Stories from the Field (of Networking): Lessons from Deploying Research Systems in the Real World.

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ABSTRACT

As computer science has grown in importance throughout the world, there's been a similarly growing drive to apply foundational computer science to address core societal issues. For networking researchers, this effort has largely focused on bringing the benefits of Internet access to marginalized populations. In this work, we reflect on more than a decade of our own work deploying such research into the world in all of rural, urban, developed, and developing regions. We share key lessons and related stories that have influenced they way we do this type of work. We conclude with a call to other researchers to add their own stories to share back to the wider networking research community.

1 INTRODUCTION

> *Some things in life can never be fully appreciated nor understood unless experienced firsthand. Some things in networking can never be fully understood by someone who neither builds commercial networking equipment nor runs an operational network.*
> — RFC 1925

In the late 1960's and early 1970's the United States' Department of Defense funded the ARPANET project, which worked to use packet-switching ideas to create a more robust nation-scale telecommunications network to share supercomputing resources and interconnect other government resources. Since that inception, the Internet has become one of the most important systems in the world, interconnecting all countries and providing a variety of basic services including social media, government functions, weather prediction, and literally more than can be listed in the entirety of this document's space. It is difficult to overstate the impact of the Internet and the contributions of the networking researchers who drove its design and adoption.

However, in 2023, it is much more difficult to have such wide social impact from networking research. Most networking research is focused on datacenters as the technical questions are more narrow and the funding more readily available. Some researchers are pushing back against these norms but most people are online and the "long-tail" of networking problems rapidly intermingle with socio-technical issues often outside of the purview of traditional networking research. Moreover, networking is an applied domain and the best research happens within partnerships. Research is much easier when those partners are multi-billion dollar organizations instead of small low-income communities.

Despite these difficulties, some networking researchers see this increase in complexity and are excited. New partners mean new problems and the intermingling of research disciplines, especially STEM and humanities, seems critical as computing's impact grows. This work is intended to be our reflection on many years of our own research work from dedicated engineers with passions for working with marginalized communities on under-explored problems. Our work crosses many borders [39], including domestic [32], international [27], developed [32], middle-income [36], and developing [20] regions, and each environment has unique challenges and opportunities. However, our goal in this paper is to find commonalities across these experiences.

Researchers working with marginalized populations or on problems with deep social components should take a deep look at literature from other fields working in similar spaces. In computer science, human-computer interaction (HCI) has tried to internalize much of these other fields' discourses, producing work such as Feminist HCI [9] and post-colonial computing [31], both of which draw from histories in critical theory. We consider these lists of best practices, with stellar examples such as "stories from the field" [4], to be required reading for someone doing this work.

In short, work deeply with genuine empathy with partners who are concretely affected by the issues you seek to resolve. Beyond this, our goal in this article is to go beyond this high level advice to share some of our accumulated knowledge and experiences, through lessons and stories, that are (to us) unique to networking research focused on working with marginalized populations. We hope this can make it easier for other researchers to take the same journeys and potentially expand the field of networking itself.

2 BACKGROUND

The authors of this paper have been working on universal Internet access for over twenty years combined, with deployment experiences across Indonesia[48], the Philippines[20], the Canadian Arctic, the urban US, Tanzania, Malawi, and others. Our lab's work has largely focused on the broad area of **community networking** [30]. Community networks are access networks that, in contrast to traditional Internet service providers (ISPs) or Mobile Network Operators (MNOs), are owned locally and operate in ways that give agency to local actors, implementers, and users. Given this broad mandate, these networks are heterogeneous in nature without clear demarcation between models. However, notable examples

SNIP2+ '23, September 10, 2023, New York, NY, USA

ACM ISBN 979-8-4007-0304-1/23/09…$15.00
https://doi.org/10.1145/3609396.3610547

exist such as NYC Mesh in New York, Detroit Community Technology Program [43] in Michigan, Rhizomatica [2, 36] in Mexico, and Altermundi [1, 17] in Argentina. Whole books [11] have been written supporting the deployment of these networks all around the world. My researchers have reflected on their work in this spac and, myriad projects have explored community networks, such as the inclusion of local services [47, 53], gendered experiences in networks [12, 29], sustainability [7, 44], their role in community agency [40], alternative topologies [42, 51], MAC protocols [8], offline access [16], and many other agendas. This work is not intended as a literature review of our wide field, but its important to understand the breadth of quality work across continents and institutions.

Our own experiences have included deployment of novel technical hardware [26] and software [20, 23, 27, 48]; development of network training materials for youth and adults [32]; community building and outreach for deployments and repair [33, 34]; IXP/ISP software development; and basically everything in between. In this section, we provide more detail for a few of our projects in order to contextualize the following stories and lessons, but note that the referenced published works only touch on a small amount of the overall work conducted.

2.1 Positionality

First, we wish to note our own positionality in the work. The first author is a German-American faculty member at an R1 research university where he has been long enough to get tenure. He is from Alaska, a rural State in the United States (though not from a particularly rural part of Alaska). He spent much of his youth in remote rural areas and developed an intuition for institutions and processes in similar areas that, in his experience, has generalized to others.

