lower frequency radio spectrum, which does not require line of sight, as this means much shorter towers can be used. However, these frequencies are either not licence-exempt or are not made available. Where they are available, the high cost of annual spectrum fees makes their use economically unjustifiable.

A good example of the economic impact of regulatory barriers in access to spectrum for upstream connections was shown in the case of Gram Marg in India. Internet links for the villages were initially deployed using TVWS equipment operating in the lower frequency UHF bands, which have the capacity to travel through trees and other obstacles over distances of many kilometres. However, IIT Bombay was unable to convince the regulator, TRAI, to extend the TVWS test licence it had been given, so it was forced to replace the links with line-of-sight links using licence-exempt Wi-Fi spectrum, which required much

higher towers. This significantly increased the cost of the network and in one instance a community was cut off because it was on the other side of a large hill from the upstream connection, and could not be feasibly connected within the budget available.

Where regulations allow, satellite links can be a more cost-effective alternative to high towers or multi-hop long-distance links. But the bandwidth available is more limited, there are latency issues, and costs are much higher.[22] Fortunately a donation of satellite capacity was obtained in the cases of Mayutel in Peru and TIC AC in Mexico. These networks have lower traffic requirements because they only need to service low-bandwidth voice traffic. Satellite fees can also be traffic-based, which makes for costly links when servicing internet traffic. For example, one of the Wi-Fi networks in Brazil depends on a consumer-grade satellite link which only costs about USD 65 per month, but data traffic is limited to 30 Gb per month, half of which is used by the network in a week.

There is also another challenge created by the high cost and consequent lack of diversity in locally available upstream links: only one of the networks studied had an active backup link in place. Without redundant infrastructure, ideally from different providers and along different physical paths, the networks are vulnerable to outages caused by equipment failure or other problems along the route to the national or international hubs. Although rural areas in the global South may be more accustomed to unreliable basic infrastructure and services, network interruptions are still likely to have a strong negative effect on the value placed on the community network, and thus on its desirability or level of use, and therefore on its sustainability.

Aside from the lack of enabling policy environments for ensuring affordable access to spectrum or to the infrastructure of large commercial operators, the absence of regulations which limit the cost of interconnection with other voice networks was also found to be a burden. For example, the cost for a small network in Mexico to obtain national phone numbers to allocate to subscribers is about USD 4 per month per number – almost double the current monthly fee paid by TIC AC's users. This is not economically feasible, so TIC AC has had to use a US-based VoIP provider with an internal numbering scheme, and has developed a smartphone application to simplify calling community members from outside their home networks.

Taxes charged by governments have also been an issue. In Brazil, government taxes and levies on the satellite service used by one of the networks double the cost of the bandwidth for the connection to the internet, which further increases the largest operating cost element for running the network. In Argentina, AlterMundi has found that import taxes double the cost of wireless routers. In Mexico, TIC AC actually took the government to court (and won the case) over taxes that were being charged related to use of spectrum.

Electricity supply

The other particularly important challenge experienced by the community networks relates to access to grid power. Poor quality electricity, or often its complete absence,

22. Lower costs can be achieved with larger and more expensive satellite ground stations using C-band, but the equipment/set-up costs are significant, and can cost as much as a tower. Annual licensing fees are also a major cost in many countries.

substantially increased the cost of network deployment by requiring costly energy-generating equipment. Where there is no grid power, generators could have been used, but renewable energy was usually adopted, mainly due to the logistical difficulties of keeping generators refuelled in remote areas (aside from the air pollution and noise they create).

Off-grid energy was therefore largely provided by photovoltaic (solar power) systems, the cost of which varied significantly, depending on the climate at the site, the architecture of the network and the use of the devices. The power equipment is not only required for each element of the network itself, but also for the end-user equipment – so in this way, lack of grid power also affects demand for the network, because few users can afford this equipment in most areas.

Even a photovoltaic system for the lowest level of need is a significant expense for a low-income household in the global South. Depending on the country, a solar charger for a phone or tablet cost up to USD 30, and a system to power a wireless router that just services the premises when needed cost about USD 150. A solar power system for a router that is part of the network infrastructure and requires enough batteries and solar panels to last for days of cloudy weather cost upwards of USD 500, while a system to power a mobile base station (which uses significantly more energy than a wireless router) cost USD 1,500 or more, depending on the power requirements, which are related to the output power of the radios used. This equipment was also often not available in the location of the community network, which resulted in extended downtimes when replacements were required, as the networks generally did not keep spares to hand.

In some cases it was also necessary to support a variety of voltages required by different pieces of equipment, which pushes up the cost of the solar power set-up significantly. For example, Wi-Fi equipment usually runs on 12 volts or 24 volts, while traditional telecom equipment often runs on 48 volts.

Another important issue in the provision of solar power systems for community networks relates to planning for expansion of the network. To ensure the power system is able to meet the needs of future growth, it may need to be over-dimensioned initially, as it can be more expensive to upgrade the system later. This can require additional start-up resources as well as experienced and skilled network technicians to make the correct decisions about the most appropriate size of the power systems.

Income levels, basic literacy and digital literacy

The institutional model adopted and the ability of the community network to scale can be influenced by the development levels of the country and in the specific location of the network. For example, the community networks providing internet access in the more developed/higher-income countries, such as those in Argentina, Brazil, Thailand and Indonesia, have users that are more likely to have the resources to purchase their own wireless routers to expand or join the network. They are also more likely to have sufficient funds to cover their costs of network usage.

Users in these countries may also need less support to make use of the internet – they are more likely to be literate, and more digitally literate, than their counterparts in the DRC and Uganda, for example. However, they may also have higher expectations of network performance, and place more demands on the network, partly because they are more likely

to have their own laptops or tablets which can consume more bandwidth. This could suggest that they may have less need for public access facilities, although other research[23] has shown that even those with their own personal access devices continue to benefit from the availability of public access facilities as multifunctional safe community spaces to gain knowledge and to socialise.

Technical skills and awareness raising

The availability of technical skills to set up and maintain communication networks in many of the more remote and low-income settings represents a substantial challenge in ensuring community network sustainability, and is similarly an issue for their potential to replicate or to expand their coverage areas. The cost of technical expertise can be high, and technicians are a rare resource in rural areas, often leaving for greener pastures after having acquired technical skills. To help address this, an important component of most of the initiatives has been the simplification and standardisation of equipment in deployments, along with ongoing training of technicians.

In addition, many of the community networks have focused on production of documentation and training materials – for example, the detailed manual for deploying mobile cellular community networks produced by Redes AC,[24] Pamoja Net's Wi-Fi deployment manual and W4C's Internet in a Box operating manual. Efforts are also being made to ensure that software and equipment are easier to set up and maintain, such as AlterMundi's Zeroconfig tool which will be used to autoconfigure new Wi-Fi nodes on an existing mesh network, and the innovative text message-based troubleshooting tool developed in the VBTS project.

Perhaps an even larger challenge for scaling and replication has been the lack of awareness in remote and rural communities in the global South that it is actually feasible to set up and operate an independent community network. Presence of this awareness is usually associated with people who have some degree of technical skills, and in most of the community networks studied here, it is evident that the presence within the initiative of people with technical knowledge is among the important factors that resulted in their initial establishment.

However, lack of awareness may not be such an issue in future. The community networks described here, along with many others, are providing examples that are beginning to become more widely known. This is not only taking place through recent efforts at national and international levels to promote knowledge of their potential for addressing connectivity gaps, but awareness has also spread locally to the communities near the existing initiatives. It can be observed that demand for similar resources by nearby communities is being expressed, and that the clustering of some of the groups of networks is the result of this more organic type of replication or expansion. The instances of this are:

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23. Sey, A., Coward, C., Rothschild, C., Clark, M., & Koepke, L. (2013). *Public libraries connecting people for development: Findings from the Global Impact Study*. Seattle: Technology & Social Change Group, University of Washington Information School. https://tascha.uw.edu/publications/public-libraries-connecting-people-for-development
24. https://www.apc.org/sites/default/files/manual-de-telefonia-celular-comunitaria.pdf, English: https://archive.org/stream/MANUALTICENGFINAL/MANUAL%20TIC%20ENG%20FINAL

- AlterMundi's *Libre, which began in one village and has since spread to four more neighbouring villages in Argentina.
- The request from the traditional authority in neighbouring South Idjwi to expand Pamoja Net's network to this location in the DRC.
- The expressed interest of the community members in which the Quilombola network operates in Brazil to extend services locally, as well as the interest of neighbouring Quilombolas to host similar networks.
- The steady growth in TakNet/Net2Home installations based on responding to the communities that have requested the service in their villages in Thailand.
- The many requests for the replication of the mobile networks in the indigenous communities that are close to earlier TIC AC networks in Oaxaca, Mexico.
- The replication of the initial Mankosi-based Zenzeleni network to a second cooperative in neighbouring Zithulele, South Africa.

This local contagion effect provides a strong impetus and argument for expansion and replication of community networks in geographic proximity. In externally supported initiatives, leveraging local efficiencies also saves on project costs and simplifies logistical issues.

RECOMMENDATIONS

Improving policy and regulatory environments

It is evident from the observations presented above that members of community networks have taken many innovative approaches and shown substantial perseverance in surmounting the many challenges in setting up and maintaining their networks. The key challenges centre around the lack of enabling policy and regulatory environments, shortage of financial resources and skills, as well as limited awareness of the technical options, and lack of time to plan and undertake tasks in remote and rural areas often with very limited resources. This section proposes some measures to help address these challenges.

As discussed above, it is evident that policy and regulatory environments in most countries limit the viability of community networks and are among the main constraints in their ability to replicate. Regulations in most developing countries are generally not agnostic about the scale of the operator, the business model or the technology used, which limits services available to the public to those provided mainly by a few large (inter)national mobile operators, while in a few cases leaving a some crumbs[25] for "special purpose" licences and some licence-exempt Wi-Fi providers.

Overall, lack of access to licences and radio spectrum for community networks is largely due to the lack of a supportive policy environment and restrictions set by national policy makers who may be: a) unaware of the need or the range of options for providing small-scale networks with the required policy environment, b) less concerned about the needs of remote and rural areas, c) uninterested in the minimal income and administrative burden

25. For example, TIC AC was only able to obtain 4 Mhz of mobile spectrum, while most operators would have 20 Mhz or more, despite not using it in rural areas.

that multiple community networks may bring them, d) concerned about protecting the franchises of large commercial operators, or e) concerned about the security issues resulting from the independence of these networks, especially in less democratic governments.

Nevertheless, if the connectivity gap between the haves and the have-nots is going to be closed, policies and regulations need to be modified to eliminate barriers to entry for small networks and to provide them with more opportunities to emerge and flourish.

Enabling policy and regulatory environment improvements should therefore focus on changes that:

- Make licensed and secondary-use spectrum available and affordable to small networks, and make additional frequencies available, either on an unlicensed basis, or on affordable and flexible authorisation schemes. As indicated repeatedly above, lack of spectrum access for small networks precludes their abilities both to provide mobile voice services and to use lower-cost or more effective systems which are based on frequencies that do not require line of sight. Such frequency bands include, for instance, the 900 MHz ISM band, TV white spaces in lower frequencies (both of which allow for low-cost and resilient long-distance links), as well as the 12 GHz and the 60 GHz bands (for which radio equipment is affordable and which can help build high-bandwidth point-to-point radio links).
- Adapt licensing regimes to allow small geographically limited and non-profit entities to qualify as authorised operators. Similarly to the management of radio spectrum, most regulatory regimes currently have a “one-size-fits-all” licensing framework which cannot accommodate small-scale community networks and institutional models with different objectives and fewer resources than those of large commercial telecommunication operators. This not only applies to aspects such as high licence fees, but also to data retention and “business plan” requirements.
- Make backhaul/backbone infrastructure and capacity more widely available (greater coverage), such as through infrastructure sharing and ensuring access to international fibre capacity. The main operating expense of most community networks is the cost of backhaul, which is ultimately reflected in cost recovery from the end-user. This also limits the number of upstream links to only one path out of the local network, which makes them more vulnerable to upstream network outages. Therefore, reducing backhaul costs can have significant positive impacts on both affordability and reliability.
- Ensure small-scale operators can interconnect with other operators in the country on an equal basis. Small networks have severe financial and other barriers to entry in gaining equal access to voice network interconnection, numbering resources, national/international wholesale capacity and dark fibre. Regulations need to make it mandatory for large commercial and government operators to share network resources without creating undue burdens on small networks. To encourage their growth, community networks could also be provided with free transit on state-owned backbones.
- Ensure universal service funds are available to support community networks. National governments have usually set up these funds to support the provision

of connectivity in rural and under-served areas, and many have accumulated large amounts of unspent funds, partly because of the limited capacity to evaluate and disburse funds, and also because of the paucity of effective projects to support. These funds could be more effectively used to encourage the development of community networks, but so far none have been able to benefit from them. In the few cases where they are accessible in theory, in practice this is often not the case because the conditions and requirements to access the funds are aimed at large commercial operators and are not adapted to the needs of small community-based networks.

- Ensure existing community networks are consulted in telecom policy and regulatory development. Governments are generally unaware of the needs or potential of community networks in their policy and regulatory development processes, while community networks have developed a wealth of experience in how local policies and regulations affect them.
- Minimise government taxes, levies and other duties when they apply to community networks, as these can often double the cost of network start-up and operations.

Of these above actions, the freeing up of radio spectrum is the most urgent and pressing issue that needs to be addressed as soon as possible, followed by ensuring that backhaul/wholesale capacity and interconnection are provided on an open access basis to small-scale networks.

Recommendations for future research areas

It is evident from the discussion above that there are many areas relating to community networks that require further research. Aside from carrying out research to address the limitations of the current research, as described in the methodology above, increasing the number of similar networks under examination is necessary in order to be able to firm up some of the more tentative conclusions, which are inconclusive due to the small number and variety of networks studied. Similarly, the research analysis could be considerably strengthened by building on this initial work and conducting follow-up visits to examine how these networks develop over a longer period.

Other areas that require further research are listed below.

Institutional strategies

Increased knowledge of the institutional strategies would provide valuable insights into how community networks "fit" within the broader telecom ecosystem and how they can be more effective. Potential areas include:

- Analysing institutional responses to changing regulatory conditions, and investment and support opportunities.
- Quantifying the economic benefits of the non-monetary contributions, such as voluntary work, in-kind provision of rights of way (access to roofs, buildings) and premises for meetings and installations, etc., as well as the positive externalities and other indirect economic impacts specific to community networks. This would in turn make it possible to more accurately measure performance and

calculate ARPU[26] and other indicators used by the telecom industry so that community networks can be characterised and compared more accurately with traditional networks.

- Identify strategies for data retention which comply with licensing regulations while avoiding compromising privacy and limiting the administrative burden.
- Identify interconnection issues and strategies for their mitigation. As indicated above, community networks face many constraints in obtaining cost-effective interconnection with other operators. These constraints arise from a combination of the regulatory environment and large operator policies. Research is necessary to define best practice in this area and to identify and raise awareness about countries and operators which perform well or poorly in this regard.

Community benefits

- Identify the potential and impact of micro work opportunities in community networks, an area which has not been observed systematically in rural communities.
- Deepen insights about local innovations and businesses that emerge within networks.
- Assess needs for building local knowledge exchanges and associated content.
- Identify local applications and services that can be built on the community network infrastructure.

Technical information and development needs

In the course of the research, many technical information gaps were identified, along with a number of technical development needs that would help community networks be more effective and sustainable, while simplifying the deployment process and improving their management. In terms of the technical information gaps, much of the knowledge is already available but is dispersed in different community networks as well as other locations, and simply needs consolidation, organisation and perhaps translation (for which an assessment of requirements is a research need in itself).

Addressing the needs identified below would not only benefit existing community networks, but would also be of value to emerging and new community networks.

- Common reference designs and equipment/software lists for small-scale network deployments – both mobile and fixed wireless – which can be assembled and shipped or carried to a location for set-up at a new site, or for demonstration purposes at events. This could be built on the work already carried out by W4C/DEF for the “Internet in a Box” project, and could include sourcing and importation advice, benchmark costs, and customisation options to adapt to local needs – e.g. types of radios (voice/data, power), types of antennas, extensible masts, alternate power supply modules (e.g. solar where needed), portability requirements, etc.

26. https://en.wikipedia.org/wiki/Average_revenue_per_user

- Designs, diagrams and materials lists for towers/masts of varying heights, varying electronic equipment and antenna weights (GSM/LTE vs Wi-Fi), with advice for design choices which are influenced by expected wind conditions and surface mounting requirements (buildings, rock, soil, sand). This would also need to include advice and designs to ensure security of equipment hosted at the tower (power and radio equipment) – protection from birds, weather (snow/hail) and theft. In addition, it would be necessary to include designs and bills of materials for low-cost lightning protection systems for masts of varying heights and expected lightning intensity, including sources for equipment and a decision framework for assessing the cost of protection versus replacement of equipment damaged by lightning.
- Designs and lists of equipment for power systems: a) UPS and power-smoothing systems for low-quality and intermittent grid power, and b) solar-powered systems. This would include advice on potential sources and on making calculations to dimension the power system based on expected weather patterns, reliability requirements and equipment power requirements (especially Wi-Fi vs mobile).
- Assessment of needs for local manufacture of antennas to reduce costs (compared to purchase/import of existing products) and if necessary, production of designs, materials lists and construction methods.
- Assessment of existing internet and GSM/3GPP network management software platforms and identification of modification requirements and strategies for ensuring the availability of software that matches the needs and skill levels of rural communities. Currently there are a wide range of different tools in use to provide network management and sometimes content management of the community networks. These range from basic bandwidth consumption monitoring tools to the use of automatic notification systems, trouble ticketing systems, captive portals and traffic shaping, using a variety of proprietary systems and open source options. These often include tools from popular equipment providers MikroTik and Ubiquiti. If a more unified and simpler set of applications could be assembled which meets the specific human capacity needs of community networks, this could substantially ease the human resource burden on network replication and scaling. Needs for multilinguality and priorities for language translation also need to be assessed.
- Design and development of a planning tool to guide geographic location and resource allocation for networks – especially for deciding on the placement of public Wi-Fi hotspots, and in some cases the timing of their activation – to reflect, for example, safety concerns of women, or the regular paths people take in their daily lives. This also extends to deciding where to limit coverage, where to sell vouchers, or where and how to provide public access facilities. This could be based on participatory mapping tools using images and digital storytelling, focusing initially on people who have been excluded. The development could start with codifying the simple rules that are already known – height, size and shape of antenna, coaxial cabling lengths, upstream wireless path distances and average distance to user concentrations, power output/sensitivity, weather, and peak/off-peak times.

- Develop guides and software tools if necessary for providing network managers and end-users with support and training resources, including a shared log of operator and user issues and a post-installation road map – cost-recovery model, bandwidth monitoring, traffic shaping, local services set-up, etc.
- Design/assemble from existing resources a local content server and associated tools (e.g. for pre-populating the server during off-peak times).
- Identify techniques for protecting data from access which could threaten the privacy of users, while ensuring it is available for legal compliance purposes.
- Develop network system expansion and migration strategies for moving from proprietary equipment to open hardware/open source technologies.
- Develop operating system and applications distribution with software applications relevant for community networks.

THE STUDY GROUP INITIATIVES IN DETAIL

This section describes the community networks studied in more detail, focusing on the evolution of the networks, and their institutional models and sustainability strategies.

AlterMundi/*Libre, Córdoba province, Argentina

AlterMundi is an initiative that emerged from, and supports, independent community mesh Wi-Fi networks in five villages in a rural area of Córdoba province that closely follow the self-provisioning model. The initiative stemmed from the technical knowledge of some of the individuals in one of the communities, and is also inspired by members of the community who are driven by strong aspirations for participating in and promoting models of community self-reliance and independence more generally. In Argentina this is supported by traditions of civic cooperation and resilient grassroots movements among less privileged people in the country who have in the past been subject to economic shocks, and where many rural areas continue to receive limited public services.

Within this context, a group of neighbours began a small network in 2009 to share the 6 Mbps fixed internet link to which one of them had subscribed. This subsequently evolved into five village-level networks which each have their own governance frameworks while sharing a common high-speed wireless network infrastructure. Using mesh networking software loaded onto wireless routers, the village residents are directly connected to local servers and to each other, either by line of sight or through a couple of hops between neighbours within the local mesh. The mesh also connects the residents to a tower on a high site, from where upstream internet capacity is obtained for all five communities, from the city of Córdoba about 45 kilometres away.

Most people in the communities have smartphones and have also subscribed to mobile service providers, although community network members usually only purchase a small amount of pay-as-you-go data for use when not in Wi-Fi coverage areas. There are also a few other wireless ISPs providing commercial services in some of the villages.

Most of the community wireless routers provide open Wi-Fi hotspots which can be used by people in the public spaces nearby. A captive portal is being developed which will give the general public a small amount of capacity, while network members receive the full capacity

available. The bandwidth target per site is currently 3 Mbps, for which a commercial connection would normally cost about USD 15 per month.

Self-installation

To participate in the network, purchase and self-installation of the equipment is expected, and regular training sessions are provided. There are also members of the community who can be paid to carry out an installation. To support ease of set-up, the equipment design has been simplified and standardised as much as possible so that little technical expertise is necessary to install or fix any equipment. In addition, a smartphone app is being developed to make installation and management easier, such as in aligning the antennas to optimise throughput and coverage, visualising traffic and identifying upstream links.

Role of AlterMundi

AlterMundi, an APC member organisation, was formed as a non-profit association to manage the shared infrastructure for the village networks and to support technical development and community network movements around the world. Each community network is independently governed and they have so far been named after the village in which they are located followed by the word Libre (e.g. QuintanaLibre), hence the "*Libre" moniker adopted here.

Free upstream internet connectivity

To provide its network with upstream internet capacity, AlterMundi was initially able to obtain 20 Mbps as a two-year donation from a local wireless ISP. Subsequently, a partnership was established with the National University of Córdoba, which provides AlterMundi with access to its unused internet capacity at no cost. The capacity available to the community networks during the day, when staff and students are on campus, is about 20 Mbps, and this increases to about 200 Mbps at night, as well as after midday on Saturday and all day on Sunday. This pattern relatively closely matches the traffic demand in the *Libre communities, which is generally higher during the university off-peak periods. Also, members of the community networks are aware that bandwidth is constrained during the day, and so try to reserve their high-bandwidth activities for the university's off-peak periods.

AlterMundi's IPv6 addresses and its AS number[27] were provided without charge by LACNIC, the regional registry for Latin America and the Caribbean, and with no backhaul costs, no permanent staff and few other overheads, the *Libre networks sustain themselves relatively easily. The network members purchase their own routers and make small financial contributions to a fund to cover the replacement of damaged equipment and other costs which may arise – most members contribute about USD 7 a month to the fund. The money collected has been used, for example, to repair and improve their network after many links were damaged by a tornado and hailstorm.

27. AS numbers are autonomous system numbers (ASNs) which are needed for independent networks with more than one upstream internet link.

QuintanaLibre is the oldest and largest of the *Libre community networks, with more than 60 nodes[28] that cover the village and the surrounding community. About 10 of these links are ethernet cable connections between neighbouring houses, which saves on router costs. The network also includes the secondary school and the cultural centre, and offers coverage in public spaces, some streets and two bus stops. In the nearby villages, the other four community networks have about 10 to 15 nodes each. Each node has an average of about three or four access devices connected to it during peak times.

LibreRouter development

Growth and replication of the five networks has slowed recently while awaiting the production of the LibreRouter – an open hardware wireless router which AlterMundi's network of technicians have been designing to meet the needs of community networks. Developed in collaboration with the University of Western Cape (UWC) in South Africa and a variety of funders,[29] it is now being manufactured by Dragino in China. Open source software called LibreMesh has also been developed to run on the LibreRouters and other commercial devices, which aims to provide additional functionality, and to minimise the technical skills needed to deploy a network.

With the LibreRouter/LibreMesh combination it is planned that new nodes will be added to an existing network simply by switching them on, and they will download the relevant configuration from a neighbouring node that is already part of the network. Aside from helping to address the needs of rural networks with limited access to technical skills, the hardware development effort was also necessary because the available commercial products have a number of technical limitations, and lack the full range of desired features needed for mesh networks.

New operating licence

In late 2018 AlterMundi received a licence from the national regulator, Enacom, for provision of non-profit connectivity services in areas of less than 5,000 inhabitants. This will allow AlterMundi to a) enter the discussion about how the regulator uses the Universal Services Fund, b) establish peering agreements with other operators within the current legal framework, and c) participate in spectrum assignment processes.

AlterMundi: altermundi.net
LibreRouter: librerouter.org
See the GISWatch 2018 Argentina chapter for additional information.[30]

28. Wireless routers in a mesh network are usually called "nodes" as they often support more than one link.
29. LACNIC's FRIDA fund, AFRINIC's FIRE fund, APNIC's ISIF fund, with partner organisations Freifunk (Germany), guifi.net (Spain) and Zenzeleni Networks (South Africa), Management Automation and ManMakeMachine (South Africa), EyeSeeTea (United Kingdom), Village Telco (Canada) and Dragino (China).
30. https://www.giswatch.org/node/6058

Associação Portal Sem Porteiras/Coolab, Monteiro Lobato, São Paulo state, Brazil

Portal Sem Porteiras began in 2015 with a small group of village residents who are self-provisioning their own mesh Wi-Fi network in a small rural town a few hours drive from the city of São Paulo. Recently registered as a non-profit association, the network was initiated by the local residents with support from Coolab, a group of community connectivity technicians in Brazil. Coolab received an award for its work with community networks[31] from the Mozilla Foundation Equal Rating Innovation Challenge, and this is being used as a recycling loan facility to support emerging community networks in Brazil. A loan of about USD 4,500 from Coolab helped Portal Sem Porteiras establish its high site in 2016, along with 10 wireless routers and some additional funds for the initial technical support.

A low-cost tower for the high site was purchased and rigged with a strip of LED lights to make it easier to align the antennas of the wireless routers in the often misty weather or at night. The network now has 12 mesh Wi-Fi nodes using the LibreMesh software loaded on commercial wireless hardware from TP-Link while the LibreRouter is awaited. The network is also using a variety of local server applications running on low-cost Raspberry Pis and set-top box devices, providing instant messaging, web hosting and file/image/video sharing. A 3 Mbps internet link to a commercial provider in a nearby town costs about USD 80 per month. Access to more internet capacity in future could be made possible by reaching an agreement with a local university.

Each member receives up to eight Wi-Fi access vouchers to give to their house guests, which are valid for 13 hours of online time (one per device). Non-members can also gain guest access to the network, but they do not participate in decision making, and are not able to draw on technical support or access to data stored on local servers. There is a plan to sell vouchers to temporary visitors, while Wi-Fi is currently freely available in the town square but is restricted to a speed of 500 Kbps. This also serves to make people living in the town more aware of the network, and is expected to encourage them to join. The effectiveness of the network is apparent in the response of local ISPs, which have since reduced prices and improved their services in the area.

Forming the association

Prior to the formalisation of the association, many preparatory meetings took place in which the community members discussed and documented the establishment of the organisation. Agreements on the decision-making and governance processes, the services to be provided and the cost-recovery strategy all needed to be made. The association members provide in-kind services such as meeting spaces, or by carrying out errands and other day-to-day chores for those who are more technically skilled in order to free up their time to work on the network.

Of note is the adoption of Sociocracy[32] as the association's decision-making framework – a methodology which appears suited to networks that are owned and operated by the community as horizontal associations, such as cooperatives, non-profit associations or

31. Coolab has helped start seven community networks in Brazil. https://www.coolab.org
32. https://en.wikipedia.org/wiki/Sociocracy

clubs. Sociocracy is a system of “dynamic governance” which aims to create productive organisations through a novel form of decision making. In Sociocracy, consent is defined as "no objections", and objections are based on the person’s ability and interest in supporting the aims of the organisation. Members discussing an idea in consent-based governance commonly ask themselves if it is "good enough for now, safe enough to try."

Cost sharing

Although the relatively small operating cost for the internet link is currently shouldered by the network founders, in future, all costs will be shared among members on a month-to-month basis. The service operates on a licence-exempt basis, and with no significant operating expenses other than the cost of the internet link and paying back the Coolab loan, the network is currently self-sustaining. Nevertheless, a detailed network management and cost-recovery strategy has been developed which is expected to help the network scale in future. It is also planned that a written agreement will be made with the land owner of the high site to provide the land for the tower in return for free internet access.

Coolab: https://coolab.org

BOSCO – Battery Operated Systems for Community Outreach, Uganda

An externally supported community network, BOSCO was established as a faith-based non-profit organisation (NPO) in 2007 by members of the Roman Catholic Church, which has a long history of social support activities in this undeveloped region affected by decades of conflict. The area was the battleground between Ugandan troops and the Lord’s Resistance Army, and is close to the border with South Sudan. As a result, it has a very large number of internally and internationally displaced people who mainly live in dispersed rural villages where they are integrated with the local communities.

BOSCO is active across a relatively large number of these rather densely populated communities, most of which are within a 100-kilometre radius of the city of Gulu, where BOSCO’s 20 technical and administrative staff are based at the Catholic Archdiocese. The Bidibidi refugee settlement, which in 2018 had about 300,000 South Sudanese refugees fleeing the civil war, is thought to be the largest refugee area in the world. The Adjumani refugee settlement has a population of about 50,000, and the town of Pabo, around which many refugees have settled, 60,000.

Solar-powered minigrids

BOSCO started by addressing the lack of electricity in the area by providing access to solar electricity systems to help school-based education and to create job opportunities for youth. This also involved deploying five “minigrid” solar power systems (of up to 30 kW) supported by a grant from the Accenture Foundation. The minigrid solar power systems are placed in schools and in a commercial centre, and costs are recovered through purchases of energy by the schools and small businesses, and by BOSCO for their ICT centres. BOSCO also planned for the sale of excess power to the grid but has not been able to obtain a licence to do this yet, pending an extended environmental assessment process.

Youth focus

While this work on electricity provision continues, the project also began providing wireless internet access and VoIP telephony in the internally displaced persons (IDP) camps by setting up public access centres which focus on digital literacy training, computer-based learning and supporting local business development for youth. Although some older people also use the centres, and cultural preservation is a priority area for BOSCO, the intentional focus on youth is an effort to stem urban migration and improve livelihoods, responding to their need to find jobs combined with their interest in the use of ICTs. With an average of about seven children per woman, there is a high proportion of young people in the population. In the country as a whole, about 48% of the population were under 15 in 2015. BOSCO estimates that over 50,000 people have benefited from the network to date.

BOSCO's strategy is based on a community "CE3" model, which comprises three interrelated areas that aim to build on one another to help local entrepreneurs grow their businesses:

1. *Entrepreneurial skills development:* This begins with an interactive course, followed by a mentorship programme, where participants receive one-to-one mentoring from a local business professional (delivered face-to-face) and an Accenture volunteer (delivered virtually via Skype and the Google Hangouts Platform) to help bring their business plan to fruition.
2. *Energy:* In each centre the energy system is set up in partnership with a local institution that co-invests, usually providing a secure facility to house the system and an agreement to pay for a certain percentage of the power.
3. *ICT connectivity:* Where possible, each site is equipped with internet connectivity, enabling the local members of the youth group to participate in web-based activities such as the entrepreneurship training.

Public access centres

The facilities are called ICT & Development (ICT&D) centres, and in total there are about 80 workstations spread across 51 centres. The centres are hosted in a variety of different institutions, ranging from schools, local authorities, churches and libraries, to refugee camp vocational training and small business support units. Most of the centres are operated by local youth groups, and MOUs for their management are normally signed between BOSCO, the provider of the premises and the local youth group.

In addition to the ICT&D centres, BOSCO has developed a number of public access kiosks called "ICT-Content Boxes", made from locally available recycled oil drums or metal cases which enclose a laptop, allowing it to be secure in a public space. Free VoIP telephony is promoted across the network, and most of the ICT&D centres are equipped with solar-powered Intel Classmate low-energy-consuming laptop computers (netbooks) designed for developing countries. Some ICT&D centres consist of offline computers connected to a local server, or set up to access data on the laptop hard drive.

Capacity building is an important component of the initiative, with each centre's management committee and trainers given instruction in basic maintenance of the computers and the solar power system. Trainers learn methods for instruction and are not qualified to be an official "trainer of trainers" until they have trained five others.

Offline content

To provide access to pre-loaded educational content on the offline computers, BOSCO is collaborating with UNICEF to use the Kolibri content management platform now called Learning Equality,[33] developed by Google with other partners such as the Hewlett Foundation. UNICEF is working to make Kolibri more accessible to those with disabilities by improving the screen fonts and providing text-to-speech capabilities.

Community radio

BOSCO has also been collaborating with RootIO[34] to help villages establish their own low-cost community radio stations, which use a smartphone and a low-power FM transmitter. RootIO radio stations share content via the cloud, and callers participating in the radio discussions can have their calls returned by the computer so people are not charged. RootIO also buys data at bulk corporate rates that are much cheaper than the retail prepaid data bundles available to community members, while RootIO's costs are offset by selling advertising to NGOs and businesses.

Human rights and ICTs

BOSCO has received support from the Austrian government development partner, HORIZONT3000, for a seven-year programme to support the use of ICTs to improve human rights. This involves four elements:

1. Fostering community debate at the centres on issues such as land conflict, gender, and alcohol abuse.
2. Holding community fairs where different communities come together in a larger space to share information on these types of issues, which is then posted online.
3. Providing ICT literacy and leadership training for community leaders, down to the household level.
4. Capacity building for the ICT&D centres, focusing on the centre management committee and training of trainers. This includes basic maintenance of the PC equipment and solar system.

Institutional support

A wide range of other international partners, ranging from private foundations such as Accenture to UN agencies such as UNICEF, have supported BOSCO's work in areas such as the solar energy microgrid facilities and public access in the refugee areas.

BOSCO as an organisation has two institutional structures – the Ugandan non-profit agency, and a US Section 501c charity. The Ugandan board of directors consists of priests, lay people from the community, and technical advisors from academia, business and NGOs. The US organisation is primarily responsible for resource mobilisation and advice on operations, finance and technical strategy. BOSCO has also recently started a research department which will focus on gathering information on the impact of development activities and needs identification.

33. https://learningequality.org
34. https://rootio.org

Upstream internet costs

Until recently, BOSCO was purchasing 20 Mbps of capacity from the government fibre backbone operator (NITA) in Gulu for its upstream internet link, for which it had managed to negotiate a price of USD 50 per Mbps per month – down from USD 250 per month for the standard commercial rate. But when the price was increased by 60%, BOSCO dropped the amount of capacity purchased to 12.5 Mbps, which currently costs about USD 80 per Mbps per month. To help manage congestion on the network, access to YouTube and other video-heavy content such as BitTorrent and Netflix is blocked from 8 a.m. to 3 p.m. daily. Traffic shaping is also used to limit YouTube downloads to 1 Mbps per user, and 5 Mbps per site for live streaming.

To distribute connectivity, BOSCO had to build its own towers in many locations because despite efforts to negotiate, the fees charged by the mobile operators for using their towers were not economically feasible. Nevertheless, tower and upstream capacity costs are the biggest constraints on the development of the network, as BOSCO now operates equipment on 14 towers (one of which is 80 metres high) to provide a total of about 45 wireless links to two main hubs, in Gulu and Pader, of which the longest chain of links stretches some 180 kilometres.

The towers connect the ICT&D centres and a number of schools, NGOs, churches, mosques and radio stations using Wi-Fi equipment from Ubiquiti. NetHope has covered the cost of connecting five of the ICT&D centres currently outside the range of BOSCO's Wi-Fi network, using 3G dongles for the first year, after which BOSCO and the community will decide how to sustain the connection.

While access to the computers and the internet is currently free, other services are charged – for example, printing costs about USD 0.25 per page and taking photographs is USD 0.50 per photo. However, to improve sustainability options more generally, BOSCO has begun discussions with community members and the institutions receiving connectivity to assess their potential to contribute to the purchase of bandwidth.

BOSCO Uganda: boscouganda.com
See the GISWatch 2018 Uganda chapter for additional information.[35]

Des Hotspot, Banda Aceh, Indonesia

Des Hotspot is an example of the entrepreneurial provisioning model. The network was started in a small town on a remote part of the Banda Aceh coast by a family-run small business – a shop providing electronics hardware repair and copy services. Although the area has benefited from government investment in fibre backbone infrastructure, and broadband connections are locally available from the national incumbent operator, Telkomsel, they are still unaffordable for many households and small enterprises. Seeing a market opportunity, shop owner Desli Yandri added low-cost Wi-Fi-based internet to the range of ICT and electronics-related services he provides.

Desli's service repackages Telkomsel's retail broadband into smaller, lower bandwidth, but more affordable wireless bundles for local residences and small businesses. The links are

35. https://www.giswatch.org/en/country-report/infrastructure/uganda

mainly based on the 2.4GHz Wi-Fi band, which is officially licence-exempt, while use of the 5.8 GHz Wi-Fi band is a grey area as the rules for its use are still being decided by the national government.

The Wi-Fi-based service is provided using the low-cost small-scale network equipment used by many of the other community networks – Ubiquiti wireless routers – which are set up on 10 towers spread across the town. The towers needed to be specially constructed because although there is a tower-sharing/infrastructure-sharing regulation, it has not included fair price controls,[36] so owners of the towers charge too much rent for it to be economically feasible for others to use them. Desli's towers are usually located in households which are given free internet access in return for hosting the link and providing the electricity they require. Fortunately, as with 99% of urban areas in Indonesia, Calang town has reasonably reliable grid power, so the high cost of solar power systems is avoided.

Desli pays about USD 105 per month for a 40 Mbps fibre connection and resells most of the capacity in 2 Mbps channels via vouchers valid for one day (USD 0.35), one week (USD 2) and one month (USD 7). In addition, subscribers can purchase a higher bandwidth service of 4 Mbps, which costs USD 14 per month, or 6 Mbps, costing about USD 21 per month. There are about 100 monthly subscribers, 60% of which subscribe to the 2 Mbps monthly service. Three freelance technicians are paid USD 14 per visit to install a new customer or to fix a problem.

Keeping customers

Although there are now about six other fixed and mobile commercial providers in Calang town, Des Hotspot has continued to keep its customer base. The business already has a number of other income streams over which the administrative operating costs of running a business are spread, resulting in a competitive service. In addition, favourable terms are often provided by Desli when his users are late with monthly payments, supported through the close relationship he has with his subscribers who are all located nearby. Also, many of the users like the unlimited service (without traffic-based charges) – they often use mobile at work during the day, and the unlimited Des Hotspot capacity at their homes.

Desli has been able to help some of the more isolated households in the area obtain connectivity by installing 3G mobile signal boosters based on Yagi directional antennas connected to a "fixed" mobile phone. Using signal boosters to access the nearest mobile base station is often necessary in many of the smaller villages in the area because Telkomsel will only set up a base station if there are at least 3,000 people living in the catchment area.

Desli also participates in the local RelawanTIK groups in Calang which have about 1,000 members, of whom 30% are women. Many of the RelawanTIK members are part of the 34 ICT special interest groups which meet regularly in the local coffee shops in the town to discuss different technology topics, to keep up to date and to share experiences in helping people adopt the use of ICTs.

36. In Banda Aceh, a state with a certain level of autonomy, some regulations from the central government are not strictly enforced, hence Desli has not yet obtained an ISP licence.

Des Hotspot: https://bit.ly/2VPSfCt
RelawanTIK: https://relawantik.or.id

Gram Marg/IIT Bombay, Maharashtra, India

Gram Marg is an example of an externally provisioned Wi-Fi network that is transitioning to entrepreneurial public-private partnership models. Initiated by the Department of Electrical Engineering at the Indian Institute of Technology (IIT) Bombay, a large state-supported technical training and research institute, Gram Marg has been a test bed since 2012 for different connectivity technologies and institutional models for rural connectivity (Gram Marg literally means “road map”).

TVWS trial

Initially, seven villages were selected for deployment of TV white space (TVWS) spectrum-sharing technology for reaching non-line-of-sight locations as a potential means of helping to meet the Indian government’s objective of universalising connectivity. IIT obtained one of the experimental licences issued by the national telecom regulator (TRAI) for a TVWS trial, and with support from the Ford Foundation, a successful initial deployment of TVWS-based internet links took place in the test area in Palghar district, Maharashtra state. However, after pressure from the mobile operators to only sanction licensed spectrum use in these bands, the TRAI did not allow any of the TVWS trials in India to continue after the test period.

Public-private partnerships and village entrepreneurs

As a result, the project reverted to the use of licence-exempt Wi-Fi frequencies in an expansion of activities in 2015 with a grant from Tata Trust to test two different institutional models for providing connectivity. This required replacing the TVWS links with line-of-sight Wi-Fi connections which required more expertise and more expensive (higher) towers. In one model, a partnership with the local authorities (known as gram panchayats) was established to provide access in 15 villages, which IIT called the Public-Private-Panchayat Partnership (4-P), while the other project aimed to test a village-level entrepreneur (VLE) model in a set of 10 other villages.

The gram panchayats are the lowest level of government, in which residents over the age of 18 decide on the priorities for provision of public services, which now include internet access. The gram panchayats are all in the process of being connected by government fibre, which could be leveraged to provide improved access for the public. In the partnership model with the gram panchayats, customer service and technical support, including the deployment of the Wi-Fi hotspots, were provided by the Common Service Centre (CSC). The CSC organisation is a “special purpose vehicle” set up by the Ministry of Electronics and Information Technology (MeitY) of the government of India, to support the implementation of e-government services through the Common Service Centres Scheme. In each gram panchayat office a kiosk was set up, comprising a computer operator, a desktop PC, printer and scanner. In addition, a total of 86 public Wi-Fi access points were installed.

