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Infrastructuring at the Margins: Studies in Community Networking

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Abstract

Infrastructuring at the Margins: Studies in Community Networking

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This work provides three case studies of people claiming power over technology through DIY infrastructure building activities within diverse settings of technological marginality, both rural and urban. These studies are conducted in the context of ongoing community network (CN) projects—networks established, owned, and/or managed by local users in a “bottom-up” or collaborative manner [35]—that I worked on during my PhD. The first study presents the material hardships of achieving local technology repair in remote rural cove communities in the Philippines in terms of seams between heterogeneous urban and rural infrastructures. To patch these seams, people dynamically construct intermittent and informal repair infrastructures based on trust. Despite structural challenges, the remote communities are able to maintain a robust ecosystem for electrical line repair, from which we generalize the model of *training grounds*—requirements for sustaining an ecosystem of practicing local experts and shared expertise, or a *community of practice* [255]. The model emphasizes the importance of in-context “actual” problems as well as access to resources such as tools and expert knowledge.

In the second study, I make use of the training grounds concept to establish an operational community of practice for building and maintaining a community broadband network for marginalized

residents and neighborhoods in an urban North American context. Through qualitative analysis of participant interviews from the Seattle Community Network (SCN) ¹ and NYC Mesh as well as my own participant observer journals from 2020-2023, the research surfaces grassroots infrastructuring processes by which CN participants embed their values and intentions into the network's socio-technical infrastructure, shaping deployed artifacts. We present a model for a non-profit, education-focused CN, termed a *community learning network* (CLN), that builds power among participants and produces a *learning commons* for in-context hands-on technical learning. Finally, we identify technical dilemmas and tradeoffs related to CNs' dependence on powerful institutional partners who contribute resources and mediate participation.

The third case also demonstrates situations where power is held by owners who contribute land to unhoused communities for use as Tiny House Villages (THVs); these power relationships constrain and shape the housing, utility, and technology infrastructure that residents can build and maintain. Through participatory design workshops of networked sensing applications with residents of two self-managed THVs where network access is served by SCN, the study investigates parameters for successful IoT interventions among low-resourced urban groups experiencing housing precarity. We identify how land ownership (public or private), management, and the local regulatory environment affect the ways in which residents can use and modify infrastructure, and how historical and current zoning of the land shapes the types of social problems that the community must navigate. Residents installing sensors or other utility infrastructure encounter the limitations of DIY and ad-hoc approaches, often mandated by resource constraints; the resulting infrastructure reproduces underlying precarities related to the residents' housing status. Meanwhile, they impose additional constraints on sensor designs for their collective protection,

¹distinct from the Seattle Community Network Association (SCNA), which was founded in the 1990's and active through the 2000's [222]

such as a strict ban on camera-based visual or audio surveillance and a preference for local as opposed to cloud data storage. They also identify opportunities for diverse sensors and actuators to improve village accessibility and alleviate resource sharing tensions.

Major Themes

All three chapters center a *DIY and hands-on approach to infrastructure*. Chapters 1 and 2 highlight the importance of *communities of practice and pedagogy* for creating long-term structural change through participation. I emphasize pedagogy as a strategy for facilitating engagement of groups who might otherwise be marginalized within technical communities of practice.

In all three cases, we find that infrastructure is composed not primarily of technical artifacts but the people whose actions produce and maintain them, and whose relationships, values, and constraints shape them. Chapters 1 and 2 describe processes by which *relational infrastructure* influences the form and function of technology. Chapters 2 and 3 make extensive use of *participant observation* methodologies, where the researcher is a participant in the activity or context being studied. I argue in Chapter 2 that such reflexive methodologies can help technology developers capture and reflect on the values and ethics, collective or personal, that shape the products they design.

Table of Contents

	Page
List of Figures	iii
List of Tables	iv
Chapter 1: Introduction	1
1.1 This Thesis	3
Chapter 2: roots Trust and Technology Repair Infrastructures in the Remote Rural Philippines	11
2.1 Introduction	12
2.2 Related Work	15
2.3 Context	20
2.4 Methodology	23
2.5 A Challenging Repair Ecosystem	27
2.6 Trust and Remoteness	38
2.7 “Training Grounds:” A Case of Robust Rural Repair	43
2.8 Discussion: Implications for HCI and ICTD	49
2.9 Conclusion	51
Chapter 3: stem “Seattle Community Network”: A Model for Grassroots Infrastruc- turing of a Technical Learning Commons	52
3.1 Introduction	53
3.2 Related work	55
3.3 Methods	61
3.4 Background: SCN	65
3.5 Findings	72
3.6 Discussion	91
3.7 Conclusion and Takeaways	98

Chapter 4: leaves Participatory Design of IoT in Self-Managed Tiny House Villages .	100
4.1 Introduction	101
4.2 Related Work	104
4.3 Methods	113
4.4 Context: Tiny House Villages	115
4.5 Results	121
4.6 Discussion: Challenges and Opportunities	141
4.7 Conclusion	148
Chapter 5: Concluding Thoughts	149
5.1 Loose Threads	150
Acknowledgments	153
Bibliography	159
Appendix A: Chapter 1: Area Profiles	182
A.1 Dikapinisan	182
A.2 Dibut	184
A.3 Diotorin	185
Appendix B: Chapter 2: SCN Community Governance	187
B.1 Monthly Community Meetings	187
B.2 Visioning Documents	187
B.3 Work Processes	188
B.4 Community Building Processes	188
B.5 Community Roles and Authority	188
B.6 Communication Tools	189
B.7 Online chat platform	189
B.8 Diverse and accessible contact methods	190
B.9 Network monitoring and management	190
Appendix C: SCN Seattle Report 2022	191
Appendix D: CN Roadmap	253

List of Figures

Figure Number	Page
2.1 The three cove sites of this study, Dibut, Diotorin, and Dikapinisan, are on the east coast of Luzon island, and the nearest large town is Baler.	21
2.2 In the closest urban center, Baler, a laptop is being debugged in one shop (left), and a TV is being repaired in another (right).	30
2.3 Two typical boats preparing to leave Diotorin. The vessels moving between the cove sites are generally small and open air, making it difficult to keep belongings dry when seas are rough.	35
2.4 A set of local repair tools (left) and "stocked" nonfunctional TVs in Dibut (right) .	43
3.1 SCN community LTE site installations	68
3.2 LIHI Southend Village network map.	89
3.3 (Read from bottom to top) The social and relational infrastructure of SCN (bottom blue half) underlies technical (yellow) and social (orange) activities, and ultimately technology and tool design/choices (red). Pink arrows represent infrastructuring processes (styled solid for upward layering, dashed for downward feedback).	92
3.4 Examples of how specific elements in lower layers of SCN’s infrastructure “stack” lead to specific technology and tool choices (especially software). Layers are color coded as in Figure 3.3, turned clockwise for readability.	93
4.1 Nickelsville CD WiFi map, showing the village layout via a satellite-view image (Google Maps). Photo credit: Seattle Community Network	119
4.2 Nickelsville Northlake brown water sample, collected by residents and shown to researchers in Sep. 2023. Photo Credit: ANON	126

List of Tables

Table Number		Page
3.1	Interviews conducted. The interviews reflect existing gender (self-identified, Masc vs Fem) imbalances in volunteer CN participation; future work specifically aims to recruit more femme-identifying interviewees.	62
3.2	Network sites by partner organizations, type, region/location, and year installed, as of Feb 2024. Abbr- OCC: Oromo Cultural Center, SPS: Seattle Public Schools, KCLS: King County Library System, TPL: Tacoma Public Libraries, LIHI: Low Income Housing Institute.	86
4.1	A summary of Ostrom’s design principles of Common Pool Resource (CPR) governance [198], adapted from [153].	105

Dedication

I dedicate this thesis to all of my future students and co-conspirators, and anyone who wishes to leverage open-source technologies in service of their broader communities. Godspeed.

Chapter 1

Introduction

The structure of this thesis reflects the arc of my projects over the past 8 years, rooted in experience with small-scale rural community network (CN) initiatives around the world and grown into local infrastructure in Seattle, from which local and global impacts may flower.

The 2020 pandemic dramatically increased the importance of internet access in people's daily lives, by forcing critical government and commercial services as well as human interaction online. The GSMA reports that as of 2023, 95% of the population lives within the footprint of a mobile network. However, only 52% living in Low and Middle-Income Countries (LMICs) and 25% in Least Developed Countries (LDCs) use mobile internet, with their chief barriers to access being affordability of devices and digital literacy skills [180]. Within the field of Information and Communication Technologies for Development (ICTD) [49] over the past two decades, there has been much research interest in community networks as a technological intervention to

ameliorate lack of access in rural remote or impoverished areas, where access challenges stem from inadequacy of existing infrastructure [121, 7] or lack of local people with the knowledge or authority [145] to operate the infrastructure and manage its pricing. Network solutions for these settings, including the open-source 4G LTE cellular networks deployed in this work, have been designed to address economic feasibility (through low cost), robustness (through 'ruggedization'), and sustainability and repairability (through community management). Meanwhile, CNs also carry inherent politics [258]—they are established, owned, and/or managed by local users in a “bottom-up” or collaborative fashion [35], often with political commitments to DIY (“do-it-yourself”) practices [80], open source principles [72], or common good. Those who implement and support community networks constitute a global “community of practice” (CoP) with a shared goal of defending all communities’ “right to co-create the Internet” [35] on their own terms.

Even in resource-rich urban areas like Seattle, where network coverage and technical expertise are plentiful, CNs can still flourish for many reasons. They can provide more affordable access for low-income users or in public spaces, higher privacy to avoid surveillance, or flexibility in disaster relief contexts [24, 116, 192, 92]. Low-income or unhoused people and other marginalized groups face similar barriers to those in rural areas, including device access, low digital literacy, and lack of affordability, especially in underserved neighborhoods [69]. Further, urban and rural CNs often have similar design goals, i.e., making network installation and extension affordable, easy, or enjoyable to implement and maintain for people without specialized skills [72, 192, 97, 3]. Given these goals, urban CNs have also historically preferred to implement wireless over wired networks. Thus, global CN developer communities share overlapping technologies and political perspectives across urban and rural settings, and products of urban resources, research, and development (as in the cellular network case [158, 114]) are often mobilized and motivated by rural initiatives. For example, the QuintanaLibre network in rural Argentina is run largely by the local hacker collective Altermundi, which maintains urban membership and participation as well

as developers who have moved to rural Quintana from nearby cities [97].

This thesis attempts to weave together my experiences and understandings from the varied CNs I have worked with throughout my graduate studies, which include NYC Mesh, SCN, Telecomunicaciones Indígenas Comunitarias (TIC AC) in rural Mexico, Altermundi’s networks in Argentina, a Nation of Hawaii network in Waimanalo, the University of the Philippines’s 2G networks in rural Aurora Province, and sovereign Tribal networks I have met as an instructor at Tribal Broadband Bootcamps [254]. By finding through-lines and knitting together shared communities of practice across urban and rural settings, I hope to help strengthen a base of solidarity and support among CN practitioners (including myself).

Through the SCN project, presented in Chapter 2, I have been able to gain a detailed and embodied knowledge of what it means to build and maintain a local community network from the positionality of a graduate student in computing. This project has become a “stem” or “backbone” that will support further community-engaged work, as demonstrated in Chapter 3, which builds on SCN’s existing partnerships with local Tiny House Villages to investigate networked sensing applications tailored for their mid-scale use case between city and home IoT. Other impacts that SCN has made in terms of internet access, device distribution, and community pedagogy are detailed in Appendix C, a 2022 report submitted to the City of Seattle. In Appendix D, I have also provided a “CN Roadmap” produced with collaborators at Athabasca University in Canada, intended as a field guide to establishing community networks in the North American context but with principles broadly applicable elsewhere.

1.1 This Thesis

This work provides three case studies of people claiming power over technology through DIY infrastructure building activities within diverse contexts of technological marginality. In all three, we see that infrastructure is composed not primarily of technical artifacts but the people whose

actions produce and maintain them, and whose relationships, values, and constraints shape them.

1.1.1 Threads

DIY and hands-on infrastructure building

All three chapters center a DIY and hands-on approach to infrastructure. In Chapter 1, practice in real-world repair scenarios is found to be crucial to successful learning of technical repair skills for both electronics and electrical grid infrastructure. In Chapter 2, CN implementers use a DIY approach to build a cellular access network and emphasize hands-on, experiential learning with equipment as essential to building community knowledge and power among participants. In Chapter 3, Tiny House Village residents and developers augmenting the CN with networked sensors encounter the limitations of DIY and ad-hoc approaches to housing infrastructure resulting from underlying land and housing precarities.

Trust and relationships as infrastructure

Chapters 1 and 2 highlight the influence of relational infrastructure in the form and function of technology, whether in the context of rural repair where networks of trust underlie the transfer of parts and labor as well as hands-on repair skills and knowledge (Chapter 1), or in the context of bottom-up CNs where participants and their relationships contribute values and resources that shape the physical infrastructure they build (Chapter 2).

Participant observation

As DIY infrastructuring projects conducted by the researchers, the studies in 2 and 3 make extensive use of participant observer field notes as data sources, where the author is a participant in the activity or context being studied. I argue in Chapter 2 that this methodology can help technology

developers capture and reflect on the values and ethics, collective or personal, that shape the products they design.

Communities of practice and pedagogy

Finally, Chapters 1 and 2 emphasize the importance of communities of practice and pedagogy for creating long-term structural change through participation, particularly among marginalized groups with less initial exposure to computing technologies. Chapter 1 introduces the concept of “training grounds” for nurturing a community of practice, which shapes the understandings presented in Chapter 2 of how CNs like NYC Mesh and SCN can cultivate a robust community of participants with the skills and knowledge to build and maintain critical infrastructure. Chapter 2 also forefronts pedagogy as a strategy for facilitating engagement of groups who might otherwise be marginalized within a technical community of practice.

1.1.2 Chapter 1: | roots | Trust and Technology Repair Infrastructures in the Remote Rural Philippines

Research Questions and Methods

Through a qualitative interview study of 32 repair technicians in three isolated cove communities and the small city nearest to them in Aurora Province, Philippines, we investigate how technology repair occurs in remote rural settings, and what challenges repairers face. This study was part of a collaboration with community cellular network deployments in these communities by Barela et al.’s team at the University of the Philippines, conducted to explore how existing rural repair infrastructure could be leveraged to keep the cellular networks operational over time.

Core Contributions

We find that remoteness from supply chains, centers of knowledge, tools, and resources shapes these communities' access to technology, including computing devices, electronics, vehicles, and electrical infrastructure. Despite the challenges, residents succeed in patching together a repair infrastructure heavily based on interpersonal trust that meets some of their needs. We find an especially robust repair system for government-supported rural power infrastructure, and build a theory of “*training grounds*” for sustainable, hands-on communities of practice around repair: (1) Material resources for repair such as tools and parts, (2) Access to practicing experts or expertise to acquire new information and skills, (3) Real repair opportunities as learners or apprentices to gain experiential knowledge, and (4) Local, accessible institutions for formal education and certification (enabling, but not required). Finally, we highlight the importance of sustainable life-cycle design and local repairability for technologies to prevent e-waste buildup in remote areas.

1.1.3 Chapter 2: | stem | “Seattle Community Network”: A Model for Grassroots Infra-structuring of a Technical Learning Commons

Research Questions and Methods

Inspired by NYC Mesh, DCTP's Equitable Internet Initiative, Altermundi's QuintanaLibre network, and many others, in 2019 I started the Seattle Community Network (SCN) as an action research project to understand urban marginalized communities' barriers to Internet access, and establish an operational CN to address those barriers. We asked whether and how local, community-owned wireless infrastructure could improve digital equity in a developed urban setting, but also how SCN could balance goals centering equity with cultivating a robust technical volunteer base. The study presents a qualitative analysis of participant interviews from SCN and NYC Mesh as well as my own participant-observer journal entries from 2020-2023 as I worked on SCN, and centers power as an analytical lens.

Core Contributions

We find that SCN participants' values of social contribution and aspirations as technology learners have shaped it into a "Community Learning Network," a created space and "learning commons;" we further characterize it as a "transformative social innovation" [200]. This created space builds power among participants by fostering a Community of Practice (CoP) that builds knowledge and solidarity, both among individuals and mission-aligned local organizations. We propose mechanisms and examples of how participants and their values, relationships, and the social structures they define become embedded in the technical infrastructure they deploy via grassroots infrastructuring processes. Community- and relationship- building activities that influence participant engagement, such as teaching and collective governance, are thus foundational infrastructuring activities for CNs and other grassroots initiatives. We find that relational infrastructuring conducted by participants grows SCN like a mesh network, with multiple points of entry and distribution for resources and power.