The second author is a PhD student in ICTD at a R1 research university who has dedicated her research output to starting, operating, and capacity building towards a local community network. A Korean-American immigrant from NYC, she grew up in a number of "third place" academic and non-academic environments that nurtured self-directed learning, DIY, and youth activism. She hopes that community networks and organizations can become such settings for future youth.

The third author is a PhD student in ICTD at an R1 research university whose research interests span networking, systems, programming languages, and human computer interaction. He is a Nigerian-American immigrant from Chicago who has lived in urban and rural communities across the US. He has experience working closely with network operators in Africa including small community networks and internet exchange points (IXPs).

2.2 Rural Community Networks

After deploying initial prototype GSM-based community cellular networks in rural Indonesia in 2013 [27], we partnered with the University of the Philippines (UP) and an unnamed local MNO to scale the community model to the rural Philippines throughout 2017. The UP team provided a majority of the "on-the-ground" connection, conducting outreach and training community partners while the MNO partner provided interconnect and a spectrum

Figure 1: A map of deployments (left) and a typical install (middle/right) for the UP Project.

license. This work included all of field explorations [10], novel core networks designs [20], exploration of repair and maintenance technology and structures [33, 34], and real deployments of over a dozen networks throughout the country. The UP team deployed fully community operated sites in the Aurora province which can only be reached by boat. The MNO partner deployed other sites in a hybrid-community model where a local NGO operated the sites with community participation. Through these deployments we provided network connectivity to over three thousand people through over three million SMS messages and fifty thousand hours of calls.

Following a successful set of deployments by the UP team (and relatively unsuccessful set by the MNO partner), the project was sunsetted as the spectrum license was to be revoked. The UP team swapped out the research equipment in "sustainable" communities (where usage could pay for satellite backhaul) with more traditional wifi installations.

2.3 Seattle Community Network (SCN)

SCN was started by the authors in 2019 as an Action Research (AR) project [18, 25, 28] to explore whether and how community-owned and operated wireless Internet infrastructure could successfully meet technology needs and improve digital equity in urban settings. As ICTD community networking researchers, the authors explored first-hand some of the barriers to access in urban contexts and the challenges of establishing and maintaining an operational community network. The vision of the project includes (1) improving documentation and public knowledge of our existing open source cellular network infrastructure [21, 24, 35, 37], and (2) producing a sustainable alternative to standard paradigms of closed-source, commercially owned and inequitably distributed Internet access networks. We also build and leverage meaningful relationships and social cohesion [3] between local tech industry and university volunteers and high-need groups, connecting all participants with traditionally gatekept computing knowledge and resources [32] through a shared community of practice [52]. We view SCN as a "community learning network" (akin to a "teaching hospital" [6]), a living research and teaching network intended to provide to participants from all backgrounds practical knowledge and hands-on experiences with network installation, repair, management and growth as well as grassroots community engagement.

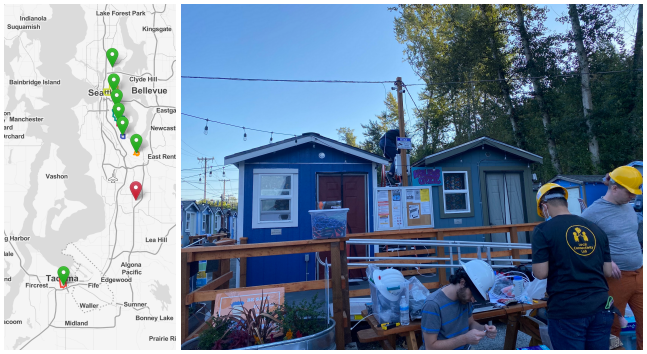

Figure 2: SCN Coverage Map (right) and install (left).

3 LESSON: HARD THINGS ARE HARD

"Hard things are hard" is an intentionally pithy and tautological reminder that we are attacking difficult, often intractable problems and solutions will not be easy and may not be possible. Any sort of action research [5], even technical work like networking, is extremely likely to center or at least address "wicked problems" [46], including things like poverty, rural/urban divides, disability, and inequity. These are problems that are both inherently difficult to manage and also make related research difficult in terms of impact, sustainability, and pretty much everything. Moreover, progress on such problems inherently requires centering non-research partners in ideation and execution; those from communities that both bear the brunt of the negative problems listed above and have the agency and ability to affect the needed change in their communities [50].

The key goal of this section is to strongly encourage researchers to internalize the journey they will be on; **if you are working on hard problems, it will be hard.** Working in poverty-stricken rural areas is hard. Building a sustainable community network is hard. Working with resource-limited communities is hard. This will make conducting your research hard.

> Story - SCN's Start-up: *"SCN was started before the pandemic, initially envisioned after the already thriving NYCMesh community network. However, the start was very slow. For a year and a half we drummed up partnerships and applied to local government grants for the infrastructure, with many leads but no concrete way forward without initial deployment funding. When calls for proposals to fill connectivity gaps during Covid-19 came, we were ready with community partnerships and grant applications that finally landed due to the pandemic use case."*

3.1 Corollary: Be Kind to Yourself

Be patient and offer yourself grace for not succeeding immediately. Persistent effort and plugging away at a problem may or may not be fruitful in the real world, or you may need to work until you find the right moment, the right opportunity, the right partner. You should not necessarily stop working on the problem, but continue building the groundwork so you are ready when opportunities arise.