Initially, 20 Mbps of free upstream internet capacity was provided by Tata Trusts through its parent company, Tata Communications, which had some points of presence on nearby towers, some as high as 60 metres. However, the donation of capacity was a limited-time

agreement which ceased later in 2018. Subsequently the CSC took over the provision of internet capacity as well providing technical and administrative support.

Tower access

Access to towers to distribute the Wi-Fi signal came from a variety of sources. Where possible, existing high towers from other operators were used. Aside from the cost of construction, towers over 15 metres high are subject to regulatory and environmental impact assessment clearance procedures. This also requires a USD 500 fee for each three metres above 15 meters. Aside from the Tata masts, tower operator ATC provided 13 towers as part of its CSR programme, and 12 defunct government voice network towers were also used after being reinforced. In addition, a low-cost 15-metre tower and a nine-metre-high monopole mast was designed, costing about USD 700. Equipped with a solar power system capable of providing a 48-hour backup, and a Wi-Fi access point, the tower cost about USD 1,200.

Community engagement

IIT Bombay also partnered with Impact India, the NGO that supports Gram Marg's outreach work and coordinates an adult learning programme based around videos[37] developed by Tata Trust, which are shown at the premises of gram panchayats and in some schools. Groups of up to five local youths in each village were recruited as Village-Level Entrepreneurs (VLEs) to facilitate video-based teaching sessions and to sell Wi-Fi access vouchers for which they receive a 40% commission. In these villages, VLEs also help community members to carry out transactions with the government and make payments on their behalf, such as for TV and electricity bills.

The demand for these services is relatively high due to the extensive electricity and TV networks available in rural areas, as well as the large number of online government services, which include certification for births, deaths, marriages, caste and domicile, as well as pension and toilet application forms, and voter, house and food rationing registration. IIT has also found that the user base fluctuates significantly over time, based on the presence of three different sets of user groups: a) permanent users, b) long-term but irregular users, and c) sporadic users who may only visit the community and use the service during holidays or festivals, for example.

Some villages have as many as five VLEs. Most of them were trained through the Pradhan Mantri Gramin Digital Saksharta Abhiyan (PMGDISHA) scheme, which was set up by the government of India to ensure that by 2020, at least one person per household has digital literacy skills. VLEs need to be able to speak Hindi and the local languages of their area, as they have an important role to play in being able to converse with the community members who may not be familiar with other languages. It is planned that the VLEs will undergo training to maintain the network; however, at this stage, the CSC's staff travel long distances to troubleshoot problems.

Entrpreneurial model

In the other set of villages where testing of the more entrepreneurial strategy is taking place, the Wi-Fi hotspot service is managed by VLEs with some technical training,

37. culpraj.org/Druv-Project, https://www.druv.org/about

supported by Kirat, a wireless ISP start-up which was established and based in IIT's Gram Marg office. Kirat works in the 10 villages using a type of franchise model with the VLEs in deploying the towers and Wi-Fi hotspots, and in sharing the revenues from the sale of prepaid access vouchers to users. VLEs receive a 40% commission on renewing the user's subscription. In one of the villages visited, six Wi-Fi access points provide service to about 50 users who pay between USD 3 and USD 11 per month, depending on the speed of the connection. A voucher for one day costs about USD 0.13.

To service the communities, based on a 1:20 contention ratio, Kirat purchases 20 Mbps of internet capacity commercially at about USD 20 per Mbps, while the VLEs cover the cost of expanding the Wi-Fi hotspot network where opportunities are identified for generating additional income from the village residents. In a novel approach to marketing and identifying popular locations for new Wi-Fi hotspots, one of the VLEs placed unconnected hotspots at potential sites which announced his phone number and potential service availability in the hotspot name (SSID). If enough people called, the VLE would connect the hotspot set up in that location to the internet.

Kirat has a district-level (Category C) ISP licence, which cost USD 2,300 for 20 years (a Category B licence for the whole state would have cost USD 22,000). The cost of rental access to commercial operator towers is lower than in most of the other networks studied, only costing USD 7/month for the space, and USD 28/month if electricity is provided. Nevertheless, with power outages and multi-hop upstream links to some of the villages, reliability has been an issue. An initial two-month period of free access was also provided in some cases, aiming to provide time for villagers to gain value from the connection.

BAIF collaboration

IIT Bombay has also recently partnered with BAIF Development Research Foundation to seed the growth of a new set of community networks in a bottom-up approach in two villages where BAIF works. BAIF focuses on supporting self-employment in rural disadvantaged areas. The project is also supporting indigenous tribal populations with capturing local knowledge and the marketing of local arts and crafts.

Gram Marg: grammarg.in
Kirat: kiratcommunications.com
BAIF: baif.org.in
See the GISWatch 2018 India chapter for additional information.[38]

Mayutel/Red de Telemedicina del Río Napo/TUCAN3G, Peru

This case is a combination of three different initiatives over the last 15 years which encompass both externally supported and entrepreneurial elements. The Madrid-based Spanish NGO Hispano-American Health Link (EHAS) Foundation,[39] which shares staff with the ICT department of Rey Juan Carlos University (URJC), has been jointly deploying and researching the potential of low-cost communication technologies in developing countries for two decades. In Peru, many of the projects were carried out in partnership with the

38. https://www.giswatch.org/en/country-report/infrastructure/india-0
39. Enlace Hispanoamericano de Salud: www.ehas.org

multidisciplinary Group for Rural Telecommunications at the Pontificia Universidad Catolica del Perú (GTR-PUCP) in Lima, which has implemented a variety of Wi-Fi, VHF and VSAT networks for public agencies (health, education, municipal government, police) in the Andean highlands and Amazon jungle.

Telemedicine

Use of connectivity to support health post administration and supporting innovations which help address the lack of medical expertise in remote areas has been a strong focus of the group, particularly for epidemiological surveillance, responding to the high incidence of malaria, and for ensuring maternal and child health. Aside from connectivity, activities also focus on the development of health care management software and telemedicine tools such as an adapted stethoscope for remote sound delivery (telestethoscopy), combined with real-time video, as well as telemicroscopy, tele-EKG and tele-ecography.

Connectivity work initially began with testing the utility of HF and VHF packet radio. With the relatively low speeds that were possible at the time (a maximum of 17 Kbps), this was only useful for low-bandwidth asynchronous text applications such as email. While this still provided significant improvements to the health system, the potential use of more data-intensive real-time applications could not be realised. Fortunately, higher bandwidth Wi-Fi and WiMAX technologies were emerging which could be used to provide internet connectivity and long-distance interconnection of the medical clinics situated in isolated subsistence fishing/farming communities.

Use of these systems first took place in 2006 around Cusco Sur in southwestern Peru, where a 140-kilometre backbone was set up with some hops of up to 40 kilometres, which necessitated adjusting the underlying Wi-Fi protocols to optimise throughput, known as Wi-Fi for Long Distance (WiLD) links. Built with European Commission funding, the network was used to connect a variety of public institutions – clinics, police stations, schools, municipalities, etc.

Then, with multilateral funding for countering malaria, an even larger backbone was deployed along a large river: the Río Napo in Maynas province, Loreto district in the Amazon basin. Based on MikroTik and other off-the-shelf Wi-Fi equipment, the 450-kilometre network was set up and connected to the internet by VSAT in the town of Santa Clotilde, as well as via an ADSL link in the town of Iquitos at the regional hospital. The longest link on the network is 55 kilometres. The project was initially supported by the Andean Health Organisation (ORAS), and was completed with funding from the Madrid City Council in 2009. This provided a platform for an extensive demonstration of the use of internet connectivity and remote diagnostic telemedicine tools in the clinics.

Large tower costs

When fully deployed in 2007, the backbone had become the longest permanent Wi-Fi network in the world, with 16 hops, many of them using 90-metre-high towers. Because of the size of the towers, the public bidding process that was required, and the substantial transport and erection costs in these remote, densely forested areas, the cost of the towers was high – over USD 20,000 in some cases.

Since 2012 the national mobile operator, Telefónica del Perú, has rented space on the network of towers for its mobile services, which has helped offset their cost, and provides some income for the local health authorities who own the infrastructure.

Autonomous VoIP services

The network continued to provide email, and aside from supporting the telediagnostic tools, also added a VoIP telephony service which allowed the health institutions to call each other directly, as well to call the public voice networks (PSTN). Although in theory a single VoIP platform with a gateway to the PSTN would have been sufficient, VoIP platforms based on the free/libre open source Asterisk software were installed at each hop/node. This level of redundancy significantly increased reliability, allowing calls to be made between parts of the network even if the upstream connection to the internet and the PSTN gateways stopped working.

Ensuring reliability

With so many hops, end-to-end throughput was an issue, as speeds were initially limited to about 3 Mbps across the backbone,[40] so a quality of service regime was also implemented to prioritise VoIP traffic over other types of internet use. In addition, because many of the clinics were dependent on multiple hops to reach the internet/PSTN gateway or the regional hospital, redundancy is an issue, especially on a network with a single trunk. So strong efforts were made to ensure reliability of the infrastructure. A maintenance plan and a protocol to deal with equipment failures were designed and paid for by the local health authorities, which involved training local people and assigning responsibilities for the replacement of devices and management of the spare parts. While finding people with ICT skills in these areas is not easy, training people with mechanical skills, such as boat repairers, was found to be one effective solution, combined with second-level technical support from the hospital in Iquitos.

Another issue was the incidence of lightning storms in the area. Equipment on the high towers was initially lost a number of times until an effective but more costly active lightning protection system was put in place, involving three separate conductors – tower, equipment and rod. In addition, a 40-metre circular conducting grid was laid out for towers standing on rock.

TUCAN3G femtocells

In 2012, with the emergence of low-cost mobile data technologies, the wireless backbone was leveraged for use as the basis for interconnecting an experimental small cell network. With financial support from the European Commission's FP7 fund, the TUCAN3G[41] project brought together 10 European and Latin American partners.[42] Using Telefónica's core network, licence and frequencies, TUCAN3G aimed to test the outdoor use of small low-cost low-power 3G base stations designed for indoor use (femtocells) in three of the communities along the river. The project also tested their integration into a heterogeneous Wi-Fi/WiMAX/VSAT backhaul environment and into Telefónica's core network. In addition, sustainable business models for provision of 3G services to isolated rural communities were assessed.

Femtocells are suitable for outdoor use if they are in a high enough position to take advantage of line-of-sight propagation to the end-user's phone. This is helped by the

40. Subsequently upgraded to 40 Mbps end-to-end and then to 80 Mbps.
41. https://cordis.europa.eu/project/rcn/108002/factsheet/en
42. Including Fondo de Inversión de Telecomunicaciones de Perú (FITEL).

wooden building construction methods in the area, which have a limited impact on signal strength. In these conditions, the radio equipment deployed in the 800 MHz band that is licensed in Peru was able to reach phones at a distance of up to two kilometres. Since the communities are more than 20 kilometres apart, interference is negligible, allowing the spectrum bands to be re-used. As the traffic levels are fairly low, and the population in the villages is relatively concentrated, one or two base stations co-located on the same tower was usually sufficient, with the second used to cover peak times, operating on a different frequency.

Saving on solar power costs and bandwidth needs

The project found that by using network design principles that specifically take into account energy and bandwidth constraints in real time, significant savings can be made on the dimensions of the solar power system and in the bandwidth required for the upstream backhaul connections. Also of particular note, TUCAN3G showed that the low or non-existent radio interference in remote rural areas allowed unlicensed Wi-Fi spectrum to be used for carrier-class deployments.

The business model analysis concluded that the areas left out of the coverage zones of the major operators could still be viable for small-scale operators. It was found that about USD 4 per month was spent on voice calls, and about 60% of the interviewees said they were willing to pay USD 3.5 per month for internet access, indicating a potential average revenue per user of about USD 7 per month.

The project also observed that in comparison to traditional rural mobile network deployment, which would normally use satellite links for these remote communities, access to the terrestrial wireless backbone halved the total cost of ownership over a five-year period. Assuming a penetration of 50%, it would be economically feasible to reach small communities (around 200 inhabitants) with these alternative business models, such as sharing a wireless network with other services, or taking advantage of public funds.

Relaxed licence conditions

Using Telefónica's licence and frequencies meant the TUCAN3G networks could have been subject to the licence conditions set by government, which do not distinguish between urban and rural networks, and require the operator to continue to maintain the service once it is launched, even if it proves uneconomic. There are also penalties for low quality of service and blackouts. After negotiations with the government, these conditions were waived, as it was recognised that such requirements make it much harder for rural networks to comply due to their more limited underlying infrastructure.

Rural commercial mobile operator Mayutel

The TUCAN3G project ended in 2016, but the network is now being used as the basis for a new project involving the deployment of mobile voice and data services operated by the Peruvian commercial network Mayu Telecomunicaciones – a new company which gained one of the rural operator licences that were issued in 2015. Mayutel continues to rely on the wireless backbone along the river provided by the local health authorities to connect mobile base stations, which use the spectrum bands of Mayutel's partner, Telefónica. In the future, Mayutel could lease capacity on the wireless backbone from the health authority, or could provide communication services in return for the capacity.

With support from the Latin American Development Bank (CAF), six communities have been provided with mobile voice and data services in the project, which ultimately aims to expand the initiative to 15 communities using base station equipment from Parallel Wireless and Huawei, while testing energy systems and validating the business models. Hispasat has also provided a donation of satellite bandwidth for the project.

Mayutel's service is a typical commercial prepaid voice and data network using air-time top-up vouchers distributed by vendors along the river. The network appears as part of the Telefónica network – in essence, the users are Telefónica subscribers which "roam" onto the Mayutel network, for which Mayutel has reached a confidential commercial agreement with Telefónica to generate its revenue. Traffic on the network currently peaks at about 5 Mbps into Telefónica's core, with about 340 Gb per month of data traffic generated by the largest community.

Mayutel says that with its strategy, the cost of deployment was reduced by 50% to 70%, and to be sustainable it is estimated that the village population covered needs to be at least 500 people. This relatively low break-even number is in part explained by the fact that about 50% of the population already have smartphones despite no coverage where they live, as they use the phones when they travel to larger-population trading centres such as Iquitos.

EHAS: www.ehas.org
URJC Telecom Engineering Department:
https://www.urjc.es/universidad/facultades/escuela-tecnica-superior-de-ingenieria-de-las-telecomunicaciones
PUCP Rural Telecom Research Group (GTR): gtr.telecom.pucp.edu.pe
Mayutel: mayutel.com
See the GISWatch 2018 Peru chapter for additional information on Peru (unrelated to the above projects).[43]

Pamoja Net, Ensemble Pour la Différence, Idjwi Island, DRC

Pamoja Net is an externally provisioned network supported by Ensemble Pour la Différence, an NGO based in the city of Bukavu, South Kivu, which helps social businesses in the Eastern Congo, aiming to improve quality of life in the region. On the impoverished and isolated island of Idjwi[44] in the centre of Lake Kivu, the work of Ensemble was initially focused on supporting economic upliftment with agricultural and small business projects.

With a population of about 300,000, and no grid power, less than 10 homes on the island have a computer. While voice and some low-speed mobile data are available, the cost is too expensive for the majority of the population, many of whom live on less than a dollar a day. As a result, the Pamoja project (pamoja means "together" in Swahili) came about in 2016 stemming from a request to Ensemble from the traditional leader of the Chefferie[45] – the king (mwami) of North Idjwi Island, Gervais Rubenga – who wanted better internet access

43. https://www.giswatch.org/node/6052
44. The ninth largest lake island in the world, with a population of about 250,000. www.worldislandinfo.com/LAKEV1.htm
45. A "chefferie" or "chiefdom" is a unit of local government in the DRC.

in order to help address the level of isolation on the island and in particular to create additional opportunities for youth.

To respond to this, a connectivity strategy was developed, and equipment based on Ubiquiti was tested in the United Kingdom with the assistance of the charity Falling Whistles, and design agency Fjord's Innovation Fund, prior to being deployed on Idjwi. Three people in Idjwi were trained to support the network (known as network guardians), backstopped by the Ensemble team in Bukavu. In addition, an installation manual has been produced, although it is currently only available in English.

Public access, screen display and cross-subsidisation

Two novel approaches were taken to help address the low-income levels and lack of ownership of access devices, while being able to provide a sustainable internet service. First, a kiosk with tablet computers and one large screen display system was set up as a public access facility in Bugarula, the most populous area on the island. The public display system is a large computer screen over which relevant content (see below) is automatically scrolled, powered by a Raspberry Pi single board computer which consumes a minimal amount of the costly solar power set-up.

Second, free access after 4 p.m. is provided to the island community through public Wi-Fi hotspots, with the cost of the service being covered by the handful of businesses and NGOs on the island which pay for dedicated access during office hours. These organisations pay between USD 50 and USD 150 per month for their fixed wireless links, which covers about 60% of the cost of the free service.

The network of Wi-Fi hotspots has steadily been expanded and now reaches eight different locations on the island. One of the sites with a fixed wireless link is a school with a computer lab, which charges about USD 0.30 per day for access, USD 0.12 for two hours or USD 0.06 for one hour. The network regularly provides access for about 100 simultaneous users, and has provided connections to about 4,000 users in total.

Local content

A website and public display system were developed to notify people of personal messages, market information, weather, local news (including Twitter news from Bukavu), cultural and educational events, as well as movie and educational screenings. The server also provides free access to a selection of news, entertainment, health and educational websites in local languages. An Android app was also developed which makes it possible to receive news via SMS and broadcast it on the display. In addition, a captive portal with payment options and an Android app were developed that allow people without a bank account or email address to buy airtime through agents. With coffee and fish being the island's two largest exports, there is strong demand for access to identify which markets will give traders the best price and to check the weather forecast to see if it is safe to cross the lake.

User protection sensitisation

Of note is that user training was carried out on the use of smartphones, including on safety and privacy issues. Similarly, internet safety posters were produced for those with low reading capability and low digital literacy. These are aimed at guiding people on how to protect themselves online, recognise spam and understand the implications of social media. In addition, an organisational manifesto, signed by the king of Idjwi island, was

developed to ensure information access on the network is seen as a publicly owned commons.

The network is extensively used by the police department, the local radio station, the local church, school teachers, the office of the king and other government outposts. There is a strong demand to expand the network, as is evidenced by the people who walk 15 kilometres to reach one of the Wi-Fi access points. Due to the success of the service in the north part of Idjwi, the traditional authority of the southern part of the island, the queen, has also expressed interest in extension of the service.

Ensemble Pour la Différence recently received a grant from the Open Cellular Grants programme of the Facebook-led Telecom Infra Project (TIP) to set up 4G base stations on the island. It is now in the process of testing their deployment. As is the case with the existing Wi-Fi network, the mobile service would also be operated under the dispensation of the king.

Upstream reliability issues

Upstream internet capacity of 8 Mbps is currently leased from a local ISP in Bukavu, and transmitted 55 kilometres from there across the lake to a high site on the island. The high mineral content of the soil on the island, and particularly around the high site, results in frequent lightning strikes. These have destroyed the electronic equipment on the 12-metre-high tower four times in the last year, despite extensive efforts to earth all the equipment. As a result of the lightning problem, which has damaged equipment at a number of other sites as well, the equipment is switched off during thunderstorms.

Another factor affecting reliability of the service is the dependence on a single long-distance link. Duplication or redundancy in this link is highly desirable given the difficulty of reaching the island quickly, along with relatively frequent upstream down times experienced by the ISP in Bukavu. To address this, Ensemble would like to access the upstream internet capacity that is available from Rwanda, which is relatively close to the island. Internet capacity is also significantly cheaper in Rwanda. However, due to the lack of fair price controls on infrastructure sharing, there is a high cost for renting space on the mobile operator's tower in Rwanda that is visible to Idjwi island, which makes this option economically infeasible. Airtel proposed charging USD 1,600 per month for space rental on the tower, which is in sharp contrast to the USD 170 per month which is currently charged by the ISP in Bukavu for access to its tower for the link to Idjwi.

Ensemble Pour la Différence: https://www.ensemblepourladifference.org
Fjord: https://www.fjordnet.com

Puspindes/Common Room and RelawanTIK, Central Java, Indonesia

Puspindes

A combination of externally supported and entrepreneurially driven community-based Wi-Fi networks are present in rural villages in the Regency of Pemalang on the north coast of Central Java province. Although the study focused on a particular group of five agricultural hamlets centred around the city with the same name – Pemalang – these are just a few of

the 211 communities in the 29 districts in the Pemalang Regency that are supported by the non-profit Puspindes[46] Centre for Information and Rural Empowerment. Established in 2014, Puspindes is the local group of ICT volunteers and "evangelists" that are affiliated with RelawanTIK, the national NGO of ICT volunteers described earlier in this section.

The primary role of Puspindes is to support the national government's push to encourage the adoption of ICTs down to the local authority level in the Pemalang district. The government has now made it a requirement that every local authority has its own website and digital information and financial management system, called the Village Information System, for which it is providing a budget of about USD 70,000. Aside from supporting the administrative functions of local government and its reporting to central government, the Village Information System is also aimed at providing platforms for preserving cultural heritage, promoting businesses online, facilitating the sale of local village products, and building awareness of the village's attractions for visitors.

Some of the 15 Puspindes volunteers develop the websites and databases for the Village Information System in the communities that need assistance. They are hosted at Puspindes' network operations centre (NOC) and training premises in Pemalang, which is provided by the provincial authority. A major part of Puspindes' work is also to carry out training courses, ranging from basic digital literacy, to information management and content management for the websites.

Using the on-site 15-metre-high tower at Puspindes' premises, Wi-Fi-based connectivity is provided to many of the village authorities, allowing them direct access to their data and websites hosted at the NOC. For onward internet connectivity, agreements are made with licensed providers, because Puspindes is not able to provide internet services due to the Indonesian licence conditions which do not recognise non-profit providers. Therefore, agreements were made with the six local ISPs and they are all present on the tower, providing villages with a choice of operators.

In the five hamlets, the ISP Biznet was selected. Through its local partner, it sells 5 Mbps Wi-Fi connections to about 50 subscribers in the five hamlets at about USD 14 per month for a 10 Mbps link. Subscribers were initially attracted to the service because the installation fee was discounted to USD 28 – they did not have to pay the full USD 105 set-up fee that Biznet would normally charge to install the connection. However, now that the promotional discount has been removed, interest has slowed, also because increasing numbers of people use 4G.

Nevertheless, two households with small businesses (a restaurant and a shop) sell their customers hourly and daily vouchers for access. Two public Wi-Fi hotspots are hosted by the village authority, one at the main office and one at a nearby ecotourism site. Access to the hotspots is free, but the password is changed every day and is given out only in cases of need when the office is not using all the capacity. The password is only given to people under 15 years of age if the parents are present.

In return for collecting payments for the Biznet monthly subscription and hotspot services, the local authority enterprise development offices (Bundes) receive a 20% commission.

46. Puspindes is a short form of Indonesian Bahasa for Pusat Pemberdayaan Informatika dan Pedesaan, which means Centre for Information and Rural Empowerment.

Biznet does not impose sanctions on late payment – even if people are as much as two months late, they simply receive a warning. This is partly because the Bundes usually pay the full amount to cover the late payment and recover the costs from the local subscribers later.

The Puspindes NOC is also equipped with a VoIP server (Asterisk), and 20 villages have so far been equipped with VoIP phones. In future, all villages are expected to have VoIP phones. A downtime alert system based on Telegram is frequently used to send notifications of problems to the core group of four volunteers. About five to 10 alerts a week are received from the 211 villages, many of which are passed on to the village level technical staff person, although not all villages have one yet. The local staff person has a one-week training course provided by Puspindes and is responsible for managing the village router and able to add blocked websites, check usage, restart, etc. All local technical staff communicate with each other via a WhatsApp group.

Common Room

In a different location and context, Bandung-based NGO Common Room[47] has been working on an urban/rural collaboration project since 2013 to help address challenges faced by the Sundanese indigenous community of Kasepuhan Ciptagelar, Sukabumi Regency. The community of 25,000 people consists of three municipalities comprising about 500 small villages which closely adhere to ancestral agricultural traditions that are now threatened by accelerating economic development in the surrounding area. In addition, there is no official recognition for indigenous territories from the government, and increasing access to electronic information is resulting in changes that affect the integrity of traditional institutions and culture in the community.

Supported by the German development agency, Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ), Common Room has been developing an "innovation factory" focusing on the use of ICTs in agriculture, with the aim of providing indigenous communities with scientific knowledge. This was driven by the recommendations of a 2016 multistakeholder meeting with the community, including the Ministry of Communication and Information (KEMKOMINFO), which identified four priority areas:

1. Environmental protection and conservation
2. Cultural preservation and development
3. Local ICT infrastructure and renewable energy development
4. Local economic empowerment and livelihood improvement.

A "mini data centre" was set up as a platform for hosting and managing local knowledge which was used in a participatory mapping project that incorporated satellite data and in-field surveys to help identify protected forest areas. In 2017 the report on the project was published and is being used as a reference for official guidelines on participatory mapping of indigenous land promulgated by the Indonesian agency for geospatial information.

By 2018 about four ISPs provided internet services in the area. However, coverage is limited, as many of the villages are located in mountainous and thickly forested areas with relatively unstable power sources. As a result, Common Room is now working to develop a

47. Common Room is also part of the Indonesian network Forum Demokrasi Digital (FDD), which consists of individuals and institutional media activists and practitioners.

plan to expand the reach of more reliable and affordable internet access to better support cross-cutting issues such as indigenous land rights, food sovereignty, environmental protection, cultural preservation and disaster risk reduction.

Puspindes: https://puspindes.pemalangkab.go.id
Common Room: https://www.facebook.com/commonroom.id
RelawanTIK: https://relawantik.or.id

Quilombola Network, Bairro Novo, Maranhão, Brazil

The Quilombola[48] mesh Wi-Fi network and public access facility began as an externally supported network and has now transitioned to the self-provisioning model. Located in the semi-urban settlement of Bairro Novo, adjacent to the city of Penalva in the remote northeastern state of Maranhão, the network is owned and operated by an existing non-profit organisation[49] established in 1979 to support women's natural resource harvesting of the Babaçu palm. Initiated by APC member Instituto Nupef,[50] which is based in Rio de Janeiro, the network was set up in 2017 with financial support from the Ford Foundation and technical support from members of the Coolab collective. A second, smaller but very similar network was also set up at the same time in the nearby town of Cajari.

Social purpose network

The Associacão Moradores Quilombo Bairro Novo was identified through a social cartography project of the federal University of Amazonas which is developing mapping tools for strengthening social movements. The community network has a strong social purpose, providing a communications platform to an area with poor coverage from the large commercial networks, as well as a location to register as traditional Babaçu palm harvesters. In this way it plays an important role in supporting women in their efforts to maintain their traditional natural resource-based livelihoods in the face of often violent intimidation from cattle ranching landowners.

Housed in one of the Associacão offices, the public access facility consists of a PC and two printers whose most important function is to support the annual government registration of the women carrying out their traditional palm harvesting. This officially "legitimises" their work by giving them recognition of their land access rights, and also means that they can request police intervention when conflict occurs with the cattle ranchers.

Aside from also providing general internet access, mainly for students, the network is used by members of the community to apply for other government benefits, and to support access to a WhatsApp group which is used to coordinate meetings or to notify the community about locations where intimidation is taking place. Smartphones are able to connect to a VoIP platform (Elastix) which was also installed; however, it is rarely used due to the lack of roaming between hotspots and limited coverage of the Wi-Fi signal, as well as the extensive coverage by 2G mobile networks in the area with unlimited call packages.

48. A quilombo is a settlement inhabited by descendants of Afro-Brazilian slaves.
49. Associacão Moradores Quilombo Bairro Novo Reserva Extrativista Enseada Mata Municipio Penalva Maranhao Adjacencia.
50. Nupef stands for Núcleo de Pesquisas, Estudos e Formação.

Following the establishment of the network, two wireless ISPs have also begun providing access in the area.

About 20 people from the community were involved in the initial deployment, to identify which of community members' houses should be locations for the routers, installing them and learning how to fix frequent problems. Covering an area of about 18,000 square metres, the seven nodes provide Wi-Fi access in public areas and in the nearby homes. Upstream internet access is provided by a residential Ku-band satellite link located at the Associacão premises. The satellite link provides a 10 Mbps downlink and 1 Mbps uplink, capped at 30 Gb per month.

Around 75 users have been given Wi-Fi access passwords which they share with other users. As a result, about 500 devices connect to the network regularly, although there are only 30 users who pay for the service. They are charged roughly USD 5 per month and these fees more than cover the only significant operating expense: the satellite link cost of about USD 65 per month. The paying users include a number of households with students who use the Wi-Fi and the public access computer for school work. Surplus income has been used to pay for electricity, to buy a second printer and to carry out some minor improvements to the premises.

The Associacão staff person who manages the network and assists people in accessing government online services receives income from other sources. Although this is currently a grey area due to recent conflicting government announcements, no licence fees are paid as the network operates under an exemption provided to wireless networks of less than 5,000 people using the 2.4 GHz and 5 GHz frequencies.

Rapid transition to self-provisioning

The network's relatively quick transition to a self-provisioning model is partly because the network is owned and operated by an existing non-profit association. It was also selected by Instituto Nupef specifically because there was a well-established governance mechanism already in place through the non-profit. In addition, the organisation's premises house the public access facility, administrative office and meeting rooms/operational spaces. The leadership of two women from the community has also been seen as key for achieving success. The project manager handles both technical and management tasks assisted by members of her family.

The success of the community network has resulted in many requests to expand the network locally, but technical, fundraising and administrative expertise are needed for this. More broadly, Instituto Nupef has been in talks with the Federation of Quilombolas and has determined that there is strong demand for connectivity from the hundreds of thousands of women spread across the 44 municipal districts in four states that are involved in Babaçu palm harvesting. This is seen as a particularly acute need considering the current political climate in Brazil, where land rights and indigenous people are under increased threat.

Instituto Nupef: https://www.nupef.org.br
See https://youtu.be/JsAwZ3yXXTU and the GISWatch 2018 Brazil chapter[51] for additional information.

51. https://www.giswatch.org/en/country-report/infrastructure/brazil-0

TakNet/Net2Home, Mae Sot, Tak Province, Thailand

TakNet/Net2Home is a mesh Wi-Fi initiative which combines external support and an entrepreneurial franchise model to provide affordable wireless internet access in a low-density rural agricultural area around the city of Mae Sot in the province of Tak, near the border with Myanmar.

The Community Wireless Mesh Networks (CWMN) project was initiated in the village of Thai Samakhee in 2013 by the Internet Education and Research Laboratory (intERLab) at the Asia Institute of Technology (AIT) in Bangkok to pilot the deployment of mesh Wi-Fi networks, designed for resilient post-disaster communications, using wireless router firmware that the intERLab had developed called DUMBO.[52]

The first village network was initially set up as an off-line facility with an educational video-on-demand server. Volunteer university students and recent graduates attending the annual Thailand Networking Group (THNG) Camp[53] assisted with initial field deployments, visiting rural villagers and convincing them to have routers installed on the external walls of their homes. Some of the routers were donated by companies supporting the THNG Camp, and others were later provided through international research projects such as with the N4D group at the University of Cambridge. After network set-ups were completed, the local technical support team was drawn from village members who were trained by the intERLab team and THNG Camp members, along with receiving instruction in how to use the network.

Sharing upstream internet costs

In 2014, with some additional technical support, village residents were able to use the mesh network to share a household ADSL internet service (10 Mbps uplink/1 Mbps downlink) provided by an existing commercial ISP. This worked well, and the model of sharing the cost of ADSL internet "gateways" was then expanded to other villages in a series of annual deployments.

Service levels within the villages are quite strictly adhered to – when a gateway has reached about 20 households, an additional upstream link is rented. Community members decide among themselves in which household to locate the new gateway and who in the community will collect the subscription fees to cover the cost of the upstream link. The expansion of the network has also coincided with the provision of faster broadband services by the local ISPs, which has increased the available bandwidth significantly, initially with VDSL (50 Mbps/10 Mbps), and later, fibre (up to 200 Mbps/60 Mbps), which costs about USD 47 per month.

Transition to franchise model

During the first three years, TakNet was maintained on a volunteer basis, where the local technicians drew on intERLab's technical staff for basic troubleshooting and collection of user fees. The fees aimed to cover the cost of the internet link, with some electricity charges added. This amounted to about USD 2.5 per month per household. However, it was

52. DUMBO stands for Digital Ubiquitous Mobile Broadband OSLR. dumbo-technology.interlab.ait.asia
53. The camp is an annual event hosted by the THNIC Foundation. www.thng.in.th/#thng-camps

found that the fees collected were not sufficient for new services, expansion or recovery in case of a breakdown such as a router malfunction.

A new cost recovery model was then developed, where the monthly subscription fee for each participant (usually a household) was increased to USD 8 per month to cover the cost of upstream internet connectivity, network equipment installation, maintenance and the use of local services (e.g. VoIP, video streaming and chat applications based on Raspberry Pis). For this, the subscriber signs a 12-month contract which commits them to not switching off the router (to maintain the mesh) and to not resell the service or use it for business purposes. The USD 8 per month fee is about two to three times cheaper than the cost of broadband from the local commercial ISPs supplying their upstream capacity, albeit for less bandwidth (a minimum of 4 Mbps vs 100 Mbps).

Although usage has increased and is now beginning to push average speeds toward the 4 Mbps committed minimum, in off-peak hours speeds are much higher, and capacity is apparently sufficient for extensive periods of internet use – a recent survey[54] indicated that many of the users spent up to four hours a day online. As a result, the demand for the community network continues to grow, and the commercial ISPs supplying the upstream links, such as 3BB and TUT, have installed additional infrastructure to be able to support more connections for the villages.

In 2016, intERLab also started a social enterprise called Net2Home, in partnership with THNICF, the foundation which operates Thailand's national ccTLD domain (.th). Net2Home was adopted as the brand for the service, which is managed by THNICF. The foundation is the ISP licensee for the service and it provides the operational administration of the network via the local entrepreneur technicians (usually existing small businesses) who install and support the connections.

Technical backup is provided by intERLab and Net2Home when needed. In addition there are dedicated "bill collectors" in the communities who take payments for service from the subscribers and pass them on to Net2Home, which manages the relationship and payments with the commercial ISPs. The local community college in Mae Sot, an adult education/vocational training facility, has also played an important role in providing outreach and coordination support. The community college is part of efforts by the Thai government to support more grassroots-based rural development such as community tourism and developing human resources at the local level by training community-based leaders and supporting networks of community organisations.

Like the Des Hotspot network in Indonesia, TakNet/Net2Home acts as a mechanism to share the cost of commercial fibre broadband services which are unaffordable for most households by reselling them in smaller packages. The price-sensitivity of the households is demonstrated by the fact that some participants dropped out after a few months due to the USD 1 per month increased cost of electricity for running the wireless router.

Similar to national government initiatives in India and Indonesia, the Thailand government's One Access Per Village Project has seen 24,700 villages connected to fibre and a public access Wi-Fi point by the end of 2017. However, with the government-provided Wi-Fi hotspots, users need to visit the public access facility, which can be quite far from their

54. https://pdfs.semanticscholar.org/6956/d3e8e8dce426437b27c2e97f8953985cd088.pdf

homes. As students are often the primary users of the network, this has caused concerns for parents, and aside from the low cost, it is one of the main reasons for the attraction of TakNet/Net2Home.

Network evolution

A typical example of a village deployment took place in 2017 in Moo 1, Mae Kasa, where 25 routers were deployed, initially serving about 50 households with a network coverage area of about 35,000 square metres. In March 2018 the internet gateway was upgraded from VDSL to fibre, and a second internet gateway was installed at the village hall. The total deployment cost was about USD 2,000.

Similar deployments have taken place in nearby settlements, and the network now operates in 17 villages, serving about 1,000 paying subscribers accessing 200 mesh wireless nodes. Fewer routers could have been used to service the same number of households; however, it was a strategic decision to make the service more attractive by providing so many households with routers.

The involvement of local entrepreneur technicians, and their gradual assumption of responsibility for running the network, is also seen as a key strength of the project, and in expanding the network to nearby areas. They are paid about USD 50 per month for ongoing support and maintenance, and are also incentivised by a scheme where they earn additional income from installation fees and commissions when additional members are signed up, and a further commission when a new village is signed up. As a result, technical capacities have increased to the extent that the most recent village deployments have taken place without the need for on-site intERLab technical support – the equipment was simply shipped to the location and local technicians did the rest.

Bill collectors earn about USD 30 per month with about 60 customers, whom they visit individually to collect payments, which must be deposited in the town of Mae Sot. They also earn extra funds by signing up new customers.

Haze pollution sensing and TVWS research

More recently, intERLab has begun demonstrating the technology and benefits of deploying low-cost weather stations and air pollution remote sensing devices connected to the village mesh networks. This provides additional value to the community networks by making available valuable data about local weather patterns and helping to identify cases and sources of pollution. In particular, the region suffers from haze caused by forest fires and agricultural-related burning (particularly the traditional burning of rice straw) which is common during the annual drought periods. With the prevailing winds this can cause significant health impacts from the resulting haze drifting in from other areas, including across the border from Myanmar.

However, government weather stations are costly and mostly located near large urban areas, so a low-cost alternative was needed. A prototype haze monitoring weather station was developed with sensors to detect air pressure, humidity, temperature, carbon dioxide, carbon monoxide, nitrogen dioxide, volatile organic compounds and particulate material down to 2.5 nanometers (PM 2.5) and deployed in TakNet/Net2Home networks with support from the French Ministry of Foreign Affairs and International Development.

Weather monitoring features are required to determine wind direction and also because temperature, humidity and rainfall affect the severity of haze in a specific area. As the haze

concentrations can be monitored in real time, analysis of the data from the sensing devices distributed across the villages has helped to pinpoint the sources of the pollution. The prototype devices cost about USD 350 each to build individually from off-the-shelf components.

With a grant from the National Broadcasting and Telecommunication Commission, the intERLab research group is now also testing the use of Carlson TVWS and LTE equipment for connecting rural and remote areas, having obtained a special approval for research purposes from the regulator. Using low-cost spectrum analyser tools built by the International Centre for Theoretical Physics (ICTP) in Trieste, spectrum measurements have been carried out to understand channel occupation and interference. Of particular interest is using LTE over TVWS backhaul links to support non-line-of-sight connections for base stations.

intERLab community wireless networks: https://interlab.ait.ac.th/cwmn
Net2Home: net2home.co.th/en
THNIC https://www.thnic.or.th/en/home/
intERLab haze monitoring project: https://interlab.ait.ac.th/HAZEMON
See the GISWatch 2018 Thailand chapter for additional information.[55]

Telecomunicaciones Indígenas Comunitarias (TIC AC), Oaxaca, Mexico

TIC AC is a non-profit association of community-owned mobile networks in Mexico, which became the first GSM special purpose licensee in the world in 2016. Building on earlier work with local community radio stations in Oaxaca, in 2014, Mexican non-profit Redes[56] leveraged constitutional provisions for indigenous communities to obtain an experimental licence for exploring the use of low-cost, open source GSM network equipment. This process was assisted by the Oaxaca-based NGO Rhizomatica,[57] which works to help disenfranchised communities take advantage of new telecommunications infrastructure.

During the pilot period Mexico's telecommunication law changed, allowing for licensing of social-purpose networks operated by non-commercial entities. To take advantage of this, Redes and Rhizomatica helped establish TIC AC in 2016, which was given a 30-year operating licence for five states, along with a 15-year no-cost concession for the use of a small quantity of spectrum (2+2 MHz)[58] in the 850 MHz band. With this, TIC AC has now helped indigenous communities build and operate 16 independent mobile 2G voice networks which cover about 70 localities in the state of Oaxaca. Three of the 16 networks averaged less than 100 subscribers a month, while the largest network had 500 subscribers.

55. https://www.giswatch.org/node/6043
56. Redes por la Diversidad, Equidad y Sustentabilidad A.C. works to support indigenous communities, diversity and sustainable community development.
57. Rhizomatica is also a 501c3 US non-profit and an APC member. http://www.rhizomatica.org
58. 2 Mhz uplink and 2 Mhz downlink. This amount of radio spectrum is limited – less than 25% of the amount assigned to a conventional mobile network operator – and is insufficient for growing many existing small networks to their full voice demand, let alone for migrating to higher capacity 3G/4G services which require much more spectrum.

The networks provide free incoming calls, unlimited calls between local network users, including roaming between the local networks and text messaging (SMS). Voice mail is not provided as there is very little demand for it; however, SMS broadcasting for general notifications is supported, and basic USSD[59] functionality is available for querying credit balances and phone number reminders.

The initiative builds on the work of Rhizomatica in developing the use of small-scale mobile voice platforms and other low-cost telecom infrastructure. In 2013 there was no equipment being produced that could be easily used to operate a small mobile/cellular network, so a custom solution was developed using a generic software-defined radio. Since then numerous companies, such as Sysmocom, NuRAN Wireless, Range Networks, Baicells and Fairwaves, have developed low-cost mobile cellular radios.[60]

In contrast to the traditional "core network" model, where switching functions take place off-site at the operator's central location, many of these new cellular base stations can be used in a "network in a box" design. This uses a low-cost laptop or PC to carry out the switching of traffic directly between users, eliminating the requirement for upstream capacity to carry the call traffic, thereby cutting costs and increasing reliability. As a result, if solar power and a tower are not required, a small mobile network could be set up for about USD 5,000, supporting a few hundred subscribers. A solar power system and 12- to 15-metre tower can add an additional USD 2,500 to this cost.

Leveraging VoIP, ISPs and satellite links

Due to the lack of fair pricing defined in the interconnection and numbering regulations for Mexico, it is too costly to provide Mexican phone numbers for each user (about USD 4 per month per number), or to have direct connections with other voice network operators. However, VoIP is used to connect with other voice networks, and TIC AC affiliated networks can call each other freely. They are also configured so that subscribers of one network can automatically roam on the other TIC AC networks.