We further argue that the project's structure facilitates the expression of power through critical and enabling contributions of infrastructure and resources by mission-aligned institutional partners, allowing the CN to leverage some of their power. However, these contributions shape and constrain both physical and relational infrastructure, mediating future activities and participation. In order to reveal these infrastructuring processes in their work, we propose that engineers and designers use personal process journaling as a tool for ethical technology design to help track the decision-making processes involved.

1.1.4 Chapter 3: | leaves | Participatory Design of IoT in Self-Managed Tiny House Villages

Research Questions and Methods

Through an ongoing partnership with the Seattle Community Network (SCN), which operates free WiFi and internet infrastructure at Tiny House Village (THV) shelters, we explore the co-design of “smart village” sensing systems through participatory design workshops and iterative prototyping cycles with residents. Run by the local nonprofit Nickelsville, the two THVs in our study are self-managed by formerly unhoused residents who collectively organize for political advocacy; their multi-resident scale present a middle ground between home- and city-level IoT, offering opportunities for novel community-driven applications and technical innovation. We also investigate implications of sensing technologies for resilience, collective politics, and data sovereignty in contexts where people experience housing *precarity*, or a state of persistent insecurity.

Core Contributions

We find that ownership in design processes does not imply ownership in implementation. These self-managed THVs struggle with precarities in their housing infrastructure based on underlying insecurities faced by their residents as well as a collective lack of ownership and agency over their land use arrangements. Residents impose constraints on their sensors for the group’s protection, favoring privacy measures such as a strict ban on camera-based surveillance even over security benefits it would afford. At the same time, they depend upon and embrace practices of DIY infrastructure building, even for critical utilities such as water, to work around barriers such as high costs. They also identify opportunities for diverse sensors and actuators to improve village accessibility and alleviate resource sharing tensions.

Positionality Statement

I grew up in New York City in the 2000s in low-income neighborhoods without fast Internet access at home, but with highly educated immigrant parents who valued academics. As a young teen I spent most of my free time at libraries and bookstores, and came to wonder what I would have done without them. I vividly remember once crouching under the awning in front of a library in the evening snow, trying to finish a large download on my netbook just about thirty minutes after closing, when the download suddenly slowed to a crawl and stopped.

I was a community organizer before I was a scientist. I volunteered in a number of “third place” environments that encouraged self-directed learning and civic engagement, including a Korean-American youth organization for immigrant advocacy and my high school’s science laboratory where a Liberian teacher organized students to collect equipment donations for Liberian schools. I have long since held personal goals to establish or enable such learning environments for both young people and adults.

In the third year of my PhD, as my work in the Philippines ran out of funding, I struggled to find another project that felt both academically and personally meaningful. On visits to my hometown in 2019, I became involved with NYC Mesh and was inspired by its vibrant community of social justice-minded network technicians to start a community network in Seattle. In 2020 amidst the Covid-19 pandemic, upon securing our first County and City funding, I was able to fully dedicate myself to organizing and technical learning towards building SCN, giving me a mission and therapeutic outlet in a world that had dissolved into chaos. I see the SCN community, and the broader global CN community of practice, as a small seed of utopia “built in hell” [233]. Working with these communities of practice has allowed me to develop the hands-on skills and experience to teach others as well as contribute to network sovereignty initiatives such as the Tribal Broadband Bootcamps [254].

Now on the cusp of graduation, my long-term career vision is to connect academic and tech for

social good communities with lower-resourced or marginalized communities in humanizing, just, and fruitful ways. I have found throughout my work that while installing technical and physical infrastructure can help solidify relationships and hold communities together, human networks are what ultimately make infrastructure-building possible, forming the underlying crucible of social change. Despite my passion for technical networking, my research has moved towards qualitative methodologies and pedagogy due to a desire to understand the deeper factors that can empower people to mobilize technology for social transformation. I hope my work will not only spark change in Seattle but in communities around the world. I hope that my future students' work will also reflect and produce direct first-person engagement with marginalized communities, amplifying their voices to drive policy change and infrastructural support.

Chapter 2

| Roots |

Trust and Technology Repair Infrastructures in the Remote Rural Philippines

Abstract

This paper analyzes the processes and challenges of technology repair in remote, low-income areas far from standard ICT repair infrastructure. Our sites of study are the fishing and farming villages of Dibut, Diotorin, and Dikapinisan in Aurora Province, Philippines, located in coastal coves against a mountain range. Residents are geographically isolated from urban areas, with the nearest peri-urban center of Baler a boat trip of several hours away, infeasible in some sea conditions. Unlike prior work in more connected rural areas, there are no local repair shops and device repair is uncommon, despite frequent breakage due to harsh conditions for electronics.

The scarcity of local electronics repair limits technology access and leads to accumulation of e-waste. While prior work demonstrates that local electronics repair capability does arise in many rural areas around the world, we must also acknowledge that the successful emergence of this infrastructure depends on the intersection of many structural conditions and cannot be taken for granted.

We present the material hardships of achieving local repair in terms of seams between heterogeneous urban and rural infrastructures, which illustrate the cove communities' marginality with respect to many forms of public infrastructure. However, intermittent and informal repair infrastructures based on trust relationships emerge to patch these seams in remote settings. We show how trust affects the way people dynamically construct repair infrastructure and why, based on their remoteness and the resulting value propositions of repair. Networks of trust between repairers, their clients, suppliers, fellow repairers, and certifying or training institutions crucially facilitate the movement of resources and expertise across the Philippines, but also reinforce the marginality of residents and repairers in the coves. Despite these structural challenges, local people are able to maintain a robust ecosystem for rural electrical line repair, from which we generalize the model of *training grounds* as a strategy for sustaining local communities of repair experts.

2.1 Introduction

Information technologies, especially mobile phones and associated networks, underlie much of the critical social infrastructure that billions of people rely upon every day. These devices are used daily for purposes such as health [166], education [154], and finance [42]. With their increasing importance and abundance comes growing pressure to address their maintenance, repair, and disposal.

Prior work has shown that these devices are often supported by a robust ecosystem of pro-

professionals specifically trained in the effective repair and maintenance of aging IT infrastructure. People learn for years how to handle common failures (such as broken screens), navigate software locks, and distribute media [232], enabling increased longevity and reduced waste. To date, studies have largely focused on urban areas (such as the capital city of Bangladesh [139]). Those that focus elsewhere, such as densely populated rural environments (e.g., the capital of a rural area in Namibia [140]), still see readily available parted-out devices, digital junkyards, and certified or trained personnel. Thus, these areas already fall within the ambit of the broader urban-centered infrastructure of repair.

The coastal communities of Aurora, Philippines represent geographically isolated areas more loosely connected to this kind of infrastructure. They are reachable from the nearest town center with repair shops by a several-hour boat ride, but they are cut off periodically during typhoon season each year as the seas are often too rough to travel. Even when seas are calm, basic services such as health care and remittance centers are too far away for quick access. Such communities face particularly challenging circumstances in terms of technology use and repair.

In this chapter we seek to de-center the discourse on rural ICT repair in HCI away from repair shops, even those in rural areas, to include communities lacking this sociotechnical infrastructure. These communities, many of which are located in extremely remote rural areas throughout the world, conduct and interact with repair in different, underexplored ways. Making technology more accessible to these populations requires a more inclusive understanding of repair infrastructure informed by the experiences of these remote places. It is instructive to learn how technology use and repair happens in these communities through their own efforts to transcend the limitations of their geographical isolation, as well as their more general exclusion or marginality with respect to other public infrastructure such as education and commerce. We interpret these combined efforts as an attempt to insist on inclusion in a technology-driven world, to provide what the system denies, and to subvert the imposed construction of their places as remote. Further, we advocate

for electronics repair infrastructure that is more accessible to these remote communities, and open the discussion on how to encourage or facilitate it.

To this end, we investigate the ecosystem of technological devices and infrastructure and the networks by which they flow between urban and remote rural areas, as well as their passage between life stages—new, old, functional, broken, repaired, re-purposed or discarded. We take a systems [59] view of repair in these coastal areas to understand how people, infrastructure, and equipment interact; systems theory addresses the *whole* social-material network and prompts us to look for interrelationships and distant connections that shape how repair does and does not happen. Through this lens we characterize the systems of repair in the Philippines as a geographically distributed and seamful patchwork [253] of overlapping and sometimes disconnected local heterogeneous infrastructures, where the locations of seams are both created by and perpetuate context-dependent challenges. We use the language of seams rather than gaps or barriers to emphasize that local people do dynamically construct their own infrastructures to overcome these challenges, as similarly described in Jack & Jackson’s work on logistical infrastructures [134]. This perspective also helps us to reveal trust, both interpersonal and system-trust [176], as critical to the activity of repair and a factor in the dynamic creation of the repair ecosystem.

We find that such challenges often tip the balance towards replacement as the more practical option over repair, even in rural Aurora where travel is difficult, and typhoons and low quality power pose consistent threats to electronics’ continued function. For example, the intersection of low economic resources and the difficulty and intermittency of sea travel reveals seams between urban and rural repair infrastructures that can be fragile. Specific tools, parts, and knowledge for electronics repair are rarer in these rural areas, so device owners must bear monetary and time costs for sea and sometimes cross-country transport as well as parts and labor, along with the inherent risks of attempting repair. These costs often outweigh that of cheaply made new items, which will again break quickly and perpetuate the cycle.

As a result, repair ecosystems which are robust and functional in the capital city of Manila and the “peri-urban” provincial capital of Baler largely exclude the broken devices present in the coves. This limits technology access and sustainability, and perpetuates digital divides both between rural and urban areas and wealthy and poor users. It also results in large amounts of stagnant e-waste, often from discarded TVs and other large, frequently replaced devices.

Despite the challenges, communities succeed in patching together a repair infrastructure that meets some of their needs. We find a robust repair system for government-supported rural power infrastructure, maintained by knowledgeable local repairers who can overcome difficulties due to weather and remoteness. Leveraging Leigh Star’s idea that sociotechnical infrastructure reveals itself upon breakdown and failure [239], we investigate what infrastructure is really required to make repair happen in these challenging environments.

This research contributes a description and analysis of how: (1) repair occurs in these remote, isolated communities, (2) remoteness shapes and creates a trust-based social infrastructure that can implement repair, and (3) HCI and CSCW can reenvision sustainable design and local empowerment to help mitigate the e-waste generated by the technology life-cycle in remote areas.

2.2 Related Work

2.2.1 HCI and Repair

HCI has a central interest in design and use of technologies that has often sidelined our experiences with their after-use moments: obsolescence, malfunctioning, repair, recycle, etc. However, a growing body of work in HCI and related fields has begun to shed light on those moments [241, 197]. These seminal works point to the imperfection, instability, fallibility, and biases in technology, and call for human art, knowledge, craft, innovation, and collaboration to fix them.

In recent years, a series of ethnographic work on repair has been conducted in different parts of the world that builds on that theoretical framing. For example, Jackson et al. studied electronic

repair practices in rural Namibia and showed how those efforts are connected with an international network of knowledge and materials [141, 140]. Jackson further developed the idea of a “broken world” that needs to be addressed with care [135]. Ahmed et al. studied mobile phone repair work in Dhaka, Bangladesh, and documented the art, craft, knowledge, and skills involved in their work [11]. Other studies in varied global contexts [10, 128, 139, 127, 217, 261, 138] discussed how repair work involves many human qualities that are often undervalued in a larger context of globalization, capitalism, and free economy. Repair is also found to be a viable business in the bustling underground markets of Bangladesh [10] and the semi-formalized “tech-shops” of Namibia [140].

2.2.2 Urban vs. Remote Rural Repair

While these prior studies have illuminated many aspects of repair practices, they have largely focused on visible core elements of functional repair infrastructure, such repair shops or professionals. We instead focus explicitly on areas lacking these infrastructures, seeking to build a more inclusive understanding of repair that renders visible the context-specific challenges and solutions of people in extremely remote, low-income communities.

As a consequence of their focus on functioning repair ecosystems, prior studies on rural electronics repair have largely focused on more connected areas, for example areas being reachable by road and/or larger in population. As such, their observations of repair infrastructure are very different from ours. In Wyche’s work with mobile phone repairers in rural Kenya [261], most rural interviews took place in agricultural market centers such as Chwele (60,000 residents) and Webuye (22,507). These settings more closely resemble our “peri-urban” provincial capital, Baler (39,000), than our cove sites (500 to 2,000 residents). Similarly, Jackson’s work on phone repair in rural Namibia [140] mainly focuses on Rundu (63,000 residents), the regional capital. While the study includes the smaller villages of Divundu (5,430) and Nkurenkuru (618), each is about a

two-hour drive from Rundu on a well-established national highway.

Meanwhile, prior work on appropriate technology in rural low-resource communities such as de Laet and Mol's Zimbabwe Bush Pump paper [74] has emphasized the importance of local engagement and management structures for the continued function of rural infrastructure. Work on NGO logistical infrastructures [134] and seamful spaces in infrastructure [253] have also highlighted the necessity of local actors' efforts in maintaining and aligning multiple heterogeneous infrastructures to achieve their goals.

In our cove communities, we seek to understand the role of local actors and infrastructure in repair. In contrast to less remote settings, there are no local repair shops, for electronics or otherwise. Repair happens by, for example, walking over to *kuya*'s¹ house and asking whether he's available to help before he heads out to the fields. This informal social context for repair stands in stark contrast to the professional, highly visible, busy, and/or salaried repairers' work in the aforementioned studies. When such professionalism, expertise, and business profits are stripped from repair work, the tensions surrounding it radically change. This chapter contributes to the body of work on repair by focusing on places where repair is irregular or informal and expanding on the social arrangements in which it happens. We contribute findings on (1) occasional and irregular repairers, and (2) tinkerers who have informal relationships with businesses and governments.

2.2.3 Trust

We draw on Luhmann's formalization of trust [176] to inform our analysis of the integral roles and forms of trust involved in repair work, especially in remote areas. Luhmann proposes that people build social systems in order to manage complexity within an environment where uncertainty about the states of people and objects (such as how well a device is functioning) increase over time,

¹*Kuya* is a Filipino term of respect for a man, akin to an older brother.

and frames trust as a mechanism for reducing that complexity. Citing psychological theory, he says trust can increase tolerance of uncertainty—for example, the uncertainty that a given repair attempt by a particular repairer will succeed. Our analysis explores a number of forms of trust: trust in a device to continue to function, trust in the expertise and good faith of a repairer, and trust in acquaintances or kin based on interpersonal relationships. The former two we associate more closely with Luhmann’s category of system-trust, or trust in a system (such as the process of formal certification in repair), while the latter can be seen as interpersonal trust. He also describes the ability of trust to be “object-mediated”—for example, in our setting of repair, through a contract or warranty certifying the trustworthiness of a replacement part.

2.2.4 Disposal and Reclamation

Concurrent to the repair discussion is an investigation of the disposal of computer equipment, especially common user-facing devices such as mobile phones and desktop computers, and the flows of this e-waste. Discarded devices are sent to recycling centers, landfills, and refuse areas near consumers [251]. In wealthy countries, rather than bury this damaged hardware, waste companies ship it to poor countries for recycling [106]. This supply of e-waste can lead to negative outcomes, such as poor health for reclaimers, but these landfills do provide a source of raw materials and a mechanism for training and learning new skills. As Jenna Burrell notes [53], youth working in the “computer import industry” in Ghana repurpose discarded computing equipment into computers for the local market as well as recycled raw metals. Lepawsky et al. went in search of e-waste in Bangladesh and instead noted that, “Amidst all this stuff we could hardly find any waste. Almost everything had value. Every object. Every component. Every material” [173].

In contrast, we find that cove residents have some limited opportunities for scrapping and recycling e-waste. However, many damaged devices are left to sit in houses and sheds with no plans for movement as it is too expensive to ship back to urban reclamation centers. Pollution of

local water and soil [105] and economic waste in the constant replacement of devices follow.

2.2.5 Infrastructure

We use the concept of infrastructure to frame our discussion of repair and maintenance. Susan Leigh Star [238] conceives of infrastructure as embedded within social structures and notes that, when successfully maintained, technical infrastructure achieves a degree of invisibility. As Graham and Thrift [104] point out, the social dependencies of infrastructure are made visible by crashes and failures, when people must be mobilized to restore service. We see the social structures and material factors needed for maintenance and repair as themselves infrastructure, especially in disaster-prone environments where breakdowns are frequent.