Even in being kind to yourself, addressing such difficult topics and engaging in such challenging research may seem daunting. It is important for a researcher to know if they are prepared to enter an action research relationship so they do not make things worse. We've experienced many places where researchers are viewed negatively due to a prior short-term research engagement leaving hurt feelings and harmed communities. Research is inherently open-ended; we cannot predict all outcomes. Instead, what we can do to be prepared is to commit to the work and the partners, knowing that even if the research doesn't pan out as hoped the researchers will still be there to help handle project outcomes. Genuine empathy and support is what all people seek, and it is no different in research partnerships.

> Story - De-deployment: *"Be sure to set up front expectations as accurately as possible about network uptime/performance, user/volunteer/employee engagement, cost, etc. One rural WISP we worked with had to de-deploy two unfortunate users' Customer Premises Equipment (CPE) because while their wireless coverage technically reached as far as those customers, serving them used up too many network resources and harmed the rest of the network. When their service was taken away, those customers were understandably upset."*

3.2 Corollary: Find Motivated Allies

It is hard to work on hard problems all the time. However, people do still work successfully on hard problems. In fact, we would argue that almost all meaningful progress is made by people working on hard problems. To this, we suggest that researchers first select topics that they are intrinsically driven to solve. For us, that is connectivity. We find joy in the process as much as the results, and that makes working on hard problems fun and rewarding. Second, they should find partners and collaborators who are similarly driven.

> Story - Volunteers: *"People and organizations dedicated to building community networks around the world, such as NYCMesh, Freifunk, Guifi, AlterMundi, and SCN, are examples of those who keep networks running through a labor of love. As with other technology such as open source software, maintainers are often hobbyists, volunteers, and activists who find joy in doing the activities involved (and have time to spare). I was inspired to start SCN by the joy, excitement, accomplishment, and sense of community I felt when volunteering with NYCMesh on installs over a winter break. Other really passionate CN mobilizers may include rural users who are extremely motivated to achieve connectivity after not having it."*

3.3 Caveat: No Gods, No Heroes

A reviewer for this work felt the above has airs of saviorism and imperialism; that it could read as though researchers are the only ones who can solve such deep problems with their incredible engineering talent, humanities insights, the depth of their community-facing work, or their access to massive resources. Such imperialism we

reject explicitly. The problems addressed above are ones without single answers and all progress is done in small spurts. Any solution to a problem like "poverty" will be an amalgamation of literally millions of different actors all moving the needle individually only slightly (and often with significant elements of moving backwards). Science has a known problem with attributing to individuals what were collective efforts [38] and given the vast scope of the work required here, researchers should strive to remain humble and realize that while computing can often have outsized impacts, their part of any success will be minuscule when compared with the work done the communities themselves.

4 LESSON: FIRST, BE HELPFUL

Prior work and best practices have strongly made the case that partnerships are key to building impactful systems in the real world[31]. Technical networks, like other infrastructure, are built on an underlying infrastructure of people-networks. Partner organizations and the people that make them up will drive the vast majority of the non-technical elements of projects, and thus will be critical in the adoption, use, and sustaining of any technical innovations. Meanwhile, partner organizations will almost certainly have goals and problems beyond the scope of your research project. Our argument is that you should empathize with, listen to , and help partners to build relationships. In particular, **computing and networking skills are rare, and solving ever-present networking issues can quickly build good will**.

4.1 Move Fast and Fix Things

In this day and age, computer networks are pervasive infrastructure, present in some form in the vast majority of environments. These can take the form of home wifi installations, shared satellite terminals, personal cell phones, or even sneakernets taking USB drivers to more traditional connectivity. Often, especially given the difficult situations researchers find interesting, partner organizations are tasked with operating these networks for their communities despite challenging environments or a lack of capacity for technically sophisticated solutions.

> Story - Arctic Radio: *"We were doing a network install in the Canadian Arctic. While discussing the installation location with the local leadership, we noticed two operating FM radio stations that would need to be turned off while we worked on the roof. At the end, we asked if there was anything else we might be able to help with and he mentioned that one FM station was operating at low power because it was interfering with the other. We perked up at this, offering our help. That night we went back, found the operating manual, and discussed with radio experts as to what might be the problem. We came back the next day and changed the frequency to avoid harmonics (while telling them to report this to the public radio org that owned it for registration purposes). With this tested, we powered it up and the leadership happily reported that elders far outside of town were now getting the radio messages they had been missing out on."*

This confluence means that, as researchers, we are often thrust into situations surrounded by obviously faulty networking infrastructure, even if that infrastructure isn't related to the research projects at hand. At the same time, many of these issues are things that can be resolved fairly easily by knowledgeable technical workers (e.g, the reader). This gives us, as networking researchers, a key way to "be useful"; simply take a moment away from your research work to assist partners in successfully operating their critical network infrastructure. This can be re-pointing antennae, exploring routing tables, assisting in application operation in multi-NAT environments, or configuring IoT devices on their network. Moreover, we should be seeking out such infrastructure, in order to demonstrate our worth and skills.