Rhizomatica developed a system to route calls into the networks using an Ireland-based VoIP/SIP provider, which rents TIC AC a Oaxaca number[61] for each network. This is linked to the village subscribers using extensions, similar to a corporate switchboard, facilitated by two servers and a firewall which are hosted at a data centre in the US. In addition, smartphone and web-based[62] apps have been developed to make it easier for off-net users to call in to the TIC AC networks. For outgoing off-net calls from TIC AC members, VoIP is used to route the calls to another international wholesale VoIP-PSTN termination provider with more competitive rates.

Until recently, connections with other fixed and mobile networks needed to use links provided by local wireless ISPs. It is not economically feasible for the villages to lease access to the wholesale fibre backbones that pass close to some of the villages because the costs and minimum volume purchase requirements of the backbone operators are too high for these small networks. As a result, the presence of an ISP was required to make it

59. https://en.wikipedia.org/wiki/Unstructured_Supplementary_Service_Data
60. https://www.rhizomatica.org/choosing-a-low-cost-gsm-base-station
61. Known as a direct in-dialling (DID) number.
62. https://webphone.rhizomatica.org

feasible for the village to set up a network which can also make and receive voice calls with the outside world.

However, TIC AC has now been able to obtain free satellite capacity to interconnect its networks, and for links to the outside world. This is the result of the Mexican state's entitlement to a portion of capacity on any satellite with landing rights in Mexico, for which TIC AC reached agreement with the Ministry of Communications (SCT) in 2018, for free use of a portion of the capacity. In preparation for this, Rhizomatica has completed the technical work needed to use satellite links to carry the networks' voice traffic. Rhizomatica has also been developing the capability to use low frequency (HF) radio links for direct connections between base stations to carry text messages and small quantities of voice traffic over hundreds of kilometres.

Network autonomy

Each of the TIC AC member networks is operated independently, with the local indigenous assemblies deciding how they will contribute to the cost of the tower and radio equipment, and who will be trained to manage it. In addition, the assemblies decide how the income generated from the network is distributed. Although there is much diversity in the nature of each of the communities, there is often a common approach to building and operating the networks which reflects a history and culture of cooperative enterprise. As a result, the communities are already familiar with a commons approach, such as in collective water and land management, when approaching communications infrastructure.[63]

TIC AC assists with technical and administrative advice in the formation stages of a new network, and subsequently with the installation, technical training and backstopping, as well as managing interconnection with other networks. After the initial enquiry from the village, the process of consultation can take three to six months before the networks are up and running.[64]

For unlimited local calls, users of the networks pay a monthly fee of about USD 2.2 to the local network administrator in the village.[65] The administrator of the local network forwards about 35% of this fee to TIC AC to cover the cost of the overall network administration (including backhaul links, etc.), helping new networks to start, and managing the relationship with the authorities.

TIC AC's negotiations with the government continue around issues such as interconnection and taxation. In relation to tax, the Mexican tax law has not been adjusted to take into account that there are non-profit users of spectrum, so social operators were expected to be taxed for spectrum use at the same rate as large mobile network operators. This has

63. Elinor Ostrom's work on the commons has found fertile ground with scholars in Mexico. See: Pacheco-Vega, R. (2014). The impact of Elinor Ostrom's research on Mexican commons governance: An overview. *Policy Matters*, 19, 23-34. https://www.researchgate.net/publication/262005080_The_impact_of_Elinor_Ostrom%27s_research_on_Mexican_commons_governance_An_overview
64. The process is documented, and includes: a collaboration MOU between the local authority and TIC AC, a receipt of equipment, a certificate of authorisation of the GSM concession, a letter requesting admission to the association and a list of people attending the assembly.
65. One network has chosen a lower price of 30 Mexican pesos (around USD 1.50) a month for member contributions.

been challenged in the courts by TIC AC, which argues that the Mexican state has been saved millions of dollars in costs for its obligation to ensure that all population centres have access to emergency communications. The courts have so far upheld TIC AC's position; however, pending the decision of the higher court, the issue remains unresolved.

An additional 5% of the monthly user fee is paid to TIC AC which holds it in a reserve account as a contribution to a mutual fund to cover any unexpected expenditures, most typically for replacing failed network equipment. This means 60% of the subscriber fees are retained within the community to recover the equipment, electricity and upstream internet costs, and to pay an honorarium for the admin staff person and for future investment in local projects.

The governing structures of TIC AC are a members' assembly and an executive body, which are supported by staff working in operations, administration, community relations, innovation and maintenance. The staff complement at TIC AC consists of about 10 people, who are mainly dedicated staff, except for the roles of bookkeeping/accounting, which are shared with Redes. In detail this means:

- Installation and maintenance (2 people)
- Technical support, configuration and operating system software (1)
- Base station equipment and power systems development and maintenance (1)
- Non-technical issues liaison and community building (1)
- Operations coordination (1)
- Bookkeeping/accounting (2.5)
- Incorporations (1)
- Communications and public relations (1).

Recovering costs

The largest single cost element for operating one of TIC AC's networks is the upstream internet link, which costs between about USD 50 and USD 80 per month for a 1 Mbps symmetric connection which can support about 10 simultaneous calls. Monthly electricity costs for a 5-watt base station are about USD 10 to USD 25 per month. Except for the largest networks, the time required for local administration is relatively small – simply for taking monthly subscriptions and top-up payments for long-distance calls, paying any monthly bills, and signing up new customers.

Assuming a USD 9,000 equipment and installation cost, the village could pay operating expenses and recoup the set-up cost within two to three years if the network averages 300 users a month.

Users also pay about USD 0.045 a minute for off-net calls to other networks (compared to USD 0.16 a minute when using the conventional commercial networks). With an average expenditure of about USD 1 per month, this gives a total revenue per subscriber of about USD 3.2 per month. During the previous year, a total of about 3,000 users made about 4.1 million minutes of calls. Around 60% of the traffic was local calls within the network, and callers averaged 108 outgoing call minutes a month in 2017. With about 3,500 users in 2018, TIC AC's total monthly turnover generated from the 16 communities was about USD 6,000.

Analysing the overall impact of the networks as a whole, TIC AC estimates about 15,000 indirect beneficiaries and an annual economic return (including incoming calls and indirect

cost savings such as for avoided travel, etc.) of USD 1.2 million. This is based on a total operating cost, including equipment depreciation, of about USD 270,000, which realises a cost-benefit ratio of about 4:1.

TIC AC: https://www.tic-ac.org
Redes: https://www.redesac.org.mx
Rhizomatica: https://www.rhizomatica.org
See the GISWatch 2018 Mexico chapter for additional information.[66]

Ungu Community 4G/LTE, Bokondini, West Papua, Indonesia

Located in the village of Bokondini in the highlands of West Papua, the Ungu[67] 4G/LTE mobile data-only network is an externally supported initiative that is partially self-provisioned, with some entrepreneurial aspects. The project is the result of a long-term collaboration with the University of Washington, which in 2013 had helped set up an informal community 2G voice network in the village.

Prior to the Ungu project, the community already had an internet link for which it had been paying USD 300 per month for a 1 Mbps satellite-based connection for the local elementary school to provide Wi-Fi for teachers, with some coverage extended to a few houses in the community via directional antennas. In 2016 the Indonesian NGO ICTWatch was able to convince the national telecom ministry (KOMINFO) to provide experimental licences in the mobile cellular bands to explore alternative technologies and business models.

The permission granted was conditional on not competing with existing commercial operators. As a result, when the dominant rural (incumbent) operator, Telkomsel, established a mobile base station covering the area, the local 2G community network was decommissioned. However, Telkomsel's service does not support internet connectivity, so this provided an opportunity to set up the Ungu 4G/LTE data-only service.

Being a pure 4G data network also simplified the set-up and billing, as the platform is all IP-based, and did not require more complex and costly arrangements for phone numbers and interconnection with voice networks, and avoids confusing the user with different charges for different types of traffic. Instead, all charges can be flat rate or data traffic-based, while telephony is carried out via apps such as WhatsApp, Telegram and Skype.

The project was implemented with USD 12,000 in funding from APNIC/ISIF, and local operational support and upstream internet connectivity from nearby social enterprise wireless internet provider, Airwaves Mission, which had been supporting the earlier 2G project and providing the school with connectivity. The base station is connected to the internet via a 50-kilometre long-distance (double-hop) Wi-Fi link to Mission Airwaves' VSAT installation in the town of Wamena.

66. https://www.giswatch.org/en/country-report/infrastructure/mexico
67. Ungu simply means "purple" Bahasa Indonesian – the colour of the SIM cards, linked to the University of Washington colour.

Developing a local core network

Extensive prior work called the IslandCell project had already been carried out at the University of Washington with support from Amazon Catalyst to develop the use of the software platform running on a low-cost PC that can operate a 4G/LTE base station on site as a standalone "network in a box". This type of EPC[68] avoids the need for an upstream core network switching system. While simpler to set up, these are usually too costly and an unnecessary loss of autonomy for small-scale rural networks in the global South. In addition, the conventional mobile architecture with off-site core would have required use of the expensive satellite backhaul connectivity to carry the traffic for every connection. Instead, the all-in-one solution keeps all local traffic local. Because LTE signalling (control data) adds significant overheads to the total data traffic, this cut the cost of needed bandwidth by about 50% and improved reliability (local activity continues even when the upstream link goes down).

Called Community LTE (CoLTE), the software is a modified version of the free/libre open source EPC platform OpenAirInterface, which was originally developed for experimental LTE networks. CoLTE also includes network monitoring and policy enforcement applications to track and bill for the traffic of each user, along with a web-based graphical interface that allows users to check on the status of their account, top up, transfer/resell credit, and buy data packages. In addition, to improve performance and save the expensive and limited satellite capacity, a local web cache and DNS server are also installed, along with local copies of educational content such as Wikipedia and OpenStreetMaps.

Base station hardware

The two 1-watt 850 MHz LTE cellular radio base stations – eNodeB, manufactured by a small US company, Baicells – cost about USD 4,000 each. The EPC software and local content are hosted on a USD 200 ZOTAC "Mini PC" with 500 Gb hard drive. The 850 MHz band was selected based on the relatively high level of handset support, good long-distance propagation characteristics (more than one kilometre), the experimental licence conditions and availability of unused spectrum in this band.

Tower costs were avoided by mounting the antennas on an existing six-metre pole. SUM cards cost USD 0.80 each when purchased as a batch of 1,000 from Alibaba, and setting up a registered NGO in Indonesia cost USD 1,000. With a solar power backup system costing about USD 4,000, the total network equipment cost about USD 14,000. As in many other countries, import taxes on fully assembled electronic equipment in Indonesia are relatively high, as are shipping costs, which are largely based on volume.

In terms of operating expenses, satellite bandwidth costs were minimised by using an asymmetric C-band service with a 3 Mbps downlink and a 512 Kbps uplink, for which Ungu pays about USD 200 a month. Administration and maintenance of the system is estimated at 10% of a full-time equivalent (0.1 FTE)[69] – about 2,400 USD per year.

68. Evolved Packet Core (EPC) is a framework for providing converged voice and data on a 4G/LTE network.
69. https://en.wikipedia.org/wiki/Full-time_equivalent

Recovering the costs

To cover the costs of the service, new users are charged USD 7 for the SIM card and initial set-up, which provides them with a 10 Mb credit. Accounts are prepaid, and traffic-based credits are loaded onto the administrative system and distributed through a central agent to whom the credits are sold and who in turn resells them at a markup of about 20% to community members.

Three data bundles are available – 10 Mb for USD 5, 100 Mb for USD 15, and 1 Gb for USD 25. Because there are volume-based discounts, this has generated a retail economy of small store vendors that buy the larger data bundles at the bulk discount rate and then resell smaller portions to individuals. This chain continues in an informal "side market" where many of the customers resell their own access by charging people to connect to the hotspot on their phone.

This informal resale of connections means that it is hard to track the total number of users of the service. Ungu only became operational in November 2018, and the testing/ debugging phase continued until the end of the year, resulting in a relatively slow initial uptake of the service. However, within four months of operations, about 70 SIM cards were sold, each generating about 100 Mb of traffic per day. Sale of data bundles generated about USD 2,300 per month in revenue.

Even without taking into account the expected growth in this new deployment, the level of income indicates that the cost of the equipment will be repaid within two years. This time frame takes into account paying for the part-time labour and the upstream bandwidth costs, but does not take into account support for shipping, installation and training provided by the University of Washington. However, with the expertise gained locally, new deployments to nearby areas could be carried out at low cost with the assistance of the community in Bokondi.

The network can scale to 255 simultaneously connected users and theoretically 150 Mbps of throughput per base station. Local speeds of up to 75 Mbs were measured within the network. Upstream capacity costs are expected to drop shortly, as the "Eastern package" of the Palapa Ring fibre optic project is planned to be completed in 2019 and includes spurs to the interior of West Papua.[70]

With the on-site controller, local traffic does not require any upstream capacity on the satellite link and this has prompted discussion of the options for implementing a "local only" traffic tariff. Local sharing of educational media is being zero-rated. In addition, a "limited services" package is also being considered. This would provide internet access to a restricted set of websites/services at a reduced cost (or free), focused around low-bandwidth services such as voice calling and texting services (e.g. WhatsApp and Skype), but could also include other select websites such as Wikipedia.

Community LTE (CoLTE): https://communitylte.wordpress.com/category/colte
Ungu report: https://isif.asia/community-lte-in-papua
CoLTE EPC software: https://github.com/uw-ictd/colte

70. Bhunia, P. (2017, 28 October). Installation of nationwide fibre-optic network in Indonesia to be completed by 2019. *OpenGov*. https://www.opengovasia.com/installation-of-nationwide-fibre-optic-network-in-indonesia-to-be-completed-by-2019

Village Base Station (VBTS) Konnect Barangay, Aurora, Philippines

VBTS Konekt Barangay is an externally supported rural mobile network research initiative that aims to transition to a self-provisioning model in partnership with a large commercial operator. The University of Philippines is testing a public-private partnership strategy with the deployment of seven low-cost mobile networks in isolated communities in the coastal district of Aurora, Luzon, which is also home to a number of indigenous groups.

Implemented with the involvement of local municipalities and cooperatives, and in partnership with one of the two dominant mobile operators (Globe), the project is financially supported by the Philippines Commission on Higher Education (CHED). It is being carried out with support from the US University of California Berkeley,[71] with linkages to the Aurora State College of Technology (ASCOT), the University of California Davis and the University of Washington. The project is also evaluating the broader impact of cellular connectivity with participatory qualitative research and a longitudinal randomised control trial with unconnected communities.

As with many other countries, virtually all the usable spectrum in the GSM mobile cellular bands have already been allocated to the conventional national mobile network operators. It is possible that other frequencies could be used, but to operate any telecommunications service in the Philippines, a franchise sanctioned by congress and a Certificate of Public Convenience and Necessity (CPCN) is necessary to prove financial, technical and legal capability. In addition, there are no mobile licences available for operating at a sub-national level and there are a number of other requirements, including environmental clearance certificates, height clearances, and the local mayor's permit. In total 25 different permits are needed for each cell site, a process that can take over eight months.

Partnership with national operator

To avoid the regulatory constraints, it was decided that the best approach would be to operate in partnership with an existing mobile operator. While this strategy could limit the independence of the community networks, it was felt that this was currently the only viable approach within the current regulatory environment, especially as regulations allow third parties to use the spectrum of an existing licensee. Successful negotiations then took place with Globe to use its licence and its 2G spectrum for voice and SMS,[72] as well as to gain access to its core network for calls to Globe's main network and the users of other networks. Globe also helped the project comply with the required National Telecommunications Commission permits.

Because the sites have a smaller subscriber base than is considered economically viable by Globe, the relationship is managed under the operator's corporate social responsibility programme. However, the community networks are independently run, purchasing their own satellite capacity to connect to Globe's infrastructure, but essentially acting as Globe franchisees. The service is branded separately from Globe's primary service to make it

71. This is part of a broader academic cooperation programme, the Philippine-California Advanced Research Institutes (PCARI).
72. A 2G voice/SMS service was deemed sufficient for this research project because of the predominance of 2G-only feature phones in the communities.

apparent that the service and quality expectations on these rural sites are different. This includes the lack of ability to roam on to Globe's main network.

Relationships with municipal authorities

The initiative also has close relationships with the municipal authorities in each community: the barangay, which is the smallest state administrative unit in the Philippines. The leadership of the barangays helped identify potential partners to operate the networks and to mobilise the local labour that assisted university-based engineers in their deployment.

In addition, the barangays facilitated the legal appropriation of the land where the towers were built, and helped expedite the various permits and clearances needed for construction of the base stations. The barangays have also allocated funds in their annual budget for the maintenance of the towers, and for the community-based security to protect the towers and equipment from potential theft and vandalism.

Solar power was used for most of the networks because even where grid power is available, poor reliability necessitated battery backups or fully off-grid solar systems. In addition, some sites were turned off every night to conserve power. Partly as a result of this, the average uptime for the sites was 40%. The unplanned downtime periods were also analysed,[73] indicating that 42% of the downtime was a result of interruptions to the upstream satellite link, 24% due to lack of power, 21% due to overheating, and 12% due broken antenna cables.

Cooperative ownership

Local cooperatives were identified as the most appropriate project partners to operate the networks. As registered commercial institutions, this made them eligible to conduct business transactions with Globe, and they are also familiar with the financial and administrative needs in managing income-generating activities. Most of the cooperatives involved in the project are multipurpose employee credit cooperatives and are primarily in charge of Globe's SMS-based air time distribution system for the local retailers.

The cooperatives order air time from Globe on a monthly basis, and the bulk order qualifies for a wholesale discount, which in part is passed on to the community retailers. The air time credits are purchased by depositing money into Globe's account at a nearby (but outside of the community) bank. The majority of the retailers are women (eight out of 10) running their own "sari-sari" (general merchandise) stores. Aside from the retailer's discount, the retailer also charges an additional convenience fee per transaction to the subscriber, which is a common practice in the Philippines. Additional sources of income for the retailers are provided through the sale of mobile phones and mobile phone accessories, as well as repair and maintenance services.

CommunityCellularManager (CCM) software

The VBTS project is the first large scale deployment in the world of the CommunityCellularManager (CCM) stack developed initially by start-up mobile equipment

73. Hasan, S., et al. (2019). Scaling Community Cellular Networks with CommunityCellularManager. *Proceedings of the 16th USENIX Symposium on Networked Systems Design and Implementation*. https://www.usenix.org/system/files/nsdi19-hasan.pdf

manufacturer Endaga, and then by Facebook when the Endaga team joined Facebook. CCM is a new IP-based cellular network management core which supports the operation of multiple community networks under one technical domain. Architecturally, it has two components, the client and the cloud, where Globe manages the CCM cloud installation while the VBTS project manages the client installations. This involved porting the client to the different base station cellular radio platforms deployed in the communities (NuRAN LiteCell and Fairwaves UmSITE), and developing additional features to assist with the administration, marketing, research and evaluation needs, including call and text promotional support. The CCM cloud handles the routing, interconnect and phone numbers for the network.

Pre-launch training and support

Prior to the launch of each network, local stakeholders were informed of the goals of the project, which emphasised community ownership and public service over profit. In addition, social science researchers carried out social enterprise training with the cooperatives in the sale of SIM cards and air time. Project engineers conducted training with community maintenance personnel on daily maintenance and basic troubleshooting of the tower and equipment (Level 1) and with ASCOT engineers who required intermediate technical knowledge (Level 2).

In a novel approach to identifying sources of technical support, an SMS was broadcast to all active network subscribers in the community requesting people interested in providing support to identify themselves. A number of respondents in the communities were identified this way and provided with training. There is also an SMS-based support hotline which is free to use by all subscribers in the community.

Another innovation was the repair environment that was specially created to leverage the community involvement in the network. The researchers implemented a set of services which help guide the community in conducting repairs. This consists of digital “repair manuals” embedded into the community cellular infrastructure. Network components are labelled with small codes (e.g. “ANT” for antenna) and an SMS shortcode (e.g. 777) that provides information about the particular system element. For instance, a user texting “hot” to the relevant shortcode receives a text message with instructions to turn off the system to allow it to cool. Labels are also printed on a poster in a building near the tower.

Traffic and revenue sharing

Currently there are about 1,500 subscribers across the seven networks, equivalent to more than 80% of the total eligible population (15 years old and up). Although individual community networks are able to set their own pricing, including use of flat rate prices for bundles of minutes and SMSs, calls were normally charged at about USD 0.11 per minute to off-net non-Globe numbers, USD 0.06 per minute to off-net Globe numbers, and USD 0.02 per minute for on-net (local) calls. Calls between VBTS networks are classified as local traffic. Not including Globe’s revenue from incoming calls, monthly average revenue per subscriber is around USD 0.60, which would generate a total annual revenue of about USD 11,000.

Outbound calls per subscriber averaged three minutes a month and 13 text messages, while inbound calls averaged 50 minutes and 10 texts a month. While SMS traffic has the same volume in both directions, the number of inbound call minutes is six times greater

than the number of outbound call minutes. This is a common pattern where subscribers in rural communities take advantage of free incoming calls and encourage their more wealthy urban contacts to call them.

The revenue from calls and texts are split, based on a revenue-sharing scheme in which the cooperative receives 80% while the remaining 20% goes to Globe. Earnings are used by the cooperative to pay the community members responsible for the network and the remainder is used as savings for operating expenses which may be incurred in future.

VBTS: https://pcarivbts.github.io
See the GISWatch 2018 Philippines chapter for additional information.[74]

Wireless for Communities (W4C), Digital Empowerment Foundation (DEF), India

Delhi-based APC member Digital Empowerment Foundation (DEF) was established in 2002 to help the "backward",[75] unreached and underserved communities of India benefit from ICTs. Since that time it has worked on a wide variety of projects related to bridging the digital divide in India, including many externally supported community-based Wi-Fi connectivity projects.

In 2010, with support from the Internet Society (ISOC), DEF initiated the Wireless for Communities (W4C) pilot project to support internet connectivity primarily for the well-known hand loom weavers of Chanderi, Madhya Pradesh. The project established public access and training facilities which provided digital literacy capacity building and access to information about weaving, a platform for archiving designs, and a means to sell weaving products online. In addition, public Wi-Fi hotspots provided a coverage area of about five square kilometres using a 25-metre-high mast. By 2013 there were about 50 households with Wi-Fi connections, 11 out of the 13 schools had Wi-Fi connected computer labs, and two of the three hotels provided Wi-Fi for their guests.

Community Information Resource Centres

The success of the W4C pilot resulted in expansion of the programme, which, aside from supporting small entrepreneurs and schools, included provision of connectivity and digital literacy capacity building for health posts, community radio stations, NGOs, government offices and village councils. From this process the Community Information Resource Centres (CIRC) were further developed. The typical CIRC is equipped with computers, cameras, printers, projectors, scanners, internet and a Wi-Fi hotspot, and is staffed by ICT-literate youths.

In the subsequent years, DEF has set up about 350 CIRCs in 95 districts, while W4C has reached 38 districts in 22 states, deploying about 200 access points which have connected about 4,000 people. Most of the W4C networks are located in tribal and backward areas where people have not used a computer or smartphone before. W4C also resulted in DEF's

74. https://www.giswatch.org/en/country-report/infrastructure/philippines
75. "Backwards" is a collective term used by the government of India to classify areas and individuals that are socially and educationally disadvantaged, usually in reference to those of particular castes. For more information, see: www.ncbc.nic.in

Wireless Women for Entrepreneurship and Empowerment (W2E2) programme. This was created to support women's micro-level social enterprise-based ICTs and to support women entrepreneurs in using Wi-Fi in four districts. In 2018 DEF initiated the Solar Women Wireless Engineers for Entrepreneurship and Empowerment (SW2E3) programme to provide solar and wireless training to women.

Aside from ISOC, support for these initiatives came from a wide variety of national and international agencies including the national government, Cap Gemini, the Ford Foundation, the European Commission, Ericsson, Intel, Microsoft and the Tata Trust.

Overall, W4C's strategy is:

- Training the trainers in the technical aspects of wireless networking to be able to set up and manage Wi-Fi services.
- Deploying wireless broadband connectivity across rural communities, focusing on areas where there are clusters of small enterprises (called the cluster-based approach).
- Operating an open forum to discuss best practices and lessons learned, and to educate people on issues stemming from both technical and policy perspectives.

Mobile Wi-Fi

Two other noteworthy DEF initiatives aim to address the need for ease of set-up and mobility in provision of internet access: the Internet in a Box and Zero Connect projects.

The Internet in a Box was designed as a complete portable Wi-Fi network. Made of aluminum, the lightweight unit (7 kg) is housed on a wheeled trolley and is divided into four sections to hold the telescopic mast made with water pipes, a printer (to print internet vouchers), a charger controller, batteries, wireless AP/router, sectoral antennas (5.8 GHz and 2.4 GHz) and manuals. A solar panel on the top of the box unit is fitted for charging the batteries. The unit can connect up to 200 devices at a time and costs about USD 1,400. Developed with support from ISOC and Goldman Sachs, the platform is aimed at rapid deployment by people with limited experience, and also for use in demonstrations of the technology at public meetings, conferences and training events.

The Zero Connect initiative provides temporary vehicle-based internet access to the nomadic Agariyas (salt farming) community in Little Rann of Kutch (LRK) in the state of Gujarat, where about 3,500 families live for eight months. Named Zero Connect because LRK is known as India's Survey Number Zero, the project is based on a van which tours the region on a regular basis. The vehicle has laptops, a large LCD display, rooftop solar panels, backup batteries, and an extensible five-metre, tripod-based tower with a dish antenna which can rotate 360 degrees.

Depending upon where the vehicle is parked, the antenna is aligned with a tower on the periphery of the LRK which provides the upstream internet access. The Zero Connect vehicle visits 17 schools and a number of settlements located at a distance of 20 to 50 kilometres from the tower with upstream internet link which provides access via the laptops and a Wi-Fi hotspot for local users in a radius of 100 metres of the van.

DEF: defindia.net
W4C: wforc.in
CIRC: circindia.org
W2E2: w2e2.org
See the GISWatch 2018 India chapter for additional information.[76]

Zenzeleni, Eastern Cape, South Africa

In the local language of isiXhosa, Zenzeleni means "do it yourselves", to reflect a mission of self-provision of “affordable, quality and relevant telecommunication services”. Based in the isolated very low-income Eastern Cape province rural district of Mankosi, Zenzeleni is the name of the cooperative[77] which operates the community-owned and operated Wi-Fi telecommunications network. Zenzeleni is also the name of a separate organisation, the Zenzeleni non-profit company (NPC). Zenzeleni NPC supports the Zenzeleni cooperative and the newly formed Zithulele cooperative located in the neighbouring community, as well as assisting new communities to seed and manage their own networks.

The initial seeds for the establishment of these Wi-Fi-based networks were planted in 2012 through the sustained engagement of a few dedicated individuals in Mankosi, supported by some grant funding. Since then the network has steadily expanded and evolved, culminating in a 2018 milestone when the South African government's Department of Telecommunications and Postal Services (DTPS) formally indicated its intention to collaborate with and support Zenzeleni during its annual budget speech in parliament.

Network evolution

The project originally sprang from action research in the field of human-computer interaction, where solar-powered, offline digital storytelling tools and audio repositories for information dissemination were being studied. Working with the local tribal authority, which manages the ancestral common land, the initiative then progressed through a number of further stages.

The next phase was a solar-powered offline intranet for voice calls between public phones in each of the 12 villages spread across the hills. Then VoIP breakout calls to the public voice networks were provided, before the current network was formally established as a wireless internet provider. During the VoIP call phase, calls were about 17% of the normal cost of calls; however, the cooperative committee decided to charge users 50% of the normal price, in order to fund itself. In addition, the solar set-ups that powered the system generated revenue from customers who paid about USD 0.25 to charge their cellphones.

Moving to sustainability

The cooperatively owned Zenzeleni network then emerged, and is now moving toward self-sustainability. It took considerable resources to set up the network because deployment costs have been significant and there are very few sources of income within the community, which mainly survives on subsistence agriculture and remittances. To cover the main areas, about 100 Wi-Fi access points have been deployed. For upstream internet

76. https://www.giswatch.org/en/country-report/infrastructure/india
77. Zenzeleni Networks Mankosi Co-op Ltd.

connectivity, to ensure reliability, dual long-distance (50-kilometre) double-hop WiLD links were set up to the nearest town of Umthata, where about 250 Mbps of capacity is purchased from a local ISP.

Initially, access was provided on a free basis, then a voucher system was introduced which provided unlimited access for USD 0.70 per month. This was insufficient to cover the operating costs, so the monthly fee was increased to USD 1.70. Reflecting the low incomes in the area, the change from free access to paid access resulted in a drop in the initial number of users by two-thirds.

Nevertheless, Zenzeleni has connected more than 11,000 people and 10 institutions (including three schools, two small businesses, a rural branch of a major South African bank and two hotels), offering prices as much as 20 times lower than those offered by existing operators, with substantially better quality.

Connections of up to 10 Mbps are supported, although availability of this depends on the contention ratio. Zenzeleni uses a 1:5 contention ratio for business customers, and a 1:15 contention ratio for public access Wi-Fi, although this can go up to 1:50 when there are a large numbers of users connecting to the same access point.

Network usage averages around 40 Mbps, but peaking to about 350 Mbps. On the two networks together (Mankosi and Zithulele) there are an average of about 500 users a day. The Mankosi network currently peaks at about 60 concurrent devices, while the Zithulele network peaks at about 150 concurrent devices, with around 750 different devices seen over a three-day period. Although backhaul links would need to be upgraded, the two networks as a whole are estimated to be able to support about 10,000 concurrent devices.

Mobile network plans

Zenzeleni recently obtained a mobile licence exemption and has plans to establish a mobile network once it is able to negotiate a spectrum-sharing agreement with one of the existing mobile operators to make use of their spectrum, which is unused in the location of Mankosi. Regulations already allow for this type of arrangement. Economic modelling shows that the cooperative could provide rates 66% cheaper than the current main operator in the area and it will only need to service half of the current outgoing calls from 500 users to provide the service on an economically sustainable basis.

Zenzeleni: https://www.zenzeleni.net
See the GISWatch 2018 South Africa chapter for additional information.[78]

TECHNOLOGY USE DETAILS

Access network technologies

As indicated earlier, the community networks mainly used the 2.4 GHz and 5.8 GHz licence-exempt ISM bands for wireless links based on data protocols commonly called Wi-Fi. These use the IEEE 802.11 family of standards for user access. For long-distance

78. https://www.giswatch.org/en/country-report/infrastructure/south-africa

transmissions with focused antennas, the same frequencies are normally used, but the communication protocols may be different (see below). Distances achieved are often up to 200 metres between Wi-Fi hotspot and user devices, and 50 kilometres is often achieved on long-distance links – often called Wi-Fi for long distance (WiLD).

It is noteworthy that so few companies supply almost all of the equipment used in the community networks. The three companies are Ubiquiti, TP-Link and MikroTik, from New York, Shenzhen and Riga (Latvia), respectively. Also in Shenzen is Dragino, the company that has started to manufacture the open hardware LibreRouter. Dragino has previously collaborated with open hardware developers on telecommunication equipment development, and has manufactured a wide range of electronic communication devices for many years.

In the case of mobile community networks, the frequencies that are normally used can range from 700 MHz to 2100 MHz, but all of the networks studied used the 800 Mhz band because these lower frequency bands have better long-range propagation characteristics than higher frequency bands. The choice of waveband can also depend on the geographic location, because frequency allocations are the result of regional agreements and national band plans. This in turn can affect the local availability of handsets which support a particular waveband. In addition, waveband choices also depend on the type of mobile technology adopted – LTE has many more bands available than GSM, including some that can be used for spectrum sharing (band 48).

The cellular base stations deployed in the mobile community networks were primarily from Quebec's NuRAN Wireless in Cyrille-Duquet, followed by equipment from Fairwaves (Boston), Sysmocom (Berlin) and Baicells (Plano, Texas) for LTE networks. For 2G base station operating system software, open source Osmocom is used on a wide range of open hardware devices such as those produced by NuRAN, Fairwaves and Sysmocom. The CoLTE version of the open-source OpenAirInterface was used for the Baicells LTE network.

Also of note here is Rhizomatica's Administrative Interface (RAI), a web-based management platform which supports higher level functions such traffic monitoring and account management. A similar application is the CommunityCellularManager (CCM), recently developed by Facebook, which has been used to manage the 2G voice networks and their integration into larger core networks, such as in the VBTS project in the Philippines.

Mesh networking protocols were used in many of the Wi-Fi-based community networks, and this can have an impact on the topology of the network, the requirements for high sites, and the speed at which the network develops. In a mesh network, growth spreads organically from the periphery as successive neighbours connect directly to each other, automatically choosing the optimal routes between nodes, sharing available upstream internet connections and local online resources.

To do this, TakNet/Net2Home (Thailand) uses OLSR as part of intERLab's DUMBO operating system distribution, while the other mesh networks are based on the LibreMesh distribution developed by AlterMundi. This uses dual mesh networking protocols (B.A.T.M.A.N. for layer 2 and BMX6/7 for layer 3, as shown in Figure 3). The software can also be installed on some commercial wireless routers. Both the intERLab and AlterMundi

distributions are based on the popular open source wireless router operating system called OpenWrt.[79]

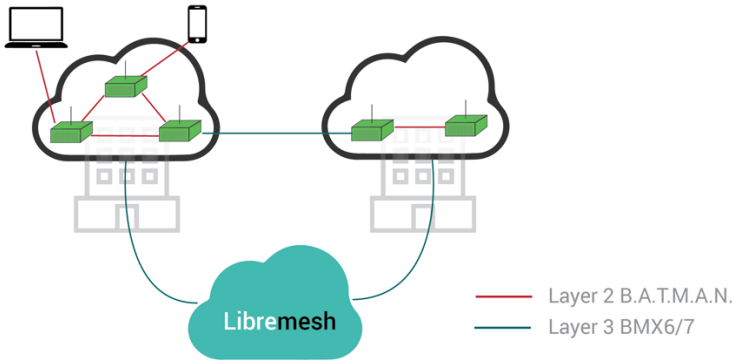

Figure 3. Mesh Wi-Fi networking using LibreMesh with BMX and Batman-adv[80]

For network management software, UniFi (developed by Ubiquiti specifically for its access points, and not open) was used in many of the Wi-Fi-based networks. MikroTik's RouterOS also plays an important role in some of the networks where MikroTik hardware manages upstream routing and QoS, while Ubiquiti equipment provides the wireless links to users. In the case of Pamoja Net, each link includes both a Ubiquiti Wi-Fi router and MikroTik router at the customer site.

Nevertheless, the overall dominance of Ubiquiti equipment and software in use by community networks is evident. This US-based company has developed a reputation for competitively priced and relatively reliable high performance equipment. In addition, some of its equipment supports the high-throughput 802.11ac standard, and its software has a system for creating/printing access vouchers. Furthermore, Ubiquiti has a proprietary TDMA-based system for optimising the use of Wi-Fi communication protocols on long-distance links (AirMax), which is almost universally used for these types of links.

As shown in Table 6, a large number of additional tools were used by the different networks, mainly to augment the functionality of the network management software provided by the equipment manufacturers. These ranged from basic bandwidth monitoring and traffic shaping applications, to captive portals and access voucher creation systems.

79. https://openwrt.org
80. https://libremesh.org/howitworks.html

Table 6. Equipment and software used in community networks[81]

Initiative and country	Access network	Upstream link(s)	Network hardware	Network software	Other applications, services and hardware
AlterMundi, Argentina	Wi-Fi (2.4/ 5.8 GHz)	WiLD, fibre	TP-Link WDR 3500/3600 LibreRouter beta[82] Ubiquiti airFiber	LibreMesh: mesh routing software LibreMap: visualising the mesh network LimeApp: node management	Nodogsplash: captive portal OpenStreetMap: navigation RRD tool/MRTG: bandwidth utilisation monitoring
Associação Portal Sem Porteiras, Coolab, Brasil	Wi-Fi (2.4/ 5.8 GHz)	WiLD, ADSL, fibre	TP-Link WDR-3500, Archer C5 and CPE210 Ubiquiti Rocket M5: WiLD link	Nodogsplash NGINX:[83] reverse proxy, load balancer, mail proxy and HTTP cache UniFi: Ubiquiti AP management software	Raspberry Pi + USB hard drive: local server Low-cost (more powerful than RPI) TV set-top boxes, e.g. EgoIggo S95X Android TV "box" Serval[84] mesh and KouChat:[85] P2P file sharing and local area network messaging Pi-hole:[86] bandwidth optimisation via adblocking and to limit phishing YunoHost:[87] easy hosting of web services (email, website, news aggregator, seedbox, instant messaging)
Battery Operated Systems for Community Outreach (BOSCO), Uganda	Wi-Fi (2.4/ 5.8 GHz)	WiLD, fibre	Ubiquiti Rocket/ Lightbeam MikroTik gateway	UniFi AP RouterOS (MikroTik): AP management system Network monitoring: Nagios Core,[88] Dude, Cacti, SmokePing, LibreNMS	Intel Classmate: solar-powered low-energy laptop netbooks Kolibri:[89] offline educational content distribution VoipBuster:[90] audio calls Psiphon:[91] VPN with Android support CM Transfer: handset-based file transfer eGauge:[92] online solar energy metering system RootIO:[93] low-cost community radio system

81. Footnotes with URLs are included for less well-known equipment and software the first time they appear.
82. https://librerouter.org
83. https://www.nginx.com
84. www.servalproject.org
85. https://www.kouchat.net
86. https://pi-hole.net
87. https://yunohost.org
88. https://www.nagios.org
89. https://learningequality.org/kolibri
90. https://www.voipbuster.com
91. https://psiphon.ca
92. https://www.egauge.net
93. https://rootio.org

Des Hotspot, Indonesia	Wi-Fi (2.4/ 5.8 GHz)	Fibre	Ubiquiti MikroTik	UniFi RouterOS Squid Cache: upstream traffic minimisation	Bosetech 3G repeaters: Access to the mobile network in remote areas
Gram Marg, India	TVWS and Wi-Fi (2.4/ 5.8 GHz)	TVWS , later WiLD, fibre	Ubiquiti MikroTik Doodle Labs:[94] TVWS LigoWave	UniFi RouterOS	DRUV box:[95] offline video streaming, using Prodia set-top box Wi-Fi Talkie: P2P VoIP app GAIUS Networks:[96] mobile app for local content production and management platform AgroStar[97] and Pashu Mitra:[98] farmer support apps EpiCollect: data collection QGIS: open-source GIS
Mayutel/ Red de Telemedicina del Río Napo/ TUCAN3G, Peru	3G and Wi-Fi (2.4/ 5.8 GHz)	VSAT, WiLD, ADSL	Ubiquiti ALIX Linksys RouterBoard MikroTik NetMetal Albentia:[99] WiMAX ip.access:[100] 3G femtocell Parallel Wireless: 3/4G base station Huawei: small cells Hispasat: SCPC VSAT	RouterOS Voyage:[101] embedded OS based on Debian GNU/Linux, with PRIO queuing system for QoS implemented 3CX:[102] IP PBX	Asterisk: SIP VoIP calling Radio Mobile:[103] link planning tool. Clear Blue Technologies:[104] smart solar charge control

94. https://www.doodlelabs.com
95. https://www.tatatrusts.org/article/inside/project-druv-tata-trusts-innovation
96. gaiusnetworks.com
97. https://agrostar.in/amp/hi/articles
98. https://www.pashumitra.in
99. www.albentia.com/EN/index.php
100. https://www.ipaccess.com
101. linux.voyage.hk
102. https://www.3cx.com
103. radiomobile.pe1mew.nl
104. https://www.clearbluetechnologies.com/en

Pamoja Net, DRC	Wi-Fi (2.4/ 5.8 GHz)	WiLD	Ubiquiti MikroTik Business customers: Ubiquiti Nanostation + home Access Point lite (hAP lite) MikroTik router	UniFi RouterOS MultiPing:[105] traffic monitoring ntop:[106] monitoring traffic of all devices pfSense:[107] firewall/traffic management/ QoS	Microsoft Surface tablets: public access Open MRS (health patient management system) Fjord: SMS news-to-display app OpenCellular[108] CommunityCellularManager client and cloud support: management, routing, and interconnect SmokePing:[109] monitoring links
Puspindes/ Common Room/ RelawanTIK Indonesia	Wi-Fi (2.4/ 5.8 GHz)	WiLD, fibre	Ubiquiti MikroTik	UniFi RouterOS Dude	Asterisk: SIP VoIP calling Squid web cache Proxmox:[110] open source server virtualisation RPI-based teaching
Quilombola Community Network, Brazil	Wi-Fi (2.4/5.8 GHz)	VSAT	TP-Link WDR3500 HughesNet Ku satellite link	LibreMesh Vulture Project:[111] reverse proxy Intel Ultratop WT6C server	Elastix:[112] VoIP TeamViewer:[113] remote assistance Kdenlive:[114] video editing VLC: online radio
Taknet/ Net2Home, Thailand	Wi-Fi (2.4/5.8 GHz)	Fibre	TP-Link MR3040, AC1750 Ubiquiti UniFi Core router and outdoor APs Carlson: TVWS	OpenWrt/OLSR UniFi	Raspberry Pi + USB hard drive: local server – chat, video on demand HazeMon:[115] monitors temperature, humidity, air pressure, particulate material (PM1, PM2.5, PM10), volatile gases

105. https://www.multiping.com
106. https://www.ntop.org
107. https://www.ntop.org
108. https://github.com/Telecominfraproject/OpenCellular
109. https://oss.oetiker.ch/smokeping
110. https://www.proxmox.com/en
111. https://www.vultureproject.org
112. https://www.elastix.org
113. https://www.teamviewer.com/en-us
114. https://kdenlive.org/en
115. www.wunca.uni.net.th/wunca_regis/wunca34_doc/19/009_SEA-HazeMon_Wunca34.pdf

Telecomunicaciones Indígenas Comunitarias (TIC AC), Mexico	GSM 2G (2+2 MHz in the 850 MHz band), testing 4G/LTE/Gxt, data and voice	WISP VSAT HF	sysmocom[116] NuRAN LiteCell[117] Fairwaves[118] Parallel Wireless[119] Baicells[120] Kuha[121]	Osmocom[122] Rhizomatica Admin Interface: custom management software Radio mobile: network coverage planning	Custom SIP/VoIP calling app for off-net users DIDWW:[123] DID numbers and VoIP/SIP service provider IDT Express:[124] voice termination Kamailio:[125] SIP/RTP calls tinc:[126] VPN
Ungu Community LTE, Bokondini, West Papua, Indonesia	4G/LTE data only 850 MHz	Microwave and VSAT	Baicells LTE eNodeB (base station) ZOTAC ZBOX Mini PC[127] for EPC	Open Air Interface/CoLTE (EPC) Custom billing system NGINX: web caching ntopng:[128] logging traffic per IP address	Local shared hard drive media server Chat server (Rocket.Chat)[129] using the Meteor full stack framework
VBTS Konekt Barangay, Philippines	4G/LTE voice only 850 MHz	VSAT	Endaga[130] NuRAN Intel NUC mini PC for CCM	CommunityCellularManager (CCM):[131] routing, interconnect, phone numbers	CCM for broadcast SMS messaging
Wireless for Communities (W4C), Digital Empowerment Foundation, India	Wi-Fi (2.4/5.8 GHz)	WiLD, fibre	Ubiquiti MikroTik Cambium	UniFi RouterOS	Wi-Fi Talkie Zero Connect:[132] roving van public access and Wi-Fi hotspot Internet in a Box:[133] portable network
Zenzeleni, South Africa	Wi-Fi (2.4/5.8 GHz)	WiLD, fibre	Ubiquiti	UniFi MikroTik	3/4G dongles + Routerboards: logging and remote access to tower equipment for technicians

116. https://www.sysmocom.de
117. nuranwireless.com/products/gsm-litecell
118. https://fairwaves.co
119. https://www.parallelwireless.com
120. https://na.baicells.com
121. https://www.kuha.io
122. https://osmocom.org
123. https://www.didww.com
124. https://www.idtexpress.com
125. https://www.kamailio.org/w
126. https://www.tinc-vpn.org
127. https://www.zotac.com/uy/product/mini_pcs/overview
128. https://www.ntop.org
129. https://rocket.chat
130. https://www.crunchbase.com/organization/endaga
131. https://github.com/facebookarchive/CommunityCellularManager
132. wforc.in/zeroconnect
133. internetinabox.in

Technology use insights

The networks studied provide many examples of the knowledge gained and rich experience accumulated in the application of the networking technologies used, along with many innovative technical strategies that were adopted to address the need for connectivity in the face of these conditions. The proverb “Necessity is the mother of invention” is particularly apt here.