Jackson and colleagues argue that standards for infrastructure represent embedded politics, and are set with assumptions that are hard to comply with for people of differing privileges [137, 136]. Many examples show how large technical infrastructures require literacy, money, expertise, legal status, and certain physical and psychological abilities to meet those standards. Lacking these characteristics, many people become detached from infrastructure-provided services and experience “residuality.” This is often depicted in the struggles of refugees [221], or in the uncertainty that characterizes the lives of people living in isolated areas like the Aurora coves. The difficulties of acquiring, using, and maintaining personal devices, which are also designed, produced, and embedded within a system of internationally and politically defined standards, echo those of operating infrastructure.

Thus, large infrastructure embodies and extends power, and how people repair breakdowns in infrastructure can reflect these politics. For example, Surana et al. [243] found that failures of telecommunications infrastructure were often correlated with associated infrastructure, such as power. His team advocated for keeping laypeople away from equipment and building multiple layers of fault tolerance. This is supported by a local Philippine telecom, PLDT, who asserts that

up to eighty percent of service interruptions are caused by third-party action [96].

In contrast, a recent body of work shows how non-professionals can bring their creativity, innovation, and skills to maintain, fix, and extend infrastructure. For example, Ahmed et al. [12] have shown how evicted slum dwellers used their skills, innovation, and collaboration to make necessary extensions to existing infrastructure. Similarly, Jang et al. found that laypeople in another rural Philippine context had some of the skills necessary for repair of local telecommunications infrastructure [145]. This chapter builds on this work on infrastructure, repair, and the involvement of marginalized communities and compares the largely functional practices in electrical infrastructure repair with a largely inadequate device repair ecosystem. We imagine new initiatives that could create more resilient technologies and communities.

2.3 Context

Our sites of study are the cove communities of Dibut, Diotorin, and Dikapinisan, located on the northeastern coast of Luzon island in the San Luis municipality of Aurora Province (see Figure 2.1). The coves face the Pacific Ocean and are isolated from the nearby peri-urban center of Baler by the Sierra Madre mountain range.

2.3.1 Provincial Centers

Baler and the nearby San Luis town center are provincial centers where local government and other regional administrative offices are located. Baler has businesses serving the Aurora province—such as banks, retail shops, and other service centers—and a robust local tourism industry. Both towns have paved roads, grid power, running water, and 4G cellular service. Electricity is provided throughout the province by the public cooperative Aurora Electric Cooperative (AURELCO). However, electrical outages (“brownouts”) are frequently experienced throughout the province. In our experience, land travel from the Philippine capital of Manila to Baler takes 6-8 hours.



Figure 2.1: The three cove sites of this study, Dibut, Diotorin, and Dikapinisan, are on the east coast of Luzon island, and the nearest large town is Baler.

2.3.2 Cove Communities

From Baler, boat travel to the coves can take 1-3 hours, with this time doubling during monsoon season. The only alternative is a full-day's walk over unpaved, thickly forested, and mountainous terrain. Due to their location, the cove sites frequently experience storms, strong winds, and typhoons, especially during September through December. These sites are also not reached by terrestrial television and radio broadcasts, and are unserved by national telecommunications companies. They are served electricity by AURELCO, but service is considered unreliable; the relatively affluent have on their own solar panels or generator sets. Water is sourced through pumps, wells or from streams where a DIY pipe network carries it to individual homes.

Dikapinisan is the largest and most prosperous of the three communities (population around 2,000) and the only one with both an elementary and high school. Dibut is the second largest around 900 residents, nearly all members by blood or marriage of the Dumagat indigenous tribe of northern Luzon. Diotorin is the smallest (around 400 residents). Dibut and Diotorin have an elementary school, but must send their children to board in Baler or Dikapinisan to continue school.

From a baseline survey conducted in November 2016, 50% of households are below the \$2.00 poverty line and 90% are below the \$5.00 purchasing power parity poverty line. Most people earn their income through subsistence farming and fishing, where harvested produce is often sold at big markets in Baler. In exchange, cove residents rely on Baler for consumer items such as canned goods, toiletries, and other household items to be resold in the coves.

2.3.3 Collaborative Community Profiles

The research team has been engaged continuously with these communities for the past few years in collaboration with an ongoing technology access project called the VBTS Project [28]. As part of our engagement in the coves, we held discussions in each site to learn about the place, people,

and their shared history and to produce a collaborative text to better include the communities in their own representation. We produced the full text of the area profiles (see chapter addendum) from the transcripts of those discussions, filtered through our own perspective as observers and researchers. As a sample, these excerpts from Dibut's profile detail some important local features, culture, and issues that also came up frequently during our interviews on repair, though they are not directly related to repair:

We have two leaderships, tribe and barangay², but they still have proper communication and solidarity with each other.

We sell [banana and coconut] outside, but we cannot complain to [the produce traders] because the price and profit is set beforehand. This had been the cause of our problems and is why the farmers are on the losing side. Now, our product prices are quite low, but we are still grateful that we have something to cook.

We have a clean environment, which is one of our important characteristics. We have a rich forest, because most of our areas here are still virgin forests with large trunks. Barangay Dibut is proud to firmly stand for the trees, despite whatever calamity we face, because these are God's treasures.

The reason why we do not get jobs is because of the lack of education. A percentage of [the children] need to graduate to be able to work with machines. But we cannot finish school because of the lack of income.

2.4 Methodology

2.4.1 Interpretive Framework

The ontological framing we use in this study is of the people, material resources, practices, and the networks of relationships between them that interact to implement repair as a sociotechnical

²Dibut and Dikapinisan are *barangays*, roughly translated as “villages” or “wards”, while Diotorin is a smaller *sitio*, or locality, within the larger barangay of Dibayabay.

system, and as infrastructure. We examine this infrastructure not as an external entity that imposes and controls actors' decisions and practices, but rather as constructed dynamically by people's activities around repair, which in turn set up patterns that guide further actions. There is not one monolithic "repair system" but many, which overlap and abut each other. Moreover, these repair systems are constantly being re-created, while what we present in this chapter is merely a snapshot, which may make some fleeting associations appear solid.

2.4.2 Sampling Rationale

Sites.

Our engagement with these communities began as a collaboration with the existing Village Basestation (VBTS) Project by Barela, et. al. [28]. VBTS is focused on deploying community-managed cellular network infrastructure in seven sites in rural Aurora. The VBTS Project prompted our discussions around repair, providing a motivation to study and mobilize or improve existing local repair infrastructure to support the sustainability of VBTS. For our IRB-approved study, we chose three coastal sites of the seven which we expected to have the greatest needs in terms of repair infrastructure as they are the most isolated (detailed in Section 2.3). We conducted observations and interviews in these sites and also in Baler, when it became clear as a central location repeatedly referenced by local repair actors.

People.

Our primary goal was to discover the existing local repair infrastructure in the coves by meeting and interviewing people who do technology repair for cove residents about their practices. We started by interviewing key informants with various leadership roles in each cove community about their repair practices as users of technology, regardless of whether they considered themselves repairers. The VBTS Project's prior experience and engagement with these small communities

was that local leaders would know almost every resident; these leaders included, for example, the Barangay Captain ³, the school principal, teachers, pastors, the Dumagat Chieftain, and local technical maintenance officers for VBTS. Based on the precedents and engagement patterns set by our partners, and seeking not to disturb these relationships to their detriment, we used the same working relationships to seed our recruitment process. We also interviewed others who seemed eager to talk with us whenever possible to increase sample diversity.

From there, we used snowball sampling by asking participants who they knew with technical skills, or who they would go to for help with repairing broken devices. We followed these referrals when possible, including to Baler. An underlying assumption was that local residents would know each other well enough that asking around would reveal those with technical expertise, although we understand that this assumption could have caused us to miss repair practices as a private hobby, for example among homemakers without named employment. We also assumed that technical or repair people within a given locale would be more likely to know of each other based on similar domain knowledge, context, and activities, again biasing our findings towards those with publicly visible technical jobs who are typically men in these contexts. We realize additionally that elected officers may have been biased by political alliances in their referrals, though we expected the combination of other seed interviewees to balance this potential bias. As the communities are small and we reached saturation for referrals, we believe we found the members of the cove communities who practiced repair on behalf of others in a publicly visible fashion.

2.4.3 Data Collection

We conducted 24 semi-structured interviews with 32 people in the three cove sites and 6 interviews with 8 people in Baler over a period of six weeks starting in May 2018. The interviews in Baler

³head of the local government

were all with repairers (1 woman and 7 men) and took place in repair shops in their normal work setting. Those in the coves took place in the entryways or receiving areas of interviewees' homes, and our sample included both repairers and non-repairers (8 women and 24 men). We also include notes from field observations of the VBTS project sites between January and August 2018. All names used in this chapter are pseudonyms.

The semi-structured interviews included questions about electronic devices or appliances owned, stories of broken or repaired items, own repair expertise, other repairers inside and outside the community, technical education or work if relevant, and sources of parts and tools. If participants had no experiences with device repair to draw upon, we asked about repair of other technologies, especially those involving electricity. Questions were added and modified as the study progressed based on emerging themes in our data as in grounded theory, which were identified through memoing and post-interview debriefs.

Four researchers from a Filipino research university and three researchers from a US-based institution performed data collection. All interviews were conducted in Filipino by one or more Filipino researchers, except for one interview in Baler that was conducted in English at the participant's insistence. All interviews were audio recorded and were transcribed and translated to English by native Filipino speakers. Interviews were augmented with notes taken during collection.

The Filipino researchers are local to the Philippines and knowledgeable about regional cultural context but not local to Aurora. The US authors are neither from the Philippines nor fluent in Filipino, and they relied on the Filipino authors for linguistic and cultural understanding through all stages of the research.

2.4.4 Data Analysis

Data analysis began with post-interview debriefs among the research team. After the last interview, we coded the interview transcripts using a combination of open codes (e.g., “Disposal/Waste”, “Desire for Cell Phone Repair”) and initial research questions as codes (e.g., “What breaks and how often?”). Coding was conducted primarily by US authors with only basic Filipino comprehension, mostly on the English translations. Coded data was synthesized from the perspectives articulated in the Interpretive Framework. Our first theme, remoteness, was identified as central to an initial research question, “What are the challenges to repair in the coves?” Our second theme, trust, was identified as central to another research question: “How does repair happen in the coves?”

2.5 A Challenging Repair Ecosystem

We now describe the repair ecosystem in the coves: the devices present, how they break down based on the particular challenges of the environment and context, and how repairers and device owners make repairs in the remote coves and in Baler.

2.5.1 Relating Remoteness and Technological Marginality

To repair a device, four material ingredients must be brought together: a damaged device, any needed spare parts, a person with repair skills and knowledge, and tools for doing the repair. In the coves we find an emergent repair infrastructure built atop existing material and human flows arising from informal social networks and interpersonal relationships. However, we also observe processes by which devices readily drop out of these flows to become waste.

In the following sections we describe the environmental and contextual challenges that contribute to the cove communities’ effective marginality and exclusion from a technological “center.” We identify the following major challenges to technology function in these communities: (1) limited overall access to devices, (2) harsh environmental conditions for electronics, and (3) lim-

ited information flows. Further, we discuss the consequences for repair of these challenges and their intersection with geographical disconnectedness and broader infrastructural (including technological) marginality.

Limited Device Ecosystem

A limited device ecosystem in the coves results in low availability of technology and experience with technology for end users, as well as low availability of parts for repairers upon breakdown.

The three sites follow similar patterns of household device ownership; most households own at least one basic cell phone, an electric fan, and a television usually paired with a satellite TV receiver and dish. However, the TVs are often very low quality and of widely different models without interchangeable parts, as one Dibut repairer noted. Households typically do not keep computers, though high school or college students staying in Baler may own and use them there. Boat owners may have a solar panel and battery on their boats for lighting at night, and a few wealthier families have a solar set at home for lighting during the frequent grid outages.

School teachers often have personal laptops, and a few laptops and desktop computers can typically be found at the local elementary or high school. However, most school teachers neither reside in nor have family in the coves, and return home via Baler once per week when possible. At the time of field work, school computer labs in all three barangays were in states of long-term disrepair, with only a few usable units and typically not enough to support classroom activities.

Environmental Challenges to Electronics

Many specific environmental challenges shorten the lifespan of electronics in these communities and increase the need for repair or replacement.

First, the infamous "sea breeze," or *umido* (also translated as "humidity"), describes the tendency for coastal air containing moisture and high salt to corrode exposed metals, leaving a hardened

layer of white crystals that cannot be removed. Both repair technicians and laypeople, particularly in the education sector, talked about the harms of the sea breeze to both electrical infrastructure and devices. The Diotorin Elementary principal described a stopgap measure to protect the school computers from the moist air by wrapping them in clothing before leaving school.

Frequent severe storms, also called “calamities,” were reported to lead to TV damage, possibly due to power surges or water entry leading to shorts and corrosion. Many houses in the coves, designed for a tropical climate, maximize airflow by having open walls or windows with wooden bars instead of glass, potentially exacerbating water entry. Both mechanisms can result in serious damage to electronics. During field work, the researchers came to expect one or more power outages per week. Furthermore, the outages limit the usage of devices that consume electricity, especially those without batteries such as desktop computers.

Stalled Information Flows

The software update and security exploit ecosystems as they exist today force us to think of some computing devices as perpetually in need of repair in the form of updates and patches, to protect against new and opportunistic ways for the device to be broken.

Among the few computers present in the communities, we were told of many software-related issues due to an update ecosystem that assumes stable Internet connectivity. Dikapinisan Elementary’s six computers were unusable at the time of field work because the antivirus was not up-to-date: “*that’s why it hangs but isn’t broken.*” Due to the lack of Internet access in Dikapinisan, an update would require bringing the computer to Baler by boat. Computer repairers in Baler confirmed that the most common problem brought in from the coves was due to teachers’ laptops with viruses (e.g., spread over USB) in need of reformatting. Sneakernets [125], the use of physical media like USB sticks for network connectivity, are one mechanism for distributing updates in these situations [70], but we did not notice any such practices in the coves.



Figure 2.2: In the closest urban center, Baler, a laptop is being debugged in one shop (left), and a TV is being repaired in another (right).

2.5.2 A Patchwork Repair Infrastructure

Remote Rural Repair: A Desire for Trusted Expertise

Initially surprised to find no repair shops in these areas despite the frequency of breakage, we asked participants about local resources for device repair and their own practices. The majority responded that there were no local electronics experts, and the typical path was to travel to a shop in Baler if repair was needed. However, replacing rather than repairing devices was the most common practice, often followed by “stocking” broken items in storage without a clear purpose in mind. A repeated sentiment was that repairing their devices in Baler did not make sense financially due to the high costs of labor, replacement parts, and boat travel (around PHP 100 or USD 2 per way), as well as risks such as sailing during bad weather and the uncertainty of how long the repair would revive the device before it broke again.

Upon insisting on local repair, we were told of a few professional repairers linked to the

community through familial or friendship ties, who occasionally visit the coves bringing spare parts and tools with them. However, they are only transiently available, for perhaps a week or two once a year. They will often spend the whole week of their visit fixing a large backlog of broken TVs, leaving many devices unfixed.

In one special case, the unusually well-connected, wealthy Dibut school principal is able to call on her sibling for repair, which sometimes has broader community benefits. As she described: *“I don’t let unskilled people fix stuff. My sibling, who is an electrician [of the town hall of San Luis], goes here... If there’s something broken. I let him sit on [my] boat... [He comes] whenever I say. Last week, he was here twice. [...] I had him install our e-classroom.”*

We were referred to one local expert repairer, Teodoro, who had worked in Manila for 6 years repairing TVs and other electronics before settling down in Dibut as a farmer. With his limited personal set of tools, he does what he can as a favor to his neighbors for only partial fees (the cost of parts plus PHP 100, or whatever they can pay). However, he faces substantial challenges getting access to critical parts, more expensive tools, and information needed for repairs. This is in part due to his social exclusion from networks for part-sharing among repairers who know each other in Baler. In his words, *“[People] seldom ask me for repair because I do not have a source for parts. I would have to source it outside. And when I do source it outside, they do not give me parts [in Baler]... They reserve the parts for their own repairs.”* Instead he must buy parts in Manila, a full day’s travel away at considerable expense (around PHP 750, or USD 15). Despite his known expertise, resource limitations prevent Dibut residents from relying on him fully for their repair needs.