> Story - The Amazon: *"We were conducting an exploratory investigation in the Peruvian Amazon. We were exploring interest in a community networking model with a nearby indigenous community by running workshops. The closest place to the communities for us to sleep was an eco-tourism hotel that worked closely with community members, assisting them in developing new businesses (beekeeping in this example) and officially documenting their territorial holdings. The hotel was in the Amazon as well and had wifi Internet access through a three hop-tower network to the nearest big city. While resting at night, we noticed intermittent Internet failures that were not shared across users. After a thorough night of debugging, we found that there were two concurrently operating DHCP servers with one having a misconfigured gateway. We found the default credentials, logged in, and turned the bad one off, improving the hotel's wifi. We can't know if it's related, but we have been invited back to continue the work."*

4.2 Caveat: Don't Make Things Worse

One huge caveat on "be useful" is the inverse, "don't make things worse". Working with researchers already takes significant partner time, which in many ways can leave partners worse off. Breaking their equipment definitely leaves them worse off.

This can be a tricky line to walk; researchers are exploratory by nature and like to engage with technical issues in an iterative fashion. This methodology can cause problems when (1) equipment fails permanently (e.g., power shorts or other significant damage) or (2) solutions don't fit research timelines (e.g., researchers leaving before solutions can be tested or "jury-rigged" in way that will fail while the researchers are gone). An alternative phrasing could be: make sure you leave things better than they were. Intentions **do** matter, but outcomes dwarf them.

5 LESSON: NETWORKS ARE PEOPLE

Through community networking, we have come to **think of positive relationships and communications patterns between people as infrastructure**. Many times over the past few years, conflicts due to miscommunication (e.g. missed emails about urgent paperwork, poor word choice leading to offense) or human mistakes (e.g. accidentally leaving a community center door unlocked after

use) have been smoothed over via sincere apologies and face-to-face interactions. Regular positive interactions tend to build trust and context over time, reducing the chance of miscommunication. We have found immense value in communicating regularly with partners, in ways as small as a weekly 30-minute phone call, or occasionally meeting for coffee.

> Story - SCN Users: *"In one case, a resident volunteer at a Tiny Home Village (homeless transitional housing) we served told us about rumors that we would not respond to their network issues because we operated a voicemail-only phone number (due to volunteer capacity constraints) and did not call back every caller. After that, we asked the volunteer to clarify on our behalf that text messaging would get faster responses, and we posted signs saying that texts to the number were preferred. After that, outage reports were timely, and we were able to text back and resolve issues immediately."*

As in other relationships, potential for partner anxiety and mistrust can be heightened by power imbalances, often present when academic researchers from an established and powerful university interface with representatives from marginalized groups who have historically struggled to be acknowledged. Always be ready to listen, affirm, and respond to expressed needs, concerns, or confusion. The second author used to keep a post-it note on her desk with the phrase 'They want to feel heard, respected, and loved' to make sure she was always responding with the right attitude to the human on the other side of any email or written communication.

Where possible, make sure to have a phone number, and be visibly responsive to the phone number to maintain user trust. In the case of a network outage, email or other online communications may not be possible. Furthermore, for less tech-savvy users and populations who are 'digitally excluded,' a phone line could make the difference between successfully reporting an outage/need and feeling helpless/unsupported.

> Story - Sunsets: *I once worked with a school in a slum where my research team set up wifi access points to provide Internet access. This backhaul was not free and when the official timeline for the project was over, decisions were made to discontinue access at the school. A couple years later (the project happened during the pandemic), I was in Nairobi and when with local colleagues to visit the school to check on this site. I asked where there was not wifi (not knowing funding stopped). I was displeased to hear from the principal that they haven't had it for months. She told me how impactful access to the internet was, but expressed significant discontent and frustration that we just stopped it like that. "How could we bring the internet and take it away just like that. This is not a lab; This is a School". The gravity of these words pulls heavy on the heart. In my mind, there is something ethically and morally unjust in what we did. And for what? A publication and marketing about our impact in a poor Nairobi slum.*

5.1 Caveat: Friends in Both Directions

While it's important to have solid communication channels with users for better tracking network failures and providing assistance to users, it's also important to understand that research networks are fundamentally less stable in a variety of ways. This needs to be communicated to users as well. If they know they are joining a research network, outages and crashes will be better tolerated. Moreover, research projects end, and a likely outcome for your network is that it gets turned off some day (with the ideal being something more akin to "hand off" to local actors). These communication channels also allow you to engage users in the process of handing off or sun-setting, which will help them manage the transition from your infrastructure onto someone else's, which is the inevitable end if they've grown to value the Internet connection.