The work on the two main building blocks – wireless routers and mobile base stations – is particularly noteworthy in this respect. Experience in operating community networks with the currently available hardware has made apparent its limitations when deploying it in the community networks. This has led to the work of AlterMundi, intERLab, Rhizomatica and others to improve on existing designs, both at the software level and at the hardware level, for example, in optimising mobile communication protocols for satellite and HF radio links, or in designing new wireless router hardware more suited to the needs of community networks.[134]

Most of the initiatives studied have developed experience in addressing lightning issues, which can regularly destroy electronic equipment in areas susceptible to these weather patterns, especially on high towers. Effective earthing is particularly important, and this can require special strategies when towers need to be mounted on rock. In addition, although relatively expensive, active lightning suppressors have been used to good effect when combined with a three-conductor design using separate cables for tower, equipment and lightning rod.

134. An important feature of the LibreRouter is that it has multiple radios. In a mesh network using traditional single radio wireless routers, the hops between nodes halve the throughput at each hop. With multiple radios, the LibreRouter can dedicate interconnection between nodes while servicing Wi-Fi hotspot users at the same time. The LibreRouter also has more powerful radios than most wireless routers in order to support longer distances, and it additionally has seven ports for antennas, an included sector antenna, two USB-3 ports, six ethernet (GigE) ports, lightning protection, and the ability to cope with a wide range of input voltages (9-30 volts). Modules for GPS and TVWS are also being designed to allow for location sensing, non-line-of-sight communications and optimised throughput on long-distance Wi-Fi (WiLD) links.

Table 7. Technology insights and innovations from networks studied

Initiative and country	Experiences, observations and innovations
AlterMundi, Argentina	Local design and construction of parabolic antennas (USD 10 for a 40 cm diameter 25dBi). Current off-the-shelf wireless routers have limitations for community networks, which necessitated the design, development and manufacture of the LibreRouter, which is more suited to needs of communities. Mimosa or Ligowave may be more suitable alternatives to Ubiquiti AirFibre for long distance links. Power over ethernet with 24 volts can provide sufficient power to devices with lengths greater than 80 metres. Wire mesh cover for solar panels is needed to stop birds from perching on the solar panels at the high site.
Associação Portal Sem Porteiras, Coolab, Brazil	LED strip on high site tower for ease of alignment (mist, distance), consumes 12W for 5 metres. Although the network is mesh-based, a relatively large number of point-to-point links are required because of the hilly topography combined with the long distances between the initial number of participating member houses that are scattered within the community. No lightning problems at one location which uses a deep (2 metre) copper rod attached to a 0.75 cm twisted iron cable with Franklin rod. MPPT charge controller is worth the extra cost for more efficient battery charging (30% improvement).
Battery Operated Systems for Community Outreach (BOSCO), Uganda	Combined solar power and ICT training support for small business. Public access kiosks made from locally available recycled oil drums. Use of RootIO open source software toolkit for community radio stations. The orientation of PCs in public access facility is designed to reflect local culture (facing inwards, toward each other). For user-level management, BOSCO has switched from UniFi (Ubiquiti) to RouterOS (MikroTik) as it was found to have more sophisticated features (including graphing tools and firewall features) as well as a higher level of reliability.
Gram Marg, India	TVWS router can be created with off-the-shelf 2.4 GHz Wi-Fi board with RF converter from 2.4 GHz to 500 MHz. Tower costs are substantially lower in deployment of TVWS vs Wi-Fi (WiLD). TVWS reduces costs of deployment because tower heights are lower – they don't need line of sight. 100 Mhz TVWS channel served 7 villages with 1 BTS over distances of 2-6 km at a speed of 14 Mbps. MIMO antennas at lower frequencies than Wi-Fi, such as for TVWS, require more space on towers (0.6 metre separation at 500 Mhz). Unconnected hotspots can be set up to solicit service interest via messages embedded in broadcast SSIDs. Cables often require protection from rats. Research on “frugal 5G” indicates that dropping mobility requirements makes the technology much cheaper. Link planning tool developed by IIT Bombay provides line-of-sight clearance and link feasibility data based on fibre pop locations and the location of the site to be connected.
Mayutel/Red de Telemedicina del Río Napo/TUCAN3G, Peru	Some Wi-FI towers needed to be 90 metres high and 20-30 metres above the tree canopy to support the long distance (up to 50 km) line-of-sight links. Interference can take place between wireless cards and antennas in the tower if they are located too close together on the towers (even when no overlapping channels are used and antenna polarisation alternates from link to link). For adequate quality of service on synchronous applications (primarily voice calls), it is important to limit the traffic circulating across the multi-hop backhaul so that none of the links saturate.

	Adjusting the MAC parameters on long-distance Wi-Fi links can allow 802.11b links to reach 105 km. MikroTik's NV2 protocol appears superior to Ubiquiti's AirMax protocol for long-distance links – based on TDMA, NV2 solves the Wi-Fi hidden node problem, provides greater throughput and lower latency, together with support for point-to-multipoint links. VPNs with MPLS can be used to effectively carry mobile voice traffic to operator networks. For satellite links carrying VoIP traffic, SCPC protocols are superior to TDM/MF-TDMA systems, providing less delay and jitter. SCPC also works with the QoS systems in use with mobile networks. An effective earthing system[135] for high towers uses 3 physically separate ground wires (for tower, equipment and lightning conduction – latter has 2 cm separation from tower) with proactive interception of lightning strikes at early stages using ESE Terminal and Charge Transfer System[136] (CTS) which reduces the probability of a strike (Charge Dissipation Terminal). Gas protection on coaxial cables is also needed. Where the terrain is rock, a 40M grid ring around the tower was deployed. Four days of energy autonomy can be achieved with 4 115Ah batteries + 4 84W solar panels. By including a mechanism to switch off the 3G femtocell base stations during periods of low demand, a 20% savings in the size of batteries and solar panels required can be made.
Pamoja Net, DRC	Frequent strong lightning combined with high mineral content in terrain can be a major problem causing frequent loss of equipment if lightning protection is insufficient. Thorough end-to-end link quality analysis is necessary to identify problems – ping tests may be okay until higher traffic levels are reached, full throughput tests are needed on each hop to identify the location of problems. Realignment of antennas on long-distance links needs to be done on a regular basis. Choice of the right LCD screens with sufficient luminescence to be able to display news and weather services during the day is an important selection criterion for public display systems. Batteries placed high on the towers improve security (hard to get to for thieves). UniFi does not appear to be reliable for network management: it can show an inactive link as active, and does not always open up access to everyone at 4 p.m. daily – often it needs to be restarted.
Puspindes/Common Room/RelawanTIK, Indonesia	No traffic monitoring tools in use reflects the low cost of bandwidth. A Raspberry Pi school teaching environment costs about USD 1 per student. Significant local + offnet multimedia/streaming traffic demand – respond with local P2P platforms and caching.
Quilombola Community Network, Brazil	Traffic shaping tools and technical skills are necessary to manage the limited amount of satellite bandwidth and to cater for more nodes. G729 codec provides best VoIP quality relative to bandwidth requirements. Smartphones connect at up to 40 metres from TP-Link WDR-3500-based access points. Signal strength on the Wi-Fi network can be reduced by tropical rain. Extensive training on use of local applications is required in an ICT non-literate community.
Taknet/Net2Home, Thailand	TP-Link equipment (MR-3040 and AC-1750 Archer C7) supports OLSR mesh protocol with 16 Gb of external storage for local content (also using RPIs). UniFi outdoor APs provide up to 200 metre range for Wi-Fi access devices (TP-Link is only up to 100 metres). Low power consuming wireless routers are needed for low-income households paying for their energy. Single-radio mesh links with over 3 hops did not provide sufficient bandwidth for end-users. Significant unwanted off-net traffic is generated by app updates and adware-based apps (e.g. CM Battery) – requires app caching and adware blocking.

135. gtr.telecom.pucp.edu.pe/download/publicaciones/1041.pdf
136. https://www.lightningprotection.com/charge-transfer-technology

Telecomunicaciones Indígenas Comunitarias (TIC AC), Mexico	Issues that need to be considered when moving from mobile voice services to mobile data: Voice services go farther than data services given the same frequency and power output. Voice uses less bandwidth and functions in lossy environments whereas each data user can be a heavy consumer of data and hence spectrum. A large number of simultaneous data users will shrink the range of a 3G/4G-LTE network. With the 2+2 MHz authorised by the regulator for TIC AC's 2G use it is not practical to support more than 6 base stations (BTS) in the same coverage area – this puts a severe limitation on expansion. Availability of cost-effective small-scale 3/4G equipment that operates with the very limited amounts of spectrum that have been made available for small-scale networks is a problem – only a few hundred KHz is needed to run a 2G voice network, but most 3/4G base stations use a minimum of 5 MHz. Less could be used but there are no vendors who build this capability into their equipment. 5 km is the effective range between handset and BTS in ideal conditions. 2G 5 watt output power BTS consumes 50-60 watts. 200 watts required for all equipment (including laptop controller/admin PC). Cost and weight increase significantly as the sensitivity of the antenna is increased, while availability decreases – 6dBI (USD 40) easily available, 15dBi (USD 200) 15kg, shipped directly from China, 20-22dBI (USD 1,000-1,500). Omnidirectional antennas have narrower beam widths. An effective low-cost coverage planning tool for small-scale community networks is not available. Many older feature phones do not support the most efficient codecs. GPRS can be used for messaging, but it is advisable to block its use for browsing on bandwidth-limited voice networks. No SIM card is necessary if encryption is not required. Handsets that support LTE are still scarce in many locations. Ensuring sufficient backhaul capacity for LTE can be a significant constraint – cost and availability of fibre especially. Sharing masts with FM radio stations can be a problem if the output power of the radio is more than 100 or 200 watts as this creates too much radio frequency noise, etc. Two patch antennas can be used to focus radio transmissions toward the village centre. Antennas can be fastened to a bamboo pole on top of a building and can easily cover the whole village, even providing coverage inside the adobe buildings (adobe is good at blocking signal). Sysmocom BTS supports up to 200 users while NuRAN LiteCell and Fairwaves BTS support up to 400 users (more channels). VoIP can be used to terminate calls, instead of the complication of interconnecting with incumbents over legacy SS7. Smartphone app makes it easier for people outside to call in to the TIC AC networks. Lightning protection planning for base stations first requires a risk assessment of the likelihood of being struck. Buried concentric rings of conductors with elements radiating from the tower is effective. Radio equipment depreciates very slowly – 4-year-old equipment is still functioning perfectly.

Ungu Community LTE, Bokondini, West Papua, Indonesia	The Community LTE (CoLTE) open source EPC on-site provides a standalone network in a box which keeps all local traffic local – WhatsApp and other OTT VoIP applications provide voice calls over the network without requiring the use of any expensive upstream satellite bandwidth. For scaling and larger systems, 2 Gb ethernet ports are needed on the PC operating as the EPC. LTE architecture has a high level of security and limits the potential for IP spoofing. IP addresses can be linked to specific users, allowing standard traffic management and QoS tools to be used to differentiate services and users rather than using the more complex LTE control plane designed to work on a network with a centralised core. This makes OTT voice services more suitable than VoLTE, especially for small-scale community-based networks. High-quality technical support received from LTE base station manufacturer Baicells. Need to set up a VPN with fail-safe measures to be able to reliably connect to the management interface when ISPs cannot provide port forwarding to allow remote access to the system. Hardware manufacturers often use agile/rolling release cycles and are continually changing their platforms, which can cause unanticipated configuration problems. Web page and local network design can have a big impact on the user experience with congested and low-bandwidth internet links. VoIP traffic such as Skype and WhatsApp can be prioritised on low-bandwidth links to improve performance without significantly impacting other uses of the internet.
VBTS Konekt Barangay, Philippines	The franchise model is a novel spectrum refarming strategy for Globe Telecom and the first large-scale CommunityCellularManager (CCM) deployment in the world with integration into the local operator's core mobile network. Systems which rely on writing to SD cards can be subject to failure due to wear and tear on the SD cards. Finding a local metalworker to construct towers can reduce overall costs significantly by saving on shipping costs.
Wireless for Communities (W4C), Digital Empowerment Foundation, India	Internet in a Box provides an effective demonstration unit and aids in rapid roll-out where skills are limited. A suitably equipped mobile/roving vehicle can provide public access for nomadic communities and for technology demonstrations.
Zenzeleni, South Africa	Ubiquiti Rocket Ms support 200 Mbps point-to-point links over a distance of 10 km for a cost of only USD 200 (2 devices). Use of equipment for licensed wavebands would cost 5 times more. Ubiquiti Powerbeam AC Generation 2 offers higher performance at relatively low cost. Very few end-user applications require more than 1 Mbps, except for large downloads. 10 amp charge controllers are needed to support up to 4 devices in each location (2 access points and 2 point-to-point links). Wind and water ingress are the primary causes of equipment issues – 20% of devices lost to water damage. Although not expensive, DC-DC converters used to provide 24v from 12v solar panels/batteries are sensitive and often need replacing due to shorting out. Lightning protection is complex – site without lightning protection has had fewer problems than the site with a lightning conductor. Mounting on a building if possible is preferable to a tower – ability to shield from RF noise is better, access is easier. Grid power may be cheaper but if not clean, can be a problem – sites with the most problems are on grid power. Low-cost power smoothers have had to be replaced 5 times, more reliable devices are much more expensive. Equipment amortisation times are estimated to be: electronics 4 years, batteries 5 years, solar panels 25 years, tower 20 years.

SECTION 3.
THE SOCIAL BENEFITS OF RURAL COMMUNITY NETWORKS IN SIX COUNTRIES AND RECOMMENDATIONS FOR THEIR DEVELOPMENT

Nicola J. Bidwell

INTRODUCTION

This section presents a summary analysis of data gathered *in situ* during 70 days spent in six community network initiatives in Argentina, India, Indonesia, Mexico, South Africa and Uganda. The research sought, firstly, to describe the roles and meanings of rural community networks in the everyday lives of the people who initiate, champion, coordinate, interact with, use and do not use them. To do so, I engaged with 152 women and 172 men in interviews, observations and focus groups, and by participating in other local events.

In some countries, participants lived in close proximity, either in the same or nearby villages or very small rural towns. A total of 273 of the people interviewed inhabited rural areas in which community networks are deployed. In Uganda and India, however, participants came from six and eight villages, respectively, that were further apart, although more data was gathered in some villages than others (see the Annex to this report). The names of the villages or towns in which data was generated are not used, to protect participants' identities; rather, these places are given a number in each country. Number order indicates the relative volume of data collected in each place (e.g. more interviews and focus groups took place in Uganda-1 than Uganda-2). Participants' accounts of their practices yielded rich insights into their operation, use and non-use of their local community network, and analysis produced common and contrasting characteristics among the different community networks.

Secondly, the research sought to identify the ways these six community networks challenge or reproduce existing inequalities in the societies they intend to serve. Analysis of the data generated in the study yielded sets of interrelated themes that comprise features of the networks and qualities of the impacts they had in their specific settings. These impacts are presented in this section as a summary that starts by synthesising 77 different benefits, supported by the data, into themes. These themes include 11 different benefits of community networks as a paradigm for connectivity that is, for instance, more adaptable to local constraints than commercial telecommunications and enables creating new solutions to the particular challenges of specific settings. The themes also encompass 38 different and wide-ranging benefits to rural economic development, from generating income to enabling people to use technology to support their learning and employment. Additionally, the themes include 15 benefits to social welfare, from increasing opportunities for personal privacy to resisting constraints that limit girls' involvement in technology. Further, the themes include evidence of 13 positive impacts on people's personal development and well-being, from fostering senses of capability to addressing isolation.

Thirdly, the research sought to determine ways to ensure that rural community networks offer benefits to the widest possible range of people in their specific contexts of management, access and use. Thus, the second part of this section overviews 27 challenges, again grouped into themes, that community networks encounter. Half of these challenges are shared with telecommunications in general – for instance, not owning a phone prevents people from access, while the geographic distribution of technical skills compromises the maintenance of community networks. Many of the challenges that community networks encounter in ensuring that they positively impact on diverse people are inherited from, or even caused by, the telecommunications domain generally. However, these issues also conflate with phenomena that arise within community networks

themselves, such as particular power differentials and gender norms. Thus, the second part of this section also includes 35 different recommendations that are included in groups related to each set of challenges, and range from developing ways to assess the benefits of community networks to improving their potential sustainability by including more women and older people.

BENEFITS AND CAPABILITIES

Community networks contribute a wide range of benefits to communities, extending far beyond providing connectivity or direct savings on the cost of communications. Some of the benefits that emerged in the data generated for the six community networks studied in depth are often considered contributors to rural economic development, for instance the local circulation of money; income from trade, business and employment; educational and learning opportunities; and local creativity and innovation. Some benefits might be described as psychological, such as gaining confidence by learning to set up or use telecommunications or feeling empowered by being able to make decisions about telecommunications operations. Some benefits enhance the local social fabric, such as sharing information with or assisting others, or reflect the way that community networks are situated in social relationships, such as improving local safety through interpersonal bonds.

The benefits and capabilities presented reflect aspects of life that participants' explanations and comments suggest they particularly valued. They are presented in themes that intend to articulate the values participants expressed – although many benefits and capabilities intersect with each other in various different ways. Their order of presentation is for clarity and does not connote how participants prioritised them.

Expressing and extending self- and collective efficacy

As well as many benefits that are quantifiable or tangibly assessable, such as contributing to local economies, education and security, community networks also contribute to, or deepen, people's confidence in their capability to achieve. Self- or collective efficacy broadly refers to people's beliefs that they can successfully organise, conduct and complete a task, personally or collectively, respectively. These efficacies arise from their performance and attainments, skills, knowledge, and various social and psychological factors. Users of local networks occasionally made explicit comments about the importance of self-efficacy in life. For instance, a teacher in a village primary school in India-3 said he used the network to download stories, poems and songs to present to his young class, and that he favoured inspirational videos, such as one that illustrated how "with the energy within, you can achieve. You can actually become a president of India. There's nothing to [stop] you; even though you are in a small school, in a small village, you can be [president]."

Members and users of some networks explained how their own achievements can inspire others in their villages. For instance, a woman in Argentina-2 said that the skills she learned to set up and fix nodes in the community network "amazed men" and she sought to

show women that they could also develop skills so that they did not have to depend on men to fix their nodes: “If I can do it, you can do it too,” she said.

Local coordinators, and often users, in villages expressed considerable pride in establishing and maintaining their local networks. Sometimes participants related pride to wider recognition of their network’s unique achievements. For instance, the chief of the village, in Indonesia, pointed with honour to a photo of himself in Geneva, in early 2018, accompanying members of the Puspindes Centre for Information and Rural Empowerment to receive several WSIS Prize Awards. The chief explained that others in the district’s Village Chief Association were also establishing local networks, but that he had “the initial idea to build the tower” to provide connectivity to his village. In Argentina-2, the sense of satisfaction in her self-efficacy and recognition of her capability by others was obvious when a woman animatedly explained that nowadays: “When someone wants to get connected, they come to see me – an older lady who knows all these things. I turn from being the old lady to the super woman.”

Often, especially in South Africa, Mexico and Argentina, when participants expressed pride they indicated the imperative of cooperative contributions and emphasised “we”. For instance, the “super woman” in Argentina explained how she had participated in a workshop with “Clara” (not her real name), who had later struggled to set up her own node, and had helped Clara, often acting as conduit for information from a founder of AlterMundi. She remarked that she “felt very proud of the process” on the day Clara finally got connected. In the impoverished village in South Africa-1, cooperative members sought recognition for their achievements: “We would like a jersey [t-shirt] with Zenzeleni written on it, so our project will shine to everyone,” one said. Pride also related to group legacies; for instance, cooperative members repeatedly said that they were motivated by contributing to a better future for their children, and a woman cooperative member said they aspired for a writer to record their story: “We want the history of the network [written] for the growing generation,” she said. “The new generation must read the history of their grandmothers and grandfathers to keep the history of this network.”

Participants in the remote, small town of Mexico-1 said that their GSM network impressed people from other communities, who often asked how they might also start such an endeavour. Indeed, sometimes pride, recognition and inspiration related to contributing to a movement that will benefit people far beyond a local network’s own constituency. The woman president of the Mexican town’s indigenous assembly had actually represented all of Rhizomatica’s networks in pioneering national legal hearings about more equitable regulatory frameworks that enable spectrum sharing. Meanwhile, cooperative members in South Africa-1 said, “We will be happy when we see this project spreading all over the world.”

While pride in achievements had varied personal and collective connotations, it was usually associated with determination and tenacity in surmounting many challenges in setting up and maintaining a local network. Challenges included a shortage of various resources, particularly the money, transport, competence and time to plan and undertake tasks; legal hurdles; technical problems; loss, theft and damage of equipment; and interpersonal disputes. The perseverance required to maintain efforts despite the challenges often seemed to reflect a quiet confidence that a community’s historical survival was based on tenaciously applying skills. For instance, an elder storyteller recounted a particular date in the late 1970s, when the road that winds through mountains finally reached the isolated

town of Mexico-1. It was constructed, he said, because local indigenous people laboured "from six in the morning to six at night" and "without using a tractor." Another elder in the same small town said, "We are 100% poor, and lack economic resources, but we work hard." In fact, many local people volunteered to help erect the tower, high in the mountains overlooking Mexico-1. A man member of the cooperative in South Africa-1 similarly described drawing on local skills to build an office for their community network: "We have the ability to build the structure, the only thing we need is the money for material."

Participants' descriptions often suggested incremental achievements, and a sense of an unfolding journey in which they gained confidence to set new goals. A first workshop in Argentina-3, for instance, simply aimed to connect by Wi-Fi to the other side of the river, yet within two months the community network members had set up six nodes. Incremental attainments maintain hope and expectations of success. In South Africa-1, cooperative members explained that the process began "slowly, slowly, slowly." However, generating revenue from cell phone charging, during the early years of using Wi-Fi for local VoIP calls, had lifted cooperative members' spirits, and the act of taking the accumulated revenue to the bank reassured them that their long-term goal was achievable. Several participants in different sites in Uganda explained that training had enabled people to make other contributions to their communities and start enterprises, which one man related to "giving hope" to youth in the region, traumatised by war and relocation.

The success of community networks amplifies people's sense of capability and their confidence to set new collective or individual objectives. While three cooperative members in South Africa-3 detailed their ambitions for an office, a vehicle and workers, several users in Mexico-1 described the improvements they seek, like lifting the current GSM tower or building a tower in a neighbouring town. The unfolding journeys that many participants referred to, in their own various ways, contrast with experiencing a telecommunications network that is constructed according to a predetermined model that is detached from their lives. Their self- and collective efficacy arises alongside the journeys of their community networks, the ups and the downs as they go along.

Ownership and walking together

Local ownership of a community network both expresses and extends collective efficacy. Cooperative members in South Africa insisted that they made the decisions. For instance, one woman member, who lived under apartheid, expressed ideals about self-determination and commitment by referring to a leader in South Africa's liberation: "Here in this project we are an example of Mama Albertina Sisulu. We are the owners of this project and we want to die in this project." In Mexico, where all adults in the area contribute to the decisions of the indigenous assembly, several users explained, "The owner is the [local customary] authority…We like it because of [our] control."

The members of neither the South African cooperative nor the Mexican assembly had telecommunications expertise; rather, their ownership and control required external initiators and umbrella organisations to provide accessible information. "We walked with [the founder of the umbrella organisation] on the telephony," a 31-year-old father in Mexico-1 explained. "We live in the field and it's what I like, and we sometimes don't manage the technological stuff." Such relationships involve openness and trust, as we observed during an assembly, when a man explained how the network began: "So, we

spoke to [the founder of the umbrella organisation], who gave us all the information and sent it to the authority. We like the way he worked," he said. "Then he personally came with this team and gave us more information, which convinced us."

The importance of "walking together" with external initiators was also expressed in South Africa, where a cooperative member said that they had other projects that failed, but had hope for their local network since they trusted the man who had initiated it, "because they [the community network initiator] is so much intellectual […] so we trusted [the project] would go further and that is why we openly gave our hearts." What was important was that the community network initiator taught the cooperative and local champion so they could make decisions about their network: "We were assisted by [local champion, community network initiator, external technician], who gave us knowledge," a cooperative member said. Indeed, cooperative members in South Africa insisted that they made the decisions and fluently referred to the network devices used, and details of funding and phases of their network.

The umbrella organisation in Uganda advises local groups who manage the ICT centres that host access points when they need to replace computer hardware, such as a mouse; however, like other umbrella organisations, it sources and supplies networking technology. A farmer in Mexico-1 explained, "If we need new equipment like solar we can pay for it. [The founder of the umbrella organisation] gets it." Thus, members and operators of community networks do not always know what is involved in procuring network equipment. For instance, the former assembly president who spearheaded the network in Mexico-1 said the first antennae they ordered had been apprehended at the border and sent back to Canada: "I don't know what [the founder of the umbrella organisation] did, but it went back, and now there it is."

While shielding people in villages from technical specifics, the organisations supporting the more successful community networks prioritised transparency about business and financial operations, and were eager to learn how they could improve their impacts. Some supporting organisations were particularly enthusiastic about receiving and responding to feedback from our studies. For instance, the support organisation in Indonesia decided to launch courses to assist elder women in learning to use the internet after we pointed out older participants' interest; and the cooperative members in South Africa received the t-shirts they told us that they desired, just a few weeks after we reminded the umbrella organisation about their importance.

Ownership also involves trust that local members share a vision of collective responsibility. Participants who made decisions in the community networks in South Africa, Mexico and Argentina expressed the importance of honesty in agreeing on goals. Cooperative members in South Africa all said that along with bringing together local society, reducing poverty and working for "the whole of the [area's] people to benefit," they also sought for the project to uplift their children's education, provide them with jobs and obtain remuneration. Cooperative members took their responsibility to their customers very seriously, and had identified the resources they needed to improve their service.

Sometimes the goals of a community network are linked to cultural emphases on local autonomy and cooperation. The overt principles guiding the Argentine community networks are autonomy and self-responsibility, and a shared commitment to self-regulate in setting up and maintaining local networks, which may reflect cultural traditions of

cooperatives. Initiators of the Argentine community networks said that they were not motivated by just wanting the internet for only themselves, and they had learned over time to invite people who "share the mind-set," who appreciate that if the network fails, no one is going to come to fix it, and they must take responsibility for learning about it. Meanwhile, in the Mexican community networks, visions for connectivity combine with a sense of identity and indigenous self-determination; for instance, participants in Mexico-1 mentioned threats to their sovereignty and fears about privatising water and exploiting minerals.

Contributing to local economies

Our data illustrated various benefits of local networks to local economies, including direct savings on the cost of communications for users, increased income from trade, business and employment, and contributing to the local circulation of money. Only the woman president, and others in the indigenous assembly that oversees the Mexican community network studied, explicitly stated that their community network economically supported their community as opposed to profiting commercial telecommunications companies. However, three other community networks offered direct savings on communications. In Indonesia and South Africa, where the only alternative for internet access is through mobile operators, many participants expressed that their networks' major benefit was the low cost of connectivity.

Most of the 15 frequent users of the South African community network we asked indicated that they now spent between 10% to 40% of what they previously spent on mobile data. For instance, a 40-year-old woman who walks out of her garden three times a day to obtain a Wi-Fi signal said, "I used to spend 150 rands a month on data, now I just buy 17 rands." Members of community networks in Argentina were attracted by reliable low-cost internet access compared with access offered by alternative ISPs. An older woman explained that prior to becoming a member, she was unable to afford a "non-crappy" ISP" and had a connection that was very "crappy" and slow. On her modest income, earned from selling clothes from her home, she "needed something that worked and was affordable." Meanwhile, a man in his mid-30s who works in a small construction business said, "every month I had to pay 240 pesos" to his previous ISP, but now "I pay that every three months."

Community networks have direct economic impacts in communities by tapping into, or facilitating, remote social capital. For instance, family members living in distant cities and countries pay for some participants' subscriptions in Mexico-1. Sometimes accessing social networks using a community network enabled raising funds for community endeavours. Men in community networks in two African countries, for instance, referred to sponsorship of village soccer teams. A young man in remote rural Uganda-2 enjoyed chatting about his progress on Facebook with a past sponsor from Japan, while in South Africa, a "soccer man" said that WhatsApp is important in many ways to connect people, and he had "put a proper photo and was going to get sponsorship" for local teams.

Use of social network platforms that was not possible, or affordable, without the local network has increased opportunities for fairer trade with people outside villages. Participants in Indonesia described marketing services and products, from mangoes to handcrafted jewellery, on Facebook and Instagram, and using WhatsApp in informal e-commerce. For instance, a man in his 30s explained how his access to Wi-Fi at the village's business enterprise office, where he volunteered, enables him to upload high

resolution photos to market his photography and videography business using personal and business and Instagram accounts, followed by 700 and 500 people respectively. Another man, in his early 50s, said he uses WhatsApp to order chickens, delivered by motorbike, which he slaughters and prepares to sell.

Occasionally e-market endeavours in Indonesia were hobbies; for instance, another young man who is a technology enthusiast regularly resells the new phones that he buys specifically to explore their features. More often, however, using community networks to access social media has increased profits. For example, two women explained that they posted photos to Facebook of the village's nationally acclaimed mangoes, which they buy in bulk locally. They sell directly to people all over Java, and pay fairer prices to local farmers, some of whom are their relatives, than external brokers. One woman with continuous access to the Wi-Fi network, through her work with the village business enterprise office, sells 10 times as many mangoes as the other, who buys airtime from the more expensive 3G provider.

Access to information about prices also has direct economic benefits for communities. The umbrella organisation in Uganda, for instance, teaches members of the ICT centres, where access points are located in villages, to avoid exploitation by brokers by using the internet to determine the market prices of their agricultural produce. Several young men participants explained that twice a month they determine the price of soybeans by consulting the Agrinet website, on computers at their ICT centre, in order to negotiate better when selling produce themselves and also to inform people in their villages. Access to online information about products and pricing is valuable for people living in remote areas, where transport is costly and time consuming and local newspapers unavailable. A woman participant in South Africa-2 said, "I look for things that are on special when I am about to go to town," a three-hour bus trip from her home, "whether there are specials in Shoprite and other shops."

Accessing online information might contribute to circulating money within a community beyond cost savings for individuals. A man in South Africa-1 explained that he often assisted people in the village when they wanted to buy a car by consulting online advertisements to "see who is selling the car." In fact, participants often referred to other community members when they described accessing information about products available far from their villages. A man in Argentina-3 said that every two months he purchased new tools for his business and would first consult online catalogues. However, once he had selected the models online, he either asked a family member to pay for them by credit card, so that the tool was sent, or took the model number to a local shop where another family member has a credit agreement to pay over three months.

Community networks contribute to the local circulation of money in various other ways. Sometimes the relationships formed by engaging in community networks increase local business opportunities. For instance, men in Argentina-1 mentioned that new social connections made through their community network led to business between them; indeed, we stayed in a rental cabin owned by one member and built by another, who would not have met were it not for the community network. The South African community network provided small loans to nine needy people, in a microfinance scheme, using some of the proceeds of charging cell phones with the solar system that powered their intranet. In three local networks, participants generated income directly through their role in providing connectivity. In the village in Indonesia, women sell hourly and daily vouchers for access to

the internet, as well as offering free access to customers in their small noodle restaurant and stationary store, respectively. In Mexico-1, the local administrator of the community network receives an honorarium for managing subscriptions, while Village Level Entrepreneurs (VLEs) in India receive a 40% commission on "recharging" subscribers' data.

The business model is stable for some initiatives but emerging in others. Many community networks are still at an early stage; for example, cooperative members in South Africa are disappointed that they cannot yet build an office, or pay for security and office workers, and a vehicle, so that if there is something broken they can quickly repair it. One cooperative member said: "The money we are getting now is not enough for construction, it is only enough for buying the network tools, etc. This is painful to me as the chairman that we have no site." In the more prosperous setting of Argentina-3, community network members agreed to voluntarily contribute 100 pesos (USD 7) monthly without knowing, to begin with, why this money might be needed. A year after starting, however, they were able to repair their network and improve a link, using the accumulated contributions, when many nodes were damaged by a tornado and hailstorm, which deposited 50 cm of ice in 30 minutes. While voluntary contributions effectively contribute to sustainability, the community network's initiator did not suggest this was a conscious plan.

Sometimes the contribution of community networks to money circulation, and local household economics, is indirect. For example, other businesses within villages have been enhanced by improved internal connectivity. This was particularly striking for Mexico-1, where a 69-year-old woman shop owner told us that she had decided to continue her subscription to the community network's service when she realised its importance to her customers. "People call me to make sure I have a product in stock," she said. "I didn't think it was worth paying again for the phones as there's no good service, but I paid again when I realised it's important for customers," the woman explained. "Almost every day I get called to see if there is a product in stock." In fact, businesses in the Mexico sites now rely on their phone network to transport products to the nearest city, organise pick-ups for labourers to work on the coffee and banana plantations, which are a two-hour walk from their homes, and enable users to fit farming around other work. A car mechanic explained, for instance, that he is on call to fix tires while he is farming.

Sometimes the contribution of community networks to local household economics is convoluted or subtle. A woman in her 60s in Argentina-1, for instance, described a WhatsApp message she had received that day from her son's teacher. The message was about returning the jars in which the woman sells her home-made pickles, so the sender would avoid paying a non-return price.

The use of ICTs provided by a local network can also generate business for other local service providers. For instance, young men explained that they took a letter they had prepared using the computers in a Ugandan ICT centre on a flash drive to a shop in their village for printing and copying, using a *boda-boda* motorbike taxi to get there. Meanwhile, skills learned through involvement in the umbrella organisation's training programme on solar energy systems and ICTs enabled one man in Uganda-1 to service people's solar systems on market day, and another to establish a cybercafé. Despite the community network's ethos of self-sufficiency and cooperation between neighbours, some community network members in Argentina-1 had paid others to set up their nodes. In contrast, in more impoverished Uganda, when the umbrella organisation teaches people in their rural ICT centres, where access points are sited, the organisation aims to foster community-oriented

business attitudes; thus, young users raised funds for their centre by hiring out chairs for functions and doing tailoring.

Facilitating employment and remote work

Participants mentioned benefits of involvement in, and access to, their local network to gain and retain employment outside their villages. A woman member of the network in Argentina-2 explained that her youngest son, who had not finished school, had built on what he learned about routers and Wi-Fi in the community network's workshop when he got a job with a commercial ISP. An administrator in a gram panchayat (village council) explained that he assisted people in India-3 to make "job cards" to help them gain employment. A number of participants in South Africa and Uganda explained that access to the internet had enabled searching for job vacancies, forwarding these to other community members, via WhatsApp, creating CVs, and sending applications and supporting documents. In fact, in both the African community networks, several participants described how use of the network had directly helped them or others in their villages to secure work.

The use of community networks in online work can reduce travel costs and bring money into villages. Sometimes access to the network freed users from travel for employment. For instance, local software developers and writers worked from their rural homes and used the Argentina-1 community network to distribute the products they created. A woman in South Africa-2 used the network to read work emails at home, far away from the place she has to live for work, and a young woman in India-1 sent evidence of her work in training other women in villages over WhatsApp. She explained, "If I don't upload the photographs on WhatsApp and send to the office, then I don't get my salary."

In some cases the local network reduced the need for costly travel to undertake administrative tasks. For instance, a VLE who has worked in India-1 for the past five years said that prior to the community network, he travelled to the city, nine kilometres away, three days a week, to fill in online forms for death and birth certificates at a cybercafé. Meanwhile, the woman president of the indigenous assembly in Mexico-1 explained that the community network enabled her to contact the assembly's secretary during her frequent trips to the provincial capital, 215 km away, which was particularly vital at that time because the Telmex landline to the assembly's office was not working.

Demands for connectivity to undertake work can sometimes feel more onerous. Mandatory use of the internet for administrative work was a driver for the Asian networks studied; for instance, installing the network in Indonesia largely responds to government requirements for interfaces between village-level and provincial information systems. The Indian government requires school teachers to fill in online forms to log children's midday meals daily, and maintain regular records about sports, books and uniforms. India introduced this online school records system in 2010 and, prior to the community networks, the education authority gave teachers dongles to access mobile service providers' 3G. Teachers explained that nowadays when the community network fails they become very stressed and need to use their personal cell phones to conduct the work that is expected of them online.

Transacting online or circulating money locally

Using community networks for e-commerce and financial transactions varied according to local economic prosperity. Only participants in Argentina and Indonesia spoke about directly using the community network in online shopping, and frequent online financial transactions. One man in Argentina-1 said his regular wire transfers made it possible for him to live away from, and avoid the queues in, big cities. Another man said he could check his bank account regularly, and ensure receipt of wire transfers for payments on the cabin he rents out, as well as receiving and paying utility bills through email. Meanwhile, a software developer, who works from home, invoices clients and monitors payments to his credit card for his work. In fact, much of the community network's own payment and accounting is done online, using home banking and emails to record transactions. Some participants in Argentina are also interested in non-physical currencies; one man explained that he did not have a bank account but used a system of online fiat money,[137] and another was developing an interface for cryptocurrency. A few participants in Indonesia and South Africa also mentioned online banking, while a member of the gram panchayat in India-3 explained that he used online banking services to monitor fellowship and scholarship funds to each individual student's school bank account.

The rarity of credit and debit cards among participants and the direct and indirect contributions of community networks to local economies, via cash transactions, might outweigh the typical benefits of e-commerce and e-banking. Several participants in Argentina and Indonesia referred to alternative payment forms for online shopping. For instance, a man in Argentina-3 mentioned shopping online using cash payment, and a young woman who created jewellery in Indonesia-1 said she bought materials online from bigger cities through bank transfer, as she has no credit card. In India-1, the VLEs make online payments to TV and electricity providers to enable local people to pay their bills without travelling to the city.

An elder man in Mexico-1 said, "We have Western Union here so we don't need to call the bank." However, the community network's phone service could be used to receive alerts from family members about forthcoming wire transfers. For example, a middle-aged man in Mexico-1 explained that when he worked in Canada, prior to the community network, he called the woman in the rural satellite telephone service to give her the receipt number to pass on to his wife so she could withdraw the money he wired. Participants in Mexico-2 said that before the community network they needed to travel to the small town of Mexico-1 to receive a call, and in the Western Union office we spoke to a man who had spent all day walking from his village and then waiting for a payment. Thus, we suppose that notifications about remote payments to people's own phones might help them organise their trips to Mexico-1 from more remote villages. Staff in the Western Union office were in danger on the two-hour drive from the nearest city to "bring the money to us," an elder man in Mexico-1 said; yet digital payment systems had not taken off. In 2011, prior to the introduction of the community network, a Chinese company, Hui, had trialled a system that provided a GSM service in the area to subscribers who saved money with them. Participants explained that "we could make bank transactions through the phone, we could pay each other through the phone." However, even though Hui's GSM service was high

137. https://cryptocurrencyfacts.com/the-difference-between-fiat-currency-and-cryptocurrency

quality, people did not save the required 100 pesos (USD 7) a month or use the financial service for payments, so Hui discontinued the service after the trial.