Underlying these responses, we note a dominant understanding of repair work as expertise rather than say, general technological literacy. Trust in a repairer’s expertise, whether based on credentials or experience, emerges as a requirement for repair work to happen, regardless of its availability locally. As a substitute, people rely on their network of personal relationships to

recruit trusted experts to meet their repair needs.

A different form of trust, embedded in interpersonal ties, is mobilized to enable the bridging of geographical distances, the use of alternative supply chains, and the identification of a pool of reliable repairers. However, in this case a lack of such ties between the coves and repairers with supply chains in Baler results in an emergent exclusion and social marginality for remote cove residents. Baler's potential as a hub for repair for the coves remains unrealized and hampered by exclusionary practices.

Countering exclusion with self-reliance, among Diotorin residents we found hints of a quiet culture of individual tinkering and DIY for fixing simple appliances. At the same time, respondents emphasized that they were not experts and would not volunteer to repair for others, asking them to place trust in their ability. One group of men said, *"The usual practice here is if no one comes yet to do repairs, try to do it yourself if you can..."* Jobert, another self-described tinkerer, explained, *[I] only [repair] for myself. Sometimes, [others] ask me to repair. I repair [their things] if possible. I only repair the easy ones like broken flashlights. If I can solder it, I do it. [...] Actually, I tell others that I don't know how to repair. [...] I don't brag [...] [T]here are other people who know more than me.*

We note that in Filipino culture the concept *masyadong pabida* refers to the rude act of brazenly volunteering or "putting oneself out there" too much without being asked or communally acknowledged. As researchers we consider that this humility may be a polite hesitance to suggest they might be better than others in their community, and potentially masks skills and capabilities that remain invisible.

Urban Repair: Ever Increasing Centralization of Repair Work

Even in Baler, itself considered a provincial town by its residents, repair is challenged by its distance from high-resourced urban centers such as Manila. However, repair shops exist and regularly overcome these challenges.

These shops are full of broken and spare machines; scavenging from irreparable devices and sharing of rare parts between personally connected repairers are common. As computer repairer Bienvenido explained, *“You can just find [CPU wire] here nearby where those are also repairing... You should have many friends so you can just help one another. If, for example, they are the ones in need, then they will come to me. Also if I am the one who needs anything. It’s a give and take for us, technicians.”*

Independent estimates from three different shops of the percentage of recycled components they use, for both computer and general electronics repair, were 70%, 80%, and 80-100%. We note that hardware repurposing and sharing practices here are similar to the Indian concept of *jugaad*, “an arrangement or a work-around which has to be used because of lack of resources,” documented among Mumbai mobile phone repairers [208].

Even so, from Baler as well as from the coves, we see patterns of movement to areas of greater centrality in search of more trusted expertise and material resources, mobilizing social relationships between people and institutions. For example, one computer repair shop sends difficult board-level repairs to a trusted “master technician” with more tools and expertise in the proprietors’ more urban hometown, Baguio City.

While consumer devices in need of repair flow readily from rural to increasingly urban areas, repairers and their expertise do not readily flow in the other direction. When we asked Baler repairers whether they would ever consider traveling to the coves, all said no for reasons including expense and the difficulty of successful repair: *“It’s far. Hassle. Unnecessary expenses.” “Just a waste of time when you didn’t finish anything.”* With enough work available locally from residents of Baler and all surrounding areas, it does not make financial sense for repairers to leave their well-stocked workshops. As a result, broken devices must move towards urban centers for repair, while training, specialized tools, and parts move by individual effort in the other direction.

2.5.3 Repair Despite Remoteness

Despite the time consuming, energy intensive, and costly nature of transport between urban areas and the coves, we found that residents' need for centralized resources and infrastructure such as paid work, education, and governance drives daily or weekly traffic to and from Baler, however lengthy or difficult. This regular individual effort forms an active transport network for people and goods between the coves and Baler. Designed to be resilient to interruption, it works to bridge the seams between many different urban and rural infrastructures, dynamically patching them together. At the same time, the coves' dependence reinforces Baler's centrality and the coves' marginality.

Robust Rural-Urban Human Networks Enable Repair

Many cove residents' mobile lifestyles, involving living in more than one place, enable the flow of materials across urban-rural infrastructural seams. Like many migrant workers across the Philippines, people from the coves hired for outside work often stay in larger towns for days or weeks at regular intervals. Christian Pastor Eduardo of Dibut explained, *"Most of us here stay in Baler, San Luis, some even in Manila to work."* Many farmers and fishermen also make regular trips to Baler to sell their goods, leading to daily boat traffic to and from the coves. Small objects like cell phones and letters hitchhike on this traffic.

People seeking specific resources such as access to education or certification infrastructures must also split their lives across multiple places. Nearly every Diotorin or Dibut parent we met with a high school age child (starting from Grade 7) had sent them to board in Baler due to the lack of a local high school. Maintaining the connections between students in Baler and their families involves frequent travel and regular visits, even during monsoon season when the sea can be too rough to travel for days or weeks. As a Dibut mother said, *"If the weather in the sea is bad, we walk."* From Dibut, the closest of the coves to Baler, travel by foot through the densely forested



Figure 2.3: Two typical boats preparing to leave Diotorin. The vessels moving between the cove sites are generally small and open air, making it difficult to keep belongings dry when seas are rough.

and mountainous terrain takes a full day.

For individual repair needs, a cove resident would typically bring their device to Baler, incurring the monetary costs and physical risks of travel. As described by local maintenance officer Carlos in Dikapinisan: *“we bring [devices] to Baler... For example, if my TV is broken, then I’m the one who will bring it to Baler... we ride boats for public commuting... [They go] almost everyday.”* On the boat ride, Dibut electrician George described, *“[An appliance] is packaged and stored in plastic so it won’t get wet and damaged.”*

2.5.4 Waste: Broken Devices Stuck in Purgatory

In Aurora we encountered a variety of processes for the creation, disposal, and recovery of e-waste from broken devices. On balance these processes lead to an accumulation of waste in the communities, due in part to the difficulty of repair and of waste transport to facilities or specialists

for reclamation or disposal. Stocks of broken and deteriorating devices remain that would have been quickly repaired, recycled, or disposed of in urban contexts.

Becoming Waste

Waste can be defined both by the lack of use of a device and the state of the equipment itself. Items become waste in a number of ways, such as upgrading to new devices, giving up on restoring their usability, or exposure to the elements eventually leading to irreparable damage. Repairing a broken object allows the owner to restore value to it and avoid waste. Even if the device is not repaired, leaving it at a repair shop, reselling it for parts, or extracting raw materials and selling them return value to the ecosystem. In sustainable design literature, this efficient life-cycling of devices is referred to as the “circular economy” [157].

However, as we have observed, the intersection of cove residents’ geographical remoteness, low income, and infrastructural marginality can increase the costs and risks of repair beyond what is seen as worthwhile. Furthermore, in some cases device owners forgo repair because they were already planning an upgrade, for example in favor of flat-screen over CRT TVs.

Though such equipment also incurs some transportation cost and risk, it avoids other risks. Many see repair as a fragile solution not expected to last more than a few months, especially when applied to what participants called cheap, “disposable,” or “China” appliances. Community members’ low incomes often lead to the purchase of cheaper devices that are *expected to fail* and are treated as such. During an interview at the public basketball court in Dikapinisan, a participant pointed out a phone that had been casually discarded as trash. *“You can find [a broken phone] loitering around here, sometimes. There’s one there.”* These dynamics reveal as part of the decision to repair a balance between trust in a new device to work as compared to trust in the repair process (or expert) to restore long-term function to a device.

The culture of replacement that emerges from this balance results in a net positive flow of

devices to the cove communities. For most people, who do not want or know how to reclaim materials from their devices, there is apparently no value proposition for their immediate removal as long as storage space is plentiful. Old devices commonly remain “stocked,” sometimes in open air near a dwelling, for long periods of time (see Figure 2.4). As an example, the researchers noted one front yard in Diotorin containing three TVs, one functional, and arranged for communal viewing and two sitting nonfunctional beside.

Unfortunately, without attention, devices will eventually degrade, losing most residual value. This process of storage and degradation has also been noted in other rural environments with other types of equipment [77], and it means that even functional but unused devices need some minimal maintenance lest they transition to waste.

Waste Recovery

Opportunities for device scrapping do exist in the coves, but they are infrequent and rewards are low for making the effort. Two Dibut residents told us of a big recycling boat that comes once a year for 5 days at a time to collect plastic, metal, bottles, broken TVs, and used appliances to melt down for copper in exchange for goods such as plastic basins and cheap jewelry. However, many interviewees do not find it worthwhile or do not know to take advantage of this trade-in.

One transient expert repairer who visits Diotorin once or twice yearly also “*buys damaged TVs, then gets the good parts*” to bring back to his workshop in Manila, but cannot take more than he can extract and carry on his own. Dibut’s local expert Teodoro also collects copper from the backs of broken CRTs and sells it to a junk shop in Baler for PHP 150 per kilo, amounting to only around PHP 30-50 (USD 0.6-1) per TV, less than the cost of the boat ride. However, he does this opportunistically with his own TVs and abandoned irreparable devices. These reclamation efforts, while helpful, are insufficient to meaningfully impact the amount of waste given the large volume and quasi-disposable nature of IT infrastructure brought into the communities.

2.6 Trust and Remoteness

The prior section introduced how repair happens materially in the remote coves and in semi-urban Baler. In this section we deepen our analysis of how various forms of trust are mobilized to overcome the challenges faced by increasingly remote repairers. Repair infrastructure is built on networks of trust, including personal relationships, obligations, reputation (of both people and components), institutional certification, and warranties. Those with repair expertise, which we define as the knowledge and latent ability of a person to repair, depend on the trust of clients who authorize repair. Repairers must trust other repairers to teach or learn from them and share resources such as tools and parts that are often hard to acquire new. They must also place trust in the sociotechnical systems that produce spare parts and other tools by relying on them; they dynamically build the repair infrastructure itself by choosing who and what to trust. These decisions, influenced by geographical remoteness and infrastructural marginality, shape who is entrusted with and can gain expertise in repair, and ultimately where repair can occur.

2.6.1 Networks of Trust to Get and Share Supplies.

In more remote environments with scant parts, networks of both interpersonal and system-trust among repairers and suppliers crucially facilitate the flow of spare parts and repair knowledge.

As noted in section 2.5, the primary sources of replacement parts in Baler are scavenging from other broken devices and the sharing of hard-to-find parts within professional or friendly repairer networks. Even when parts are purchased new or acquired across long distances from urban centers, networks and relationships of trust are crucial to the movement of resources. Every repair shop we encountered in Baler buys tools and replacement parts from Manila, with the exception of one repairer couple, Beo and Maria Clara, who source parts from Baguio (a city closer than Manila) where a family member ships them from particular trusted suppliers via a daily passenger bus.

Since quality and prices of parts can vary widely, sources and business relationships create competitive advantages. For example, during an interview with a college student employee at a hardware and repair shop, the owner overheard us asking where they source spare parts in Manila, which prompted him to stop our interview. He considered these details “*business secrets*,” not to be shared. Computer repairer Jose Maria prefers the twofold more expensive electronics market in Greenhills over the cheaper one in Quiapo (both in Manila) for motherboards because of the 6 month warranty as opposed to 1 month: “*It takes a month to deliver the package, so after that, if it breaks, the warranty is over.*” The difference Jose Maria highlights is not in the price or material value of a specific part, but in the contractually enforceable trust in the seller via the warranty.

The common practice of sourcing parts and goods from distant metropolises instead of local retailers, even from Manila over closer cities, reflects popular beliefs about electronics from more urban locations having higher quality. They are perceived as more trustworthy, perhaps due to less exposure of the systems that produced them to perceived risks such as counterfeiting, cheapness, or even just age associated with distribution time. Computer repairer Beo explained: “[A] lot of people here would rather go to Cabanatuan which is the nearest city here, or to Manila or to Baguio, to buy whatever tech things they need. Because it’s really more of a trust thing, because they feel like if you buy it from this retailer here [in Baler], ‘Oh that’s fake,’ or ‘You’re not that rich because you bought it here.’”

Likewise, networks of interpersonal trust between repairers exclude those who are not already familiar as friends or established as repairers. Teodoro from Dibut travels to Manila for parts because he does not have social connections to repairers in Baler. These practices again reinforce the marginality of more remote areas by increasing their central dependence.

2.6.2 Trust of Customers in Repairers

We also note the importance of the trust placed in repairers by clients who give them their devices to repair, which may manifest as system-trust in the repairer's qualifications or reputation as well as interpersonal trust if personal connections are leveraged or built up over time. Without this active trusting by the customer via giving up their objects to be unmade and remade, repairers would not have opportunities to practice repair and gain experience. A repairer in Baler described the trust required to hand over a computer to a shop: *"Mostly it's a trust thing here in the province. Because you would invest on a 20,000 peso [around USD 400] laptop and you earn a meager living. And then you will bring it to someone who will just swap out the parts and tell you it's dead."* He also mentioned that especially in the case of computers, strict data privacy was crucial to maintaining the trust of clients, who included both local government officials and political dissidents: *"Your doggy pictures and the top secret data that they have, it's the same thing here in the shop."*

Formal accreditation, reputation or recommendations via other repairers or former clients, and even simply the existence of a repair shop as an established place of business (not to be taken for granted) all serve as sources of trust, manifesting some definition of "expertise" or "professionalism" for people seeking repair. We note that all of these are much easier to acquire in typical urban contexts with repair businesses and training institutions than in geographically isolated areas with low population and relatively few devices.

2.6.3 Expertise and Training as Trust Relations, Mediated by *Aktwal*

Repairers in both the coves and Baler were clear that the best way to gain expertise and become more trusted with repair was through what they called "*aktwal*," not through formal education. The Filipino word *aktwal* (from the English "actual") refers to learning by manipulating a real system. The concept encompasses not just the passive observation of an "actual" system, but the active hands-on practice of "actual" repair or other technical work on real broken systems. Such

experiences typically had to be found outside of the context of formal education, for example during practical apprenticeships or other paid work.

Although seminars, schools, or degrees can provide important knowledge, one can learn to repair without them. Five of eight repairers we talked to in Baler had started undergraduate degrees related to electronics or computers, but only three had graduated, and two had finished degrees in unrelated fields such as Nursing. As Beo said, *“Being highly unregulated here in the Philippines, we are able to go into this business without even showing any requirement for us to be in the repair business.”* Beo’s wife and business partner, Maria Clara, now the primary repairer in their shop, learned repair through Beo and self-study: *“The first year, 80 percent of my knowledge came from my husband, so 20 [was] mine. Then after 3 years... when he went back to Baguio and studied; that was really the time that I dug into my knowledge. Google is my best friend.”*

In contrast, training or apprenticeships with experts is highly valued by repairers, as seen in other repair sites across the world [140]. Trainees can get access to the *aktwal* experiences they need to gain expertise by effectively borrowing the trust that customers have in the experts they learn from. One student repairer we met at a shop in Baler was pre-training before his degree-mandatory “on the job training” (OJT) in Manila to finish at the Aurora State College of Technology (ASCOT),⁴ showing institutional recognition of *aktwal*. Beo and Maria Clara explained that taking inexperienced OJTs fresh out of school was seen as a public service obligation for established shops: *“They (ASCOT) give out requests for us to take in some of their students.”* *“They don’t know how to really repair a computer, even a basic one with the CPU, because that’s the basic thing that you should know in repairing.”* We again note that these training environments are easier to find in urban centers, perpetuating the centralization and concentration of repair knowledge.

⁴A public technical college in Baler.

2.6.4 Trust and the Marginalization of Local Repairers

Distrusting Repairers “From Here”.

We noted a strong self-bias against trusting the expertise of electronics repairers in remote contexts. A Diotorin electrical lineman cited an expected lack of exposure or familiarity with equipment: *“If they are from here, they are hard to trust with things like [solar panels]... We rarely use solar panels here.”* Again we see that the limited availability of technology associated with geographical remoteness, low resources, and infrastructural marginality results in a practical disadvantage for obtaining “aktwal” experience and expertise. Cove residents do not expect those “from here” to have repair skills, especially for less common technology, unless it is known that they had formal training or practical experience from outside. This may be a reason for most local repairers’ extreme humility about their own skills, like the tinkerers from Diotorin in section 2.5, and may contribute to the bias that there are no repair skills in the coves.