6 LESSON: NETWORKS ARE PHYSICAL AND ARE DESIGNED FOR A PURPOSE

> Story - Capacity Building: *"Effective teaching and training in real-world networking happens on the job, hands-on and in the physical context of the network. Many technical people have come into SCN as volunteers or other participants, often with extensive networking expertise. However, those who have so far demonstrated the most confidence and initiative to plan and lead SCN installs on their own are those with the most hands-on experience with the physical aspects such as mounting and cabling, as well as the ability to coordinate with install site personnel/users. NYCMesh's very successful hands-on training strategy depends on having frequent enough installs, led by an experienced installer and open to new learners, to keep building up new volunteer capacity as the network expands."*

Today, a large amount of networking research explores how software and programmable hardware can be leveraged to make networks more dependable, verifiable, and correct. This "software will eat the world" disposition minimizes the physicality of networks and downplays the criticality of the basic hardware mediums that mediate communication flow and the people that build and maintain these mediums. Often, when building solutions to bring Internet in low-resource settings, we face a variety of related problems: unstable electrical grids [49], lack of middle-mile or last-mile connectivity infrastructure, lack of internet exchange points and traffic localization, over-reliance on wireless networking and increased non-congestive failures, and so on. The key here is to move beyond broad assumptions about networks in these environments and to instead ground the work in a specific location. For example, many IXPs (and specifically African IXPs) are making increased use of remote peering [13–15, 19, 41, 45]. This seemingly 'wrong' practice [1] instead mitigates other issues seen by IXPs, such as interconnect complexity. Other examples like spectrum can have a significant impact of access and quality of service and experience. It is incredibly important to approach our work from a research

[1] Remote peers hide hop count from BGP.

from a point of view that provides us a contextualized **understanding of why 'things' are the way they are to provide richer understanding of what is possible.**

6.1 Corollary: Errors are local

As has been seen in (what we consider) seminar prior work [49], when working in challenging environments the hardest problems to solve are often ones caused by physical problems. While software errors will almost certainly continue (as researchers aren't traditionally the best software engineers), software issues tend to be transitory and relatively easy to resolve assuming that network connectivity hasn't been affected. Conversely, hardware issues can inherently require a "truck roll" and are difficult to understand remotely as system failures can be complete.

For this, our only advice is to (1) understand this reality when designing the network and (2) set up measurement infrastructure that can capture some subset of physical errors. For us, this has included a raspberry pi conducting network performance, OS watchdogs that detect disconnections quickly, and (as mentioned above) quick pathways for user reports. Additionally, training of local staff and users in the basics of network functions can also dramatically speed up responses.

> Story - Super Typhoons: *"As a positive story, the UP networks were deployed in an area where supertyphoons hit regularly; like three times a year. A big part of the training was about hardening the equipment, and communities, for this inevitability. I was never able to publish this, but one time one came through and the UP team wasn't able to come out to help. The community not only tore the network down to protect it through the storm, but also set it back up afterwards. To me, this speaks to the value of training and the value of the system."*

> Physical Story - Geckos: *"A small palliative care clinic in Malawi was attempting to restructure their IT infrastructure to extend connectivity to different parts of the clinic beyond the main office. We worked with them to design a new local network architecture which required a central server for LDAP and Samba services. The existing LDAP server would intermittently shut-off and the backup would not even start up. After addressing the issues with the first, we spent hours attempting the diagnose the issue with the second. After opening up the server and removing the fan, we found the dry and skeletonized remains of a house gecko wedged between in the blade and wall of the fan. We were eventually able to remove the gecko's remains and re-install the fan. We learned that when attempting to debug issues in the field: first look for bugs, then look for geckos."*

6.2 Corollary: Scale is overrated

We consider it important to understand that some networks have natural sizes. While this point was made eloquently in prior work [22], it seems appropriate to reiterate in this document as well. Not all organizations seek to take over the world; many have smaller goals that are situated within their community, region, or country. Due to the influence of the "five computers" [2], there's a general feeling that the only successful network research operates on their international scales, crossing administrative and national boundries to provide services. While engineering for these organizations remains critical to the overall growth of the network, literally thousands of other ASs and IXPs exist and provide the foundational elements of the Internet's interconnect. We consider supporting them, and other organizations that bring the network to places that the current Internet ecosystem does not, something that should be a first-tier goal of the research community.

> Story - Scale: *"In our early days, after every successful deployment, we'd go to our partners and beat the drum for scale. 'Let's do it again!' However, it almost never happened. It took years to understand that the stakeholders in place were interested in covering their communities, not becoming regional ISPs. Unwilling to switch to work with organizations far from the communities, we began our exploration of federated models that better support different organizations working together. Essentially, we scale by finding new partners, not scaling existing ones."*

7 CALL TO ACTION

Despite the difficulty of the problems being tackled in this work, it is important to note that there are unique opportunities as well. By working with populations underserved by traditional (often market) systems, many new insights can be generated. Indeed, this is a key reason to work with such partners; they invite extreme novelty in all levels of system design. Moreover, learnings from community can similarly demonstrate reasons for alternative solutions. Lastly, the lack of "one-size-fits-all" solutions suggests the generality sought in many systems designs and encourages the broadening of our field.

While we believe that the above stories and lessons will be helpful to researchers starting to explore deploying networks in difficult areas and with marginalized populations, we are very aware that we learn more with every installation. Similarly, a big part of enjoying this type work is celebrating and supporting the diversity of Internet users, system designs, and infrastructure choices made on in the long tail of access. As such, we hope this work (and its eventual presentation at the workshop) can be a call to action to compile such lessons from the broader research community, especially those from communities and areas that have not engaged with researchers before, and present them in venues with junior researchers or particularly excited practitioners, such as SNIP3+ or the IRTF's GAIA. If interested in sharing your own stories, please reach out to the authors and help us on the next steps.