Extending online time for learning and just-in-time information

Our data illustrated the benefits of local network access to formal and informal education, and in particular the value of unconstrained time online, and timely, livelihood-relevant, socially situated and self-directed learning contexts. Participants accessing four community networks mentioned their importance in formal education, from research to peer learning using WhatsApp groups and submitting assignments. Over a third of participants in South Africa described using the community network's internet connectivity in their own, or their children's, school work. High school students, without access to textbooks, researched the internet for classes and projects, and work-based learners and a diploma graduate studying Teaching English as a Foreign Language (TEFL) online said that they could not have done their studies without it. Further, applications for colleges and universities significantly increased as the network and its precursor project evolved, stimulated by the presence of university researchers, who raised awareness about application processes, and then by using the network to apply online.

The initiative in India prioritises internet access for teaching and learning, and over a third of the participants in interviews and focus groups were teachers or learning facilitators. Teachers in three villages described using the local network to download videos to support their teaching, such as preparing children for examinations and bringing things in textbooks to life. Some teachers are also part of the Tata Trust's IT programme, which fosters skills in facilitating children's self-directed learning, such as using the internet appropriately in research for school projects.

Several participants in South Africa referred to the specific value of unconstrained internet access for learning English. Many local people are not proficient in English, which is required for employment and most high school classes in South Africa. Participants remarked that extensive time to watch YouTube and to search with Google, in both English ("Googlish") and isiXhosa, the local language, was particularly beneficial to developing language skills. Two young women earnestly explained that not worrying about using precious data was essential to effective learning.

Participants in four community networks also referred to just-in-time information. Access to information about healthcare and medicine was often mentioned; for instance, a woman in her 40s in South Africa-1 described using the network to Google for information about headaches as an example of searching for whatever information she needed at the time, while in remote Uganda-3, a young man studying nursing created a WhatsApp group to post questions about medicine. Social network platforms often serve to provide timely, locally relevant information, such as in health concerns. A drugstore owner in Uganda-1 explained that news about deaths caused by fake drugs was rapidly transmitted over Facebook, and to get advice he shared suspicious results of his own tests of samples to various Facebook groups.

Livelihood-relevant, socially based learning is vital in communities that cannot afford the cost of secondary education or have poor quality education locally. In India, the NGO that supports Gram Marg's outreach also coordinates an adult learning programme based around videos at the premises of gram panchayats. Videos on topics ranging from

personal hygiene (e.g. handwashing), to agriculture, sewing skills and basic mechanics (e.g. fixing washing machines) are created by the Tata Trust and served offline on a "DRUV box".[138] VLEs, who are mostly men, facilitate sessions and also use the local network to enhance their training by downloading from YouTube. They encourage participants in their teaching sessions to use the internet for self-study. A VLE in India-2 explained that during a DRUV session on agricultural production, he demonstrated how to access additional information by searching for content on YouTube about what needs to be sown at what time of the year.

There is some evidence of using community networks in informal social learning contexts. For instance, in India-1, between eight and ten young men students regularly gather in the evenings to speak about politics and news, and sought to improve the signal to the place that they met, perhaps so they could better integrate online information into their discussions. Meanwhile, men participants in South Africa-1 mentioned that they had used the network to access online information to settle debates. Relationships between sharing information and ongoing learning were prominent in Uganda. Entrepreneurs, who own small, solar-powered electronic repair shops in Uganda-1, developed skills to repair electronic hardware by teaching themselves and learning together, and described their need to continuously update their shared knowledge and know-how. With no formal electronics training available, and encountering new components and models every day, they routinely use and share information about components with many similar small businesses across the country using WhatsApp groups.

Community network implementations often focus on developing people's abilities to set up and/or use technologies and services in social settings that are part of, not apart from, everyday rural life. The community network in South Africa hosts practical workshops in local homesteads to teach young and old community members how to install networking equipment. More informally, the network administrator in Mexico-1 teaches users who come to him, several times a week, to reset their phones to receive the GSM signal, and the secretary in the chief's office in Indonesia teaches children about computers when they come to him.

Intermediating, disseminating and producing information

Many users mentioned using community networks to disseminate information and had various tactics to include people who did not have access. All participants who accessed their local network gave concrete examples of assisting people without access, and most participants who did not use the network gave examples of such assistance.

Participants in many of the villages visited described how their villages had several or many WhatsApp groups, including groups for administration, sports, volunteer or community work, ride-sharing, schools and sometimes specifically for their community network. A teacher in India-2 said the community network had improved the ease of dissemination, and described posting videos and sending messages about meetings through the school's WhatsApp group. Participants also described compensating for other people's lack of access to WhatsApp. In India-3 the *sarpanch* who heads the gram

138. https://www.tatatrusts.org/article/inside/project-druv-tata-trusts-innovation

panchayat mentioned using an online SMS server for "digital governance" to disseminate information – for instance, about a forthcoming Gram Sabah[139] meeting – and had entered between 300 and 350 phone numbers to ensure they could send messages to at least one phone in every household. Often, however, participants said they adapted to each person's individual communication circumstances, to assist others and pass on messages. For instance, the woman sarpanch of India-5 said that she sends an SMS to a village headman who was not conversant with WhatsApp. Women participants in Indonesia knew about the focus group they attended because the village chief's wife came to one woman's house who then posted a message to a WhatsApp group which included the neighbours of three women who did own phones. "This often happens," the women said. "It's always the situation."

Participants mentioned many examples of assisting others in communication and to access information. Participants who did not own phones or have access to the internet in most villages described how people would call a neighbour to send a message, while others illustrated assisting other community members and their children. A middle-aged woman in South Africa-1 described receiving the bank statement of someone in a town two hours away, via WhatsApp, for the purposes of someone without a phone. Sometimes helping others access information occurred in face-to-face intermediation, and sometimes through other media.

Participants also mentioned many examples of assisting others to access information either in face-to-face intermediation or through other media. Participants in India-1, for instance, said that if one person in the house has a smartphone, that person downloads a movie and then everyone in the house watches it together. In Indonesia, participants recounted letting people look at their phones to see the soccer match schedule online, and a woman explained: "My grandfather is a retired government employee. When he looks for his 13th month salary he will ask me, and I check to see if the government announcement has been made."

The overseeing organisation in Uganda cultivates an ethos of sharing information among users of its community network. In the remote ICT centres that host access points, computers are arranged facing inwards on a single table to encourage people to share skills and experiences according to Luo traditions of *wangoo*. Participants in Uganda-2 explained that they shared information they found on the internet about the market prices of agricultural products, such as beans, maize, soybeans and millet, with many people. While sometimes they benefited from a share of the profits, they said that they enjoyed being part of a process that enabled people in their villages to negotiate fair prices. The electronics repairers in Uganda-1 also explained that they share information among themselves. Other times, participants described using various media to broadcast information and produce new content. For instance, participants in the small town of Uganda-1 told of using the local Rootio hyper-local radio station in advertising and awareness raising. Shop owners also described advertising their products and services on the radio in jingles that someone in the local computer centre created. Meanwhile, young men in the remote Uganda-3 ICT centre described printing 1,000 invitations to an event that

139. www.arthapedia.in/index.php?title=Gram_Sabha

they posted on trees around their village, while in front of another ICT centre a group of young people performed small dramas to draw attention to issues of concern.

Human connectedness: Care and communality

Community networks contribute to vital felt experiences of human connectedness and may counter the social fragmentation that can accompany increased use of technology. In villages, where homes are spread across hills or mountains, and transport is costly or unavailable, participants related the value of connectivity to averting loneliness and feeling the presence of intimates. A middle-aged woman in Mexico-2 explained that users no longer need to walk to have valuable human contact, and prior to the community network, "people were locked in their houses and alone." Another explicitly indicated the intrinsic worth of this contact to psychological wellness: "Before, when we didn't have telephony – I was sad, I felt like I didn't exist," she said. Women in Mexico-1 also mentioned, with satisfaction or jokes, that their husbands call them to ask them about food. One, who works long hours in her little cantina, described with a hint of pleasure the small mundane exchanges with her husband that punctuate her day: "Yesterday, like almost every day, he called to see what time I was coming home."

Many participants referred to the practical and emotional importance of contact with remote relatives, such as ongoing awareness and support at difficult times. Indeed, most participants in Mexico mentioned the importance of the community network's connectivity to frequently communicating with family members far away. Some elderly participants said that migrant family members, in distant cities and countries, paid for their monthly subscriptions to the community network and, in Mexico-1, several participants explained that prior to the community network they had little communication with their many relatives who temporarily or permanently lived elsewhere in Mexico or in the USA. In Argentina-2, a woman in her 60s with constrained mobility, who cares for her elderly mother and a son with a disability, said that she had only one local friend, but many acquaintances. The network affords ongoing communication with her family, and from the moment she awakes in the morning to the time she goes to sleep at night she exchanges WhatsApp messages with her daughter, son and other relatives.

A poignant illustration of the impact of community networks on relationships with loved ones was shared by a man user of the community network in South Africa. "Many years ago, there was a young brother [of mine] who went away," he recounted. "We were not knowing where he goes, where he went. Not knowing any place. So, I used internet to search his name, as it's likely he uses social media, to find him. Checked him on Facebook." When asked if he had found his brother, he smiled gently. "Yes. I found him, took pictures, and we communicate," he said.

Community networks present many examples of the role of care in building or sustaining community. Users gave a wide range of concrete examples of assisting others, from helping to physically set up others' access, facilitating messages or a call on WhatsApp for people without access, and using online services on others' behalf. Participants implicitly or explicitly indicated the felt experience of their contributions, and recognition of their contribution, be they doing technical tasks or reliably attending meetings. Some users in Mexico-1 said they supported the community network because it enabled access to more disadvantaged inhabitants, not because it enhanced their own access to

telecommunications. Several cooperative members in South Africa who do not own phones that are able to access Wi-Fi explained that the earlier intranet system, which enabled them to use special handsets to make VoIP calls between villages, had been very valuable to them, but that their achievements in bringing the internet benefited their children and other youth in the area.

An overt sense of communality featured in interviews and discussions for five of the six initiatives we studied. Sometimes community networks manifested existing collectivist principles. The community networks in South Africa and Mexico are founded on ancestral and family ties, and cultural norms and values about communality, and many local people undertook voluntary work to erect the community network mast in the mountain over Mexico-1. Older members of the Argentine community networks also referred to cooperative traditions and solidarity movements. One woman said, “I have a consciousness, for example, as a child, my parents would go and help people clear land. It was common. It was ordinary. I always had that sense.” Indeed, The community networks in Argentina seem to attract people with communalist interests, or as a 60-year-old man who immigrated to the country explained, “The ones who are part of the network are those that have a tendency to do social things. It allows me to distinguish people who are similar to me.”

A communal characteristic can serve as a bridge between different parts of local society, for instance, intergenerationally and between people with ancestral ties and newcomers. Younger participants in Argentina-1 and 2 explained the importance of “being there”; when 35 people gathered to relocate a node, “children came and everyone carried something up the mountain, from tools to batteries.” The Argentine community networks can serve as a bridge between newcomers who migrated permanently to the area within the past five or six years and people whose families have lived in the area for generations. Participants with historical local ties said that the community network had facilitated connections between residents who would not have met otherwise, which offered new opportunities for business and socialising. On the other hand, participants who were newcomers said that their community network had facilitated new collectives for action about other concerns, such as organising political protest, as well as groups for trips, horticulture and paddle games.

Participants in Argentina also explained, however, that some community network members do not understand the collective approach and neither pay nor participate in activities, and one woman said some people who had just joined her community network had rejected her offers to help them. A software developer in Argentina-1 explained that, over the past year, the community networks had decided to limit the impact on community network members by “free riders”, who use the network without becoming part of the collective, by giving them the chance to use it for short periods only. Indeed, there were 13 nearby houses who had extended “the network of others freely” by purchasing and installing repeaters, the coordinator of the community network in Argentina-3 explained.

The communalist orientations of the community networks can express cultural identity and offer opportunities to counter social fragmentation and dysfunction. The community networks in both South Africa and Mexico were created based on customary governance structures in traditional and indigenous areas, respectively, where elders seek to improve opportunities for their children in the modern world and also preserve their cultural identity. For instance, many cooperative members in South Africa are unable to use the internet

themselves but they still try to help others connect to the Wi-Fi; meanwhile, young people often assist their elders. This contrasts with the situation in Indonesia. Few women use the network, and older women attributed younger women's increasing disengagement from communal activities to their use of cell phones connecting to mobile internet.

The initiative in Uganda tries to re-establish unity in communities that were traumatised by war and displacement for many years and now host millions of refugees. Severe conflict, and some post-conflict actions, scattered and destabilised communities, undermined people's trust in institutions, neighbours and even family members, and contributed to high unemployment and disaffection among the youth. The Ugandan initiative's founder prioritised peaceful coexistence in all activities by emphasising traditional practices of coming together in dialogues to manage disputes, such as about land or water, and organising host-refugee events, like football matches. The founder rationalised cohesion by explaining, "You won't go anywhere with excluding because tomorrow you might need the people that you exclude." This was reiterated in various ways by participants at the different rural ICT centres. For instance, a site manager explained that the youth share their individual talents to help each other, and that he always sees a few of them doing activities together like going to church, or the gardens. A young man user said, "Through the computer centre we have been more united," and another older man said that engaging youth in activities motivated them to avoid involvement in "doing bad things." The site manager related that some youth tell him that their unity brings them happiness, and that their familiarity with each other enables them to "disclose their troubles." In two rural ICT centres, the youth organised drama and traditional dance activities, rekindling a tradition from the past, as one participant explained: "The idea of a drama group started way back in the settlement camps when people were all scattered. The elders thought of doing something together [to preserve] cultural practices, rituals, celebrating birth, and community work. When camps were decongested the different groups scattered again."

Involving children and teens, and regulating their access

Attitudes to, and strategies to manage, children's and young teens' access to local networks, mobile phones and the internet varied, often shaped by local customs and religious commitments. Children were frequently more technologically literate than their parents, yet some evidence also suggests that community networks offer opportunities for teaching children about technology and resisting constraints and stereotypes that limit girls.

Attitudes to children's and young teens' use of mobile phones and the internet varied. Parents, grandparents and other family members in most countries raised concerns about children's and teens' access to "negative" or harmful content, such as porn, the distraction of social media from school studies, and "playing with the mobile phone, until 1:00 or 2:00 at night." A young parent in Argentina-1 also raised concern about the doctrine of consumerism fostered by videos on platforms like YouTube. Only participants in Uganda, where there is lower phone ownership and internet access, rarely mentioned these concerns, and the umbrella organisation limits access across its network to some websites, like YouTube, during daytime.

While strategies to manage and control children's and young teens' access to the community network are shaped by local customs and religious commitments, it is primarily

the parents' and guardians' responsibility. Rhizomatica's founder explained that some of the communities in Mexico sought to shut their network for three hours during traditional assemblies, consistent with sanctions on adults who do not attend, and that communities have discussed age barriers on phones. In Indonesia, a woman who sells vouchers to access the internet in her small chicken noodle restaurant said that she does not allow children to use the Wi-Fi after 4:00 p.m., when it is time for their Quran study, and she is always aware of what they do on the internet, which is mostly playing games. In Indonesia, participants explained that adults with younger children run out of mobile data quotas quickly, and young teens sometimes request more pocket money to buy extra data.

Older non-users of the community networks said that they needed to monitor use by "taking a peek" at what children and teens were doing on their phones, or calling them from their rooms when they felt "suspicious". Elders in Indonesia said that they warned youngsters not to "use negative content, as it harms themselves" or spend too much time online, and sometimes had "to be tough to reprimand them." They also referred to religious emphases in education from elementary school onwards, and an Islamic teacher said that the internet was important "to spread Islamic education. I am worried children become terrorists." With their father observing our conversation on the veranda of the family's shop in India-1, two teenage girls explained that he subscribed to the network for their use and trusted them to access appropriate content. Indeed, parents and guardians are mostly responsible for controlling children and teens' access to a community network just as they do for access to commercial providers. In Mexico-1, a mother explained that their son uses their laptop at home to do homework and, aware that "social media sucks up time," she ensures the children do their household chores and buys half an hour of Wi-Fi access so he can use the internet only for school work.

Sometimes strategies to control children's and teens' access to community networks conflated with other network management constraints. For instance, the chief in Indonesia said that he limited use of the Wi-Fi after he found adolescents gathering behind the office accessing negative content, and that children can get the password only if they are with adults. However, we later learned that password access also relates to network speed and managing the volume of users. Rhizomatica's founder also said that previously, when the threshold for the network saturation was lower, one community in Mexico had limited families to two subscribers to ensure every family had a phone number, but this restriction had been lifted.

Even within areas, there is considerable variety in different schools' approaches to using community networks, e-learning, and policies for staff and learners' internet access. Most primary and high schools in the village in Indonesia-1 have dial-up access and only three of them subscribe to the community network. For two primary schools, this network subscription is only for teachers' use; however, a technical high school provides routers in each class for learners' 24-hour unlimited access. Four young men participants who attend the school explained that they logged in using the class password outside lesson hours, and teachers encouraged them to use the internet for assignment-related materials and not to access "negative content". Participants in Indonesia also explained that schools did not make it mandatory for children to have smartphones, because they could go to someone who rents phones out hourly, or borrow a friend's phone if they needed to browse for something. Meanwhile, another participant explained that a grandchild attended a school in another district where teachers confiscated students' phones. There is similar variety for

schools in India-1, India-2 and India-3, which are separated by 60 km and 12 km respectively. A teacher explained that cell phones are prohibited in India-2 schools because they cause disturbance and introduce distinctions between learners who do and do not own costly phones. However, a woman in India-3 explained that her own children's homework gets sent to her via WhatsApp messages, and a high school teacher in India-1 explained that all students in 9th Standard connected to the school's WhatsApp groups every day on their own phones, and 80% owned smartphones or feature phones.

Evidence of children using community networks to learn together with parents and guardians varied between places, as different literacies sometimes limited opportunities. In Argentina-2, a mid-20s woman described using the community network with her eight-year-old nephew to learn the English names of colours to fit in with his lessons at school. She explained that her nephew does not have uncapped internet at his home, in an area beyond the community network, and uses his mother's prepaid internet, so when he visits her at weekends, he devotes his time to playing online games and continuously drains his phone's battery. The previous day she noticed he had been playing on the phone and she suggested they use the phone in learning to multiply instead. A grandmother in Argentina-2 also described using the community network in a video call with her grandson to help him with his homework.

Several young children in a primary school class in India-3 explained that they watched videos of poems and cartoons on their mothers' or fathers' phones on Sundays and other non-school days. However, perhaps because of varied access and literacies among parents, it appeared that resources to support parents and children in learning together were not a priority. For instance, the children and their parents were shown different versions of handwashing videos using the DRUV system. Indeed, often children and young teens in India, as well as in Indonesia and South Africa, were more likely to own smartphones than their elders. For instance, the high school teacher in India-1 said that many of the parents of the learners in 9th Standard who owned phones were illiterate and did not use cell phones. Meanwhile, four teens in a focus group in Indonesia had used the internet since they were 12 years of age, when their parents had bought them smartphones for school use, and only one of them had a parent who also owned a smartphone.

Community networks in a country with good education illustrate opportunities for teaching children about technology and, perhaps, countering gender constraints. Teenagers participated in technical workshops to set up the community network in Argentina-3, sometimes assisting their parents. Meanwhile, a grandmother in Argentina-2 and a mother in Argentina-1 took their six- and eight-year-old grandsons and pre-school children, respectively, on their rooftop expeditions, and involved them in their work by asking them to pass them tools. The mother in Argentina-1 explained, "I love that the kids learn by seeing. [My daughter] has her own hammer, I didn't give her toy tools, I give her real small tools". She recounted, "One day I was working on electricity in my mum's house, and [my daughter] climbed a ladder and said she wanted a tool to cut. I gave her a screwdriver, not a cutting tool – 'This is not a toy, it's a real tool.'"

Local awareness, visibility, safety, security and privacy

Our data illustrated that community networks can build on, and extend, awareness of others in rural communities. This has contributed to improved safety and emergency response. It has also contributed to controlling intrusive uses of technology, and provoked some communities to reflect on what privacy means in places where everybody knows everybody else.

Connectivity contributed to rural people's sense of security, and to practical and psychological responses in emergencies. Men in a focus group in Argentina-1 explained how both the social relationships forged by the community network and the network itself enabled them to organise themselves to capture a burglar who had robbed a local home. Meanwhile, in Mexico-1, a man said the introduction of the community network service "was a big change because now there is no need to walk, we now immediately know what is happening. For example, if you start listening to shootings you immediately know." Others mentioned being called from far away during personal tragedies so they could be present for others emotionally. A church standing in the plaza of Mexico-1 bears the scars of an earthquake that affected millions in Mexico, just six months before our visit, and a participant said, "During the earthquakes of September, Telcel's services were saturated, but this network was very accessible to make calls in that moment."

A third of participants in Mexico-1 and Mexico-2 mentioned the importance of the community network to call for taxis and help in emergencies. A man explained that, prior to the network, when people needed medical assistance or other urgent help, they had to "get a taxi at the wall [taxi stand] or walk all the way to the house or go to [the nearest cities, two hours and six hours away]," but nowadays help can come to them. One said that if they had not had a phone to call a taxi to come when someone fainted in the coffee plantations, then a strong young man would have had to carry the person for two hours. Two women participants described using the phone to call a doctor, and another explained that she had called a taxi and the nurse so the clinic was ready for her arrival when she was very sick.

The operations of some community networks were prompted by, or involved, the existing visibility of others in rural communities. For example, a member of the Argentina-3 network explained that, at first, their house was the only one connected to the already established Argentina-1 community network, 14 km away. Some local people, especially university students, noticed the open access point at their home and started to sit outside to use the network, without asking permission. The participant and her husband were not bothered by the situation until police cars that parked outside to use the internet shone their lights on their home at night. This inspired her to think about a network to address the need for affordable connectivity in her neighbourhood. The visibility of others' routines, such as walking in to collect water or firewood and everyday social engagement in rural areas, also enables some operations. For instance, some participants in South Africa said they knew when a family member was available at the sub-headman's houses for them to purchase vouchers to access the community network without having to phone them.

Community networks also afford new ways to be aware of others, and the reach or specificity of existing awareness. For instance, men users in Indonesia mentioned that they knew that their friends must be close to the Wi-Fi if they were online on WhatsApp. Sometimes new modes for awareness provided previously unavailable privacy. Every half hour or so the voice of the rural phone service operator can be heard around the small town

of Mexico-1 broadcasting, over a loudspeaker, the name of a person who must come to the phone service's premises to receive a call on the satellite phone, so the whole town is aware when a person receives a call. The satellite service has been running for over 30 years, and public alerts continue former practices, such as when horns called people to do community work and bells rung when a home was burning.

Participants in Mexico-1 contrasted the awareness afforded by the community network with the need to walk to find out more information or receive a call. The assembly's vice-president explained that since the launch of the community network, fewer people made use of the authority's radio phone, used to reach designated people over the mountains, and participants mentioned that the radio lacked privacy since it required intermediation. Participants explained that the community network's service enabled them to stay abreast with what was happening in the plantations far away, and regularly and discreetly check on people to ensure they were okay. The importance of direct communication between people was clearly illustrated by the frequency of participants' critical remarks about how the community network's system can misdirect SMSs and calls. The risk of an unintended recipient can make users hesitant about sending SMS "if it's something compromising," a participant explained, adding that one day she had received "a message that wasn't for me and it said 'things'."

The community network in Mexico that we studied has provoked local consideration of privacy in communication. In contrast to the satellite phone operator in Mexico-1, who continues to broadcast the name of a call's recipient, only the network administrator and traditional authority leaders can access the phone numbers of community network subscribers and call records, and they do not divulge this information. The umbrella organisation's founder explained that they do not collect data about users, delete call records daily and other data after two months, and destroy all data after six months. Indeed, in establishing the business model, the umbrella organisation had asked the different assemblies that run the services whether they should to generate income to the network by selling the meta data, which represents a rich corpus of information about a vast federated network. The assemblies unanimously resisted: "No!" they told the founder. "Are you insane? No way!" Nonetheless, participants also explained how the local network administrator and traditional authority leaders' access to call records can be used to curtail using the service to harass or stalk. For instance, a mother reported to the authorities that her teenage daughter had received unsolicited text messages, and the perpetrator ceased.

Achieving a balance between privacy and the visibility permitted by small rural settings is particularly important for women. Young women in India-1 explained various regimes imposed on their use of phones with commercial GSM services, which ensured they "are on the right path" and protected from unwanted communications. Our data in several villages in India shows that women store only about 10% of the number of contacts on their phones as men in their village, while young women in India-1 said that they give their phones to their brothers if they receive a call from an unknown number, and male family members routinely check their sisters' and daughters' phones. Such control curtails women's freedom yet, in India, threats to women's safety are very real. For instance, during our studies, one young woman explained that she always lets her mother know her entire day's activities, and she told us about her narrow escape from extreme physical violence at the hands of a man a few years ago in another village. Password protection has also been applied to some access points in Argentina after a woman living alone was disturbed by

eight men who rented a neighbouring house and acted carelessly while they loitered outside her home using free internet.

Creatively connecting technology to local settings

Our data suggests that community networks offer important opportunities for people with little experience to learn about technology by relating computer networking technologies to their familiar physical and social settings. This not only helps to empower but can also stimulate new creative solutions appropriate for particular settings.

Many participants, particularly older people, said that their lack of education and exposure to technology precluded knowing about technology. They often conceptualised the network, and suggested solutions to its problems, by relating it to a deep familiarity and everyday engagement in their rural settings. For instance, in Mexico-1, people explained that the signal of an antenna was not strong at night and when it is cloudy or raining, because it is powered by solar. Indeed, in all six networks around the world, participants' comments indicated that they are conscious of natural environments, often mentioning the weather and vegetation when referring to their community networks – from storms and winds, to growing and falling trees.

Participants in each continent also used familiar social geographies to scaffold thinking about technological networks. In Argentina-1, a woman recounted using binoculars as she stood on a roof looking for a place with line of sight for a new node that would allow everyone to be connected. "We found it," she said as she gestured upwards, "on the house of one of my relatives," and pointed towards her right. Another woman illustrated links between mundane details of home life and technological networks, when she explained how an upstream node was affected by a member's housework routines: "Each time he cleaned his house our network got disconnected. Same time every time."

Participants' comments also demonstrate that they learned about the limits of networks in relation to people's use. In Indonesia, participants explained how network speed related to volumes of use, and in Mexico-1 and -2, participants said that calls were problematic when the network was saturated. Different men participants in their 20s in India-1, who had not been taught anything about the network, combined a familiarity with local social practices, people's use of devices, and an understanding of line of sight when they suggested moving an access point. The young men explained that one access point was rarely used in its current position, while another, used regularly by many people, had too weak a signal. Moving the first unused access point, they said, would extend the network to a place where young men gather to talk each evening.

The mundane actions, events, norms and values that constitute people's ordinary settings shape the ways they appropriate technology and innovate new uses. Some evidence suggests that a community network can foster types of appropriations that differ from those that are manifested in urban technology development contexts because they embody local values. For instance, small solar-powered electronics repair businesses in Uganda-1 have integrated various sharing practices in appropriating technology. These businesses originated because of the umbrella organisation's training initiative and, while they no longer access the community network's internet service, they continue to use the solar energy equipment that it set up. Three separate shop owners share knowledge and tools, assist each other with customers' repairs and routinely communicate about

electronic components with similar small businesses across Uganda in WhatsApp groups. The shop owners also record advertising jingles that the local community radio plays for a small fee that helps the radio sustain itself; meanwhile, one shop owner's son inserts advertisements for their businesses into Nollywood movies, which he dubs with audio in local language and distributes nationally.

Relating technology to users' embodied understandings of the local world is valuable in designing technologies for their settings, and is heightened when software developers live within the communities served by the technologies they build. A software developer, who has built his home in Argentina-1, explained "we are both users and technicians and part of the community." Members of his community network had recently started using a new cell phone app that the developers had designed, "based on collective experience," to assist aligning nodes and diagnosing faults. The app's interface displays the status of nodes in the network, and a woman who had learned all her technical skills through her membership in the community network explained how she used the app by incorporating her knowledge of local social and physical geography. Members of the community network use WhatsApp or Telegram to communicate to each other when maintaining the network and their messages illustrate how their use of the diagnostic app is embedded in the ongoing trajectory of their everyday lives. Open source software development usually involves users in testing and debugging, yet richer understandings of, and accountability to, users occur when this unfolds amongst a developer's proximal neighbours. That is, more appropriate and effective software emerges when technologists have ongoing, intimate, lived experience of users' social and physical settings.

Making and setting up things for familiar people often expresses care. Such sensitivities were observed and expressed by many participants in different umbrella organisations. Engineers in Uganda, whose roles involve not only programming and network monitoring but also teaching people in villages a broad range of skills, from ICT and entrepreneurship to life skills and gender inclusion, explained that their engagement with people in villages fosters empathy. Resource constraints often prevent the Ugandan umbrella organisation from delivering the internet to all the villages that request it, and the engineers said, "We feel the pain of somebody. […] It's not easy to tell someone to go away. I almost fear encountering them, when they say, we believe that today you have come with internet."

Often care has gender associations, and the overt link between care and creating material things in community networks might offer new opportunities for women to engage in technology. A woman in Argentina-1 observed that dexterity and care in finer physical assembly meant women were better than men in soldering, crimping wires and assembling components; and a woman researcher in the labs of the initiating organisation in India enthusiastically displayed the circuitry of a router prototype she had built. Indeed, in five of the six local networks studied, women participants routinely referred to their own material creativity, from weaving baskets and rugs, to sewing and upcycling fabrics, from crocheting to making pom-poms, jewellery and many other crafts. These references frequently had social connotations.

CHALLENGES AND RECOMMENDATIONS

Community networks offer a diverse array of economic, social, cultural and personal benefits in rural places. However, like all telecommunications systems, their benefits in people's lives can also amplify existing gaps between people, and advantage some more than others. This section outlines factors that contribute to unequal involvement in decisions about, and access to, community networks, and their effects. National policies and regulatory frameworks that limit most community networks to using Wi-Fi, rather than other transmission technologies, directly contribute to factors that exclude. For instance, the spatial coverage of Wi-Fi conflates with local social, cultural and/or bodily constraints on some people's mobility and restricts their access to places where connections are available. Other factors inherit from phenomena in the telecommunications domain, including the way different skills are valued, the geographic and demographic distribution of technical skills, and what age groups telecommunications products should target. That is, community networks make visible some of the hidden ways that telecommunications in general exclude.

The motivation and potential of rural community networks to address factors that contribute to exclusion contrast with those of commercial telecommunications systems. Firstly, the incentive to address factors that exclude is stronger in community networks. The enormous exclusion of people by commercial telecommunications that value-price their services for only populations that can afford them is a feature of their persistence; in contrast, the sustainability of many community networks is profoundly adversely affected by excluding people in their local constituencies from access and involvement in their operations. Secondly, the factors contributing to exclusion can be easier to specifically identify in community networks.

Thirdly, mitigating and resolving many of the factors that contribute to unequal access to, and involvement in decisions about, community networks can potentially occur faster and more effectively than for commercial telecommunications, by virtue of their scale, organisational structures and the familiarity of the people involved with the particular issues affecting their communities. That is, unlike vast commercial telecommunications systems, which impose standard processes and deployments across many heterogeneous social and economic settings, community networks can adapt with greater agility to their local contexts. Some community networks in the study, for instance, have considerably developed in the six months since our visits. Thus, in this last section I propose recommendations to improve community networks that respond to the problems and limitations that participants mentioned and explain how these are, or can be, addressed at this early stage to enable community networks to realise their full potential.

Inclusion in the benefits

Like other telecommunications systems, the social and economic benefits of community networks can amplify existing differences between people. People's access to their services is affected by many of the same factors that limit access to commercial telecommunications, such as phone ownership, literacy, language and gender norms. In addition to not benefiting financially, educationally and so on, the consequences for people without access include lack of autonomy and privacy and feeling left out.

In our study, access to, and inclusion by, community networks also conflates with whose views were represented. This is not merely a methodological frailty but, in fact, reflects organisational structures and power relations in community networks. Just like involvement in decision making about any telecommunications systems, involvement in community network decisions reinforces existing power differentials. However, the local nature of community networks makes this effect more visible and, thus, more fixable.

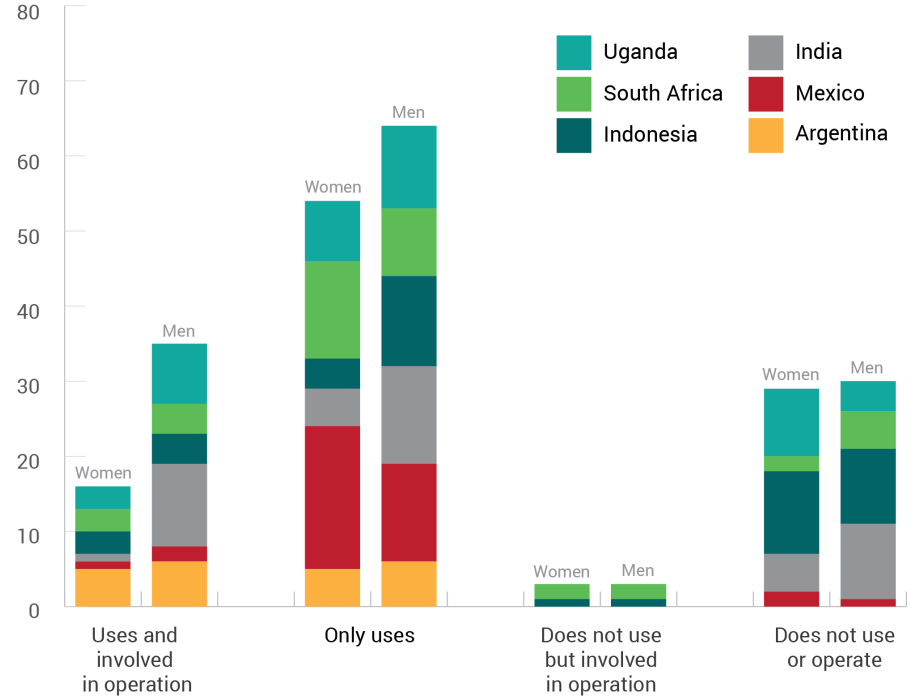

Figure 1. Numbers of people involved in village-level operations, used and/or did not use the local access network who spoke in interviews, focus groups, observations and meetings

Unheard voices

Relationships between participants and the community networks, and between ourselves and the host networks, influenced the sample of participants and the contexts in which they expressed their experiences and opinions. This is not merely a methodological frailty, caused by the framing and timing of the research, but also reflects some of the ways that community networks are organised.

We sought to conduct interviews and focus groups with non-users in three initiatives, one in each continent, but did not achieve this consistently. At the village level we heard perspectives from a total of 104 women and 131 men, of whom 25% and 32%, respectively, did not use the network directly themselves – even if they were involved in operations (Figure 1). Various factors compromise the extent to which participants in studies were representative of people with and without access, and could speak freely.

Firstly, five of the six initiatives studied allocated interpreters for interviews and focus groups; in four, these people were closely connected to the network(s); in three, champions or managers facilitated most interviews and recruited participants; and in one initiative, interpreters were the children of members of the cooperative. The intentions behind these

allocations were apparently oriented by pragmatics, offering people who were sufficiently familiar with the network, and able to speak English, to assist. However, these allocations are inherently laden with complex power relations. We were able to walk around to chat with local residents informally and arrange interviews with them directly, without champions or managers, in only three initiatives. Thus, participants' freedom of speech was influenced by interpreters' relationships with them and with the community network.

Secondly, in some cases it was impossible to turn people away from focus groups. Sometimes the size of focus groups meant many participants did not speak, other than to raise their hands in response to "yes/no" questions about their access or connectivity. The largest scheduled "focus group", in Uganda-4, was attended by 24 women and six children. The size of focus groups was further complicated by gender relations. While we requested that men and women attend separate focus groups, in some large groups this did not happen. In Uganda-5, a focus group was attended by 11 men, five women and three others under 16 years of age. Meanwhile, 11 men and two women from the support organisation, of whom only four people were directly involved with local operations, attended a focus group in Indonesia. Thus, although a total of 152 different women and 172 different men were present in interviews and focus groups, including employees of umbrella and support organisations, transcripts represent the words of only 68% and 76% of them respectively.

Thirdly, people who spoke only Mixtec or a tribal Maharashtra language were excluded from data in Mexico and India, respectively, since interpreters in these places spoke Spanish and Hindi. Language exclusion is reproduced by community networks; for instance, the subscription system is in English at the India sites, and in English and Spanish at the Mexico sites.

Our sample of non-users also conflates with the proximity of participants to the centre of influence in host initiatives. For instance, in Indonesia, many participants were members of village volunteer groups that undertake social welfare and village enterprise work locally, and coordinate themselves through, and meet at, the chief's office. Indeed, community networks appear to advantage users who are already active in the civic life of their communities. For instance, while some participants who did not use the network in Indonesia said that they were unaware of the village website, others with access to the network explained that they posted stories about the village and that the website had a "Hello Chief" feature designed to enable villagers to send their suggestions directly to the head of the local authority. Meanwhile, men beneficiaries of an ICT centre in Uganda described posting comments and asking questions on the umbrella organisation's website, in contrast with women non-users at another ICT centre that does not have internet access, who explained that there was no salient information available.

Amplifying existing differences

Participants with access to local networks often said that people who wanted access had access. For example, users in Mexico-1 presumed that everyone had a phone, saying, for instance, "No one is without… even the grandmas like me have a phone." Elsewhere, users assumed that people without access could obtain support; for instance, the 20-year-old secretary of the village's business enterprise office in Indonesia, with access both through his voluntary work and at home, said, "There will be different situations, but there won't be any problems as we are solid, and we will help them." Yet, many non-users of this network

suggested otherwise. Young men who were new volunteers at the village's business enterprise office said that they were too shy to ask for the password to access the network; a man in his 40s said, "We are stupid elders. […] We feel sometimes inferior if we can't use it," and a women in her 40s said she felt "left out".

Non-users of community networks said that they cannot afford subscriptions or handsets, or said their handsets did not work. Participants in Indonesia said, "We don't have money here," and a woman in Mexico-1 said she regularly lent her phone to people who did not own one; in fact, in the previous 20 days, two people aged 48 and 50 had used her phone because it was too expensive for them to own a handset. Sometimes access is enabled by wealthier social contacts; for instance, in Mexico and South Africa, some users said family members based elsewhere paid subscriptions or had given them pre-used phones. However, as the vice-president of the assembly in Mexico-1 explained, access is not simply about income. Although he did not have demographic data about who did and did not own phones, he said people without access to phones were principally aged 50 to 60 and, while they might live alone with no income, they also tended to be people who do not know how to use phones, speak Spanish and/or read or write.

Women's exclusion is so normalised in India that men VLEs did not even consider them when discussing the prevalence of smartphones in households. A woman user in her 20s explained that only herself, two other younger women and two women from government services in India-1 had smartphones and access to the network.

Various participants mentioned that text and/or technological illiteracy prevented access. A high school teacher in India-1 said that the parents of most of his students in 9th Standard were illiterate; and several participants in Indonesia said, "Not all of us have cell phones because we can't write." In fact, 80% of participants aged over 45 in Indonesia said they relied on their children to assist them with services, using WhatsApp and making video calls. Several men aged over 70 in Mexico-1 mentioned an unfamiliarity with phones, and conveyed a sense of helplessness and lack of confidence. One man said that as he did not know how phones work, he does not know what to do when it fails. In South Africa, five cooperative members and their family members aged over 50 said that while they founded and operate the network, they do not use the internet because they do not own devices or know about the internet.

The participants in the study who did not use the community network are unlikely to be very representative of non-user populations in the four initiatives where we spoke to them. Participants who were non-users were generally older than users if they were men, but not necessarily if they were women, and there was great variety between initiatives (see Figure 2). The average ages of the 31 men non-users and 57 women non-users were 38 and 28, respectively. The average ages of all 66 men and 65 women participants who were users were 34 and 36, respectively. However, median ages varied considerably - for men non-users, ranging from 29 to 47, and for women, ranging from 22 to 38 years.