Accessing Trusted Repairers from Outside.

In contrast, a large amount of trust is placed in the small group of transient visiting expert repairers who carry tools, parts, and expertise into the communities in response to familial or friendship obligations, leveraged by cove residents to achieve repair. These infrequent visitors make themselves available to a wide group of acquaintances, but overall demand is too high to meet.

Joshua, a repair shop owner in Manila, visits family in Diotorin once or twice yearly on holidays. A local government leader described, *“Since he is really handy in fixing things, before he arrives the people ready the things they want to have fixed... Probably since he is knowledgeable in electronics, he already knows what commonly breaks and brings the parts needed for those repairs. [...] Usually he stays for a week... Probably [he repairs] a lot [of devices] because his week’s stay is not enough to have everything fixed.”*



Figure 2.4: A set of local repair tools (left) and "stocked" nonfunctional TVs in Dibut (right)

Local repairers' strong trust in these visitors stands in stark contrast to their own humility. As Diotorin electrician Romeo commented, "*He is skilled and experienced like a master. [...] I know him because we are friends. [...] I trust him because he already mastered this.*" While the occasional presence of these experts can present learning opportunities for interested local repairers, the visits are also too short and intermittent to substitute for long-term apprenticeship or *aktwal*.

2.7 "Training Grounds:" A Case of Robust Rural Repair

Despite the challenges, we found robust local infrastructures for electrical line repair (for home wiring and public grid lines) in all three communities. Examining the factors leading to this success, we develop the concept of *training grounds* and how they create the conditions for successful and sustainable rural repair.

Electrical lines were installed in all three sites between 2006 and 2010, connecting them to grid power. Tools and parts are usually available locally, and numerous residents in each cove have

experience with these repairs. We met nine resident “electricians” or “linemen” in the coves who were readily able to repair public electrical lines serving their community and home installations.

We find that training grounds promote a healthy repair ecosystem by supporting the sustained growth and maintenance of a local repair community. We identify four factors, of which three are crucial to repair and define the training grounds, while the fourth supports and enables the others:

Training Grounds

1. Material resources for repair, such as tools and parts, must be readily available to both experienced repairers and trainees.
2. Trainees need access to practicing experts or expertise to acquire new information and skills.
3. Opportunities to practice “*aktwal*” repair as a learner or apprentice are required to gain experiential repair knowledge.
4. Locally accessible institutions for formal education and certification play an important role in enabling access to all three aspects of training grounds.

In the context of rural electrical repair in Aurora, AURELCO and the Technical Education and Skills Development Center (TESDA) in Baler provide relatively accessible institutional support for repair in the surrounding rural communities. Such institutions counteract the typical centralization of repair by extending the global network of trust, knowledge, and resources for repair to increasingly remote areas in a sustained way, as shown in the following cases.

1. Availability of Tools and Parts:

TESDA is known to give tools to trainees upon graduation that they might not otherwise be able to afford. A group of Diotorin residents explained of a young man who had left his community for

college: *“He does a lot [of repair]. His tools are complete ... He gets to keep them after graduation. They’re his.” “Where do you find someone who can buy his own tools?”*

The Dikapinisan barangay electrician, Francisco, has a kit of specialized tools on hand for line work: *“[The ‘shotgun stick’] made of fiberglass that we use to grab onto the power line. So we don’t get electrocuted. [I also use the] safety belt. Plus the step belt, to use going up the post. Pliers, electrical tools.”* Transport infrastructure is available for going at a moment’s notice up the mountain to where the electrical lines come from barangay Dibayabay and return within a day: *“They’re going to pick us up somewhere in the other town. We’re just going to walk to where the boat is waiting for us.”*

The provincial electrical coop AURELCO also ensures a regular flow of tools and parts by sending personnel monthly (when possible) to check the physical infrastructure and collect payments. Teodoro, the expert repairer in Dibut, told us that *“when [AURELCO personnel] come here to perform repair [then I am able to ask for some spare supplies for electrical installations].”* As a result, Teodoro was once able to perform an emergency repair at the school upon the principal’s request. She relates: *“I saw that the line was hanging close to the ground. I called [Teodoro]... The children might get electrocuted. So he removed it.”* This critical repair could have taken much longer without local supplies and a trusted repairer available to be mobilized at a moment’s notice.

The institutionally managed flow of repair resources can be seen as effort or care that works to patch seams between disconnected rural and urban infrastructures, similar to the NGO logistics in Jack & Jackson [134]. However, forms of care like the provision of tools to trainees enable and empower local actors much more than they are a top-down form of control.

2. Experts to Learn From:

By working together, electrical line technicians transfer knowledge and skills outside of the process of official accreditation. Via these working relationships that foster interpersonal trust,

some of the system-trust associated with credentials can be informally passed from accredited to non-accredited repairers. For example, Teodoro from Dibut described that *“I tag along and observe while AURELCO does maintenance,”* which contributed to his ability to perform the school repair above. Carlos from Dikapinisan, while not certified himself, also learned his skills as an electrician’s “helper” in Baler and would in turn teach his helpers while working: *“Sometimes [an assistant] will cover the live wire with electric tape... I teach them.”* Over time, these processes of knowledge transfer can allow other community members to place their trust in a local repairer’s reputation over their credentials.

3. Opportunities and Funding for Practice:

Technicians are able to practice their craft often to gain experience, learn from a mentor, and earn money that they could be making in other work. As in Baler, though the repairers were positive about any formal education they had, they were clear that most of their learning was through experience and placed the highest value on “aktwal.”

Due to the difficulty of sending personnel from AURELCO, local technicians get an opportunity to work whenever people build new houses, wiring gets damaged, or lines are disconnected due to lack of payment. As Romeo from Diotorin described, *“Here, if people are not able to pay [AURELCO], their electricity will be cut off. When they pay, the engineer does not come here anymore and just teaches me what I have to do for them to get their light back. The labor fee is 85 [pesos] for connecting the line, and they [pay] me.”* Romeo’s informal financial relationship with the electric company provides funding for repair work in addition to experience.

A further incentive to repair is that electrical line repair is seen as easier than farming, with income that is guaranteed when due by AURELCO or the local government. The promise of good pay leads to more sustained effort towards accreditation and learning. Technicians are also empowered to provide private home services to relatives and friends for free, while charging for

other labor.

4. Accessible Formal Education and Institutional Certification:

Formal degrees or accreditation, while not materially necessary for repair, can reduce uncertainty in a repairer's expertise for new customers or employers by acting as a symbol of system-trust that they can place instead in the accrediting institution and process. It can help local repairers manage risk in case things go wrong and can help them find work outside a local social network that trusts them.

Seven of the nine linemen had participated in formal training, two of them at TESDA. TESDA, a government institution whose mandate is to develop the skills of the local labor force, issues certifications that act as credentials for employment. AURELCO also provides training seminars and issues line repair certifications. Leon of Dikapinisan explained, *"I am a certified electrician of AURELCO [though] I am not a maintenance personnel. [If something breaks] I have the license to fix it; I can do work throughout Aurora even though I am not [employed by] AURELCO anymore."*

At the same time, the strict requirement of such certifications in order to take any action can be a barrier repair, especially if trustworthy experts can still be excluded due to externalities. Teodoro, who considers himself too old to go through the effort of certification, explained his hesitancy to work on public lines except in an emergency: *"It is difficult to attempt repair [if one is not authorized]. If something goes wrong, I will be blamed."* However, he and other technicians still frequently do work on electrical lines without official accreditation within their barangay, suggesting that well-reasoned exceptions are made for trusted community members based on reputation.

2.7.1 From Individual Tinkering to *Bayanihan*

Motivated by the repair goals inspired by the VBTS Project, we briefly explore some possible strategies for operationalizing our understanding of training grounds and how institutions can provide resources and infrastructure to support local repair in our remote contexts.

For example, a community-oriented repair and learning space or group could be established to transform the practice of repair from individual tinkering to a form of *bayanihan* (or *atag*, as it is known locally in Aurora), a Filipino concept roughly meaning “cooperative work in care of the community.” *Atag* is regularly contributed by adults in all of these communities to help maintain shared infrastructure such as public buildings and school yards. Coordinated activities such as collecting e-waste from homes and helping to restock repair tools or supplies when in Baler could be incorporated as service activities towards care. We liken such an institution in spirit to a makerspace [29], hackerspace [109], or repair cafe [157], similar spaces focused on bringing together community resources and expertise for goals such as learning about technology and sustainable living [231]. However, we focus on activities that might be appropriate to our context.

The space could stock specific components, tools, and manuals for disassembling, understanding, fixing, or ruggedizing common devices such as mobile phones, the repair of which many cave residents identified as a severe unfulfilled need. It could also provide training and teaching, as makerspaces commonly do as a core part of their mission [46]. This training, perhaps combined with device collection and repair by students, could allow local repairers to get the experience and practice (*aktwal*) they need to learn repair skills.

There would be many challenges to overcome in such a project, for example a potential lack of government or institutional support from an AURELCO or TESDA (though such support would be welcome), and a pragmatic commitment that the communal space also help support people’s livelihoods. However, as researchers and designers we recognize a need to think about possibilities for sustainable community structures that can enhance technological self-reliance and autonomy

from regional power relationships in the long term.

2.8 Discussion: Implications for HCI and ICTD

The difficulties of sustainable device cycling for people in the cove communities highlight the residuality of these communities as consumers and repairers of technology. Despite the body of literature demonstrating that local electronics repair capability does arise in rural areas, we must also acknowledge the reality that the successful emergence of this infrastructure depends on many factors such as environmental, institutional, and resource-based conditions, and should be explicitly supported rather than taken for granted. We believe this chapter provides important contributions for technologists focused on rural areas that experience infrastructural marginality and remoteness.

A need for occasional or extended self-reliance is fundamental to the rural experience. ICTD and HCI4D projects must address that most resources, be they technical (such as datacenters) or social (such as universities and other institutions), may be remote from their rural users. We suggest that focusing on the community and their own abilities and resources, as in Asset-Based Community Development [179], is one way to address this reality. In the prior section we discuss what a local community-based institution supporting repair might look like in this context. Another could be co-locating new repair-related resources within in the community itself, explicitly designing (and co-designing) them for the difficulties present in these areas. Wyche et al. [261] provides one example of this, postulating a phone optimized for ruggedness rather than features due to the difficulties of operating in the users' environment. From a government or policy perspective, we also suggest that some form of municipal transportation infrastructure specifically targeting technology reclamation, recycling, or repair could be effective for reducing the large amount of devices being consumed and wasting in "purgatory," both in these remote contexts and elsewhere around the world.

Bringing a system perspective to processes in the technology life cycle like repair allows us to think about a broader ecosystem around use, breakdown, and repair of devices that can be considered even in areas like our field sites without consistent or formal repair infrastructure. Rather than limiting our knowledge of rural repair to practices and infrastructure in central areas with repair shops, we seek to understand the seamful patchwork of intermittent and overlapping infrastructures that extends to more remote rural areas—what resources are accessible, where, and when, and what causes seams to appear. To do this, we must better understand the lives of people in these areas, including their knowledge, skills, relationship with urban people and places, systems of trust, options for communication, and more.

We note the importance of networks of both interpersonal and system-trust for recruiting resources in rural areas with less institutional infrastructure and centralized resource provision, particularly for collaborative technical work like repair. Long-term, stable engagement in communities, for example through local institutions, are crucial for establishing *training grounds*, which can provide a foundation for trust in repair processes and people. While trust has long been acknowledged as crucial in ICTD interventions [167, 207], this chapter suggests that we be aware of the myriad forms trust relations can take in different contexts and its role in shaping collaborative networks.

Finally, we join the call from the wider research community encouraging researchers and practitioners to consider the processes of recycling, disposal, and wasting as part of their designs [129, 173]. The dominant technology design culture of frequent obsolescence and replacement, even made cheap to arguably increase access to low-income populations, can be particularly unsustainable in remote places. Designers must acknowledge that their devices will eventually be discarded, and create sustainable devices or mechanisms to support their repair or reclamation.

2.9 Conclusion

This chapter characterized a seamless patchwork of repair infrastructure for electronic devices that exists in Dibut, Diotorin, and Dikapinisan, geographically isolated cove communities in Aurora, Philippines. Despite frequent breakage due to a harsh environment for electronics, there are no local repair shops, and local device repair is uncommon due to the difficulty of mustering the material resources, tools, and expertise needed for repair. Confronted with their communities' remoteness and marginality with respect to many forms of public infrastructure, cove residents largely take a disposable view of their equipment, often buying cheaper ICTs with the expectation of their inevitable failure, and leading to extensive local e-waste. However, device owners occasionally do travel long distances to bring broken devices to repair shops in the nearby peri-urban center of Baler, following a typical pattern of rural-urban flows echoed by Baler's repair shops sourcing expertise and parts from more urban Manila.

We found device repair infrastructure in the cove settings to be more informal, intermittently available, and largely mobilized by individuals based on personal relationships. Both interpersonal and system-trust and their mediators crucially enable repair. Networks of trust between repairers, their clients, certifying or training institutions, suppliers, and fellow repairers facilitate movement of material resources and expertise, but also reinforce the coves' marginality. Under these circumstances, local people successfully maintain a healthy and robust ecosystem for rural electrical line repair. From observations of this ecosystem we developed the concept of *training grounds* to sustain local communities of repair experts. Finally, we outline a number of ways these concepts can inform future efforts to make repair a more accessible option for people living in isolated rural areas.

Chapter 3

| Stem |

Seattle Community Network”: A Model for Grassroots Infrastructuring of a Technical Learning Commons

Abstract

This work introduces the design and implementation of an operational model, termed a “community learning network” (CLN), for a non-profit, educational community broadband network formed to identify and address internet connectivity needs in an urban North American context. Through qualitative analysis of participant interviews from the Seattle Community Network (SCN) and NYC Mesh as well as journal entries from 2020-2023 by the researcher who founded and organizes SCN, we reveal grassroots infrastructure-building processes by which community network participants can embed their values and intentions into the network’s socio-technical

infrastructure, shaping deployed artifacts. We show how the CLN builds power among participants, producing a *community of practice* (CoP) and a *learning commons* for hands-on technical learning opportunities, and propose strategies to support more equitable participation in technical infrastructuring. Finally, we identify technical dilemmas and tradeoffs related to CNs' dependence on powerful institutional partners who contribute resources and mediate participation, drawing parallels to “transformative social innovation” (TSI) work, which also seeks to create contexts and spaces that transform power dynamics.

3.1 Introduction

Community Networks (CNs) and Community Wireless Networks (CWNs) are network infrastructures established, owned, and/or managed by local users in a “bottom-up” or collaborative fashion [35], often with political commitments to DIY (“do-it-yourself”) practices [80], open source principles [72], or common good [35]. In this work I introduce an operational model for a grassroots “Community Learning Network” (CLN) and examine its consequences and limitations with respect to participation and building community power.

The Seattle Community Network (SCN)¹ project is a non-profit, educational CN based in the Puget Sound area that aims to provide free or low-cost internet access and technical education to local marginalized groups. It can be usefully characterized as a grassroots “civil society” [68] or “mutual aid” [236] initiative largely organized by volunteers, and as a “transformative social innovation” (TSI) seeking to manifest alternative economies and values that frame internet access as a basic utility and a human right, mobilizing open-source, DIY, and community organizing [200]. I started SCN in 2019 as an action research (AR) project [119, 101, 124] supported by the University of Washington to explore whether and how local, community-owned and operated wireless

¹distinct from the Seattle Community Network Association (SCNA), which was founded in the 1990's and active through the 2000's [222]

internet infrastructure could successfully meet technology needs and improve digital equity in an urban North American setting. I sought to discover urban residents' barriers to access and the challenges of establishing and maintaining an operational CN to address those barriers. I further interrogated how SCN could balance and combine goals centering equity with cultivating a robust technical volunteer base and learning environment, and whether this model could work to sustain an active, functional community network. Throughout this work, I use the pronoun "we" to refer to the research team conducting the academic work and the third person "they" for SCN participants, with the understanding that the researchers are also included in the latter group.