ACKNOWLEDGEMENTS

The authors thank the many communities and community members who have guided all of the associated research. This work was funded under NSF award number 2125101 and the Public Interest Technology Network.

[2] Amazon, Microsoft, Google, AliBaba, Netflix

REFERENCES

[1] [n. d.]. Altermundi. http://altermundi.net/. ([n. d.]). Online.

[2] [n. d.]. Rhizomatica. https://www.rhizomatica.org/. ([n. d.]). Online.

[3] Abdelnasser Abdelaal (Ed.). 2013. *Social and Economic Effects of Community Wireless Networks and Infrastructures:*. IGI Global. https://doi.org/10.4018/978-1-4666-2997-4

[4] Yaw Anokwa, Thomas N Smyth, Divya Ramachandran, Jahanzeb Sherwani, Yael Schwartzman, Rowena Luk, Melissa Ho, Neema Moraveji, and Brian DeRenzi. 2009. Stories from the field: Reflections on HCI4D experiences. *Information Technologies & International Development* 5, 4 (2009), pp–101.

[5] David E Avison, Francis Lau, Michael D Myers, and Peter Axel Nielsen. 1999. Action research. *Commun. ACM* 42, 1 (1999), 94–97.

[6] John Z Ayanian and Joel S Weissman. 2002. Teaching hospitals and quality of care: a review of the literature. *The Milbank Quarterly* 80, 3 (2002), 569–593.

[7] Roger Baig, Lluís Dalmau, Ramon Roca, Leandro Navarro, Felix Freitag, and Arjuna Sathiaseelan. 2016. Making Community Networks Economically Sustainable, the Guifi.Net Experience. In *Proceedings of the 2016 Workshop on Global Access to the Internet for All (GAIA '16)*. ACM, New York, NY, USA, 31–36. https://doi.org/2940157.2940163

[8] Somprakash Bandyopadhyay, Kazuo Hasuike, S Horisawa, and S Tawara. 2001. An adaptive MAC protocol for wireless ad hoc community network (WACNet) using electronically steerable passive array radiator antenna. In *Global Telecommunications Conference, 2001. GLOBECOM'01. IEEE*, Vol. 5. IEEE, 2896–2900.

[9] Shaowen Bardzell and Jeffrey Bardzell. 2011. Towards a feminist HCI methodology: social science, feminism, and HCI. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 675–684.

[10] Mary Claire Barela, Mae Sincere Blanco, Philip Martinez, Miguel Carlo Purisima, Kurtis Heimerl, Matthew Podolsky, Eric Brewer, and Cedric Angelo Festin. 2016. Towards Building a Community Cellular Network in the Philippines: Initial Site Survey Observations. In *Proceedings of the Eighth International Conference on Information and Communication Technologies and Development*. ACM, 55.

[11] Luca Belli, Bruno de Souza Ramos, Panayotis Antoniadis, Virginie Aubrée, Roger Baig Viñas, Aris Dadoukis, Paolo Dini, Mélanie Dulong de Rosnay, Nicolas Echániz, Spencer Sevilla, et al. 2018. The community network manual: How to build the Internet yourself. (2018).

[12] Nicola J Bidwell. 2020. Women and the sustainability of rural community networks in the global south. In *Proceedings of the 2020 International Conference on Information and Communication Technologies and Development*. 1–13.

[13] Ignacio Castro, Juan Camilo Cardona, Sergey Gorinsky, and Pierre François. 2014. Remote Peering: More Peering without Internet Flattening. *Proceedings of the 10th ACM International on Conference on emerging Networking Experiments and Technologies* (2014).

[14] Nikolaos Chatzis, Georgios Smaragdakis, Jan Böttger, Thomas Krenc, and Anja Feldmann. 2013. On the benefits of using a large IXP as an internet vantage point. *Proceedings of the 2013 conference on Internet measurement conference* (2013).

[15] Nikolaos Chatzis, Georgios Smaragdakis, Anja Feldmann, and Walter Willinger. 2013. There is more to IXPs than meets the eye. *Comput. Commun. Rev.* 43 (2013), 19–28.

[16] Michaelanne Dye, David Nemer, Josiah Mangiameli, Amy S Bruckman, and Neha Kumar. 2018. El Paquete Semanal: The Week's Internet in Havana. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. ACM, 639.

[17] Philip Garrison, Esther Han Beol Jang, Michael A Lithgow, and Nicolás Andrés Pace. 2021. " The Network Is an Excuse": Hardware Maintenance Supporting Community. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW2 (2021), 1–20.

[18] Sucheta Ghoshal and Amy Bruckman. 2019. The Role of Social Computing Technologies in Grassroots Movement Building. *ACM Transactions on Computer-Human Interaction* 26, 3 (June 2019), 1–36. https://doi.org/10.1145/3318140

[19] Vasileios Giotsas, George Nomikos, Vasileios Kotronis, Pavlos Sermpezis, Petros Gigis, Lefteris Manassakis, Christoph Dietzel, Stavros Konstantaras, and Xenofontas A. Dimitropoulos. 2018. O Peer, Where Art Thou? Uncovering Remote Peering Interconnections at IXPs. *IEEE/ACM Transactions on Networking* 29 (2018), 1–16.