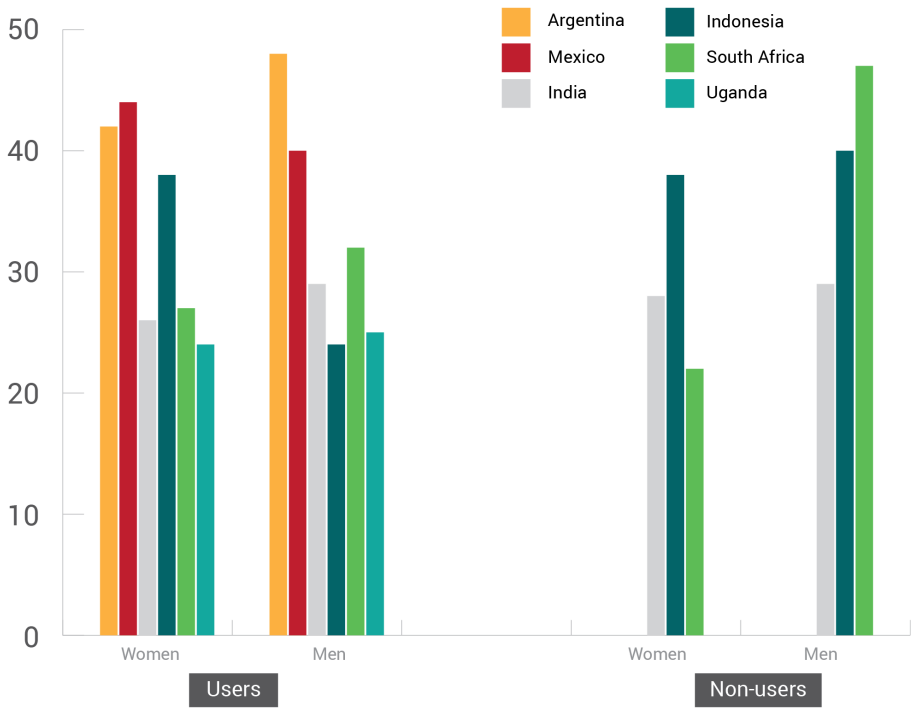

Figure 2. Median age of users and non-users that participated in studies, where known

Community networks can economically advantage users over non-users. This is clearly illustrated by data about two women participants in Indonesia who use Facebook to sell mangoes. One, a 22-year-old single woman who completed junior high school, is employed by the village's business enterprise office, where she has constant access to Wi-Fi; the other, a 30-year-old university graduate, married with three children, spends 50,000 rupiah (USD 3.51) on 4G data every month. Both women post photos of mangoes that they have just received from local farmers to their status updates on Facebook, where they both have the maximum permitted number of friends. Both also sell mangoes directly from their homes, and by delivering them on motorbikes and couriering them to customers farther away. However, the first woman's constant access to Wi-Fi at the village's business enterprise office contributes to much higher turnover than the second, as she immediately posts her daily consignments to social media and monitors posts on WhatsApp. During the mango season, the first woman regularly sells 60 kg of mangoes in a day, and sometimes handles orders over 100 kg, whereas the second handles orders of 7 kg a few times a week.

A strong communalist ethos in many villages means other people often intermediate for people who do not have personal access to connectivity. However, people lack privacy when they rely on others for access to information and communication. For instance, in Indonesia a man in his late 40s said, "I don't even know money transfer. My son pays my electricity bill online, see, it's very convenient because he transfers it himself at home." When asked if they would pay to use a neighbour's phone, participants in Indonesia said, "No, of course not. People help each other here." However, several women described difficulties when the person who normally facilitates calls could not do so. One explained that she could not speak to her husband in Jakarta when her child was sick, another said

she could not get in touch with people when her husband died, and yet another woman said she had communication problems when her child was involved in accident. Four of five women in a focus group discussion in India-4, who connected to the internet using 3G, explained that they relied on their husbands to either give them money to recharge their phones or use their husband's phone as a hotspot to access commercial mobile providers. The women laughed as one explained that she wanted to start working so she can spend her own money. However, the difference between the women's and their husbands' privacy went unsaid, perhaps because a man "helped" interpret our discussion. That is, like other telecommunications systems, community networks can amplify existing differences between people's power to access their rights to privacy, and particularly affect older people and women.

Selective support

While the motivation in developing and supporting community networks is about assisting people who cannot access affordable telecommunications, the scale of exclusion means that community networks are also themselves instruments for amplifying differences between the areas they do and do not serve. This is, of course, not the culpability of community networks themselves, but the economic systems that bear upon connectivity and the telecommunications environment in general. To prudently and pragmatically manage meagre funding resources, for instance, the initiative in Uganda must be selective in its support and adopts a sustainability strategy for its network that builds on the existing ability of groups to coordinate. Thus, a youth group in a remote village was selected because sub-county leaders had identified it as one of three groups that were most organised. The group had already coordinated savings schemes to buy and sell produce, and the umbrella organisation's support further united its members and enabled them to extend their activities by, for instance, generating income from photocopying. Yet, in the shadows of groups that receive support are many groups in areas that are not selected.

The amplification effect, between areas with and without community networks, can work together with national e-governance, e-education and e-healthcare programmes to advantage some areas. Consider how, in several countries, connectivity for some rural schools contributes to increasing requirements for all schools to input data online, and pressure on teachers who do not have access. A teacher in Argentina-3 explained, for instance, that if principals do not undertake online administration tasks they do not receive their salaries. Meanwhile, teachers in India and Indonesia working without community network access must use their own mobile connections to satisfy requirements.

Recommendations about understanding exclusion and disadvantage

Detailed insights about factors contributing to, and the consequences of, people's lack of access to community networks are essential. Community networks must be supported in gathering data about the demographics, characteristics and experiences of people without access to the community network, both within the coverage area of their community network and in neighbouring areas. This support should accentuate the value of reflective and critical evaluation to improvement.

The current emphasis of funding and advocacy regimes on certain measures of success and comparison with commercial telecommunications is a disincentive for community

networks to invest resources into evaluating gaps. That is, funding, policy and technology paradigms that encourage community networks to prove they compare favourably with commercial telecommunications can actually encourage community networks to reproduce the exclusions that commercial telecommunications manifest. Yet, demonstrating how expediently community networks can identify and address exclusion not only justifies their existence but can set benchmarks for better practice by commercial telecommunications.

Support should enable inhabitants of the areas that the community networks serve to gather detailed and accurate data and thoroughly analyse the factors that contribute to, and the consequences of, people's lack of access to their community network. This support should provide easily customisable strategies that ensure a wide range of local perspectives and experiences are included in data about exclusion, address local power structures that can impede this, and provide robust and culturally appropriate ethical guidelines and simple tools to support data collection and analysis.

Support should also be provided to community networks to enable them to integrate into their decision-making analyses of the factors contributing to, and the consequences of, exclusion. Support should include easily customisable processes and tools. For instance, the business model canvas, which has recently been promoted in endeavours to develop community networks, might be further developed to encourage insights about the factors that exclude people from involvement in, or access to, a community network in decision making.

Involvement in, and awareness about, decisions

Part of being able to access the services of a community network is knowing that they exist. At this stage, awareness among local inhabitants of the presence of a community network in their neighbourhood varies considerably. As described in a previous section on "Local awareness, visibility, safety, security and privacy", local awareness by, and visibility of, and their activities often characterised some of the rural places visited. However, the intangibility of telecommunications signals and the small size of most transmission devices means that becoming aware that a community network exists locally will also involve some combination of people's expectations about and needs for telecommunications, technological familiarity or literacy, exposure to marketing information or decision-making processes about the network, or social and/or physical proximity to people influencing or coordinating the network.

In two community networks, where participants were not solely recruited by the host initiative, some participants were unaware that there was a community network. A technologically able teacher in India-1, who approached us to discuss opportunities to improve the situation for his high school, did not know the network existed, even though an access point was installed in the primary school just 200 metres away from the school where he has worked for several years. Even in villages where there tends to be high awareness of others' movements, participants mentioned they did not know access points existed. For instance, in South Africa-3, a young man who is socially well connected in his village did not know that the local network provided access to the internet or the location of access points, and some young people said they discovered the network because they happened to see Wi-Fi symbols on their phones. While cooperative members did not

explicitly say that their aspirations for a local office and a t-shirt with the community network's logo would specifically help to publicise their services locally, several referred to the importance of the community network's visibility and identity.

Sometimes participants' unawareness reflects exclusion from decision making, particularly when access was planned by authorities in response to government requirements for digital work. For instance, authorities in India and Indonesia provide access to clerks in gram panchayats and the chief's office, respectively, to fill in online applications and print documents for constituents. A technically interested young man in India-1, who approached us as we walked in the village, said he did not know the reason behind the specific locations of access points, but he and other young men had suggested relocating some of the routers to improve the signal and usage volume. He explained that they had made this suggestion to the gram panchayat two or three times in the past five months, but a decision had not yet been communicated to them. Women non-users in Indonesia explained that only male heads of households were invited to meetings about plans for the Wi-Fi and, although husbands usually tell wives what is said in community meetings, they did not tell them about plans for the Wi-Fi "because they felt we know nothing about it."

Wide or free access was mostly limited when local authorities planned networks in response to government requirements, despite initial intentions. For instance, in a meeting in Indonesia two years ago, the District Communication Office advocated for Wi-Fi based on open access around the village's administration and business enterprise offices. However, this open access rarely happens, and participants said that "people are aware that connection is only there for the staff." Staff in the village administration said that the network had slowed when they gave the password to other people, yet both they, and volunteers at the village business enterprise office, also said that they used the network for non-work activities, including their own businesses.

Exclusion from decision making also occurs in more grassroots-driven community networks. Only members of the Argentine community networks decide about their networks, and membership requires attending technical workshops. However, there can be tensions between the community network's principles in relation to the commons and other local inhabitants' perspectives on communality. For instance, we detected 157 Wi-Fi networks as we walked between Argentina-1 and Argentina-2, and the founders also recounted the objections raised by a man living in the area over the community network's contribution to the Wi-Fi pollution. The man had relocated to the area in pursuit of his Arcadian ideals and felt that radio signals intruded on his meditation. Meanwhile, a woman participant in her 60s uses the network in Argentina-1 as one of about 10 "godchildren" of community network members. She is permitted to use the network even though she has not attended a workshop and does not participate in the community network's internal communications, such as its WhatsApp group. The community network set up its first antenna on a tower on the roof of the participant's house, which her husband had built to receive a TV signal. She had agreed with the community network's use of the tower, as she thought the network was a communal service without profit, but after a while, the house started showing signs of damage that might be caused by the tower. The participant informed the community network that she would like to remove the tower if it could be done without cost to her, and as the tower is now redundant because of network changes, a couple of community network members planned to help. Unfortunately, the participant had little communication with the couple who sought to help and found them on her roof

without her permission. Thus, although the participant uses the network and receives assistance from community network members, who ensured she was amply heard in our interviews, the meaning she associates with communality differs from that embedded in the community network.

Recommendations about wider participation

The potential for community networks to sustainably "connect the unconnected" increases when people living in their vicinity are aware of them. Community networks must be supported in publicising their services and the locations where services are available. Undoubtedly, publicising initiatives will introduce complexities as more people contribute different perspectives, holding divergent opinions about, for instance, the meaning of communality, rights to transmit radio signals locally, principles, organisation and use of community networks, and so on. Therefore, community networks must also be supported, with information and strategies, to enable them to engage in discussions effectively, and account for different perspectives in decision making.

Resources for maintaining networks and services

There is scope to address challenges for rural community networks that arise because of the low availability of technical resources in rural areas. Human technical capacity and various physical resources to support logistics are very limited in four of the six rural areas studied and, as explained next, their impacts on service reliability have social and business consequences. However, community networks can also adapt more deftly to local constraints than commercial telecommunications, which impose standard processes and deployments across many heterogeneous settings that also affect their quality of service. Founders and operators of many community networks demonstrate a willingness to learn and change, organisationally and operationally, and the escalation of communication between different community networks has dramatically extended opportunities to share experiences, wisdom and practical support in order to develop new practices best suited to a community network's specific setting.

Resources to address technical issues

The current status of local human technical capacity and availability of other resources to address technical problems can compromise the quality of service that community networks provide. Most community networks we studied rely on technical personnel at umbrella or support organisations, while the community networks in which local inhabitants had sufficient technical skills to independently maintain and troubleshoot often lacked access to resources needed to undertake this work, such as transport.

Local technical skills are available in some community networks. For instance, Argentina-1 and Argentina-2 are within a few kilometres of the home of the technically expert founders. Nonetheless, the community emphasises the importance of increasing the extent and depth of other inhabitants' skills. Its community networks are unusual because nodes are located in the homes of members who have committed to learning to set up and maintain them, or in the homes of people that members take responsibility to support. Argentina's economy and high-quality, mandatory education mean local people are generally widely

exposed to technology, literate and numerate. Thus, members have agency to learn to solve problems, even if their ability to invest time in maintaining the network varies. One active woman member explained that she always talks with the founder to make crucial technical decisions, not because she seeks corroboration but because this helps to "solidify her knowledge." Several participants in Indonesia also had extensive education, and some had strong technical skills. However, these were not applied to setting up or maintaining the network, which was undertaken by the local provider in a town 25 km away. In contrast, in South Africa, with telephonic support from the remote umbrella organisation 1,300 km away, the community network's local manager and technical support can fix most technical problems that arise. The community network in South Africa began teaching a small group to install some of the equipment seven years ago, and at the time of our study had commenced technical workshops, to install new equipment, for 10 men and women.

The other three community networks we studied planned for local inhabitants to learn sufficient technical know-how to maintain the network. The network administrators at some of the Mexican sites do try to fix problems themselves with knowledge gained in helping to set up the infrastructure, and support each other via a Telegram chat group. However, in Mexico-1, the local authority said that they needed to involve more highly educated local people in maintenance, and a middle aged-man remarked that insufficient local people understand the infrastructure. Similarly, most knowledge for the VLEs in India, and the managers of ICT centres in Uganda, is limited to selling vouchers or subscriptions, turning on switches and managing the power reserves of solar set-ups. In rural Uganda-3, the manager of a local ICT said, "Sometimes we realise the line was tampered, like the time the power inverter was off because someone had poked a pen and switched it off, and as we had been trained by [the initiating support organisation], we were able to rectify it."

The VLEs in India-1 who sold coupons and facilitated DRUV video-based teaching sessions did not know the criteria for siting access points, installed by personnel of the Common Service Centre (CSC) that delivers the government's e-services. When the internet failed or they had trouble with the subscription software, they relied on CSC personnel to advise them remotely or drive two hours to fix problems. Their inadequacy to address problems was heightened because the interface to the software they used to manage subscriptions is written in a language they do not understand.

Even when technical skills are available, other resources, in particular transport, compromise the quality of service that community networks deliver. Transport to sites to repair failures or replace components impedes local inhabitants who are technically competent to make repairs themselves, as the cooperative members in South Africa continually reiterated in describing their need for a vehicle. The availability and/or cost of transport makes frequent visits to community networks difficult for umbrella organisations also. Engineers in Uganda must pragmatically schedule their routine maintenance trips and often feel frustrated because funding constrains the transport available to go to remote sites to fix things in between.

Service unreliability and distrust in local operations

As a consequence of limited local technical capacity or other resources, many participants said that services were unreliable and there was a lack of responses to complaints. In

South Africa, Wi-Fi was fixed fairly soon after it went down, but subscription vouchers were not delivered for several days, and participants said they did not have a place to go to report and fix problems. During our studies, either the Wi-Fi was not working or there was a problem with log-in at most of the sites in India, and local VLEs were helpless to address the problem. In Mexico-1, participants said that because of signal problems and network saturation that caused interference, some calls were inaudible, some calls dropped, or calls and SMS were diverted to unintended recipients. These problems were irritating, caused embarrassment and complicated emergency or urgent situations, yet the network administrator offered no solution when they reported them to him.

The problem of quality of service is not simply a matter of unreliability, since other telecom services in most of the countries we visited also fail regularly. Indeed, as a participant in Mexico-1 explained, "I've lived in Oaxaca, Puebla, Mexico City, and even if you get 3G or 2G, the saturation always happens." Nor is service quality a matter of local competence or attitude, since even lodging a complaint or speaking to a representative of a major telecoms operator is impossible, or unaffordable, in many rural areas. Rather, quality of service implicates local people who live in the communities they serve, and are present and answerable, not anonymous customer agents trained and paid by commercial providers to field and deflect complaints.

Sometimes the very people who interface with paying users lack detailed knowledge about, or influence over, a network's implementation, management and processes that affect their service to customers. A participant in South Africa said that a manager who lived locally but was paid by an umbrella organisation determined when nodes were installed and had not explained the system for printing vouchers or how many vouchers are printed monthly. The cooperative only sees the manager once a month and often its members did not have any vouchers to sell, even though there was no real limit on the number that could be sold. The somewhat exploratory prototype voucher system was relatively new, and the umbrella organisation, located far away, had not given the manager enough information about it. This situation, however, not only limited cooperative members' ability to provide access to people wishing to buy vouchers, and to keep accounts, but undermined the trust between manager and cooperative.

Unreliable networks or lack of knowledge among local operators compromises trust and engagement. For access that does not involve payment or work, of course, unreliability simply reduces the volume of users. For instance, a user of free Wi-Fi access to the internet via the local network in India-5 explained, "From starting I maybe used it for 15 days continuously. But after that the log-in did not [work], so I never went back."

Distrust in the network and its processes is especially damaging when people have chosen to support services that are trying to develop a business approach. For instance, the log-in to the community network in South Africa did not work on the new phones of 10 people, and since operations did not allow unused vouchers to be redeemed, several participants expressed that this was a disincentive to others who might buy a new phone in order to use the service. Similarly, several participants in India-1 explained that they had ceased buying vouchers from VLEs after the Wi-Fi went down for the entire duration of their subscription. The VLEs explained how distrust meant they had only provided their electricity and TV bill payment service to five or six people: "People don't have trust in us because people want a receipt when they pay their electricity bill and because we do it online, they don't have a receipt."

Users who prefer "to pay and call the provider" when services do not work are similarly inhibited from joining the community networks in Argentina, whose members are collectively responsible for reliability. However, this plays out differently in the different networks. Participants in Argentina-2 mentioned receiving calls in the early hours of the morning to attend to network problems, and participants in Argentina-3 described times when the network did not operate for months. An initiator in Argentina-3 said that since it started, the network had "spikes and valleys of strengths"; sometimes it deteriorated, members felt depressed, and months would go by before they coordinated to improve and restore service. This requires people to motivate others, as the treasurer explained, "Sometimes the network work gets delayed, so I try to push the work forward. Some members are more active or passive. Sometimes there are complaints about participation, but everyone has their own commitments." The Argentine community networks are often lenient about collecting fees; in fact, recently, one community network decided against taking fees from those who were up to date with payments "until everyone got to the same level," because some members lagged behind. Principles are more important to this community network than money, yet, as the treasurer in Argentina-3 noted, "Not all of us have the same motivation for the network. We live in a more selfish world. It's a problem when the service doesn't work. People invest money in something that isn't working."

Most of the organisations supporting community networks indicate that they are addressing technical issues that inevitably arise in trials and new implementations, such as problems with voucher systems. However, the consequences of distrust that emerges during trials can wound precious interpersonal relationships in communities. In Uganda-1, the manager of a solar set-up explained that they had cut the electricity supply to a hair salon because a hairdryer drained the battery, while the salon owner said, "They didn't tell us. […] We don't have light now." On learning about the situation, an umbrella organisation coordinator said he would encourage the community network to check the wiring to the salon and assist its owner in selecting a low-wattage hairdryer. In another community network, a manager who mediates between the local people and the umbrella organisation, which pays his salary, is particularly vulnerable when new processes are trialled. Participants suggested that the manager had started to act as a gatekeeper between themselves and the umbrella organisation, and attributed their sense of exclusion from decisions about the network to the manager's opinion about their intellectual capabilities.

Recommendations about local technical resources

Not only does the potential sustainability of community networks increase when local people have technical skills, but so do the opportunities for community networks to deliver and extend their educational, employment, innovation and empowerment benefits. Community networks should be encouraged to communicate with each other, using the increasing channels available, to share experiences, wisdom and practical support. This includes supporting members' and operators' everyday remote conversations with others supported by the same umbrella organisation, as illustrated by Rhizomatica's Telegram group between all the network administrators. It also includes supporting the different communication channels within nations, regions and internationally, such as the peer networks working together in APC's project funded by Swedish International Development

Cooperation Agency (Sida).[140] These vibrant and supportive conversations not only assist individual people and the network's development but articulate and refine a body of knowledge about local adaptations of the community network's telecommunication paradigm.

Local languages must be attended to closely. Initiators of community networks and umbrella and support organisations should be supported in creating technical teaching and learning materials in the languages that operators, users and non-users usually speak or read in everyday life. Similarly, interfaces to systems, diagrams and descriptions of the network, such as the rationale for siting access points, must be accessible to people with different languages and literacies.

Geographies of access and involvement

Sometimes geographical distance from access points and network administration disadvantages people, especially those with mobilities constrained by physical abilities and/or social and cultural norms, such as people with disabilities and/or women. Some restrictions to access are similar to those in other types of telecommunication operations, such as the social, economic or physical freedom to travel to a town to buy a SIM card or somewhere where a mobile operator's signals are stronger. Other disadvantages arise because community networks are limited to using Wi-Fi, and tend to adopt certain criteria and conventions in locating Wi-Fi equipment. Like all telecommunications, community networks can reinforce the exclusionary effects of the restricted mobilities of women and girls, such as access to places that are safe or where decisions are made. Once again, however, the local nature of community networks both exposes the ways telecommunications in general reproduce inequalities and provides new opportunities to creatively address these that commercial providers can learn from.

Places restrict access

The community network in South Africa we studied had only two working access points at the time, although apparently more than 40 have since been installed. Thus, some people could get a signal throughout their homes, some in one room, others only at the bottom of their garden, while many others walked to a certain place. This distinction made the wife of one cooperative member with an access point on her home feel uncomfortable: "I feel ashamed, sometimes they are standing [outside] and it is cold and raining."

A difficulty with few access points, and limited coverage, in rural areas is, of course, that people who need cheap access most are also those who spend their days working in fields. A VLE said that around 70% of households in India-1 had at least one smartphone, but their owners are often people who work in the nearby city so they do not use the Wi-Fi network during the day. In the meantime, he added, "Most of the people who are uneducated are also agricultural labourers, so they go to the field from the morning to the evening and they are not using the Wi-Fi."

140. https://www.apc.org/en/project/connecting-unconnected-supporting-community-networks-and-other-community-based-connectivity

Participants in Mexico who used the one community network we studied that was not constrained by Wi-Fi repeatedly mentioned the benefits of access while they worked in fields and plantations. Nonetheless, participants in Mexico-2 also said that the community network's GSM phone signal did not cover everyone's homes and they needed to go into their gardens to call. Some users also explained difficulties in having a community network office only in Mexico-1, where they needed to go to pay their monthly subscriptions, and more often if they wanted to load credit to make long distance calls, even when they had "nothing more to do in [Mexico-1]." The location of the office financially disadvantaged subscribers who lived in faraway villages, especially elderly people; for instance, people walk downhill to Mexico-2 from Mexico-1, which takes two hours, and take a taxi uphill "but it's a waste of money – 20 pesos per person," one man explained. Some participants said "sometimes we do ask others favours to pay for us." The network administrator in Mexico-1 explained that some people undertook workarounds to re-sell credit locally, and an elderly man said that he sought to establish a subsidiary office in Mexico-3 to collect subscriptions.

Occasionally the location of equipment constrains opportunities to use and fix it at certain times of the day. Often equipment must be sited in places with guaranteed security, such as public buildings, but this introduces other restrictions. For instance, the server at a community network in India-2 is housed in the corner of a primary school classroom, and the access point in the school grounds. The class teacher explained that users came only after 5 p.m. when school was finished, and an operator said, "If there are many people who come in to see and start using it and there is some problem then I escalate it to the sirs in the school or my supervisors." However, people had broken the gate on entering the school grounds to use the access point, and when we were shown the server during a visit, we clearly disrupted the lesson. The teacher explained that he could bear the disruption if the internet brings development to the village, but also made untranslated comments that seemed redolent of concern.

Women's paths and places

The location of access was frequently a specific barrier for girls and women, and amplified existing gender differences in freedom of access to information. Many women non-users in Uganda-4 said that they do not have enough time to come to the ICT centre. For instance, one middle-aged woman said, "I have a lot of work; I must come here from the garden far away. It takes two hours to walk to the gardens from here." Young men in an ICT centre in Uganda-3 attributed the absence of women and girls to local culture: "The reason why girls don't come," one said, "is because of lots of rules and regulations that don't want to allow them." Girls in the region are often denied secondary education because families cannot afford the cost, and therefore they need special assistance to use computers, and according to the same young man, "They are so much involved in home activities period it's not easy to mentor them." However, a participant in the umbrella organisation explained that men in ICT centres actually make women feel uncomfortable: "The other week, we went to the training and there was no lady. Then the first thing I asked them, 'Why is it that there is no lady amongst you?' Then they told us, 'Ah! We have some of them, they are going to come.' But we ended the training, and none appeared," the participant recounted. "Then after the training I asked them. They told us that these men have bad manners, that's

why the ladies don't come here. Some girls used to come but now they fear to come due to their… because of the behaviour of these other boys or men."

Gender exclusion by ICT centres and computer education is well documented around the world, and restricting access to a community network via centres and computers can add to this exclusion. The concern here, however, also refers more generally to the relationship between locations of access and cultural and social restrictions on the mobility of women and girls. Three men VLEs explained that "all the people with mobile phones" sat close to access points in India-3 in the evening to obtain a good signal and giggled when asked if "all" included girls and women. One said that the internet "was more to do with men than women," and "girls will sit on the veranda of the house or the courtyard of the house," which usually means they had access to a poorer signal. In India-1, a group of young women participants explained that as they all happened to live near the gram panchayat they could access the Wi-Fi from their homes, and when asked whether there was a place for an access point that would suit women, they said there was "no special point where the girls want" as they are discouraged from moving far from home. Our discussion was interrupted by a brother of one woman who said that he wanted an access point where young men from the village gather in the evening.

Community networks are embedded with gender norms about who is permitted privacy and safe places in which to speak. These norms were demonstrated in our study by the ways our interactions with men and women were arranged and facilitated. We sought to have separate interviews and discussions with men and women, and have men and women interpreters to facilitate these spaces, respectively, to increase the chances for women to speak freely, unconstrained by gender relations in mixed groups. Despite continuous requests, this was rarely achieved. In two countries we were provided with only a man interpreter, in two countries a man and a woman, and in two countries only a woman. Thus, in a total of 34 small or large focus groups, 10 included only women participants and interpreters. A total of eight focus groups comprised only men participants and interpreters, excluding myself, and a further 11 comprised 65% men, excluding myself. In other words, women constituted a majority of participants in less than a third of focus groups, even though I, the researcher, am a woman and was sometimes accompanied by only a woman interpreter.

In the two countries where only men interpreters were provided, we were told that there were not any women able and available to undertake translation. In one country we requested a specific woman, with excellent English and communication skills and familiarity with the networks, who had told us she was willing; however, we were told that it was not possible to relieve her from her assignment to a fairly basic help role that week. In another country, where we were provided with only a man interpreter, a focus group of women challenged him about the arrangement, asked him to sit outside, and said they would muddle through translating languages between themselves.

Even when we had only women interpreters and participants, men were frequently in close proximity, because we were offered places where more men than women worked, or because men came and loitered around the places where the women had invited us to talk. Men's intrusion happened even on the verandas of private homes, where men sat themselves within hearing distance, often within a metre, watched, and sometimes tried to contribute to interviews, often appearing to have helpful intentions yet ignoring our efforts to politely resist. There was only one instance of the reverse situation, when discussions or

interviews with men were joined by a woman, other than myself and interpreters. Inabilities to afford privacy to women in our study are not simply methodological weaknesses, but reflect norms about the roles and influence of men and women, and their access to places and the conversations happening there, that are perpetuated in the organisation of some community networks.

The long distances between umbrella organisations and the rural networks they support also seems to conflate with differences between the expectations of technically skilled women in cities and their experiences in rural places. None of the many women technologists working in one organisation chose to accompany teams to rural villages, and in another organisation a woman network engineer mentioned how uncomfortable she was visiting access locations with no women in them. She added, "I think it is also challenging for a married lady. […] Sometimes maybe the spouse may not give their permission for a woman to go to the field, things like going up on the tower."

Recommendations about inclusive and gender-sensitive topologies

The physical, social, economic and cultural factors that restrict people's mobility and comfort and safety in certain places and thus their access to a community network's services will partially be addressed if coverage is not constrained, such as by using GSM rather than Wi-Fi. However, the factors that constrain mobility and physical access also affect people's movement to, and presence in, places to learn about technology, purchase subscriptions, inform others about harassment, participate in decision making and undertake technical tasks. Thus, community networks should pay close attention not only to places where connectivity is provided, but also to the places where personal and community-owned equipment is used, monitored and fixed, subscriptions are sold and managed, and organisational, technical and strategic decisions are made. The locations of all aspects of operations must account for and creatively address the many different ways that access is constrained by gender, age, physical abilities, class, ethnicity, caste and financial resources.

While it may be tempting to adopt a compensatory approach to address gaps in access with existing technologies, such using repeaters to extend Wi-Fi or GSM coverage, this also limits creative approaches to the underlying issues. Thus, a more innovative recommendation re-imagines the way deploying telecommunications can respond constructively to the spatial practices of different groups of people. Consider, for instance, alternatives to determining the placement of network components according to conventional criteria for network optima, such as robustness, and the locations of existing authorities, such as sub-headman's homes, gram panchayats or chief's offices. One alternative might be to ensure that the location of access points accounts for the routine paths that different groups walk, such as routes through villages taken by women and girls to collect water, by elderly people to avoid hills, or by agricultural labourers on their way to a farm. Insights from participatory mapping processes of different people's practices in moving through and accessing places in their local setting might inform the design of more accessible community networks, while also providing new expressions of local innovation. Participatory mapping processes can also offer opportunities for local people to gather their own data about the material and spatial ways community networks reproduce power structures, and resources to incorporate a wider range of perspectives in a community network's decisions.

Community networks should be encouraged to explore opportunities for women-only spaces for learning about technology use. Where appropriate, opportunities for technically skilled women to directly support women-led networks should also be promoted, such as AfChix's WomenConnect project[141] in Africa and radio projects led by women in Brazil.

Temporalities of involvement and access

Community networks depend on social relationships in ways that differ from commercial telecommunication provision. Social relationships also involve time, which is used and experienced in markedly different ways by different people in communities and in endeavours with voluntary aspects. The time available for local people to use and contribute to setting up and maintaining a community network varies, which has important consequences for how work is internally and externally determined, managed and assessed and strategies to include diverse people. Like other personal and collective technology endeavours, often community networks have characteristics that are incompatible with constraints on many women's time. However, because the sustainability of community networks depends on social relationships, they can also offer new approaches to technology endeavours that are more congruent to women's time.

The worth of social relations

Valuing social relationships in accounting for time is vital to community networks, yet frequently deprioritised by technology support organisations and funding regimes. Members of the Argentine community networks explained that time spent fostering social relations in the community network was important, and certainly the volume of messages on their different WhatsApp groups illustrated this investment. In fact, a member in Argentina-2 said that she allocates an hour a day to the community network's WhatsApp messages, in order "to reply to everyone who talks," rather than distribute exchanges throughout the day.

Some umbrella organisations are well tuned to the role of regular telephonic contact in building relationships with people in the remote villages they serve; for instance, engineers in Uganda explained that their communications were not only about technical issues. However, the technological bias of umbrella organisations can promote prioritising time for technical tasks rather than social relationships. For instance, the founder of one initiative has never visited the sites where the network is deployed, and the programme invests its resources in advancing technology rather than understanding people affected by deployments in the villages far away.

Schedules for implementing programmes that are externally funded contrast with the pace and incremental emergence of community networks that are wholly financed by their members and users, and where social and technical aspects deeply entwine. The schedules of funding regimes, designed to achieve accountability, can contrast with the rhythm of work in community networks, where network tasks inherently involve personal relationships. Deprioritising the worth of social relations in accounting for time influences the ways impact and success are assessed, often emphasising volumes, scales and the

141. http://www.afchix.org/projects

monetarisation of intangible concepts. For instance, an external organisation had given a woman participant in India-4 a smartphone and a year of mobile internet data and set the task of introducing 700 women to the internet within six months; meanwhile, a VLE in India-1 explained that potentially, local network users can "save the time" they would need to travel to the city by doing things online and devote that time to agricultural work.

Admittedly, while cultural constructs about time often differ between rural and urban areas, telecommunications are influencing rural people's experiences and expectations. A woman in Mexico-1 explained, "I say nowadays we can't wait five minutes, we have trouble assimilating time." The expected immediacy of telecommunications framed participants' perceptions of the Mexican community network's service; they said, on the one hand, that the service had shortened the distance between people but, on the other, "the process is too long." Technologically advanced young men users in India-1 said that they had limited time to go to the access point to use the network and ceased going when it was unreliable. That is, constructing time as a commodity, or a resource with financial implications, introduces tensions in local networks. Much of the work of the coordinator of the initiating organisation in India is directed towards fundraising, especially to support young technologists working on software and hardware development; meanwhile, the coordinator of the umbrella organisation in South Africa spoke about relentless demands to report on funds. These demands reduce the time available to support social relationships.

Time for involvement

Respecting other people's time is especially important to community networks. People in umbrella and support organisations often work extremely long hours, motivated by strong senses of responsibility to the communities they serve, despite their limited resources. For instance, volunteers who support village-level information systems in Indonesia, and technicians who support the community networks in Mexico, said that they were always on call to troubleshoot problems, even at home in the evenings. Respecting others' time is also vital to community networks in which members are solely responsible for maintenance. Several participants in Argentina said that considerable time was spent coordinating to schedule activities to ensure people could undertake tasks together. A woman in Argentina-2 described reserving between three and five hours for group tasks, such as setting up or replacing a node, but that she could spend 10 hours making arrangements and preparing all the necessary equipment during a busy week.

While respecting other people's time is vital to community networks, it is also complicated. Network administration and software experiments in the Argentine community networks tend to be done overnight to reduce impact on members' network usage. Thus a woman in Argentina-2 described being frequently woken by a message from the community network's founder, after he has spent the night hours working on the network. She said, for instance, "At 5:00 a.m. this morning I received a WhatsApp message to go to the roof of the meat packer to align the antennae with the mountain." She explained that she sleeps with her phone next to her ear because her family is away, and any call at night must be important, and also she sometimes has insomnia. She mimed opening one eye to look dozily at her phone, and said she decided not to reply, went back to sleep, and dealt with the issue three hours later. The woman joked that the community network exploited her commitment, but that she liked to do this community work.

It is possible that there are times in people's lives when they are better disposed to undertaking the work in community networks. For instance, a man in his 60s in Argentina-2 said that, as well as being able to offer tools and carpentry skills to set up nodes, he also had time. "The task," he said, "is to be aware," since participation in the community network was less about sophisticated technical skills than being accountable: "Mostly people understand what they see in terms of antennae and signals, but they don't know how the network works." Having time available to be aware of both the network's technical status and social relationships may be improved by involving people of diverse ages. A woman in her 20s, in Argentina-2, remarked that younger generations are less worried about communality, and older generations are more concerned about their neighbours. That is not, of course, to suggest that older people's time is more disposable, as a grandmother in Argentina-2 made clear: "I would like to invest more time but I also need to live." Nonetheless, a 70-year-old man in Argentina-1 said that since his retirement from paid work he had "more time to sleep and more time to be in touch with friends," in contrast with a man in his 50s who explained that work on the network was delayed because most members of the Argentina-3 community network have young families: "Even though all [members] are young professionals that have time available, they have flexibility, they also have kids."

Temporal exclusions of women

Temporal constraints often exclude women from use of, and involvement in, technical operations. Barriers are created not only by inappropriate, hostile and unsafe locations of access points, but also the fact that where they are and what they offer are incompatible with women's everyday routines. For instance, while the youth programme run by the Ugandan initiative includes gender sensitisation, few women came to some of the focus groups held in their ICT centres, and those who did often left early to prepare lunch, because sessions were scheduled to account for the times that participants returned from agricultural work but not the times that women must be at home cooking.

Understanding constraints on women's time is vital to their use of local networks. Consider, for instance, a woman in her mid-40s who works from 4:00 a.m. until after 7:00 p.m. to prepare food and serve up to 50 people a day in her little cantina in the market in Mexico-1. Her husband encouraged her to use WhatsApp, but she said she did not have time: "If I sit down to chat I feel like I am wasting time." Contrast two women primary teachers in India-1 who said they did not have enough time to use the internet, with two men VLEs in India-2 who said that they were easily able to swap roles and cover for each other when one was unavailable to work. Compare a young man's explanation that his duty at an ICT centre in Uganda "doesn't stop me doing other things," with women at another ICT centre who asked, "How will I apply the knowledge [here] in the kitchen?" In all countries, a substantial proportion of women in focus groups or interviews either needed to attend to the babies and children they bought with them or rush away afterwards to undertake family work.

The gendered division of labour also affects women's involvement in, and focus on, technical tasks. For instance, while technicians in one umbrella organisation can work until 7:00 p.m., a woman technical intern explained she needed to be home by 6:00 p.m. to cook for her family, and it was not safe for women to travel after 8:00 p.m. In Argentina, women involved in technical operations explained that, in contrast to men, who focused on

technical tasks for extended periods of time, they needed to split their focus as they multi-tasked on family responsibilities. Indeed, when we observed women and men undertaking technical tasks in Argentina and elsewhere, while men were fixated on the computer screens, women were more often interrupted.

Recommendations about scheduling

All consideration of community networks must account for the time required to foster and support social relationships, and cultural constructs about time that can differ between rural and urban areas. Funding strategies should better acknowledge the time demanded for social relationships, which are integral to the success of community networks, in assessing milestones, impact and success; and support organisations should seek to balance time for technically and socially oriented tasks.

Deeply understanding constraints on different people's use of time is vital to supporting their access to and involvement in community networks. First, in all aspects of scheduling, from timing access and training to technical operations and travel, community networks are encouraged to closely attend and respond to the details of the timing of the kinds of labour different people undertake, from childcare to gardening and domestic work. This includes recognising that people who are expected to undertake certain responsibilities, such as caring for families, providing hospitality or psychological support, frequently split their time and focus, and considering how technical and other tasks can be organised to accommodate these overlapping responsibilities. Second, community networks are encouraged to involve men and women of diverse ages in all different aspects of their set-up and maintenance, and consider how different approaches and attitudes to time can be deployed in accomplishing technical and coordination tasks.

Access and involvement across generations

Often people who make the decisions about the ownership and operations of rural community networks are older, while people with technical literacy and skills tend to be younger. Widely held assumptions about what age groups should be targeted in designing and deploying technologies and services influence people's perspectives about the value of technical skills at certain stages of life and what age groups should warrant training. Such assumptions undermine older people's confidence in using technology in general, which has a self-reinforcing effect upon the technologies and services that telecommunications companies focus upon. However, because the sustainability of their operations is compromised by exclusion of any particular group, community networks offer important opportunities to promote and support the interest and competencies of older people.

Generational exclusions compromise sustainability

We sought to include participants of diverse ages in interviews and focus groups, and their representation in different categories indicates their relative involvement in community networks. The workforce in umbrella and support organisations is much younger than people making decisions about community networks. Whereas the median ages of participants in umbrella and support organisations ranged between 28 and 37 years, the median ages of people overseeing community networks in villages ranged between 32 and

55 years (see Figure 3). This age difference reflects that decision makers in rural societies tend to be older than technical staff and people based in towns and cities.

Decisions about deployments for the networks in India reside with gram panchayat officials, in Indonesia with the local elected chief's office, in Mexico with local traditional assemblies, and in South Africa with cooperative members, who are mostly sub-headmen in the tribal authority or their wives. Their seniority often means that local decision makers have lower technological literacy. For instance, few participants who were cooperative members in South Africa use the internet or own smartphones, while the woman sarpanch (head) of India-5's gram panchayat, who is in her late 30s, explained that she "uses mostly handwriting and pen to write everything down," and the man computer operator uses the internet more.

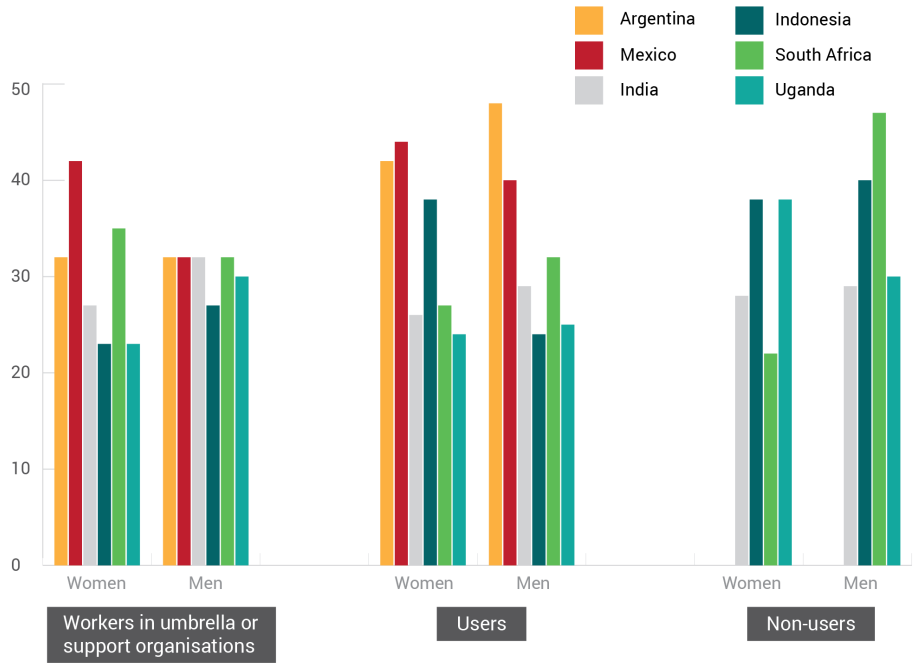

Figure 3. Median age of participants who worked in umbrella or support organisations or were users or non-users, where known

Generally, participants in villages assumed that basic computer literacy and skills in networking equipment are for younger people, and only the Argentine community networks consistently involved older people in learning and using technical skills. In South Africa, the umbrella organisation encouraged diverse ages to participate in workshops to learn how to install nodes, as cooperative members, who sell and account for subscriptions, tend to be older. However, cooperative members often insisted that they wanted youth to be technically involved since they used the network more; for instance, a cooperative man said, "We are old, we were interested to put their children first. There are some things we don't understand, but we want to give the computer to children, the software." Yet, as conversations with older non-users in South Africa and Indonesia unfolded, it became apparent that earlier indications of their disinterest in learning about technology might actually reflect a lack of confidence and knowledge about the value of the internet to them.

For instance, after a week of interacting with older people in Indonesia, many expressed considerable enthusiasm to us for learning more about smartphones and the internet.