Based on first-author autoethnographic journals and qualitative interviews of members from two urban community networks (SCN and NYC Mesh), we show how participants' visions, values, identities, and grassroots infrastructuring practices shape the physical network, creating a layer of *relational infrastructure* on which the *technical infrastructure* is built. These practices establish SCN as a *commons* [72, 198] of opportunities for learning, ownership, and positive social contribution. We conceptualize the model of a Community Learning Network (CLN), a living research and teaching network comprised of the "learning commons" and the public community of practice (CoP) built around it, which invites participants from all backgrounds to collaborate on hands-on experiences with both technical networking and grassroots community engagement. Through the lens of power, this participation transforms power relations by building power through technical knowledge and experience, as well as through community relationship-building. However, we also show how power relations established through contributions of funding and critical resources from institutional partners have consequences for the network's socio-material realities, resulting in infrastructural dilemmas (both technical and relational). Using the framing of CN as TSI, we highlight the tradeoffs of dependence on more powerful sponsor institutions for resources and mediated participation.

3.2 Related work

This inter- and cross-disciplinary work on Community Networks draws on methods and concepts in Human-Computer Interaction (HCI), Computer Networking, Information and Communication Technologies for Development (ICTD), Action Research, and Science and Technology Studies (STS).

3.2.1 Community Networks

A large variety of CNs exist in global urban [211, 24, 92, 192, 83, 230] and rural contexts [186, 8, 150, 95, 151, 212, 210, 133, 243, 115, 16, 117, 153], with differing motivations, operating principles, and deployed technologies. A unifying principle is their focus on promoting the “right to co-create the Internet” or on people building and managing their own networks, whether out of necessity due to “market failures” [114] and a lack of modern infrastructure or an intentional subversion of existing networks and their power structures [84, 203, 3, 4, 245, 218]. These principles often intersect with the politics of DIY [192, 72, 92, 24, 80], grassroots organizing [97, 72], rural development and digital inclusion [95, 211, 158, 13, 122], decentralization [84, 152, 121], or surveillance avoidance [116].² As Crabu of the Ninux Community Wireless Network (CWN) in Italy notes, “[CWN]s are usually raised by groups of people rooted in media-activism, hacking and technical hobbies, engaged in the implementation of these infrastructures on a voluntary basis, as they commonly share a set of goals and political beliefs... These infrastructures are mostly self-built, as volunteers adapt existing software, hack hardware, set up coordination rules, and, last but not least, materially install antennas on the roof.” CNs are often described as a type of “collective action” or “civic participation” project that can encourage communities to mobilize towards common goals [97]. CN organizing can generate “social capital,” or value derived from social ties, and increased “social

²We note that adding the word “community” to “network” creates the concept of a CN as a technology artifact with inherent politics [258] (though the specific politics may vary).

cohesion” where “all groups have a sense of belonging, participation, inclusion, recognition and legitimacy,” though it can also result in internal social pressure causing attitudes and beliefs to converge [3]. We later introduce the concept of “transformative social innovations” (TSIs) to describe CNs that drive social transformation by manifesting these values, beliefs, and social capital into socio-material change, such as new physical infrastructure in underserved areas, alternatives to traditional paid models for access, or new ways of associating with other participants to build or govern infrastructure. [200] At the same time, research has also addressed limitations to equitable participation and technology appropriation in CN projects, for example from women in patriarchal contexts [39, 41, 40] and other vulnerable communities they seek to benefit [178].

CN Financial and Sustainability Models

All CNs consider themselves “community based” in some way [66]. They are typically owned or operated by someone local to the region as opposed to a wide-area Internet Service Provider (ISP), or involve some degree of non-commercial participation or interaction with users. However, the organizational structure, business model, and nature of community participation can be as diverse as the people and groups involved. A small rural for-profit ISP with its operations grounded in local community relationships [15, 117] might still consider itself a community network. Other networks charge for service but have a non-profit organization at the helm to support costs with grants and other resources [192, 122]. Still others operate as a cooperative or federation of small commercial networks [24] or entirely on grant funding [230]. Given CNs’ frequently radical political tenor or low-resource context, standard commercial business models for financial sustainability (through customer payment to a for-profit service provider) may not always be the best fit. Thus, CN developer communities (across academia, industry, and open-source) work to drive down the expected capital and operating costs of networking technologies intended for CN implementation and explore social factors beyond technology design that might improve their

sustainability [114, 243, 5, 8, 95, 181]. We contextualize our volunteer- and open-source-based model among these efforts to drive down costs while democratizing the knowledge needed to make adoption more feasible and sustainable for low-resource groups.

Abdelaal and Ali [5] and others [218, 4, 244, 245] have outlined typologies of CN business models around the world. Among these is a university-supported, non-profit educational model similar to SCN's, with the Omaha Wireless Network [3] as an example presented only in concept, without detailed analysis of operational dynamics or disadvantages. While many CNs around the world are materially supported by university infrastructure or research funds [97, 243], they do not necessarily collaborate in other ways or work jointly towards educational goals. Our CLN model can be seen as a hybrid of what Abdelaal and Ali's Typology refers to as the "education-centric" and "community wireless network" models of CWNs [3].

3.2.2 Action Research and Autoethnographic Methods

We next situate SCN's implementation as "action research" (AR), which "calls for action—by both the researchers and their community partners—as an explicit part of the process of inquiry." [119] As an "invervention experiment" to address an agreed-upon problem of urban connectivity needs, SCN is thus "value-laden" via its choice of problem and solution [124]. Action research is often characterized by "plan-act-observe-reflect" cycles, or "praxis" [93], over a number of years, with observations and results fed back iteratively into planning and action by researchers. It emphasizes co-creation of action and produced knowledge, with participants as partners in the research [93, 227]. Value sensitive design (VSD), participatory design (PD), and other participatory methods similarly seek to benefit particular communities via their input, with different means and degrees of researcher and participant involvement [259, 155, 94, 227].

This chapter represents a snapshot of ongoing reflection within SCN from my perspective as a participant. Thus, we draw on methods from "autoethnography" [85, 17, 142, 58, 50, 216, 73,

175], or reflexive self-narrative that “self-consciously explore[s] the interplay of the introspective, personally engaged self with cultural descriptions” [85] and autobiographical design [78, 187]. Autoethnography involves “making contributions to knowledge; valuing the personal and experiential; demonstrating the power, craft, and responsibilities of stories and storytelling; and taking a relationally responsible approach to research practice and representation” [215]. By promoting a “large amount and quality of time spent with a system” integrated with a designer’s life, “autobiographical design” produces a “detailed and experiential understanding” of designed objects [187, 78], in our case the social and technical infrastructure of SCN. As in other inherently subjective inquiry methods, the goal of these methods is not necessarily generalizability [187]. Hayes describes action research as inquiry where “trustworthiness is a valid and appropriate alternative to generalizability in scientific inquiry, [...stemming from] credibility, transferability, dependability, and confirmability.” [119] Other AR sharing similar first-person perspectives includes the Gram Vaani organization by Seth in *Technology and (Dis)empowerment* [223], Ghoshal and Bruckman’s work on technical systems for grassroots organizing [101], and Halperin and McElroy’s reflexive ethnography of technology use in an advocacy organization against housing precarity [110]. Ghoshal et al.’s work in particular [101, 102] highlights the importance of “grassroots inclusivity” practices to combat technocultures of exclusion often embedded in ICTs.

3.2.3 Communities of Practice, DIY Infrastructure, and Learning Commons

SCN builds a “community of practice” (CoP) centered around the installation and management of physical network infrastructure and around maintaining the community of participants itself. CoPs are formalized by Wenger as a “community created over time by the sustained pursuit of a shared enterprise.” [255] In the space of CNs, this pursuit is building and operating networks. While many other CoPs of network-builders exist around the world, e.g., via online forums and discussion groups, CNs often blur lines between operators and users, cultivating CoPs at the

intersection of network infrastructure and “DIY” or “do-it-yourself”—simultaneously a political ethos, an orientation or design goal, and a set of practices surrounding hands-on implementation and personal or communal ownership of knowledge, tools, or infrastructure [80]. Theories of infrastructure and repair note that functional infrastructure achieves invisibility for its users, while breakdown can make it visible [138, 217, 11, 128]. We interpret DIY infrastructuring projects as tackling extreme “broken-world” scenarios, where desired infrastructure is missing, prohibitively expensive, or otherwise unattainable, that must be “repaired” by building it from scratch. Thus, DIY processes of world-building can bring infrastructure into the foreground for both builders and observers. For CNs, the non-existence of affordable Internet connectivity or resources for digital access is often what is broken or missing in the world. However, we emphasize that human as well as technical and physical infrastructuring [172] are necessary to maintain both networks and communities of people and has been known to provide crucial capacity-building resources underlying the success of other ICTD projects [220].

We therefore introduce the concept of a “learning commons” as a pool of hands-on “connected learning” [132] opportunities through network infrastructuring, which SCN cultivates via human infrastructuring processes. Marttila, citing Ostrom, describes “commons” as “shared resources in which all parties have an equal interest and that are vulnerable to social dilemmas.” CNs are also often characterized as “network commons” for sharing limited network resources such as bandwidth [153]. Marttila describes infrastructuring activities similar to SCN’s within the Finnish OpenGLAM movement, which creates “a reservoir of shared, collectively produced knowledge” as well as a network of relationships or “community as commons.” [2, 198] Other studies have identified network breakdowns as learning and community-building opportunities, observing that “for implementors of new CNs and for organizations supporting CNs, ... a primary challenge is building and nurturing a community of learners” [97]. Many CNs incorporate extensive training and participation opportunities through repair, sometimes supported by pre-designed social or

technical affordances [242, 146, 145, 82].

3.2.4 Power and Transformative Social Innovations (TSIs)

While our current study does not provide as detailed and as in-depth of a participant power analysis as in Seth [223], we briefly summarize key concepts in theories of power to support our subsequent discussions of power relationships within CNs. In their “powercube” framework, Gaventa and Pettit summarize four expressions of power outlined by VeneKlasen and Miller: “power-over” to repress or coerce others, “power-with” to express solidarity or collective strength with others, “power-to” to shape the world through action, and “power-within” to affirm personal self-worth and capacity [252] (known in some other fields as self-efficacy). The latter two are sometimes referred to as individual “agency” [99].

We draw links between power and CoPs for “DIY” infrastructure-building, which we argue build both agency (power-to and power-within) through knowledge as well as power-with through community-building. Foucault argued that knowledge and power are inextricably linked, though the nature of these links is contested [22]. Foucault also argued that power relationships are enacted or manifested, not merely held [99]. DIY, hands-on infrastructure-building encourages and enables the use of power-to to overcome power-over relationships (such as with commercial ISPs) that may hold a group of people in marginalized conditions (such as lack of internet access they can afford). These activities also present opportunities for participants to manifest solidarity with others by directly contributing physical infrastructure, resources, knowledge, or collaboration, as in “mutual aid” frameworks [236], building power-with in their communities.

We characterize CNs organized with the intent to alter societal power dynamics in this way as “transformative social innovations” (TSIs). Theorized by Pel, Haxeltine, and others, TSIs are “changing social relations involving new ways of doing, knowing, framing and organizing” that seek transformation in a specific socio-material context by “challenging, altering, or replacing dominant

institutions.” Pel presents Makerspaces, Participatory Budgeting, Time Banks, Basic Income, and Slow Food as examples of TSI processes involving “diverse transformations based on different social relations, values, and ideas of progress” and outlines 12 propositions on development of TSIs via an empirical study of 100 local manifestations of 20 translocal SI initiatives [200]. Our detailed case study of SCN, with its in-depth, personalized approach, complements this wide-ranging study and augments the relatively new emerging literature on TSIs. Particularly relevant to our power analyses of SCN are Propositions 7 and 9 on TSIs’ relationship to “institutional homes” or “dominant institutions” that may sponsor or conflict with it [200, 118], with consequences for infrastructuring and participation. We also consider the “spaces” for participation in transformative processes that CNs manifest, which Gaventa defines as “opportunities, moments and channels” where members “act to potentially affect policies, discourses, decisions and relationships that affect their lives and interests.” These may be “closed,” “invited,” or “claimed/created” from different community members’ perspectives [98].

3.3 Methods

3.3.1 Data

The action research we undertook extensively draws on participant observation via ongoing detailed field note-taking and reflective journaling on the my daily challenges and activities necessary to build and upkeep SCN. It also includes qualitative interviews with urban CN participants intended to shed light on the values, motivations, and activities of people involved with the organization. Here, we describe the field note data and collection, qualitative interview sampling and data collection, and data analysis (determined as exempt by the UW Institutional Review Board).

Table 3.1: Interviews conducted. The interviews reflect existing gender (self-identified, Masc vs Fem) imbalances in volunteer CN participation; future work specifically aims to recruit more femme-identifying interviewees.

ID	Gender	CN	Year	Involved
1	F	SCN	2021	4 yrs
2	M	SCN	2021	3 yrs
3	M	SCN	2021	3 yrs
4	M	SCN	2021	4 yrs
5	M	SCN	2021	3 yrs
6	M	SCN	2021	3 yrs
7	F	SCN	2022	2 yrs
8	M	NYC Mesh	2022	7 yrs
9	F	NYC Mesh	2022	2 yrs
10	M	NYC Mesh	2022	1 yr 3 mo
11	M	NYC Mesh	2022	2 mo

Participant Observation (PO)

I kept field notes in a running online document, typically written with a few days between observation entries but occasionally logging daily or weekly. The entries began in October of 2020; there were 29 entries in 2020, 41 in 2021, 98 in 2022, and 157 in 2023. As of March 2024, the entries total around 250 pages ranging from “To-Do” lists, meeting notes, emails, and links to/pieces of other documents to reflections on activities, events, interactions, and emotions in SCN work.

Qualitative Interviews and Sampling

Semi-structured interviews began in the Summer of 2021, conducted primarily by another research team member, also a UW graduate student and SCN volunteer. Interviews were held over Zoom video calls, in English, and each lasted 45 minutes to one hour. By having the other researcher

conduct interviews, we aimed to avoid participant response biases [76] related to my perceived authority or seniority on the project or role as an instructor. However, due to scheduling difficulties, I performed one interview (with Participant 7).

Interview questions focused on volunteer core values, motivations for joining the project, perceived advantages or disadvantages of participating, and suggestions for how to make participation more engaging, including possible monetary incentives. We conducted 11 interviews with two women and nine men, detailed in Table 3.1. Participants were selected as “key informants” [72] in varying roles within SCN, including UW-affiliated student volunteers or project founders, employed “Digital Stewards” trained in network installation and maintenance, and non-UW community members. NYC mesh interviewees were added in Winter of 2022 for comparative purposes, with two recruited as key informants from among currently active volunteers in the organization. Two volunteers were additionally recruited opportunistically at a NYC Mesh network install event.

3.3.2 Analysis

We use a multi-method analytical approach on the data described above, beginning with the 11 semi-structured interviews with CN volunteers from SCN and NYC Mesh.

Our preliminary analysis consisted of an initial coding pass through the recorded and transcribed interview data, beginning with a short list of provisional codes [219] based on our research questions about broad factors that could impact participation. For example, these included “organization structure,” “paid participation,” and “identity” and were expanded to include “values or philosophy,” “mobility,” “professional goals,” “role in CN,” “community or social structure,” “barriers or challenges,” and others based on the data. We noted rich narratives of participant motivations and activities: why they join and stay involved with the CN, what their involvement entails, and how it fits into their lives, held beliefs, and identities.

We then performed a second pass, creating subcodes that emerged in common among re-

spondents, e.g., “difficulty of unstructured learning” and “remote support” under “barriers,” and “replicate CN model,” “role modeling,” and “helping others” under “values or philosophy.” Finally, we consolidated subcodes into the major themes and observations presented in the Findings and Discussion.

We triangulated and validated these codes and participant experiences with the PO field notes as well as community-produced SCN documentation, e.g., monthly meeting notes, install procedures and checklists, publicity materials, instructional guides, and voted-and-approved governance documents. We examined all materials encapsulating the relational infrastructure of the CN, which covers:

1. Governance and legal entities
2. Participant recruitment and onboarding, including teaching/training programs
3. Team dynamics, roles, work style, and meetings or organizing processes
4. External partnerships and programs
5. Resources and funding, and the impact/role of money in decision making and activities

From the data, we reconstructed an overarching project narrative and timeline over several years of infrastructure-building processes. These narratives included both *relational infrastructure* (onboarding, education/training, communications practices) and *technical infrastructure* (platforms, software, network technologies, and engineering choices that manifested them). Within these implementations, we noted how the infrastructure reflected human and institutional values, both explicitly and implicitly. Finally, we organized and presented these findings through the lens of power relations between participants and the organizations that influence their participation and access to resources.