[20] Shaddi Hasan, Claire Barela, Matthew Johnson, Eric Brewer, and Kurtis Heimerl. 2019. Scaling Community Cellular Networks with CommunityCellularManager.. In *NSDI*.

[21] Shaddi Hasan, Yahel Ben-David, Max Bittman, and Barath Raghavan. 2015. The Challenges of Scaling WISPs. In *Proceedings of the 2015 Annual Symposium on Computing for Development*. ACM, London United Kingdom, 3–11. https://doi.org/10.1145/2830629.2830637

[22] Shaddi Hasan, Yahel Ben-David, Max Bittman, and Barath Raghavan. 2015. The challenges of scaling wisps. In *Proceedings of the 2015 annual symposium on computing for development*. 3–11.

[23] Shaddi Hasan, Kurtis Heimerl, Kate Harrison, Kashif Ali, Sean Roberts, Anant Sahai, and Eric Brewer. 2014. GSM whitespaces: An opportunity for rural cellular service. In *Dynamic Spectrum Access Networks (DYSPAN), 2014 IEEE International Symposium on*. IEEE, 271–282.

[24] Shaddi Hasan, Amar Padmanabhan, Bruce Davie, Jennifer Rexford, Ulas Kozat, Hunter Gatewood, Shruti Sanadhya, Nick Yurchenko, Tariq Al-Khasib, Oriol Batalla, Marie Bremner, Andrei Lee, Evgeniy Makeev, Scott Moeller, Alex Rodriguez, Pravin Shelar, Karthik Subraveti, Sudarshan Kandi, Alejandro Xoconostle, Praveen Kumar Ramakrishnan, Xiaochen Tian, and Anoop Tomar. 2022. Building Flexible, Low-Cost Wireless Access Networks With Magma. (Sept. 2022). http://arxiv.org/abs/2209.10001 arXiv:2209.10001 [cs].

[25] Gillian R. Hayes. 2011. The relationship of action research to human-computer interaction. *ACM Transactions on Computer-Human Interaction* 18, 3 (July 2011), 1–20. https://doi.org/10.1145/1993060.1993065

[26] Kurtis Heimerl, Shaddi Hasan, Kashif Ali, Tapan Parikh, and Eric Brewer. 2013. An experiment in reducing cellular base station power draw with virtual coverage. In *Proceedings of the 4th Annual Symposium on Computing for Development*. ACM, 6.

[27] Kurtis Heimerl, Shaddi Hasan, Kashif Ali, Tapan Parikh, and Eric Brewer. 2015. A longitudinal study of local, sustainable, small-scale cellular networks. *Information Technologies & International Development* 11, 1 (2015), pp–1.

[28] Kathryn Herr and Gary L. Anderson. 2015. *The Action Research Dissertation: A Guide for students and faculty*. SAGE.

[29] Tigist Shewarega Hussen, Nicola J Bidwell, Carlos Rey-Moreno, and William D Tucker. 2016. Gender and participation: critical reflection on Zenzeleni networks in Mankosi, South Africa. In *Proceedings of the First African Conference on Human Computer Interaction*. 12–23.

[30] Internet Society. [n. d.]. Community Networks. https://www.internetsociety.org/issues/community-networks/. ([n. d.]). Online.

[31] Lilly Irani, Janet Vertesi, Paul Dourish, Kavita Philip, and Rebecca E Grinter. 2010. Postcolonial computing: a lens on design and development. In *Proceedings of the SIGCHI conference on human factors in computing systems*. ACM, 1311–1320.

[32] Esther Jang. 2020. Community Networks in Seattle: A call to action. (Nov 2020). https://medium.com/seattle-community-network/community-networks-in-seattle-a-call-to-action-b11e944d0a19

[33] E. Jang, M. C. Barela, M. Johnson, P. Martinez, C. Festin, M. Lynn, J. Dionisio, and K. Heimerl. 2018. Crowdsourcing Rural Network Maintenance and Repair via Network Messaging. In *Conference on Human Factors in Computing Systems (CHI)*.

[34] Esther Jang, Philip Garrison, Mary Claire Barela, Ronel Vincent Vistal, Thessa Cunanan, Philip Martinez, Mia Perez, Matthew William Johnson, Andoy Evangelista, Ishtiaque Ahmed, Josephine Dionisio, and Kurtis Heimerl. 2019. Trust and Technology Repair Infrastructures in the Remote Rural Philippines: Navigating Urban-Rural Seams. In *Proceedings of the 22nd ACM Conference on Computer Supported Cooperative Work and Social Computing (CSCW) 2019*. ACM.

[35] Matthew Johnson, Spencer Sevilla, Esther Jang, and Kurtis Heimerl. 2018. dLTE: Building a More WiFi-like Cellular Network: (Instead of the Other Way Around). In *Proceedings of the 17th ACM Workshop on Hot Topics in Networks (HotNets '18)*. ACM, New York, NY, USA, 8–14. https://doi.org/10.1145/3286062.3286064

[36] Matthew William Johnson, Esther Han Beol Jang, Frankie O'Rourke, Rachel Ye, and Kurtis Heimerl. 2021. Network Capacity as Common Pool Resource: Community-Based Congestion Management in a Community Network. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW1 (2021), 1–25.