The initiative in Uganda, and support organisations associated with the Indian and Indonesian initiatives, all focus on training in computer literacy for livelihood and business, rather than on setting up, maintaining or managing networks. In Uganda, this specifically focuses on youth upliftment because they are the poorest and there is a high mortality rate. "You are lucky," said an employee of the Ugandan initiative, "if you survive to 50 years if you are a man, or 45 years if you are a woman." However, reflecting on assumptions about the value of training older people, he also said, "It's not really right to say it [access] is irrelevant to those who are 60 and above." He added that, since older people would also be "looking for money to push to their children," computer literacy was more important for everyone compared with a few decades ago.

Overemphasis on younger people in using and technically operating networks might actually compromise the sustainability of operations and autonomy, since younger people are usually more mobile and, once trained, seek income based on the skills they have learned. For instance, the initiative in Uganda has a training-of-trainers approach that intends to have a multiplier effect, to mitigate the high turnover of trained people. Yet the success rate of this approach can be disappointing, since people select among themselves to determine who is expected to be competent enough for training and passing on their skills. An employee of the Ugandan initiative explained that usually only five of 12 people trained remain active. The community networks in Argentina present a clear example of the value of including diverse age groups in operations to foster sustainability.

Table 1. Median age of participants who undertook technical work for which data was generated and proportion of the population over 40 years of age in the region, where (n) is the sample size from which the median was derived

	Age range of all participants (years)	Umbrella or support organisation	Local workers	Users	Percent of province/district's population aged over 40
Argentina	22-63	32 (4)	42 (10)	48 (21)	37% of Cordoba province
Mexico	22-72	37 (4)	38 (3)	41 (28)	32% of Oaxaca province
India	17-56	30 (8)	32 (13)	28 (13)	22% of Thane district
Indonesia	16-70	25 (13)	41 (6)	30 (32)	35% of Central Java province
South Africa	18-65	34 (4)	56 (6)	28 (23)	27% of Eastern Cape province
Uganda	17-69	28 (11)	34 (7)	28 (21)	14% of Gulu district

Recommendations about involving older people

Community networks offer important opportunities to promote and support the interest and competencies of older people in using, setting up and managing technologies in rural areas; indeed, this is vital for their sustainability. Thus, they must be encouraged to ensure that people of diverse ages are taught about all aspects of their network's use and

deployment, from technical literacy to set up and maintenance. Community networks should identify the enthusiasm and build the technical confidence of older people and, at the same time, recognise that they bring experience and other attributes that contribute to community cohesion. Planning training should account for culturally appropriate and personally comfortable contexts for learning; for instance, considering when and when not it will be effective for younger people to teach technology skills to their seniors.

Women and technical work

Community networks inherit gendered conventions from the telecommunications domain generally. There are fewer women in all categories of people involved with or using community networks (see Figure 4). Men are more likely than women to undertake technical tasks in community networks, and since technical rather than other tasks are more often remunerated, men are over twice as likely to be paid. Further, widely held gender associations with technical tasks and gendered division of labour exclude women. Gender exclusions inherited from the telecommunications domain more generally often conflate with gendered power relations, expectations about voluntary work and conventions of teamwork practices in communities. There are indications that this situation can repel younger women who are interested in technology and technology endeavours from becoming involved in community networks, which creates discontinuities between younger and older women. Yet, as at least one community network demonstrates, there is significant potential for community networks to support generational continuities among women.

Figure 4. Proportions of roles in the networks for 152 women and 172 men in interviews and focus groups (individual people may have more than one role, e.g. worker and user participants)

Gendered and valorised labour

Bearing in mind that we actively sought to include women in all categories, men participants in brief and long interviews and focus groups constituted:

- 78% of nine founders, initiators or champions
- 70% of 47 workers in umbrella or support organisations
- 69% of 48 workers at village level
- 54% of 171 users
- 35% of 88 non-users.

Men are not only more than twice as likely to work in umbrella or support organisations in cities and in the community networks in villages, but are also more likely to undertake technical tasks. Women comprised under a quarter of participants in umbrella and support organisations that worked on technical tasks, such as software development, network administration and installing and monitoring equipment. This reflects the broader context of telecommunications throughout the world and gendered associations with technical skills. The employees of the umbrella organisation in Mexico who we interviewed, one of them a man and the other a woman, both noted that there were no female applicants when they recruited for technical positions in the past two years. The woman explained that cultural and educational factors contribute to this. The man, an engineer, explained that 40 students commenced the university software engineering programme he had studied in the past six years; of these, 10 students were women, and only seven of them completed the programme. Like other staff of the organisation, both were enthusiastic to have women employed in tech support, even though they said that some of the communities involved in their community network do not trust women in these roles. In fact, across all the community networks, men comprised more participants in villages who worked on computer-based tasks, such as basic network monitoring and using computers to create accounts and sell subscriptions.

As well as constraining the time for women to focus on technical tasks, gendered division of labour further affects the scope for women to undertake technical tasks in community networks. This happened even in the Argentine community networks where women were often involved in technical work. For instance, the coordinator in Argentina-3 said that “in most of the houses where there are couples, only the man participates,” and that when they were gathering to repair their networks, “in general the women are downstairs – coordinating things, fetching tools. All the families are with the kids, so they [the women] are responsible for a group of kids.”

Gender associations with technical tasks also excluded women. For instance, conversations with members of different networks about their achievements were often dominated by references to erecting and climbing towers and poles, and this achievement tended to be associated with men. This is not only because the labour and equipment involved in working with towers is publicly conspicuous. In Uganda, a young man technology intern said that men were more able than women to climb towers because of their strength; and employees of the umbrella organisation in Mexico reported that they heard comments like “A women on the top of the antennae might fall,” which reflected cultural expectations that men should work with physical things. The issue, of course, is not women’s fragility or their inability to climb. A grandmother in Argentina-2 said that while she was able to carry her ladder, even though it was very heavy, she rarely climbed

roofs alone as she always tried to take someone with her "so they learn," and often had her children or grandchildren with her to help. The issue, instead, relates to the ways towers, ladders and technical equipment are infrastructures for performing certain masculinities. Women members in Argentine community networks explained how one was scolded for climbing a ladder while pregnant, and another refrained from ascending a tower because she was concerned that this might be perceived as hindering an important team activity. A concern that climbing a tower disrupts teamwork not only reflects gendered power relations in community networks that affect who gets to ascend ladders and towers, but also conventions of gendered teamwork practices, and women's perspectives on the meaning of collective work and their duty to a team. Women in several community networks mentioned the vital importance to their own confidence of promotional media that depicted women climbing towers.

Conventions of practice, inherited from mainstream telecommunications and engineering disciplines more generally, also include valuing certain sorts of work. For instance, the work of social coordination, which women often do, is not treated with the same reverence, or ascribed the same monetary value, as the work associated with software and network engineering. In umbrella and support organisations, people were usually paid for technical and coordination tasks, except for in Indonesia and Argentina, where the majority of their work to support the network is voluntary. Payment and income varied at the village level, but tended to be for computer-based and technical tasks, and since the people performing these tasks are more likely to be men, men are over twice as likely to be paid (see Figure 5). Bearing in mind again that we actively sought to include women in our studies, on average, 75% of men and 100% of women participants interviewed in umbrella or support organisations were paid, while at village level, only 28% of men and 11% of women participants interviewed were paid. One umbrella organisation is actively addressing gender imbalance by recruiting many more women interns, yet these positions are unpaid.

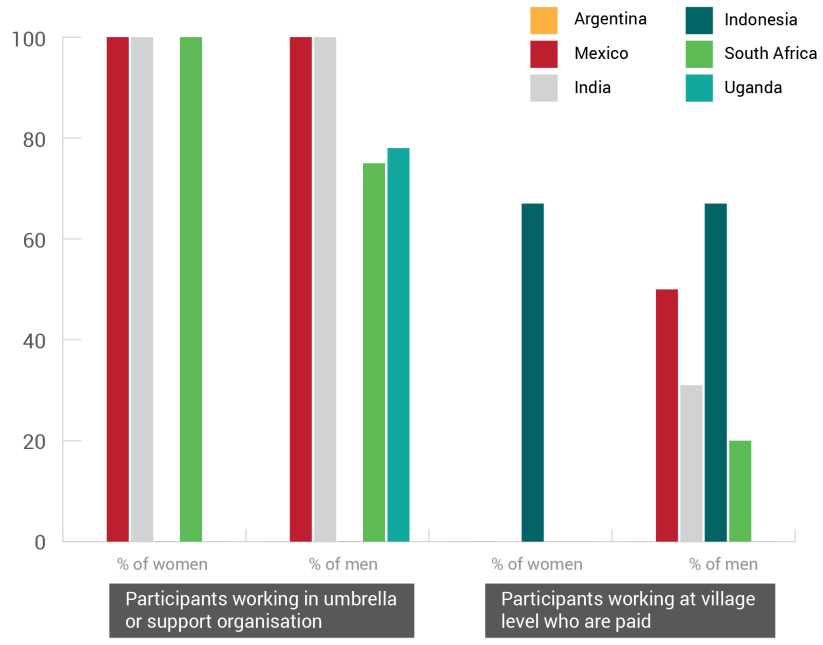

Figure 5. Participants in focus groups and interviews who receive remuneration as staff of umbrella or support organisations or at the village level through commissions and employment

Generating income can be a motivation for involvement at the village level, and exclusion of women from paid work conflates with traditional expectations about women doing voluntary work for their communities. In South Africa-1, several members of the cooperative explained that as "people don't like to work without payment," they wanted to start something that would result in "something to eat." One commented, "We thought that later, or eventually, we would get paid. We will have income from the bank, so later we will get paid. That's our ambition." Yet, there were tensions around whether their own or their wives' attendance at meetings, decision making, overseeing cell phone charging or selling subscriptions warranted remuneration.

Two women participants in South Africa mentioned that women, including those with roles in meetings, were expected to cook and serve dinner without payment. Similarly, when we asked a men's focus group in Mexico-1 whether it was only men who cleared the land for erecting an antenna, one man said, "Some women helped carrying sand, water and alcohol. It was both community [voluntary] and paid work; the carpenter had paid work." Meanwhile, for seven days we observed women in the Indonesian village's community volunteer organisations spend all morning preparing elaborate lunches for ourselves and the workers in the chief's office administration who used the network.

Keeping "women downstairs" compromises sustainability

Participants in Argentina noted that the competences required by a community network went beyond technical skills; for instance, referring to a "person who was more technical, later we found out he wasn't collective." In fact, special skills are required to coordinate complex social relationships in the volunteer and neighbourhood settings of rural community networks, as the man treasurer of Argentina-3 explained: "We have certain expertise in group management, collaboration. It's not the same as friendship and it's important in this group."

While some community networks recognised the need for non-technical skills, this did not necessarily mean all of those who undertook non-technical work were valued. Women employees of the umbrella organisation in Mexico observed how a traditional, male-dominated governance authority that oversees one community's GSM phone system were determined to speak only with technicians, who were men, including about non-technical aspects of their network. The intersection between gender and the value of work is, perhaps, a reason why young women engineers in India are reluctant to work at the network's rural sites and prefer to develop software in a lab. Paradoxically, the low worth ascribed to some work may offer new opportunities for women's agency in technology. Nearly 40% of the networks in Mexico, where traditional, male-dominated governance authorities make decisions, allocated local administration to young women because the most visible everyday work is secretarial, such as registering subscribers and record keeping. Yet, these roles also provide opportunities to develop technical skills, meet others in different villages and, according to one woman employee, had fostered self-confidence in the women who participate.

Gaining confidence by learning together about network installation in Argentina, two women with no formal qualifications, who undertook a gas plumbing course together, asserted, "If we are together we can fix anything." The friends shared the costs of the

equipment to participate in the community network, and discussed in rich detail their contributions; they are, they said, as close as "underwear and butt," sharing life despite an age difference of nearly 30 years. This situation juxtaposes with that in Indonesia, where few women use the community network and older women, who spent hours cooking all week as part of their community work, attributed younger women's disengagement from communal activities to their use of mobile phones. In other words, young women find alternatives when community networks exclude them.

Exclusion of women from technical work may compromise the sustainability of local networks. In our sample, men non-users of community networks tended to be older than men users, but women non-users tended to be younger than women users (see Figure 5), and our data suggests that younger women might be more excluded or repelled by constraints of men-dominated institutions that many community networks manifest.

Indeed, younger women increasingly pursue their own technology enterprises. A 40-year-old single mother who has worked outside South Africa-1 in the past and uses the community network regularly said: "It's not a new thing for women to be involved in technology. I buy airtime with my own money; women can say their opinion freely." She asked if it was possible for her to pay to install a router in her house and connect to the network, to improve the signal.

Women under 40 years of age operate three of the four local Wi-Fi internet providers in Mexico-1, separate from the local GSM community network. This contrasts with women being only one in 25 people attending the traditional assembly that makes decisions about the GSM network, and only one in four of the local network administrators of all the community networks that Rhizomatica supports. Meanwhile, the woman owner of the hair salon in Uganda-1, whose solar-powered electricity had been disconnected by the community network, said, "We want a separate one, there's money. If we need to, we will pay it alone."

Recommendations about women's labour and technical involvement

Engaging, recognising and remunerating women of all ages is imperative to the sustainability of community networks, given the increasing availability of alternative connectivity options. The very low representation of women in telecommunications in most countries and the discomfort felt by technically skilled women in undertaking work in some rural areas demand various gender-sensitive approaches.

Community networks should actively recruit women, and other people who confront gender exclusion, in all roles, and explore with them ways to ensure women's safety and comfort in all work contexts. Devoting the time and attention required to do this is not only vital for long-term sustainability but acknowledges the value of the diverse skills and qualities that are needed by and for community networks and that different parts of society bring. While the low worth ascribed to some work may offer opportunities for women's agency, confidence and networking in technology, care is needed to avoid reproducing meanings that devalue women's labour.

Opportunities must be created to teach women and girls about community networks at different regional and international events, such as was undertaken at the Women and Girls in Technology event in Accra, Ghana in 2018. Significant international mentoring

opportunities are required to enable more experienced women to assist, encourage and share experiences with those with less experience; however, at the same time, it is essential that experienced women are not overburdened with too many roles, since these women must also have visible platforms at a wide range of policy and movement-building forums.

Women of all ethnicities and ages must be represented in all media used in promoting and teaching about community networks to counter the ongoing, overt gendering of tasks, equipment and public and policy platforms. All training about community networks must include representations of women of all ages undertaking the full range of activities. Both men and women advocates for community networks must ensure their audiovisual material represents women engaged in all the activities within, and on behalf of, community networks.

ANNEX I.
SHORTLIST OF ESTABLISHED COMMUNITY NETWORKS IN THE GLOBAL SOUTH

Michael Jensen

The 40 networks listed below were identified in the initial search for established networks as potential candidates for further data gathering.

Network name	Location	Region
Mesh Bukavu	Democratic Republic of Congo	Africa – Central
Pamoja Net	Democratic Republic of Congo	Africa – Central
Battery Operated Systems for Community Outreach (BOSCO)	Uganda	Africa – East
Kampala Municipal Wi-Fi	Uganda	Africa – East
Mawingu	Kenya – multiple locations	Africa – East
Poa	Kenya – multiple regions	Africa – East
Surf/Everylayer	Kenya – multiple regions	Africa – East
Kwiizya	Zambia	Africa – South
Macha Works	Zambia	Africa – South
Murambinda Works	Zimbabwe	Africa – South
Soweto – SoWUG	South Africa	Africa – South
Zenzeleni	South Africa	Africa – South
Hayotel	Senegal	Africa – West
ZittNet Fantsuam	Nigeria	Africa – West
ASORCOM	Myanmar	Asia
Batam Wireless	Indonesia	Asia
Bhutan Wireless	Bhutan	Asia
Community Radio CN	Bangladesh	Asia
Dilli	East Timor	Asia
Gram Marg	India	Asia
Maewo Telecom Committee	Vanuatu	Asia
Microsoft TVWS Trial	India	Asia
Nepal Wireless	Nepal	Asia
RelawanTIK	Indonesia	Asia
Taknet	Thailand	Asia
Ungu	Indonesia	Asia
VBTS	Phillippines	Asia
Wireless for Communities (W4C)	India	Asia
AlterMundi	Argentina	Latin America
Cuban hacking hotspots	Cuba	Latin America
Fumaça Nuvem	Brazil	Latin America
Ik' ta K'op	Mexico	Latin America
Maré	Brazil	Latin America

Mayutel/Red de Telemedicina del Río Napo/TUCAN3G	Peru	Latin America
Coolab	Brazil	Latin America
Phonas Jurais	Brazil	Latin America
Quilombo Community Network	Brazil	Latin America
San Paulo Women's Network	Brazil	Latin America
Say Cell	Nicaragua	Latin America
Telecomunicaciones Indígenas Comunitarias (TIC AC)	Mexico	Latin America

ANNEX II. METHODOLOGY USED IN EXPLORING THE SOCIAL BENEFITS AND CHALLENGES OF COMMUNITY NETWORKS

Nicola J. Bidwell

INTRODUCTION

This document describes the methods applied in exploring the social and gender impacts of rural community networks in six cases in the global South. The year-long study, from October 2017, applied a multiple case methodology to describe relationships between social, economic, political, gender and communication technology factors in people's access to, use of, and interactions with a local community network. The exploratory study sought to:

- Characterise the impacts of community networks in their local constituencies.
- Identify the ways that community networks exclude people in their local constituencies, particularly women.
- Determine opportunities for widening the benefits of community networks in local constituencies.
- Adapt the preliminary methodology to different community network contexts.

The study produced mostly qualitative descriptions about how and why people coordinate, interact with and are affected by their local community networks; although it also produced some quantitative descriptions about people's use of the community network. The descriptions relate to the activities of various people involved in setting up, maintaining and using community networks in rural villages and in organisations that support community networks. The research did not produce descriptions that are statistically generalisable to entire populations of community network organisers, users and non-users, or propose that cases are typical or atypical. Rather, the research uncovered some common characteristics of community networks that are situated in their specific contexts of management, access and use in different regions in the global South. Identifying these characteristics contributes to a richer understanding about the ways that community networks challenge or reproduce existing social, economic and cultural inequalities than is obtainable from assessing management, access and use of community networks based on, say, traffic and household surveys, were it even possible to draw representative samples.

Common characteristics in community networks include their benefits, problems that must be addressed to expand benefits to diverse people, and opportunities to address these problems. These benefits, challenges and opportunities may be invisible to people connected to a specific community network precisely because they arise in normalised practices and familiar situations. Drawing attention to particular characteristics, derived from descriptions of people's interactions with their local community networks, can focus stakeholders on ordinary phenomena that contribute to, or undermine, the value of community networks in connecting the unconnected.

Background to the methodology

The methodology for this research was produced at the intersection of APC's advocacy for community networks and Bidwell's long experience of generating insights about the use, and non-use, of technologies in rural regions of the global South. APC proposed a multiple case approach to explore whether community networks, in three continents, enable "the unconnected to connect themselves," using an informal definition of community networks

based on the team's existing knowledge (see page 174). The subsequent methodology was further constructed through:

- A working definition of a community network used to identify potential cases (see page 174).
- Potential social impacts (see page 177) and inclusivity (see page 178) based on desk-top research about technical, social and economic characteristics of 23 community networks in 19 countries in the global South.
- Decisions to sample particular cases based on certain criteria (see page 174).

Bidwell shared a draft methodology (V1.1) with the research team lead, Jensen (31 December 2017) and, based on comments, sent a revised version (V1.2) to the Local Access Networks project team and the leader of a proposed case (2 January 2018). Further refinements were made and the provisional methodology (V1.3) was circulated to the project team and APC Women's Rights Programme staff (5 January 2018). Over the next 10 months, methods were adapted to address issues arising in the cases explored, and reflections on interactions and data generated, both with the selected cases and with the broader community network project. Thus, the process was both iterative and reflexive, and responds to the perspectives of practitioners in community networks, experts in network solutions for the global South, and activists for enabling policy and regulation.

Identifying community network cases

This research identified community networks from a list produced at the Local Access Networks project inception meeting (Oaxaca, October 2017), based on team members' prior knowledge, and further desk research and contact with APC members and partners. During the study, 40 candidate networks were considered to potentially offer the data required by the broader APC project. There are undoubtedly a vast number of sites in the global South where people share network resources but do not self-identify as, or indeed even know a definition for, a community network, or are not visible to APC members and partners. Thus, integral to this research is a critical awareness of the way the definition of a community network and the selection of community network cases are mutually constitutive and, further, influence discourse about community networks.

While the Local Access Networks project aims to support community networks in the global South, the "field", when talking about this "field study", did not originate "out there" where the community networks visited are geographically, politically, culturally and economically located. The field, of course, not only includes the community networks' geographic sites but all the reasoning embedded in the Local Access Networks project and in studying social and gender impact. This reasoning originated close to the "centre" – where the practices, rules and standards that govern and invest in technologies and research projects are produced, where development agendas are forged, and where research insights are interpreted, consumed and acted upon. Thus, the research frame is affected by centre-periphery power relations that determine, for instance, who gets to choose, and why they get to choose: what the research questions were; which community networks were included in the studies; how visits were timed and coordinated; how studies were ordered and moved to; what methods were used to generate, record and interpret community network data; and what is written about the research, where it is read, and who it is read by.

Table 1. Timeline between proposing and visiting cases

Region	Proposed host case	Proposed date	Selected date	Contacted	Confirmed	Trip	Prep time (months)
Asia	Gram Marg, India	Oct 2017	Nov 2017	Nov 2017	Nov 2017	Jan 2017	2
Latin America	AlterMundi, Argentina	Oct 2017	Dec 2017	Oct 2017	Dec 2017	Mar 2018	3
	Rhizomatica, Mexico		Dec 2017	Oct 2017	Dec 2017	Apr 2018	3
Africa	Idjwi Island or Mesh Bukavu, DRC	Oct 2017					
	BOSCO, Uganda		Jan 2018	Jan 2018	Jan 2018	Jun 2018	5
	Zenzeleni, South Africa		Dec 2017	Oct 2017	Dec 2017	Aug 2018	7
Asia	Asorcom, Myanmar	Oct 2017					
	VBTS Konekt, Philippines		Apr 2018	May 2018	Not confirmed		
	Assadesa/RelawanTIK, Indonesia	May 2018	Aug 2018		Oct 2018	Oct 2018	0

Selecting community network cases

The selection of sites contributed to the definition of community networks and construction of this methodology. Jensen selected from about 40 community networks, based on:

- The community network's visibility to APC contacts
- The community network's duration of establishment
- Logistical feasibility and predicted accessibility of sites in visits of short duration
- Opportunities to obtain data about a diversity of technologies, cost models and internet and voice services
- Languages spoken
- A balance among the continents.

To a lesser extent, the selection was also refined according to potential impacts from a preliminary review of online documentation of 23 community networks in 19 countries (see page 177). Selection was not based on the familiarity of contacts with people in the community networks' constituencies, or whether community networks were led by women. Jensen made contact with the shortlist of prospective networks and, from 13 proposed, chose seven for Bidwell to study for social and gender impacts shaped by the interest they expressed and sustained (see Table 1).

Categories of participants

The research sought to understand the ways that community networks affect and are affected by the people who initiate, champion, coordinate, interact with, use and do not use them. To do so it sought to partner with, and talk with different people involved in, each community network case. Participants were categorised into four, sometimes overlapping,

categories (see Table 2), which responds to the different ways that people are connected to community networks because the organisation of community networks varies.

The community networks identified and selected in this study had various forms of organisation. One had the character of a "Western democratic" form, where users set up, operate and govern the network, and relationships between management and use are, ostensibly, horizontal. Community network members are combinations of initiators, volunteers and users, and are geographically close to each other and to access points. However, community networks that operate where there is less local technical capacity, such as in resource-scarce regions, often have support or umbrella organisations that maintain network and business infrastructure for groups of beneficiaries via geographically distant access points. Initiators, leaders and technicians in umbrella organisations are often paid employees, based in towns or cities, far from access points in rural villages.

In contrast with community networks that are set up by members with or without external support, some community networks facilitate access to network and support services provided by other entities, such as commercial providers and voluntary training organisations. These involve remote access points at village authorities such as a chief's office or gram panchayat. Unlike the other types of community networks, users do not directly influence community network decisions.

Table 2. Overlapping categories of participant types

Site	Participant type	Includes
Umbrella and support organisations	1	Initiators, leaders, champions and technicians
Specific CNs in rural villages	2	Managers, coordinators, volunteers and operators
	3	Users of CNs, who might also be in participant Type 2
	4	Non-users living in the coverage area of a CN who have not used the network directly themselves because they cannot or chose not to, or because other people mediate their interactions. Can also be in participant Type 2.

PROBLEM STATEMENT

Community networks may offer access to phone and/or internet services to people in the global South who are typically excluded by dominant models of telecommunications. However, their proliferation is constrained by limited knowledge among agencies that promote access to telecommunications, and obstacles created by national and international policies. Few empirical studies have examined the efficacy of community networks in providing meaningful access to telecommunications, or inclusion in decision making of rural people who are often disadvantaged by telecommunications models, particularly women. This limits both advocating for community networks as a way to "connect the unconnected" and the full potential of community networks to support rural telecommunications needs. Comprehensive understanding of the social and gender impacts of community networks is vital to both decisions by agencies that support, promote and legislate about telecommunications, and to ensuring that community networks benefit all people in their constituencies. The rest of this problem statement

summarises claims about the positive impacts of community networks, and insights that suggest community networks may perpetuate exclusion.

Potential social impacts

Advocates claim that community networks can constructively contribute to local societies. A preliminary review, at the end of 2017, of online documentation found claims that community networks positively impact on:

- Communication beyond a geographic community, e.g. more frequent communication with remote family members, better communication between different communities.
- Access to electricity where none is available.
- Household economics, e.g. decreased household expenditure on communications or transport, increased household income, improved access to household necessities.
- Local income generation, e.g. local e-commerce, enterprises, employment opportunities.
- Educational improvements, e.g. increased literacy, exam passes, school attendance, vocational skills.
- Technology literacy and internet safety improvements.
- Healthcare improvements, e.g. changed practices due to improved access to health information, telemedicine outcomes, improved patient referral to hospital.
- Agricultural improvements, e.g. VoIP calls to veterinarians, use of market information for production and sales, changed agricultural practices, improved yield, sensor networks for water.
- Physical safety and psychological welfare, e.g., specific initiatives for refugees, displaced people, safety protection in conflict zones, trauma care, resilience, healing.
- Disaster preparedness/response improvements, e.g. better logistics response in emergencies.
- Greater inclusivity in local decision making, e.g. greater participation in local governance, increased representation among local authorities.
- Increased participation in national political processes, e.g. e-government, e-voting, presence at high-level political meetings.
- Increased representation of local issues in other media, e.g. link to community radio, newspaper articles about initiatives that raise awareness of local challenges.
- Improved intra-community communication or cohesion, e.g. increased frequency of events involving diverse sectors of the community.
- Identity and self-determination, e.g. adapting technologies to specific cultural practices or values, using network to promote or protect community rights.
- Improved religious inclusivity, e.g. use of network in places of religious worship or religious education.
- Greater security of cultural heritage and traditional practices, e.g. use of network in preservation of traditional skill or to promote their cultural values in other places.
- Increased support of local languages, e.g. local language education resources/curricula, contribution of local language to web resources.

- Evidence of a novel innovation or creation, makerspace,[142] locally suitable adaptations of technical infrastructure, application of knowledge learned over the internet to solve a local problem.

Social and gender concerns in community networks

It is well documented that the dominant models of telecommunications perpetuate exclusion of already disadvantaged groups, particularly rural people and women. Formal research about relationships between community networks and inequality is, however, limited to a 2016 gender analysis of operations of a community network in Africa.[143] Informal observations suggest that community networks may exhibit some of the characteristics that exclude people from access and involvement that are shown in studies of rural access interventions and community-based technology initiatives in the global South and in open source communities. These observations suggest inclusion and agency in rural community networks may be limited by, for instance:

- Hierarchies that privilege certain groups in decision making.
- Normalised local and global power relations that exclude certain groups, particularly women, from technology.
- Physical, social and cultural distance between initiating and supporting organisations and the constituencies served.
- Inappropriateness of services to the everyday lives of some populations, including women.
- Invisibility of the work done by certain groups, particularly women, in telecommunications systems.

While these concerns sensitised the research, they do not comprehensively summarise potential phenomena that limit community networks, since many studies on technology show that gender impacts are culturally situated, wide ranging and insidious.

RESEARCH OBJECTIVES

This research aimed to:

- Describe the roles and meanings of rural community networks in the everyday lives of the people who champion, coordinate, interact with and are affected by them.
- Identify the ways community networks challenge or reproduce existing social, economic and cultural inequalities in the local societies they intend to serve and contribute to community social structures.

142. Cavalcanti, G. (2013, 22 May). Is it a Hackerspace, Makerspace, TechShop, or FabLab? *Make:*. https://makezine.com/2013/05/22/the-difference-between-hackerspaces-makerspaces-techshops-and-fablabs
143. Shewarega Hussen, T., Bidwell, N. J., Rey-Moreno, C., & Tucker, W. D. (2016). Gender and Participation: Critical Reflection on Zenzeleni Networks. *Proceedings of AfriCHI'16 African Conference for Human Computer Interaction, Nairobi, Kenya*. ACM Press. 978-1-4503-4830-0.

- Determine ways that community networks can produce the most positive social impacts for the widest range of people situated in their specific contexts of management, access and use.

RESEARCH DESIGN

The research explored the roles and meanings of community networks with a wide range of people in different types of interviews and focus group discussions (FGDs), supported by observations and data from soft and hard documents in the settings of each community network. Documents included media that illustrate participants' use of the community network (e.g. WhatsApp messages); interfaces to applications and systems comprising the community network; and various objects in community network settings. Additional data was generated by observing people's interactions with other participants in the study, and with documents and other objects in settings (see page 188). Thematic and critical analyses of this data provided concrete examples of benefits, challenges and opportunities.

Community network practices

The research adopted an ethnographically informed, practice-based approach to data. The main unit of analysis is *community network practices*. Community network practices include individual people's:

- Accounts of their own, and other people's, activities when they interact, and do not interact, with people, objects and settings that comprise their community network.
- Accounts of the impact of the community network on their lives based on their real-world experiences, ideally linked to documents such as media.
- Observed practices while doing the research, for instance, the way a participant organises, facilitates or interacts during research activities.

A practice-based approach has a long history, and was used by de Lanerolle et al.[144] to observe gender impacts on mobile phone use among low-income groups in South Africa, and in studies of the use of communal phone-charging stations, which were the precursor to Zenzeleni Networks.[145]

144. de Lanerolle, I., Walton, M., & Schoon, A. (2017). *Izolo: mobile diaries of the less connected*. Making All Voices Count Research Report. Brighton: IDS. https://opendocs.ids.ac.uk/opendocs/bitstream/handle/123456789/13348/RReport_LessConnected_FINAL.pdf
145. Bidwell, N. J., Siya, M., Marsden, G., Tucker, W. D., Tshemese, M., Gaven, N., Ntlangano, S., Robinson, S., & Eglinton, K. A. (2014). Walking and the Social Life of Solar Charging in Rural Africa. ACM *Transactions on Computer-Human Interaction*, 20(4). https://cs.swan.ac.uk/~cssimonr/publications/Walking-and-Solar-Charging.pdf

Feminist standpoint theory and grounded analysis

Exploring the roles and meanings of community networks in accounts by diverse people about their practices is compatible with feminist standpoint theory and the inductive approach of grounded theory. The approach recognises that understandings about community networks are socially situated, and that the lived experience of marginalised groups gives them a greater awareness of the ways that inequalities in access and use are perpetuated, such as through power relations. While the methodology is sensitised by possible positive impacts and concerns about the exclusionary potential of community networks, data generation prioritises meanings situated in participants' contexts, and their interaction with the researcher.

The study intentionally and explicitly deployed research instruments in an open-ended way, and appraised situations as interactions unfolded. In other words, interview questions, observations, and document gathering aimed to avoid posing initial hypotheses – for instance, asking participants in an interview to "describe who uses the networks and who doesn't and suggest reasons why" rather than "What are the differences between women and men's use of the network?"

The researcher attended closely to responses, accounts and dialogue, prompted elaboration and further explanation, and always attempted to situate prompts in participants' own accounts of practices. That is, theories about relationships between community network practices and local, and global, structures and norms emerge in the data as it accumulates in each specific community network context. *Ex situ* analysis, after visits, coded the data to create concepts (see page 193), synthesised themes for all the community networks, and distilled theories about relationships between practices, benefits and challenges.

Adaptation

Insight about a community network's roles and meanings was generated primarily through interviews and FGDs of specific types for different categories of participants. They included:

- Orientation overviews with host contacts (usually participant types 1 or 2), to contextualise the community network and studies.
- Semi-structured individual interviews with initiators, leaders, champions and technicians (type 1 participants) about motivations and goals for the community network, and changes to these, their tasks and activities, participation in decisions, users and non-users, and problems and challenges.
- Semi-structured individual interviews with managers, coordinators, volunteers and operators (type 2 participants) about their activities, relationships between different parts of the community network's organisation, users and non-users, problems and challenges, and purposes and benefits.
- Semi-structured FGDs with users (type 3 participants) about their use and non-use of the community network, and the way it fits into and/or has changed their lives.
- Diary accounts by users (type 3 participants) about the details of their use either in specific individual interviews or included in FGDs.

- Semi-structured FGDs with non-users, or people whose use is mediated by others (type 4 participants), about why they do not use the community network or how their use is facilitated by others.
- Brief open-ended contextual interviews with all categories of participants in situations as they arise, drawing on topics included in and beyond the topic guides.

Interviews and FGDs were broadly framed by topic guides (see the Appendixes to this Annex), which were greatly adapted to unfolding situations and unanticipated participation.

SAMPLING

The population in this research are the people who initiate, champion, coordinate, interact with, and are affected by rural community networks in the global South.

Cases, community networks and sites

The study sampled perspectives in the research population in six cases. Due to the different types of community networks and host's motivations, these cases comprised different numbers of separate community networks (see Table 3). Cases in Indonesia, Mexico and South Africa comprised just one community network each, and data was gathered in two, three or four hamlets or villages/small towns served by the community network within a few kilometres of each other. In Argentina, data was gathered in villages that were also quite close together, but had three different, although related, community networks. Although coordinators of host initiatives were encouraged to select two sites, in Uganda and India they took us to six and eight sites, respectively, separated by distances of up to 100 km.

Table 3. Sites and networks included in the research and balance of field study time

Country	Initiative	Visit to umbrella or support organisation		Visits to CNs				Lodged near CN
		Location	Duration (days)	Number of CNs	Sites	Most data gathered	Duration (days)	
India	Gram Marg	Mumbai city	3	8	8 villages	2 villages	9	No
Uganda	BOSCO	Gulu city	4	5	4 villages, 1 very smvall rural town, 1 refugee settlement	1 small town	7.5	No
Indonesia	Pusbindes	Pemalang city	1	1	2 hamlets in village	1 hamlet	7	No
Mexico	Rhizomatica	Oaxaca city	3	1	2 villages and one very small rural town	1 small town	6.5	Yes
Argentina	AlterMundi	In village		3	3 villages	2 villages	13	Yes
South Africa	Zenzeleni	Cape Town city	1	1	4 villages	1 village	12	Yes

Participants in cases

The research sought to explore the roles and meanings of community networks with a wide range of people in different interviews and FGDs specifically oriented for different stakeholder types. The research also purposively sampled more users and non-users than other categories of people, as data about these categories can yield insights into inclusiveness and wider socio-technical impacts in a community. The research aimed to include around 200 users and 40 non-users in rural villages ("intended" in Table 4) in total, and ultimately involved 163 and 88, respectively. However, there was wide variation among community networks in recruiting users and non-users which reflected:

- The organisational form and character of the community network (see page 175).
- The familiarity of hosts with their respective community network constituencies (see page 196).
- The ways hosts facilitated and scheduled different activities (see page 189, page 196).
- Local politics, power relations and technocentric priorities, where hosts consider that people close to the centre of a community network's operations should represent the perspective of others.

Table 4. Numbers of people participating in different categories across studies

Region	Initiative/ type of network	Umbrella and support organisations		Specific CNs in rural villages					
		1: Initiators, leaders, champions and technicians		2: Managers, coordinators, volunteers and operators		3: Users (may also be in type 2)		4: People who do not directly use the network themselves (may also be in type 2)	
		Actual	For region: actual (intended)	Actual	For region: actual (intended)	Actual	For region: actual (intended)	Actual	For region: actual (intended)
Asia	Gram Marg Wi-Fi CN	8	21 (4)	14	20 (8)	20	44 (66)	15	33 (14)
	Pusbindes Wi-Fi CN	13		6		22		18	
Latin America	Rhizomatica GSM CN	4	9 (4)	3	14 (8)	36	59 (66)	3	3 (14)
	AlterMundi Wi-Fi CN	5		11		23		0	
Africa	Zenzeleni Wi-Fi CN	5	17 (4)	7	16 (8)	26	60 (66)	12	52 (14)
	BOSCO Wi-Fi CN	12		9		34		40	

Across all categories of participants, the study aimed to sample diverse perspectives by encompassing as wide a range as possible of profiles, experiences and situations. Again, the character of community networks and sites where samples were drawn significantly affected participant diversity. Sampling sought to involve people of diverse:

- Genders
- Ages from 16 years and older
- Social groups, castes, ethnicities or tribes
- Occupations and employment/unemployment

- Education and written literacy
- Incomes
- Technological skills/experience
- Technology ownership (e.g. mobile phones, laptops, etc.).

The research also aimed to recruit women in higher proportion than their presence in the broader community network population. For instance, even if women constitute only 10% of technicians or operators or 30% of users, samples sought to comprise 25% and 50% respectively. This required not only proactively seeking women and members of other marginalised groups, but also discussing with hosts the reasons for difficulties in recruiting participants from certain groups, since men and younger people usually dominated all categories of participants, except non-users.

Table 5. Numbers of men and women participating in interviews, FGDs and observations

Region	Initiative/ type of network	Umbrella and support organisations		Specific CNs in rural villages					
		Participant type 1: Initiators, leaders, champions and technicians		Participant type 2: Managers, coordinators, volunteers and operators		Participant type 3: Users		Participant type 4: People who do not directly use the network themselves	
		Men	Women	Men	Women	Men	Women	Men	Women
Asia	Gram Marg Wi-Fi CN	5	3	13	1	19	11	9	6
	Pusbindes Wi-Fi CN	10	3	3	3	11	11	9	9
Latin America	Rhizomatica GSM CN	2	2	2	1	15	21	3	
	AlterMundi Wi-Fi CN	3	2	6	5	12	11	0	0
Africa	Zenzeleni Wi-Fi CN	4	1	5	2	11	15	7	5
	BOSCO Wi-Fi CN	9	3	6	3	25	9	5	35
	Total	**33**	**14**	**35**	**15**	**93**	**78**	**33**	**55**

RESEARCH INSTRUMENTS

While interviews and FGDs were the primary data source, they often worked together with observations and document collection. Interviews and FGDs comprised seven main forms:

- Individual overviews by host coordinators in umbrella organisations.
- Individual interviews with people responsible for setting up and maintaining the community network, including:
    - Leaders, initiators, champions within umbrella organisations
    - Coordinators, technicians, operators and volunteers at local community networks.
- Diary accounts by users of the community network.

- Brief, often serendipitous, contextual interviews with coordinators, technicians, operators, volunteers and users.
- FGDs with:
    - Frequent or occasional users
    - Non-users.

Table 6. Types and numbers of interviews and group discussions during the research

Type	Total number undertaken
Orientation or introductory interviews in umbrella organisations and CNs	23
Full interviews with one person only	65
Brief interviews with one person only	27
Full FGDs with 5 to 20 people	30
Other types of group discussions	8
Total	153

Orientation and community network overviews

Research visits began with orientation discussions led by the host champions or coordinators in umbrella organisations, and sometimes community networks. These introduced the community network's technical and business model(s) and overviewed operations and the social and geographical contexts of sites. Often, champions in umbrella organisations had prior experience in presenting these overviews, such as in hosting visits by funders. The researcher sought to rapidly familiarise with local constructs and protocols, establish trust and confirm the schedule and contacts for forthcoming activities.

For each case there were between two and six orientation and introductory interviews. In two cases, the orientation discussion was followed by one or more trips from the umbrella organisation to community network sites in rural areas. These provided valuable insight into the physical distance between the umbrella organisation and community networks. However, in the second case, they consumed precious time that would have been better spent interacting with local operators, users and non-users.

Individual interviews

Interviews with people responsible for setting up and maintaining the community network, locally and/or within an umbrella organisation, generated data on the motivations, operations and adaptations of the community network from the perspectives of leaders, initiators, champions, coordinators, technicians, operators and volunteers. Independent semi-structured interviews used one or a combination of two topic guides (see Appendix 1: Topic guide for individual interviews with community network initiators/leaders and

Appendix 2: Topic guide for individual interviews with community network operators and volunteers).

Interviews with community network initiators and leaders explored how the goals of the community network related to what specifically they do/have done to set up, maintain and improve the community network. These discussed:

- The original motivations for the community network.
- Changes in goals of the community network and reasons for changes.
- How the participant does/has done their own activities with the community network.
- Who else is/has been involved in the participant's specific activities with the community network and how these people are involved.
- Any challenges in engaging diverse people in using and coordinating the network.

Interviews with community network coordinators, operators, technicians or volunteers gained insight into both the everyday organisation and management of the network, and relationships between the goals of the community network and how people in the network operate, troubleshoot and make decisions. These discussed:

- The participant's role in the community network, and the details of their routine practices in undertaking it.
- Changes in the participant's practices and reasons for changes.
- Everyday problems in undertaking their roles.
- Everyday enjoyments and benefits in undertaking their roles.
- Unusual challenges faced in setting up, maintaining and making decisions about the network.