3.3.3 Validity and Limitations

As in other HCI action research that uses evidence based on personal field notes, we acknowledge limitations in generalizability and claim the value and validity of the knowledge generated to be largely in terms of trustworthiness and confirmability [119]. The semi-structured qualitative interviews of CN participants from both SCN and NYC Mesh, while limited in number, support this confirmability. In future work, we intend to include perspectives from a broader cross-section of CNs and participants. This work also remains subjective and potentially biased because of my intimate involvement and central role in SCN. The research methods share qualities of immersiveness and first-person perspective-taking with autobiographical design and autoethnographic methods, and we take care to address known tensions in these methods [78]. We use additional trusted authors to collect and analyze data, as is done in other action research [101], with considerations for the ethics of privacy and the risks of integrating research with personal life. We also recognize that reliance on occasionally sparse field notes or experiences recalled from memory, which may be imperfect and selective, colors written accounts through the lens of personal histories. We take special care to anonymize some narratives to the extent that we reveal only what is ethical given that our stories involve others as well as ourselves [58].

3.4 Background: SCN

3.4.1 Founding and Organizational Principles

I started SCN in 2019 during the third year of my PhD in Information and Communication Technologies for Development (ICTD), a subfield addressing the impacts and design of computing technologies for social change in global South, low-resource, or otherwise marginalized settings. When struggling to find a thesis project that felt both academically and personally meaningful, she visited her hometown of New York City and became an active volunteer with the non-profit

NYC Mesh community network [192]. She was inspired by its operational model and vibrant community of practice to start a CN in Seattle.

However, as an ICTD researcher, she had only studied and implemented CNs in equity-driven contexts, e.g., with organizations or local governments in rural remote areas, often supported by research initiatives [35, 121, 153]. While participating in NYC Mesh, she noticed that lower income neighborhoods had yet to be reached, and also that most participants seemed to be professional engineers. She also realized that in her current, less densely developed and more geographically segregated city of Seattle [107], such participant dynamics could reproduce and aggravate existing inequities related to histories of redlining and gentrification [91]. When considering alternative models, I drew from the digital equity- or justice-oriented focus of CNs such as the Detroit Community Technology Project's Equitable Internet Initiative (DCTP EII) [230], Rhizomatica (known as Telecomunicaciones Indígenas Comunitarias AC in Mexico) [214], Zenzeleni [263], Altermundi [20], and others [35]. I and a few lab members studying CNs at the time envisioned the following objectives for SCN:

- **Prioritizing equity.** To find and serve those in our urban environment who remain without adequate access to the Internet and technology infrastructure, especially by establishing CN presence in low-income neighborhoods.
- **Building human relationships.** To foster interpersonal interactions and social cohesion [3] across the largely segregated groups of community-minded tech workers in Seattle and marginalized residents in need of better technical infrastructure or resources. To create pro-social motivating reasons and contexts for people to learn and engage in technical work [144].
- **Creating a community of practice for hands-on learning.** To nurture a local movement of people with the expertise to support and teach community networking. To themselves

gain deep experience and practice building and maintaining (or even “dog-fooding” [72]) a live production network using open source LTE technologies that our research group had deployed and supported in rural areas.

- **Fostering education and open knowledge.** To democratize knowledge and power-to-build networks and internet infrastructure for the broader public, e.g., via documentation and hands-on learning opportunities.

Based on their ICTD and open-source roots, lab members envisioned scoping technical research and educational agendas leveraging research grants and UW infrastructure to subsidize free services for marginalized groups and decommodify Internet access. They founded the nonprofit organization LCL to support SCN and other CN initiatives around the world. They also highlighted these guiding principles in initial documentation and promotion of SCN to the general public, unlike NYC Mesh, which did not explicitly forefront such a mission.

3.4.2 Building Community Participation

Based on prior examples, e.g., the EII and TIC AC, SCN’s initial vision of sustainable CN management involved recruiting community partner organizations to actively support and host network sites for Internet access in low-income neighborhoods. However, soliciting partner commitments was slow in 2019 due to the lack of funding, despite a year of consistent effort via phone calls, emails, in-person visits, and contacting personal referrals, which often led to the most fruitful connections. SCN’s eventual first site host FCS was proposed by a referral from the lead organizer of Seattle Mesh in the 2010s, whom I serendipitously met at an unrelated local event. After an initial conversation with a board member, interactions stalled for a year since SCN lacked funding for equipment, though the executive director remained sympathetic to the project due a personal affiliation with the UW. At the time, the only SCN volunteers were UW academic collaborators

Figure 3.1: SCN community LTE site installations

(a) SCN volunteers mounting an LTE panel antenna at the Garfield HS installation, initially serving Nickelsville CD Village.



(b) SCN volunteers and BBR Digital Stewards working at the KCLS Skyway Library installation.



(c) Nickelsville CD: a resident participated in the installation of a shared CPE and WiFi router on their home in the village.



and undergraduate student researchers.

The Covid-19 pandemic brought equity issues in Internet connectivity to the foreground in public discourse. In October of 2020, SCN received grant funding and support from both local government and private foundation sources to deploy a handful of 4G LTE cellular network sites within a few months. The funding and immediate pressure to deploy infrastructure, along with prior groundwork and continued outreach, catalyzed groups with similar goals to connect and partner with SCN. This produced a network of human and organizational infrastructure upon which future SCN activities could operate. In the months that followed, I was contacted by a now major partner the Black Brilliance Research Project (BBR), who had been pursuing a similar project inspired by the Detroit EII, as well as the organizer of a connectivity initiative from the local nonprofit API Chaya with a coalition of Kent-based activists and educators who began to

pursue a cell site location. Since then, multi-year collaborative research grants received in 2021 by coalitions of these partners has crucially enabled continued work and weekly meetings on joint initiatives between members of UW and LCL, BBR, Tacoma Cooperative Network (TCN), and others towards building and maintaining the network, recruiting users, educating or employing participants, and bringing resources to the CN.

Volunteer engagement was also catalyzed by the sudden urgent labor needs after funding was received, after which I presented an online talk to a local Decentralized Web interest group connected through a friend in the global CN community and released an introductory “Call to Action” blog post in November 2020 [144] directed at local tech workers. These materials, presenting values along with charismatic photos of cellular network hardware (exotic in the DIY space), became a reference point for new members and partners to understand SCN’s aims before other documentation existed and coalesced value-aligned community participants who began to establish social and collaborative processes. A dormant online public chat group on the Slack platform (now transitioned to the very similar platform Discord), established and modeled after NYC Mesh’s, became active. Weekly online team meetings to touch base on progress began, which continue until today.

3.4.3 Modes of Participation

SCN is structured as a project rather than its own organization, with *operational partners* and *site hosts* (such as the UW) positioned as contributors. For example, major operational partners include: LCL; TCN, which leads network operations in nearby Tacoma; BBR, which runs “Digital Stewards” technician training (after the DCTP model); Filipino Community of Seattle, which trains IT/broadband technicians and hosts a LTE site; and The Silent Task Force (TSTF), which installs and maintains new WiFi sites at Tiny House Villages. All operational partners work to solicit funding and new partners (many not named here). Site hosts, listed in Table 3.2, provide

roof and indoor space for equipment, power, building access when needed, and assistance with regular maintenance tasks. Each partner mediates participation, contributing different modes of participation to the CN, as discussed in Sec. 3.5.2, and influencing its infrastructure.

User Recruitment and Device Program

SCN's growing 4G LTE and WiFi network serves about one hundred users, primarily living in Tiny House Villages (THVs), a type of emergency shelter [250], and other low-income housing. With their initial CARES Act funding, LCL also ran a free device distribution program for eligible recipients (Seniors, Homeless, Unemployed, and majority Non-English-Speakers, and later public school students) who expressed need. Recipients chose between (1) an unlocked mobile smartphone with LTE service available on SCN networks (with built-in WiFi hotspot capability), or (2) a WiFi-capable small laptop along with SCN-attached LTE modems (known as CPE, or Customer Premises Equipment) and WiFi routers needed to achieve Internet access at home. SCN promoted these offerings via flyers, presentations, and tabling events at or near existing or planned sites. In 2021-2022 at FCS, volunteers also provided an in-person weekly "Community Technology Help Desk," including sign-ups for Internet access. Phone or web form-based requests for service are followed by user call-backs or email coordination, followed by site surveys and installs if surveys are successful. If SCN wireless coverage does not reach prospective users, SCN offers help enrolling them in government assistance, such as Lifeline [65], the (now ending) Affordable Connectivity Program [64], or other low-income ISP plans if available. However, the majority of SCN users have been recruited through direct coordination between network installers and THV leadership, or via tabling at low-income housing complexes; this participation is mediated by the nonprofits who operate the housing.

Volunteers

Over the past three years, SCN has maintained 10-15 very active volunteers at any given time, with an additional 20 or so less active ones, primarily managed by the nonprofit LCL. This is typically augmented by 5-10 UW undergraduate and graduate students recruited through the researchers' UW research lab, with more students when SCN partners with project-based engineering courses. A service learning program through another university partner Seattle Central College over the past two years has contributed several interns to LCL for course credit. Community volunteers are largely local professional software, electrical, IT, or network engineers, often between jobs, motivated by the digital equity mission as well as the personal enjoyment of learning and exercising technical skills. Others have come with varied backgrounds or experience levels in IT but similarly seeking hands-on learning opportunities and a community of practice for technical and professional development. A few THV residents from the user group have also participated as volunteers.

Operational Partners and Trainees

SCN's operational partners—BBR, TSTF, FCS, and others—have run programs that have trained and employed numerous community members over the years to support SCN's network operations and related digital equity projects. BBR and TSTF have adopted the Digital Stewards (DS) model, championed by DCTP EII, Red Hook, CTNY, and others [205, 262]. BBR's first DS program in 2021 was a virtual, paid 3-4 month training course taught by me and SCN volunteers. Since then, additional DSs through BBR and TSTF have received hands-on on-the-job training from me and have in turn helped instruct in-person DS cohorts with BBR, partners, and volunteers. SCN, BBR, and other partners also co-instructed two stipend-based cohorts of a Youth after-school version, YDS. Further, FCS runs a large-scale Broadband Technician training program focused on certification and employment for justice-impacted people, which collaborates on SCN network

installations, co-hosts monthly SCN Hack Nights, and has employed one of the original BBR DS trainees in a permanent Digital Navigator [14] role.

3.5 Findings

Our findings seek to address the questions of whether and how academic researchers could instigate and sustain a local community network centering equity while cultivating a robust participant base, and what operational models and impacts the resulting project would produce. We show how SCN has become a “Community Learning Network,” a created space and “learning commons” shaped by participants’ values of social contribution and aspirations as technology learners. This space builds power among participants by fostering a Community of Practice (CoP) that builds knowledge and solidarity. Thus, community- and relationship- building activities that influence participant engagement, such as teaching and collective governance, are foundational infrastructuring activities for CNs and other grassroots initiatives.

We also argue that the project’s structure facilitates the expression of power through critical and enabling contributions of infrastructure and resources. Participants recruit institutional partners, who are incentivized through mission alignment to contribute assets, relationships, and credibility to the project, allowing the CN to leverage some of their power. However, we also show how these contributions from powerful institutions shape both the physical and relational infrastructure, constraining and mediating future activities and participation.

3.5.1 Participation and Values in Grassroots Infrastructuring

We first investigate the factors that drive participation in both CNs. We find that in SCN and NYC Mesh, participants are attracted by the combination of values with technical interests or aspirations, reflecting the centrality of politics to CNs. Ten of eleven total interviewees identified helping others as a primary motivation for joining. A SCN Digital Steward identified technical

work as his chosen means of giving back to the community:

*Because I had the focus in technology ... my strength to give back to the community was in technologically related things. So whether that was helping kids, teaching them STEM, teaching adults how to use their computers, how to use their devices. I've taught robotics. I've always felt like I'm giving back to the community, but I'm also leveraging a passion that I have. And I just feel very strongly and **I don't want to leave this earth whenever that is and not say I was able to give back to my community.** And on top of the fact, I'm from Seattle, so it's another kind of connection- I'm giving back to the neighborhood that I grew up in, I've lived my entire life. - P2, SCN*

One of the first SCN volunteers from outside the University, a then-unemployed IT professional, also compared SCN to mutual aid initiatives he had joined during the 2021 Black Lives Matter protests, noting that he stayed with SCN longer because it “struck [his] core interests” in a way that other initiatives had not. (P6, SCN) A NYC Mesh volunteer noted that some participants “have worked on Occupy Wall Street or...on monitoring the cops’ behavior...[or] on anti poverty ...Another common thread is that they’re technical people ...So they have both a social justice drive, and they are harnessing technology to make [the Internet] accessible. ...it’s a really unique project. And I think the reason for its success thus far is that kind of draw where **it’s fulfilling on a number of levels.** (-P9, NYC Mesh)” Despite NYC Mesh’s less explicitly equity-focused messaging, we see the internal values held by members and social mechanisms other than messaging working to align the community’s values, perhaps demonstrating social cohesion [3]. The shared rhetoric may also reflect political roots common to the urban and broader global CN communities of practice, as described in Sec. 3.2.

In addition to bringing engineers into mutual aid contexts, SCN promotes hands-on technical learning outside gatekept school enrollment or paid employment that can also provide on-ramps to the tech industry. It demonstrates applications or aspects of engineering that may be abstracted

away in classroom environments. One locally born and raised UW student volunteer with a passion for community organizing observed that his interests in engineering deepened when he realized it could be used to help people, which “gives [him] energy or is enjoyable, so it doesn’t really feel like as much as work.” Despite being an engineering major, he initially felt less confident in engineering because growing up, he “never really did hands-on Legos, or robotics, or stuff like that. This was an opportunity to get free access to equipment and a mentor, and learn. I was able to say I can do this, and I can also help others with it, even if I’m not an expert” (-P5, SCN). Another recent UW graduate volunteered for several years, appreciating the chance to explore different projects freely without the constraints of employment:

*[It’s] a pretty good environment to just kind of learn and grow at your own pace. And it’s not scary... **It’s nice to be in a nice safe community.** ... now I can try web development, and then front end or back end things. [I]t just provides me a lot more opportunity to make an impact. And then hopefully [I’ll] find a place in community where I can do that, or a job... Volunteering definitely feels a lot less stressful (than paid work). I’m still in a position where I definitely need to learn before I start applying. (- P7, SCN)*

Many volunteers have used SCN for resume building to support finding work or transitioning to new areas. A NYC Mesh participant recounted similar professional development opportunities, mentioning “an electrician, who I think got some experience with NYC mesh doing the IT stuff and now works in IT. ... there’s definitely some (beneficial) aspect of learning about the different processes involved with all this wireless technology and all this networking, and then being able to take that forward to a job interview...” (- P11, NYC Mesh). Both SCN and NYC Mesh volunteers called CN activities a chance to “keep your brain fresh” (- P10, NYC Mesh) or “keep the skills sharp” (-P6, SCN). Finally, one volunteer expressed a fascination, which I share strongly as an infrastructure researcher, with learning about the processes of infrastructuring itself, or, as he described, “these behind the scenes engagements that happen to coordinate everything... **I wouldn’t ever come across**

***this in my day to day life.** Being able to see a group communicating with a NYC Department or commissioner or something, that's really cool to see.” (- P11, NYC Mesh)*

Members have found strength and solidarity in a culture of knowledge sharing, which we find to be crucial infrastructure promoting engagement in the CoP. One SCN operational partner expressed: *“Being in contact with folks that are doing similar work is a big help for me personally, professionally. It fuels me, it keeps me energized. **It makes me feel like I'm not alone in doing this work**”* (- P1, TCN). We frame this as building “power-with” among the CoP membership, as well as “power-to” organize and build live production networks. I reflect that these aspects of SCN also meet my own needs as a learner, illustrating the effects of the CN being a “created space” by students including myself. Having entered computing with a non-traditional background based on specific interests in DIY Internet and social change, the I have previously felt intimidated by academic peers with more ‘hard’ skills. Within the CLN, I gain intense personal satisfaction from learning through hands-on collaboration with more expert members from the tech industry, and works to reinforce this culture of sharing by also providing mentorship, public documentation, and curricula about all I learn.

We also find that membership in and contribution to SCN can be a source of social credit and self-esteem, building individuals’ “power-within.” One Digital Steward appreciated the social recognition he received for community technology mentorship via his named role in SCN, which he had previously done only informally. The organization’s mission aligns with his existing interests and activities, strengthening and validating identities he holds.