[37] Matthew William Johnson, Esther Han Beol Jang, Frankie O'Rourke, Rachel Ye, and Kurtis Heimerl. 2021. Network Capacity as Common Pool Resource: Community-Based Congestion Management in a Community Network. *Proceedings of the ACM on Human-Computer Interaction* 5, CSCW1 (April 2021), 1–25. https://doi.org/10.1145/3449135

[38] Thomas S Kuhn. 2012. *The structure of scientific revolutions*. University of Chicago press.

[39] Neha Kumar, Susan M Dray, Christian Sturm, Nithya Sambasivan, Laura S Gaytán-Lugo, Leonel V Morales Diaz, Negin Dahya, and Nova Ahmed. 2017. HCI Across Borders. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems*. 3065–3072.

[40] Kgopotso Ditshego Magoro and Nicola J. Bidwell. 2022. *Land, Letsema and Leola: Digital Transformation on a Rural Community's Own Terms*. Springer International Publishing, Cham, 59–78. https://doi.org/10.1007/978-3-031-12825-7_4

[41] Fabrício M. Mazzola, Pedro de B. Marcos, Ignacio Castro, Matthew J. Luckie, and Marinho P. Barcellos. 2022. On the Latency Impact of Remote Peering. In *Passive and Active Network Measurement Conference*.

[42] Shree Om, Carlos Rey-Moreno, and William David Tucker. 2015. Towards a scalability model for wireless mesh networks. (2015).

[43] Detroit Community Technology Project. 2015. Teaching Community Technology Handbook. *New America's Resilient Communities: New York* (2015).

[44] Carlos Rey-Moreno. 2017. Supporting the Creation and Scalability of Affordable Access Solutions: Understanding Community Networks in Africa. https://www.internetsociety.org/resources/doc/2017/supporting-the-creation-and-scalability-of-affordable-access-solutions-understanding-community-networks-in-africa/. (23 May 2017).

[45] Philipp Richter, Georgios Smaragdakis, Anja Feldmann, Nikolaos Chatzis, Jan Böttger, and Walter Willinger. 2014. Peering at Peerings: On the Role of IXP Route

Servers. *Proceedings of the 2014 Conference on Internet Measurement Conference* (2014).
[46] Horst W Rittel and Melvin M Webber. 1974. Wicked problems. *Man-made Futures* 26, 1 (1974), 272–280.
[47] Mennan Selimi, Amin M Khan, Emmanouil Dimogerontakis, Felix Freitag, and Roger Pueyo Centelles. 2015. Cloud services in the guifi. net community network. *Computer Networks* 93 (2015), 373–388.
[48] Spencer Sevilla, Matthew Johnson, Pathirat Kosakanchit, Jenny Ting Liang, and Kurtis Heimerl. 2019. Experiences: Design, Implementation, and Deployment of CoLTE, a Community LTE Solution. In *Proceedings of the 25th Annual International Conference on Mobile Computing and Networking (MobiCom) 2019*. ACM.
[49] S. Surana, R. Patra, S. Nedevschi, M. Ramos, L. Subramanian, Y. Ben-David, and E. Brewer. 2008. Beyond Pilots: Keeping Rural Wireless Networks Alive. In *Conference Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation*. Berkeley, CA, USA.
[50] Various. 2018. Global information society watch 2018. Community networks. *Association for Progressive Communications* (2018).
[51] Davide Vega, Llorenc Cerda-Alabern, Leandro Navarro, and Roc Meseguer. 2012. Topology patterns of a community network: Guifi. net. In *Wireless and Mobile Computing, Networking and Communications (WiMob), 2012 IEEE 8th International Conference on*. IEEE, 612–619.
[52] Etienne Wenger. 1999. *Communities of practice: Learning, meaning, and identity*. Cambridge university press.
[53] Mariya Zheleva, Arghyadip Paul, David L Johnson, and Elizabeth Belding. 2013. Kwiizya: local cellular network services in remote areas. In *Proceeding of the 11th annual international conference on Mobile systems, applications, and services*. ACM, 417–430.

APPENDIX - MORE STORIES

Physical Story - Roaches: *"A few years into the deployment in Indonesia we had reached a steady state: hardware repair was done locally (with successful examples like hard drive replacement) while software was managed remotely over VPN. Unfortunately, a new outage arrived and it looked bad: nothing would boot despite power being good. After a long discussion, the basestation had to come down and the local team discovered that the weatherproofing had gone. However, the weather wasn't the issue. Instead, we learned that (1) bugs love RF, (2) cockroach urine is conductive, and (3) motherboards are easy to short."*

Human Story - Spectrum: *"While working with partners to deploy novel networking tools into a rural Indonesian village, it became apparent that the best answer would require use of licensed spectrum. As this was an extremely remote area, there was zero chance of collision with incumbents at that time. We went to the local regulator to ask for permission but were told essentially 'stop talking to us'; they could not help but didn't want to sink the project. We went on with building the system which has remains operational after over a decade. Spectrum policy is driving the rural-urban gap, and that was out of scope for a technology project."*