For each case there were between two and four individual interviews.

Diary accounts by community network users

Diary accounts provided insights into users' lived experiences of the community network as a communications and information system and as a socio-technical system, and the details of the community network's relevance to the rest of their lives. Diary accounts are annotated chronological records that yield quantitative and qualitative data about participants' mundane practices and everyday use of the community network in context, and about specific opportunities and difficulties caused by the community network in the participant's communities. This type of data is difficult to obtain in interviews and discussions, especially by external researchers, because participants tend to generalise their experiences, and researchers' questions are not always well contextualised. Diary accounts occurred either as a short series of dedicated individual interviews over a week, following a topic guide (see Appendix 4: Diary accounts of users of community networks), or were included in an abbreviated form as a part of another interview or FGD.

A dedicated diary study comprised two or three in-depth interviews with each participant, individually, on two or three days separated by a day or more. Each interview lasted from 30 minutes to an hour and was conducted wherever the participant was at the time, in their home language, with simultaneous translation into English when feasible. Participants were asked to have their devices with them, and were prompted to reconstruct their day

following de Lanerolle et al.'s adaptation of the Day Reconstruction Method.[146] Participants summarised activities and events occurring the previous day and then grouped these into a series of "scenes". Next, participants identified scenes in which the community network featured in some way. This might be:

- Direct use of the network.
- Activities related to network use, e.g. payment for services, walking to use the network, checking credit, fixing the network, etc.
- Indirect use of the network or interactions with someone else using the network.
- Social interactions with people who run the network, e.g. ad hoc or organised meetings, etc.

For scenes in which the community network featured, participants then described what took place, and the researcher asked open-ended questions about the details of activities, such as what they were doing while using the network, who they were interacting with, what problems occurred, etc. Interviews included questions such as "Please show me an example?" and participants used their devices or media on them to help their explanations.

Dedicated diary studies were difficult to organise especially when time *in situ* was constrained and, while for some cases there were 11 interviews of this type, in two cases there were none. The research achieved sets of dedicated diary interviews with two or three participants in each of four field sites; these were most detailed and comprehensive for Argentine community networks. Diary accounts were also included in other types of interviews and discussions. This provided rich contextual detail about the community network and was useful in assessing how integral, or occasional, a community network is to everyday practice. For instance, when a participant stated that they "always use the community network," the researcher asked them to describe the last day this happened, and it often transpired that it did not mean every day.

Focus group discussions (FGDs)

There were between two and seven scheduled FGDs with users and non-users of the community network for each case. FGDs provided insights into the relevance and contribution of the community network to personal and communal life; how the community network works as a socio-technical system; and factors shaping access and exclusion. FGDs with frequent or occasional users followed a topic guide (see Appendix 3: Topic guide for focus groups with users of community networks) which explored participants' articulated understandings of:

- The ways they use the community network and their purposes in using the network.
- The changes the community network has made to their own and others' communication and/or information access practices.
- The relationship between specific changes in their communication and information practices and the rest of their lives, including their livelihoods, agency and aspirations.
- The community network as a socio-technical system, including power relations and relationships within the local communicative ecology.

146. de Lanerolle, I., Walton, M., & Schoon, A. (2017). Op. cit.

- Difficulties they have experienced in using specific facilities offered by the community network and challenges.

FGDs with “non-users” included people who had never used the community network, or whose interactions with the network are mediated by others. Discussion topics focused on participants’ understandings of:

- The relevance or irrelevance of the community network to their lives.
- Practices that exclude or marginalise them from engaging with the community network.
- Relationships between exclusion and the rest of their lives, e.g. livelihoods, agency, etc.
- The community network as a socio-technical system and relationships within the local communicative ecology.

Brief interviews and emergent group discussions

The researcher took every opportunity to interview participants *in situ*, and integrated topics from the interview and FGD guides into unfolding situations. These impromptu, opportunistic interviews were critical particularly when hosts had been unable to recruit sufficient or appropriate participants or schedule enough time for formal interviews and FGDs. In such cases there were up to 11 brief interviews.

For three cases, group discussions with users or non-users were unscheduled and emerged more spontaneously. Again, the researcher integrated topics from the interview and FGD guides into unfolding situations.

Documents

Some community networks had documents that promoted or reported on the networks, which familiarised the researcher with perspectives, potential impacts attributed to the community network, and certain social, economic and cultural characteristics at sites. However, none of the community networks were able to share up-to-the-minute data.

The researcher examined and recorded a wide range of documents *in situ* in the settings of each community network, including media that illustrate participants’ use of the community network (e.g. WhatsApp messages, websites); interfaces to technical applications and systems comprising the network; and records in sign-in/visitors’ books, posters, instructional manuals, signs, maps, and so on. Documents were photographed and sometimes video recordings were made of participants interacting with or describing them. On many occasions examples of media that would have provided examples of use were precluded because the network that the community network served was down at the time of the interview or observation. Sometimes this was addressed by sharing a hotspot from the researcher’s phone connected to a GSM network in order for participants to access material; however, obviously, this was impossible when the community network was the only local source of connectivity.

Observations

The researcher used every chance to participate in activities that were presented and make ad-hoc and opportunistic observation of people's interactions with other participants in the study and with documents, equipment, devices and other objects in settings. When unobtrusive and ethically valid, photos and videos recorded observations; otherwise, handwritten or voice notes were recorded soon after observations. Detailed observations were made, for instance, of an intensive workshop that an umbrella organisation hosted for the community networks; a drama performance about domestic violence that participants in a rural community network computer centre staged following a FGD; and an indigenous assembly where the researcher was invited to hear perspectives on the community network and answer questions about the research. The researcher accepted informal invitations, for instance, to visit participants in their homes, accompany participants to a coffee production plant and pineapple plantations, perform in a social media advertisement for a village mango festival, and join morning exercises in the public square with 100 other women.

Many challenges impeded observing use of equipment and interactions with others at access points or administrative hubs in community networks, including the places and times of access. Diary study interviews in which participants showed examples of use on their phones significantly assisted generating data about access.

PROCEDURES

The study and research instruments were adapted to circumstances as they arose.

Liaising and planning with community networks

Direct contact was established between the researcher and people in five umbrella or support organisations of community networks, and two local community networks, facilitated by the umbrella organisations. In all but two cases, this contact involved Jensen introducing the researcher (Bidwell) on behalf of APC. The multiple lines of contact sometimes slowed contact, and in one case, Indonesia, the researcher did not have any direct contact prior to her research visit. In most cases, these people continued to be Bidwell's main point of contact, hosted visits and mediated with people at specific community network sites. In one case, the umbrella organisation decided that the timing of the visit was untenable, so the visit was cancelled, and in another, they referred us to interpreters. Thus, researcher-host preparation prior to visits occurred with:

- Employees of umbrella organisations based outside of community network sites (Gram Marg, BOSCO, Rhizomatica).
- Nominated translators who had worked with community networks (Rhizomatica).
- A volunteer with an umbrella organisation who occasionally lives in the community (AlterMundi).
- An employee of an umbrella organisation based at a rural community network (Zenzeleni).

Research overviews, in simple English, were sent by email. These included summaries of the aims, approaches and methods and informed consent information in writing, audio or video. In several cases, host contacts translated the informed consent information into local languages, and in one they shared this with potential participants prior to the research visit.

Planning visits accounted for local conditions, such as wet conditions that impede access to sites, and hosts' priorities, for instance, scheduling trips around particular events. However, beyond logistical concerns, the planning exchanges sought to establish understanding and convey the value of the research to the hosts. In four cases, the hosts' responses indicated that they perceived considerable value in partnering in research; however, for two of these, it became clear during visits that they had difficulty in arranging in-depth engagement with participants. In one case, the hosts were particularly engaged in planning, raised various concerns and questions, and the exchanges that ensued ensured that the visit was well scheduled.

Recruiting diverse participants

The research depended on generating data with participants of:

- Four types:
  1. Initiators, leaders, champions and technicians
  2. Managers, coordinators, volunteers and operators
  3. Users of community networks, who might also be in participant Type 2
  4. Non-users of community networks, who have not used the network directly themselves, or because other people mediate their interactions, and who might also be in participant Type 2.
- Diverse genders, ages, social groups, castes, ethnicities, tribes, employments, livelihoods, educations, literacies, languages, incomes, and technological experiences.
- An equal balance of women and men.

Hosts were sent an explanation about the value to the research of having diverse participants, criteria for recruiting participants, and minimum and maximum limits on participant numbers for sessions. Criteria for participants reiterated the need to include only participants over the age of 16 and the need for single-gender FGDs. Host umbrella or support organisations usually appreciated the merit of research insights about community networks from the perspectives of the leaders, initiators, champions, coordinators and technicians. The value of emphasising the perspectives of users and non-users was not, however, always immediately clear to them. Sending example schedules helped some hosts in considering scheduling. For instance, the example in Figure 1. was sent as a picture and line-by-line as a WhatsApp message to a coordinator.

Host contacts directly or indirectly facilitated access to local operators, volunteers, users and non-users. In smaller networks, a champion or coordinator directly organised interviews and FGDs and recruited participants. In large community network programmes, however, champions in umbrella organisation chose specific networks to visit and asked the community network or an intermediary organisation, such as a local support organisation, to recruit people before or during a visit. In these cases, local managers recruited participants or broadcast a call for participation. In two community networks this meant that far too many participants arrived for FGDs, participants did not represent diverse

people, FGDs were not gender segregated, and men outnumbered women. The researcher discussed the phenomena that caused this in detail with the hosts that facilitated access.

Day (August)		Morning		Afternoon	
Friday	**3**			Individual interviews with initiators/leaders, e.g. [Name]	2 hrs
Saturday	**4**	Individual interviews with local coordinators, operators, volunteers, e.g. [Name]	2-3 hrs	Focus group with 6-8 men who sometimes use CN	2-3 hrs
Sunday	**5**	Individual interviews with 2 people who sometimes use CN: Man 1, Man 2	2 hrs	Interviews with 2 people who sometimes use CN: Woman 1, Woman 2	2 hrs
Monday	**6**	Focus group with 6-8 women who often use CN	2-3 hrs	Individual interviews with local coordinators, technical operators, volunteers, e.g. [Name]	2-3 hrs
Tuesday	**7**	Focus group with 6-8 men who often use CN	2-3 hrs	Individual interviews local coordinators, technical operators, volunteers	2-3 hrs
Wednesday	**8**	Individual interviews with 3 men who often use CN: Man 3, Man 4, Man 5	4 hrs	Individual interviews with 3 women who often use CN: Woman 3, Woman 4, Woman 5	4 hrs
Thursday	**9**	Individual interviews with initiators/leaders, e.g. [Name]	2 hrs	Individual interviews with initiators/leaders, e.g. [Name]	2 hrs
Friday	**10**	Individual interviews with 3 men who often use CN; Man 6, Man 7, Man 8	4 hrs	Individual interviews with 3 women who often useCN: Woman 6, Woman 7, Woman 8	4 hrs
Saturday	**11**	Focus group with 6-8 women who sometimes use CN	2-3 hrs	Individual interviews with 2 people who sometimes use CN: Same people as last Sunday, Man 1, Man 2	2 hrs
Sunday	**12**			Individual interviews with 2 people who sometimes use CN: Same people as last Sunday, Woman 1, Woman 2	2 hrs
Monday	**13**	Individual interviews with 3 men who often use CN: Man 3, Man 4, Man 5	4 hrs	Individual interviews with 3 women who often use CN. Woman 3, Woman 4, Woman 5	4 hrs
Tuesday	**14**	Focus group with men who do not use CN	2-4 hrs	Focus group with 6-8 women who do not use CN	2-4 hrs
Wednesday	**15**	Individual interviews with 3 men who often use CN: Man 6, Man 7, Man 8	4 hrs	Individual interviews with 3 women who often use CN: Woman 6, Woman 7, Woman 8	4 hrs

Figure 1. Example timetable sent to host prior to visit

Scheduling and locating FGDs and interviews

Interviews with leaders, initiators and coordinators in umbrella organisations usually occurred at the start of and towards the end of visits, and lasted two to three hours. Interviews with local coordinators, operators, technicians or volunteers tended to be spread across visits, and lasted about 30 to 90 minutes. FGDs with users mostly occurred in the first half of the visit, as they generated data that opened up the analytic space, and FGDs

with non-users occurred in the second half of the visit, since they often yielded important information to follow up with champions and operators. Each FGD lasted two to three hours, but different scheduling factors meant great variability in when activities took place. Much richer data was generated when the researcher observed participants operating and using community networks at different times of day and had ample time to converse in organised discussions, interviews and informally. This was really possible only when the researcher was able to stay for several nights within the rural villages, as in three cases (see Table 3). In two of these cases, the researcher was also able to walk around to chat with residents informally and arrange interviews with them directly.

Interviews with leaders, initiators and coordinators in umbrella organisations and with local coordinators, operators, technicians or volunteers took place at community networks' administrative centres, access points or operation centres, and occasionally telephonically. Hosts were encouraged to locate interviews and FGDs with users and non-users in undisturbed places that are accessible to and comfortable for participants, and to consider informal places, such as homes. However, FGDs were often hosted in council, assembly or gram panchayat rooms or offices and in some cases, it was clear that participants censored their opinions.

Research intentions to segregate FGDs by gender, with an interpreter of the same gender as participants for the session, were often thwarted by scheduling and other factors. Usually men's FGDs preceded women's, which followed local norms and helped the researcher to understand local power relations. In some large groups, gender segregation not happen; for instance, one FGD was attended by 11 men, five women and three other people under 16 years of age. In one case, the researcher remunerated a woman intern in the umbrella organisation to conduct brief interviews after the field visit in order to compensate for restricted representation of women.

Interpreting

Interviews and FGDs were conducted in English only if people were fluent, and otherwise in the participants' home language, with simultaneous interpretation into English whenever feasible. At least 80% of interactions were mediated in over eight languages other than English, including Hindi, Marathi, Luo and Nilotic dialects, Mexican and Argentine Spanish, isiXhosa, and central Javanese. In one case, professional interpreters were appointed, which incurred logistical overheads, such as organising their travel. Five of the six initiatives studied allocated interpreters for interviews and focus groups: in four, these people were closely connected to the network(s); in three, champions or managers facilitated most interviews and recruited participants; and in one initiative, interpreters were the children of members of the cooperative. Intentions behind these allocations were apparently oriented by pragmatics, offering people who were sufficiently familiar with the network, and able to speak English, to assist. However, the quality of interpretation and facilitation of interactions were significantly affected by the interpreter's familiarity with, and positionality with respect to, the participants and community networks; power relations between interpreters and groups; as well as the interpreter's prior translation experience and linguistic expertise. We explained to hosts that if it was not possible to have both a man and a woman, then a woman interpreter is preferred. Two initiatives provided only men.

Generally, before interviews and FGDs, the researcher and interpreter went through the relevant topic guides, which include questions, prompts and scenarios specific to the type of participant. This made it possible to prepare home language translation of certain concepts and consider contextually appropriate examples and prompts; decide how long should be spent on questions and topics; and determine ways to facilitate and manage group interactions and effects, with particular sensitivity to locally potent hierarchies (e.g. age, caste, occupation). Despite preparation, it was sometimes necessary after interviews and FGDs for the researcher to suggest improvements to the interpreter, for instance, encouraging their avoidance of leading questions and prioritising participants' dialogue rather than their own. Topics were also refined based on insights emerging from the preliminary analyses of preceding interviews and FGDs.

Interpretation, and analysis, occurred as dialogue with participants unfolded during FGDs and interviews, as the researcher and interpreter appraised content and interactions. This required careful listening, suspending judgement and prompting participants to expand on their comments. After sessions, the researcher and interpreter reflected on the session and ambiguous interpretation. This enhanced the depth of data generation and analysis and enabled adapting methods and topics in successive interviews to insights that emerged in preceding interviews. Financial resources, constrained time in research sites, and who the interpreter was in relation to the community network case precluded full post-session translation to English from the local language and more detailed analysis with the interpreter.

Recording

When participants were literate, demographic data about them was collected on paper at the start of interviews or FGDs, to optimise time. Sometimes this data was collected in introductions at the start of sessions.

All interviews and FGDs were recorded by audio and, when participants permitted, video for the purposes of transcription, correcting notes and analysis. While video enhanced the quality of transcripts, especially in FGDs by presenting who was speaking, time was not devoted to setting up intricate recording arrangements that distracted from time listening to participants. When it did not obtrude into the situation, and when ethically valid, photos and videos were used to record observations and brief impromptu interviews; otherwise, notes were handwritten or voice notes were recorded as soon as possible after observations. Participants sometimes interacted with equipment and devices, such as cell-phones, and often referred to applications and media, such as social media posts and websites. Where appropriate, the video camera was specifically focused on participants' interactions with devices as they expressed themselves, and photos were taken of their examples of media.

When simultaneous interpretation was available, the researcher also handwrote very detailed notes of the conversations and interactions. These notes provided valuable material to revisit in between sessions and at the end of each day and also closely focused the researcher's attention on the participants' perspective *in situ*. Considerable time was devoted at the end of each day to maintaining records, in order to ensure rigour in reporting and ongoing reflection.

ANALYSIS AND SYNTHESIS

Analysis is not something that starts only after data has been generated and ends upon the submission of a first research report. Rather, it begins from the moment of deciding to conduct studies – such as about community networks and connectivity in the global South – and continues throughout data generation, and afterwards when different lenses and perspectives are introduced. The high-level themes presented in section 3 of this report were synthesised from data generated in this exploratory research, and represent a point about two thirds of the way through a more detailed analysis and synthesis process.

Grounded analysis

After interviews, FGDs or observations, both the researcher and interpreter reflected together on what had transpired. *In situ* systematic high-level analysis was precluded by various factors, in particular, constrained time *in situ* and who the interpreter was in relation to the community network initiative (e.g. a champion). However, preliminary analysis immediately after interviews and discussions considerably enhanced the depth of data generation and enabled determining additional themes and topics in subsequent interviews.

Careful transcription of English interpretation of all interviews and discussions occurred as soon as possible after interactions. Professional transcription services were too expensive for the research, and the pace of field visits often meant full transcription was delayed. Nonetheless, the researcher's investment in listening in detail to audio records and videos in order to transcribe assisted the vital aspect of "reliving" the data in data analysis.

Grounded analysis of transcripts started between research visits and continued after all visits. This type of data analysis involves identifying the concepts behind the actualities and deriving categories from groups of concepts. Grounded theory, like other qualitative data analysis, uses codes to label properties and dimensions that are noticed by the analyst in the data, such as a transcript or an observation of local practices. The ongoing analysis codes transcripts and field notes line-by-line by assigning labels to words, word sequences and observed interactions and generates, from these codes, core categories, related concepts and dominant themes.[147]

To achieve the analysis so far, all data has been open, axially and selectively coded at a high level. Open coding codes all the data in every way possible to give a rich, dense theory where nothing has been left out. For instance, "What is the participant's main concern when she explains she must use someone else's phone?", "What does it mean when a participant cannot explain why there are no vouchers available?" Selective coding codes data according to a specific theme, such as "How is this incident gendered?" Axial coding relates codes to each other to determine categories, concepts and patterns, within a particular interview or discussion, and between interviews and discussions. While open, axial and selective coding has been undertaken at a relatively superficial level to date for all

147. Corbin, J., & Strauss, A. (1990). Grounded Theory Research: Procedures, Canons, and Evaluation Criteria. *Qualitative Sociology*, 13(1).

the data generated, it has already produced many important themes. Further analysis, ongoing for another six months, will refine many more categories, concepts and patterns.

Reporting and recommendations

Categories, concepts and patterns that emerged in the data were drawn together into themes that represented a large set of benefits of, and challenges posed by, community networks. Some categories and concepts are common to many community networks, while others emerged for only one or two. A total of 18 high-level categories, supported by considerable data, were presented in note form to the Local Access Networks project team (December 2018) for comment. Some of these themes provided strong evidence of the benefits of community networks to their constituency, while others highlighted weaknesses and flaws.

Based on the Local Access Networks project team's suggested refinements of some descriptions about themes, to improve their clarity, a draft narrative was constructed and circulated (January 2019). This writing expanded the themes and enriched the account with excerpts from transcripts of English interpretations of participants' comments. It also reflected on relationships between the insights that emerged, and the ways observations were made and interviews and FGDs were hosted, organised and facilitated. The draft went through four further revisions in response to critique from Local Access Networks project team members and a few comments by host initiatives on a third version. The final version restructured the second half of the document, about the weaknesses of community networks, to respond to team members whose role is to advocate for community networks, by presenting recommendations for improvement alongside the problems exposed.

RESEARCH ETHICS

Prior to visits, and/or at the start of FGDs and interviews, hosts and/or interpreters played translated audios/videos or translated information about the research. This clearly and comprehensively explained to potential participants the aims of the study, the purposes of the data collected, what would happen during the relevant session and their rights in volunteering to participate. Only participants who recorded informed consent orally or using a form were included.

All drafts of reports and papers were circulated to host contacts at least a week before the deadline, inviting their comments. This has happened with three reports so far. No objections have been raised by hosts.

Confidentiality

The researcher undertook to protect the confidentiality and anonymity of individual participants by limiting recording participants' identity and ensuring that all reports safeguard participants' privacy. Participants' names or other identifying details are not disclosed in written reports unless they explicitly request this. Any comments made by participants will not be possible to link to the participants. All data collected will be kept securely for five years after the research concludes and thereafter will be destroyed.

Attempts to address representativeness and confidentiality in FGDs involved facilitating opportunities for each participant to express their views on a topic and encouraging participants to respect the privacy of others in their group. However, it cannot be guaranteed that participants did not or will not disclose information, or that a range of factors did not impede their free expression.

Beneficence

The researcher discussed compensation for participants' time with hosts prior to or during visits. In two cases, the researcher gifted each participant with a simple home-crafted African bead necklace, from her home. However, some hosts preferred no compensation for participants, as it did not align with the philosophy of the community network, and for these the researcher purchased modest refreshments during sessions. Other hosts preferred a donation to the support organisation or village entity.

All but one community network indicated at the end of the visits that engagement in the research or preliminary insights fed back to them were valuable to their operations. Benefits mentioned included providing:

- Emphasis on specific positive impacts of a community network that are invisible to hosts because they are so familiar with the context, alike "not seeing the forest but only the trees."
- New perspectives on situations that might improve operations or sustainability, e.g. indicating practices that work to exclude parts of the population.
- Mentoring local people who acted as facilitators or interpreters or fledgling local research assistants.
- Empathetic attention to people demonstrating pride in achievements or reflecting on their challenges.
- Opportunities to link people in community networks with others around the world.

LIMITATIONS

APC's original proposal envisaged studies over several years, rather than 10 months. This proposal encompassed extended research visits, follow-up visits and more cases, but was curtailed by budgetary constraints. Insights about community networks in the global South, most of which are at an early stage of their evolution, are significantly limited by shorter study time, thus the multiple case approach should be considered exploratory due both to the abbreviated research and the dynamism of community networks. The approach has produced rich insights into a wide array of benefits of community networks and problems, by juxtaposing diverse perspectives in, and about, different community networks and enabled scoping the research space. However, the abbreviated study limited deep insights, and relationships with hosts in order to co-design the research objectives and methods. The brevity also impacted the ability of four hosts to facilitate access and recruit diverse participants into the research.

Relationships

An external researcher enables juxtaposing the cases in the study and noticing phenomena that are invisible to local people who are familiar with the context. However, the researcher's positionality performs in the data and insights generated. (The researcher is a middle-class, middle-aged, Western-educated, white woman, who has lived in rural Africa for the past 10 years, often in low-income communities, and who established a community network near her home). Ideally, researcher and hosts must sustain communication for at least five months prior to any visit to ensure hosts are fully engaged and have time in their busy schedules to shape, contribute to, and become integrated into, the study. This vital component of research was thwarted by the pace needed to cover all six initiatives. Thus, on average, contact with hosts preceded trips by three months, and in one case there was no prior contact. As a result, insufficient dialogue occurred between the researcher and some host initiatives to develop a shared understanding about the study and mechanisms to ensure benefits to hosts. This situation was exacerbated because resource scarcity compromises community networks' ability to generate, store and share data. Few coordinators of host initiatives provided documents about local demographic, economic and cultural characteristics in the vicinity of community networks and the past and current social structure of the community network. Indeed, access to selected pre- and post-implementation data relevant to social impacts was only available pre-visit for three community networks.

Access

Opportunities to generate data were compromised in three different community networks because the hosts' umbrella organisations lacked familiarity with sites or had reservations about the comfort or safety of the researcher staying within sites where data was gathered. Field visits hosted by two umbrella/support organisations comprised lengthy travel to rural sites from a hotel in a town, which curtailed interactions with participants and compromised data. This limited time for interviews and FGDs and precluded observations, for instance, when access in public places occurs only in the evening. Further, more initiators, leaders, champions and technicians in umbrella organisations (participant type 1 in Table 2) were included when the researcher was unable to stay in the rural village where a community network was located.

Other challenges impeded observing use of equipment and interactions with others at access points or administrative hubs in community networks. Only three initiatives included access points in publicly accessible places or computer centres (BOSCO, Zenzeleni, Gram Marg), and for two of these, people were also able to get signals in their homes. Further, in some cases, access points were not working.

Representation

The exploratory nature of the research, provisional definition of community networks, and criteria used to identify and select cases (see Table 6) means that it is impossible to determine whether cases are typical, particularly significant, deviant or extreme.

Further, although a total of 152 different women and 172 different men were present in interviews and focus groups, including employees of umbrella and support organisations, recruiting diverse users and non-users of community networks for interviews was particularly difficult. Firstly, it was hard for some host umbrella or support organisations to access diverse people in their constituencies because they are located socially and physically far from a community network. Some umbrella or support organisations interface only with a high-level coordinator and do not know local populations of operators, users or non-users. Secondly, host umbrella or support organisations might be reluctant to expose their constituencies to external researchers or consider the work required to facilitate contact with users and non-users an inefficient use of scarce resources. For instance, in a short visit, an external researcher lacks contextual familiarity to produce the volume and scope of data that meets expectations of dominant measures of success. Alternatively, hosts may have conducted, or be about to conduct, some form of impact analysis themselves for the purposes of reporting internally, to funders, or for research; this was the case of BOSCO, Gram Marg and another community network approached in the research. Thirdly, positionality, and past experiences, can undermine trust that an external researcher will act in the best interests of the community network and the community network's constituency.

Research intentions for marginalised groups to represent themselves were often thwarted by scheduling, and contexts that limited gender-segregated interactions. While exclusion and lack of appropriate contexts for interactions can indicate sets of practices that constitute the community network, they also reflect the time available for establishing shared understanding with hosts. For instance, non-users participated at some Asian and African community networks because they came to FGDs intended to comprise users, while few non-users participated in Latin American sites because of time constraints at one community network. Sometimes the size of focus groups meant many participants did not speak, other than to raise their hands in response to "yes/no" questions about their access or connectivity; the largest scheduled FGD was attended by 24 women and six children.

Quality of interpretation and facilitation were affected by many social and cultural factors. In three cases, interpretation was undertaken by people at the centre of power in community network umbrella organisations who controlled the context of interactions with users and non-users, which obviously impeded the research. In one case, this person asked leading questions and spent more time talking than listening, and in another, participants appeared to want to please the interpreter. There is greater certainty about ethical and methodological validity of the four initiatives in which women interpreters were available.

APPENDICES

Appendix 1: Topic guide for individual interviews with community network initiators/leaders

Questions and topics	Help and prompts	Time (mins.)
What were the original motivations for the [Name of initiative/CN]? **Get participant's insights about the time when they started with [Name of initiative/CN] networks and what they thought then, not what they think now.**		15
Describe all the goals that you hoped that [Name of initiative/CN] would achieve; remember to focus on what you thought then.	Can be practical personal, social, economic, cultural, ideological goals. Don't worry if they seem irrelevant or different now. Were there any other goals? Repeat until no more goals.	
Which goals did most people involved in [Name of initiative/CN] agree on? Describe any different opinions about the goals among the group of people involved in [Name of initiative/CN].	Reassure that people always have different opinions about what is good to achieve and what can be achieved. Were there any other differences in opinions about goals? Repeat until no more.	
What motivated you personally to start or join [Name of initiative/CN] networks? Explain, specifically, anything that happened or people that made you interested or committed to [Name of initiative/CN] or the idea of CNs. Why were these people/events/situations especially important?	Prompt: Did anything else motivate you? Repeat until no more. People, events or situations that motivated could be local or international.	
What goals have changed for [Name of initiative/CN] and the reasons for changes? **Compare the situations now to when participant started or joined [Name of initiative/CN].**		15
Explain everything that setting up and operating [Name of initiative/CN] actually achieved or impacted, based on real situations.	Prompt participant to be specific and give concrete, real world examples.	
Which of [Name of initiative/CN]'s original goals are the same?	Remind them about the goals they mentioned in topic 1. Were there any other goals that are the same? Repeat until no more goals.	
What goals are different, and why did they change?	Insights into evidence of impact. If goals changed because a situation changed, how did you know the situation changed? E.g. If more people own phones now than before, how did you know that?	
How do you do your work and activities with [Name of initiative/CN]? **Get participant's perspective on their own work and activities for [Name of initiative/CN].**		50

List all the activities you did in the past 2 months that contribute to [Name of initiative/CN] and describe what you personally did. Include all the routine things that you usually do. Where do you do each of these activities? Who else is involved, and how were they involved? Are technologies involved in these activities, and how are they involved? How does each activity fit into the rest of your life?	Activities can be technical (e.g. set up routers, software), admin. (e.g. track user accounts, payments, etc.), fundraising, organisational (e.g. meetings), communication (e.g. talk to users, other stakeholders), teaching and supporting people, etc. Prompt participant to be specific and give real world examples. Prompt participant to think about whether activities happen in different places, at different times and involve different people.	
Which of your activities do you think is most important and which most benefits you or other people?	Focus on the participant's own opinion of importance and benefits the activity.	
For all your activities that are most important or beneficial: When did you start doing the activity, and why? Describe any changes in the activity and explain why you do it differently now.	Changes in activities might be because of changes in a situation (e.g. network expansion) or issues that have arisen, changes in people involved, etc.	
Describe activities you used to do but don't do now. Why did you stop?		
Who makes operational and strategic decisions about the networks? Get participant's experiences of all the different people who set up, coordinate and support the network, to understand engagement of people of different gender, age, etc.		10
What are the reasons that people get involved in setting up and running the networks? In your opinion, what stops some people from getting involved?		
Who uses the networks and who doesn't, and why? Get participant's experiences of all the different people who use the network, and their opinion about why people don't use it, to understand access difficulties due to gender, age, etc.		10
Describe any types of people who don't use the network and suggest why they don't use it.		
What are problems and challenges in the activities you do? Get participant's experiences and opinions about difficulties in their activities for [Name of initiative/CN].		5
Describe the main problems or challenges that arise in your work/activities. Why do they arise, and how do they affect you or others or [Name of initiative/CN] in general?	Problems or challenges can be small everyday problems or unusual challenges. Prompt participant about how other people are involved, and their age and gender.	
Is there anything you would like to discuss more?		

Appendix 2: Topic guide for individual interviews with community network operators and volunteers

Questions and topics	Help and prompts	Time (mins.)
How do you do your own daily or weekly activities with [Name of initiative/CN]? Get participant's account of their own work and activities for [Name of initiative/CN].		15
List all the activities you personally do that contribute to [Name of initiative/CN]/network. Where and how do you do these activities? Can you show us? Who else is involved in the activities, and how? How do these activities fit into the rest of your life?	Activities can be technical (e.g. set up routers, software), admin. (e.g. track user accounts, payments, etc.), fundraising, organisational (e.g. meetings), communication (e.g. talk to users, other stakeholders), teaching and supporting people, etc. Prompt participant to be specific and give real world examples. Prompt participant to think about whether activities happen in different places, at different times and involve different people. Prompt participant to think about how activities fit into other work, or social life.	
Describe activities for [Name of initiative/CN] you used to do but don't do now, and explain why you don't do this activity anymore.		
What are the relationships between different parts of [Name of initiative/CN] networks? Get participant's perception of the relationships between their local network and [Name of initiative/CN] as a whole.		5
Describe what you think [Name of initiative/CN] is as a whole and explain how your own activities fit into it.		
What are the most important and most beneficial activities you do? Get participant's opinion of their own work and activities for [Name of initiative/CN].		10
Which of your activities do you think is most important, and which most benefits you or other people?	Prompt for participant's own opinion of importance and benefits the activity.	
For each most important or beneficial activity: When did you start doing it, and why? Describe any changes in it and explain why you do it differently now.	Changes in activities might be because of changes in a situation (e.g. network expansion) or because of issues that have arisen, changes in people involved, etc.	
Who uses the network and who doesn't, and why? Get participant's experiences of all the different types of people who use the network, and their opinion about why people don't use it, to understand access difficulties due to gender, age, etc.		10

List as many reasons as you can for why people in your community use the network. Describe any types of people who don't use the network and suggest why they don't use it.		
Problems and challenges in activities you do. **Get participant's experiences and opinions about difficulties in their activities for [Name of initiative/CN]; get insights into social and gender barriers.**		5
Describe the main problems or challenges that arise in your work/activities. Why do they arise, and how do they affect you or others or [Name of initiative/CN] in general? Are you able to solve problems, and if so, how do you solve them? If you can't solve them, what do you do?	Problems or challenges can be small everyday problems or unusual challenges. Prompt participant to think about challenges in setting up, maintaining and making decisions about the network. Prompt participant to think about how other people are involved, and their age and gender.	
Is there anything you would like to discuss more?		

Appendix 3: Topic guide for focus group discussions with users of community networks

Topics and questions	Help and prompts	Time (mins.)
What do you use the [Name of initiative/CN] network for? **Get a broad account of all uses of [Name of initiative/CN] networks, by asking participants in turn and repeating the questions until participants no more different uses are said.**		
In turn: What did you use the [Name of initiative/CN] network for the last time you used it? Describe something that people use [Name of initiative/CN] networks for that participants have not said yet.	Prompts: WhatsApp, phone calls, email, posts to Facebook, Instagram, YouTube, website, filling in forms, writing blogs, sharing photos in cloud. Prompt participants to be specific and give real world examples. Repeat until no more new uses are said.	15
How do you use the [Name of initiative/CN] network to communicate or interact with people you know who are nearby? **Get accounts of using the [Name of initiative/CN] network in everyday communication with familiar nearby people (within INSERT APPROPRIATE km) and understand how this differs from before the network. Start by asking people in turn about uses and repeat questions until no one says any different uses.**		
In turn: Describe an example of the way you most often use the network to communicate with people nearby. For each of these different uses, how many people do you communicate with, and how many of them do you usually see face-to-face?	Prompt: WhatsApp, phone/video calls, playing games. Once one participant has mentioned a use, then ask, is this similar for others? Prompt participants to be specific and give real world examples.	10
Before the [Name of initiative/CN] network, how did you communicate with these people?	If appropriate, show an example on your phone, laptop, etc. of a communication with nearby people that was impossible before the network.	
How do you use the [Name of initiative/CN] network to interact with people who are far away? **Get accounts of using the [Name of initiative/CN] network in everyday communication with people who are far away and understand how this differs from before the network. Start by asking people in turn about uses and repeat questions until no one says any different uses.**		
In turn: Describe an example of the way you most often use the network to communicate with people who are far away, e.g. (INSERT APPROPRIATE km), and say whether these people are family, friends, colleagues, people you met online, etc. For each different use: How many people do you communicate with, and how many of them do you usually see face-to-face in a month?	Prompt: WhatsApp, phone/video calls, email, social media messages, playing games. Prompt: Numbers of WhatsApp messages, groups.	10

Before the [Name of initiative/CN] network, how did you and these people communicate?	If appropriate, show examples on your phone/laptop of a communication with people far away that was impossible before the network.	
How do you use the [Name of initiative/CN] network in more formal communication? Get accounts of using the [Name of initiative/CN] network in communicating for official or impersonal reasons, understand how this differs from before the network. Start by asking people in turn about uses and repeat until no one says any different uses.		10
In turn: Describe an example of the way you often use the network to communicate with organisations or people you don't personally know, and why you communicate with them. Are there any other ways you use the network to communicate with organisations or people you don't know personally?	Prompt: Could be synchronous communications (e.g. phone calls), asynchronous communications (e.g. WhatsApp, email); broadcasting (e.g. posts to social media, posting content on YouTube, blogs), filling in forms online, playing games.	
Before the [Name of initiative/CN] network, how did you and these people communicate?	If appropriate, show an example on your phone or laptop of a communication that was impossible or difficult before the network.	
How have changes in the ways you or other people communicate affected you? Build accounts of the major impacts of changes in communications since the [Name of initiative/CN] network.		15
In turn: What are the biggest changes in the way you communicate with other people since the [Name of initiative/CN] network began? In turn: Describe an example of a way that changes in communication can be beneficial. In turn: Describe an example of a way that changes in communication can be negative.	Prompts: How many more contacts on your phone, email, etc., do you have? How much longer or how much less time do you spend trying to communicate now? E.g., do you travel less to speak to people?	
What information do you get by using the [Name of initiative/CN] network and why do you get? Get accounts of using the [Name of initiative/CN] network to get information from the web or other internet services and understand how this differs from before the network. Start by asking participants in turn about uses and repeat questions until participants say no more different uses.		20
In turn: Describe an everyday example of using the network to get information, and say its main role (work/study/official/interest/activism/ fun), how you get it (cell-phone/laptop) and where you are when you get it (home/school/ work/elsewhere). Are there any other ways you use the network to get information, and how has this information benefited you?	E.g. access daily news? Prompt participants to be specific and give real world examples.	
Before the [Name of initiative/CN] network, how did you get the information you described?	If appropriate, show an example on your phone/laptop of information that you got that was impossible or difficult to get before the network.	

How has the [Name of initiative/CN] network changed the ways you or others get information? Build accounts of the impacts of changes in getting information since the [Name of initiative/CN] network.		20
In turn: What are the biggest changes in the way you get information since the network began? In turn: Describe an example of getting information that is beneficial. In turn: Describe an example of ways that getting information can be negative.	Prompts: How much less time do you spend trying to get information now? E.g. young people's access to inappropriate material.	
How does the [Name of initiative/CN] network fit in with the rest of your life and the community's life? Build accounts of the overall local ecology of communicating and getting information (e.g. face-to-face, print, digital) and the social aspects of the [Name of initiative/CN] network.		20
In turn: Explain a recent example of communicating or getting information that did not use the [Name of initiative/CN] network, and why you didn't use the network for this. In turn: How did you find out about the [Name of initiative/CN] network, and how often do you speak to someone that helps to operate it? In turn: Did anyone in the community help you to use the network for any of the things you have mentioned today? Does anyone help someone in their family or community to use the network for anything?	Prompt participants to be specific and give real world examples.	
What difficulties have you or others experienced in using the [Name of initiative/CN] network? Build accounts of challenges to understand access difficulties due to gender, age, etc.		20
In turn: Describe something that stopped you from using the network when you wanted to use it. What problems have happened with the network or the way the network was run, and how were these fixed? Are there people in the community that don't use the network? Why don't they use it?		

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Appendix 4: Diary accounts of users of community networks

Topics and questions	Help and prompts	Time (mins.)
First day		
Reconstruct the previous day by grouping activities and events into "scenes". Participant summarises what they did the previous day, from when they awoke until they went to sleep, by grouping activities and events into scenes, like in a play.		10
Explain that a new scene starts when they start a different activity, move to a different place, different people come to where they are, or something distinct happens.	Prompt with examples of scenes, e.g. getting myself/family ready at home, doing housework at home, travelling to work/school/errands, farming in the fields, worshipping at church, drinking and chatting at a friend's house, preparing lunch at home. Remind participants that we respect confidentiality.	
Identify scenes in which [Name of initiative/CN] had a role. With participants, identify scenes in which [Name of initiative/CN] played some "role".		15
Explain that this "role" can involve directly using the network, doing something that enables their own or others' network use, or interacting with someone who helps run the network.	Prompt with examples of roles, e.g. phone call, internet use, paying for services, walking to use the network, checking credit, waving to someone who helped set up the network as they pass by. Remind participants that we respect confidentiality.	
Describe the action when [Name of initiative/CN] networks are in the scene. Participants describe in detail their network use and experiences when [Name of initiative/CN] played a role.		20
Select scenes that exemplify the relevance of [Name of initiative/CN] in the participant's life. Ask participants to describe the details of their interactions and to show use, e.g. messages, photos, call logs, etc.	Prompt with: How did you do that? And then what happened? Approximately what time was this? How long did that take?	
Clarify any difficulties related to using the network		
Subsequent days		
Topics and questions	Help and prompts	**Time (mins.)**
Reconstruct the previous day by grouping activities and events into "scenes". Participant summarises what they did the previous day, from when they awoke until they went to sleep, by grouping activities and events into scenes, like in a play.		5
Remind them that a new scene starts when they move to a different place/start a different activity or different people come to where they are, or something distinct happens.	Remind participants that these answers are treated confidentially.	

Identify scenes in which [Name of initiative/CN] had a role. **With participants, identify scenes in which [Name of initiative/CN] played some "role".**		10
Remind them that this "role" can involve directly using the network, doing something that enables their own or others' network use, or interacting with someone who helps run the network.	Remind participants that these answers are treated confidentially.	
Describe the action when [Name of initiative/CN] networks are in the scene. **Participants describe in detail their network use and experiences when [Name of initiative/CN] played a role.**		20
Select scenes that exemplify the relevance of [Name of initiative/CN] in the participant's life. Ask participants to describe the details of their interactions and to show use, e.g. messages, photos, call logs, etc.	Prompt with: How did you do that? And then what happened? Approximately what time was this? How long did that take? Remind participants that these answers are treated confidentially.	
Clarify any specific difficulties related to use of the network.		