*I'm glad I'm here, **at least I'm being recognized for my hard work.** And also, that will attract or motivate the people that I'll be mentoring or guiding... now my identity is more than just a Black guy, more than just [NAME]. Now I'm part of this Seattle Community Network... it adds another value... In my community, when they had an issue with their computers, I was the person that they contacted, I help them. I set up the*

computers, I teach them how to connect to the Internet. I've done that individually, but at an organizational level this is my first time... It was naturally fitting for me to join this. - P3, SCN

Meanwhile, as cautioned by Cornwall about self-selection to civil society organizations based on identity [68], we see that the learning and activity spaces of SCN are “claimed” or “self-created” for those who join based on existing identities such as P3 and myself, while perhaps being only “invited” for network users or those who do not yet identify as technologists. Facilitating participation and entry of invitees is challenging, mediated by power dynamics and structural circumstances, especially given the marginalized groups SCN serves. Viewing Internet access as a basic utility, SCN does not demand or depend upon the users’ active participation to make the network function. However, recognizing the strong impact of the participants upon the organization itself, SCN contributes explicit resources and effort to engage users through community-open educational programs and regular outreach events.

3.5.2 Building the Learning Commons

Recognizing the centrality of participation, recruiting participants and their capacities to contribute both labor and network resources such as bandwidth is an explicit part of both CNs’ social and physical infrastructuring. A NYC Mesh volunteer discussed how the “mesh” topology of the network allows any members to contribute bandwidth, making the task of recruiting members and network site hosts overlap:

... all I want to do is make sure we're getting into the neighborhoods that are underprivileged, underserved... then [other members] were like, Hey, listen, yeah, that's our goal, to get these communities. But doing the rich people is not a waste of time, or causing this to be a non-democratized system. That being a mesh, every connection out there makes it stronger, and they have more bandwidth than they know what to do with right now off of

*their dark fiber connections ... And the chances that the **people in rich neighborhoods are going to have some more free time to volunteer once they have their piece in place to help support other pieces of the puzzle** also works. ... I'm also going to make sure that they spend a little extra time hands-on helping me as I get things installed, so maybe, later on, they can [support others]. -P10, NYC Mesh*

However, we note that even with the mesh architecture, most users connect to the network through a small number of high-value tall rooftop “hubs” that can reliably provide line-of-sight to large swaths of the city, highlighting the importance of individual powerful contributors.

SCN’s network is currently not based on mesh networking technologies, making the task of network site recruitment more explicitly focused on high-value hubs in target neighborhoods. (We discuss this choice further in Sec. 3.5.4.) A TCN mobilizer noted that “*Lately, [the work has] been a lot of community engagement. The last couple of weeks, it’s been meeting and talking with leaders in Tacoma, like city leaders, community leaders, business leaders ... to get some more folks in Tacoma on board with a community network. And that’s kind of been my role so far. Before that, and probably soon, I’m going to be more hands on managing the installations and the rollout of the equipment. That’s where my forte is. I have a lot of experience in both tech and community organizing, but my passion is on the tech side*” (- P1, TCN). These coordination activities, including both site host and user recruitment, are crucial because they generate the community-connected opportunities for installing real networks that make participation meaningful, adding these opportunities to what we call the “learning commons” (as introduced in Sec. 3.2.3). Participants can then “appropriate” from the commons to achieve hands-on learning, personal satisfaction, professional rewards, or other aspirations. Recruiting and maintaining community partnerships thus becomes a key infrastructuring task for the Community Learning Network (CLN). Partnerships with organizations already serving marginalized groups and neighborhoods are especially invaluable for collaboration on user outreach as well as for hosting sites.

SCN's most active participants skew heavily towards those with primary interests in technology, like P1 and P6, whose passion or "forte" may not necessarily be interpersonal communications. At the same time, being responsible for relational infrastructuring gives participants the power to recruit partners and choose sites based on their own relationships and neighborhoods of interest, increasing their ownership and accountability over the resulting infrastructure. We observe tensions between the core objective (Sec. 3.4.1) of centering participant capacity building by encouraging less-experienced members to lead (and struggle or fail in) all infrastructuring processes—including relationship building, communications, site planning, network installation, and maintenance—and SCN's underlying accountability for users' Internet access at existing sites. Effective communication strategies and tools for managing and sharing this accountability are an active area of exploration within SCN.

Resource contributions from powerful institutional partners such as the University are likewise recruited and mediated through individual participants' efforts to construct or leverage relationships with them. Mediators can pursue opportunities for resources based on their own and group opinions, leaving some room for "generative refusal" [260]. Thus, while partners can hold power-over SCN by making access to resources conditional, the CLN does not structurally depend on any sponsor. We find that relational infrastructuring processes grow SCN like a mesh network, with multiple points of entry and distribution for resources and power. This network of relationships builds power-with among mission-aligned local organizations, growing community capacity and sustainability as found in other CN studies [178].

Participants from among local activists, nonprofit providers, or long-time residents of Seattle (such as the TSTF DSs and FCS trainees) often have more numerous or stronger existing relationships with marginalized communities that SCN hopes to reach, empowering them to plan and mobilize their own installs more easily. However, barriers exist to incorporating individuals from these groups into the social and operational fabric of SCN's technical volunteer community. These

may include lifestyle factors (such as spending less time online) and other core priorities (such as parental responsibilities) that make it difficult or less natural to “claim” this space despite the open invitation. For example, Digital Steward (DS) trainees have found the chat server-based Slack or Discord interactions, especially amidst jargon-heavy or disorganized conversations, hard to integrate with their often busy lives combining multiple income streams and interests unrelated to technical networking.

Thus, a number of infrastructuring strategies have emerged as crucial to facilitating these members’ participation, including providing pay for participation and training from curricula designed for inclusiveness, assuming no prior knowledge of computing concepts. The latter methods are central to CN organizations such as DCTP EII, who focus on this category of participants without a CoP of technical volunteers; all of their installers are trained and paid, and they largely choose commercial technologies requiring less expertise and training than open-source. By contributing resources in support of participant training, pay, and easier-to-use technologies, institutional partners can mediate and benefit CN participation. However, this can give them substantial power-over the participants they enable, shaping their participation and the infrastructure they build.

Paid Participation.

Three of the seven SCN interviewees have been or currently are financially compensated via grants and partner organizations. I am also paid through SCN-related research assistantships for my participation, enabling me to contribute working hours to project-related activities without overly compromising academic obligations. While NYC Mesh has a few paid roles for specific tasks (e.g., accounting, inventory, or certain fiber-optic cabling jobs), the NYC Mesh interviewees are volunteers in full-time technical jobs, though install leaders receive a \$50 “tip” from users for home installations. They described these tips as either unimportant to their participation or barely

covering material expenses for installations.

As in other educational contexts and CoPs, paying participants can crucially promote their engagement in the face of challenging life circumstances. One SCN DS, living in a Tiny House Village (THV) shelter when recruited, told us before being hired that his constrained budget while seeking permanent housing meant he could not start any work until the pay schedule was guaranteed (unlike another THV resident, who preferred to volunteer, feeling unready for the psychological stresses of employment). The lead organizer in Tacoma also felt limited due to life constraints: *“I’m disabled, and fighting the system has been hard. So getting a little income would be nice at some point... it would enable me to justify either more time or to take time from other things that I might be getting paid for, up to even a part-time position... **When we’re working at the speed of volunteers, personal stuff comes up first, health comes up first. Other, possibly paid opportunities may come up first.** So that can limit you when when you’re just trying to pay the bills”* (- P1, TCN). Her participation is now compensated through University research grants, and she supports the work part-time along with another full-time IT job. However, she notes that other potential participants are limited by similar situations, which has stalled volunteer recruitment in Tacoma.

Another strong benefit of paid positions is that urgent infrastructure needs and repairs sometimes arise when volunteers with day jobs are not available. Debugging unpredictable failures can often be the most valuable learning opportunities, requiring persistence and attention, but often have a limited time window for participation due to their urgency; as P1 observed, the “speed of volunteering” can be highly variable and sometimes fail to address user needs. At the same time, volunteers willing to contribute weekend or off-hours to address emergencies and accommodate user schedules can also improve quality of service. It is an ongoing design problem to build better communications between volunteers and employees to address urgent requests efficiently.

Teaching As Infrastructuring.

Explicit teaching and learning activities can facilitate more equitable appropriation from the learning commons, e.g., classes can motivate participants with a “student” identity to claim challenging spaces in the interest of learning. They can also provide structure via predictable times, assignments, and logistical scaffolding, lowering barriers to entry such as limited time and attention to track online chat-based coordination or difficulty traveling to sites. For example, a Tacoma-based organizer could not join hands-on activities in Seattle as much as she would like due to time and mobility constraints. After attending the first Zoom-based DS cohort in 2021, she commented: *“The abrupt stop in the class was one thing that kind of shifted my focus [away from CN activities]. I had finally gotten into a routine with those classes. And then we had to stop because of literally everything else going on”* (- P1, TCN). Another 2021 DS also wanted more classes, citing difficulty balancing “all the other projects and stuff you’re juggling” and wishing he could say *“alright, let’s take two weeks off everybody, three weeks off, and just go learn the stuff you want to learn, and then come back”* (- P2, SCN). From my experience, classes can be extremely labor-intensive to organize and teach on a volunteer basis while maintaining CN operations and academic commitments, arguing for greater resource allocation towards teaching. At the same time, the classes have had a low retention rate (one or two DSs per cohort) for new CN participants after the end of training, with varied contributing factors including the end of funding and changing life circumstances.

Part of the challenge is that like other engineering work, CN activities often require unstructured, hands-on self-learning outside of classrooms, which can be hard under time or resource constraints. A NYC Mesh volunteer observed: *“The common thread is that we’re self taught. Because [for] the kind of technology that we’re learning, you need some logic and some math skills, but... the actual operation or the interaction of the [equipment] is not documented. So you have to learn about it. And how do you learn? You see what other people said about it, you play with it, you*

read about it” (- P9, NYC Mesh). Despite the challenges to participation P1 faces, she described thriving in hands-on and informal learning contexts, which is how she gained her prior IT and networking experience and instigated a CN in Tacoma: *“I don’t hold any major technical degrees. Everything I do has been self taught, or I’ve picked up for one thing or another.”* (- P1, TCN) P9 described further barriers due to intimidation and perceived complexity: *“How does somebody get from the point of doing two or three installs with support to taking on the full responsibility of getting the equipment there, spec-ing out the job, troubleshooting? **It’s intimidating, and it’s hard. It’s a steep learning curve**”* (- P9, NYC Mesh). Providing classes with dedicated equipment to take home and a stipend, as done for DS cohorts, can give students space and time to engage in self-learning, growing their power-within over the technology.

Another way to combat these challenges can be on-site, hands-on teaching and learning, onboarding participants directly into real CN contexts; this can slow down individual installs but reliably builds power-with through working relationships between participants. My ability to instigate SCN arose primarily from intensive hands-on work with NYC Mesh (see Sec. 3.4.1). In SCN, my most successful DS cohort for ongoing participation has been an apprentice-style cohort of just three, whom I mentored hands-on in field settings and who subsequently led two THV site installs thus far. One mentee, a self-motivated young Black woman, went on to instruct a classroom DS cohort of 20 justice-involved Black women, and her empathy as a recent learner sharing experiences in common with the students shaped the course. With sufficient ongoing contributions of technical opportunities to the commons, the CLN can provide a living laboratory for real-world learning experiences, or “training grounds” [146], in conjunction with classroom settings.

In NYC Mesh, the learning commons is much more abundant than in SCN due to the large number of self-requesters who sign up for service online, for whom installs are scheduled on a shared calendar by a volunteer. Given a tenfold larger CoP membership and a mesh consisting of

mainly single-household user sites, there is a higher frequency of installs or repairs to join (often multiple per week), with relative similarity or repeatability compared to SCN's more complex sites. For example, in one week in 2019 I was able to support or lead nearly ten installations and repairs, very quickly gaining practical skills; install opportunities continue to arise at a similar ongoing rate. Building momentum and growth on a larger scale in SCN while continuing to prioritize the underserved is an area of future work that will likely require important community governance changes.

Collective Governance.

Community power-over collective resources and their governance, long considered a core tenet of CNs [97] and of Ostrom's sustainable commons [198], is another important factor in enabling participants to co-create the learning commons. A NYC Mesh participant explained, "***I think [influencing people's engagement] means giving them a budget.*** So, for example, if there's a neighborhood where there's a lot of NYC mesh people, if there's 20 nodes on a two block radius, I would like to get them all onto a text group or an email list or something. And tell them look, if you have a meeting with each other, we will give you a budget of, let's say \$2,000... Do they want to put up access points in the park nearby? Do they want to put up signs? Do they want to subsidize installs for their neighbors? Do that. And I would like to give them the ability to have that conversation" (-P8, NYC Mesh). In response to another conversation with P8, I proposed a community budget allocation process from LCL's budget to provide a fluid and transparent approval process for new installs and projects, which was approved by vote. Equity challenges still exist related to initiative and ideation for proposing budget spending—a more familiar and accessible activity for engineers and tech industry workers than other participants, especially for those who have personal equipment or budgets to experiment with first. However, we hypothesize that adopting and demonstrating transformative social structures that give participants power-over community

resources and technical infrastructure can foment broader transformation, e.g., through other groups in which the same participants are involved. The Appendix provides a more complete snapshot of SCN's current collaborative work and governance practices (subject to community change).

3.5.3 Expressing Power through Contribution

We find that the CLN's goals incentivize more powerful organizations with aligned missions to distribute their social and economic power. The framing of the network as a commons and social justice intervention draws contribution both from individuals via their own agency and from institutions through the infrastructuring labor of individuals, largely without financial motivations. Further, the commons' dependence on real-world learning opportunities and impact requires SCN to maintain productive working relationships with local anchor organizations, adding pressure and accountability for CN contributors to maintain high-quality services. Thus, powerful institutions are able to gain reputation, "social capital," [3] and other value through their association with the project. Meanwhile, the CLN's mesh-like relational structure means that SCN could still exist (even if diminished in form) if any individual contributor were to withdraw support.

We note that the University's support through reputation and credibility has been instrumental for gaining access to partnerships, funding, and other resources, as documented in other civil society projects such as Mobile Vaani [223]. Universities often empower their members (while potentially disempowering outsiders) by staking claims of intellectual authority and expertise for ideas and projects generated in its spaces before the wider public. Further, the project's structure and goals as a CLN (by design) align it with the University's research and educational goals, e.g., enabling my research advisor to leverage his role within the University to obtain free rooftop access and internet connections for network equipment. These ongoing contributions, coupled with use of grant-funded or donated equipment, volunteer labor, and open-source software, allow

SCN to maintain low operating costs. With these resources, SCN has bootstrapped the built network, relationships with other well-reputed institutions such as FCS and KCLS, and its network user count, gaining credibility and power in its own right. However, we consider below how the values and influence of especially powerful contributors (such as the University, City, County, and others) have shaped the physical infrastructure and mediate participation in ways that are ambivalent to the network's users and core goals.

3.5.4 Technical Design Tradeoffs

Access Network Design

The current network (Table 3.2) spans 12 sites that serve wireless Internet to approximately 100 end-users in total, with an additional 3 sites housing backhaul infrastructure only. As noted in Sec. 3.4.1, initial wireless site designs used open-source 4G LTE technologies, primarily a result of SCN founders' backgrounds as ICTD researchers specializing in installing cellular data networks for remote rural contexts. As a result, initial proposals and grant applications for SCN focused on LTE networks using the recently opened radio frequency spectrum band known as Citizens' Broadband Radio Service (CBRS), "3.5 GHz," or "LTE Band 48," [63], with which we could now transmit in the US. We proposed using standalone 4G network sites on host organizations' rooftops to serve wireless Internet to local neighborhoods, potentially covering up to 1-2 miles depending on terrain and line-of-sight, which resembles prior designs for rural village networks that we deployed previously on extremely constrained electrical and monetary budgets. Each site included one or more rooftop commodity "microcell" access points (called an "eNodeB" or eNB), controlled by a generic (indoor) computer running open-source "evolved packet core" (EPC) software called "open5gs" [194]. To lower costs, our typical hardware included a lower-end model of eNB at around \$3-4K USD per sector and a commodity "mini-PC" at \$200-400 USD, along with low-end (under \$100 USD) gigabit routers and switches as needed. The SCN documentation website contains

Table 3.2: Network sites by partner organizations, type, region/location, and year installed, as of Feb 2024. Abbr- OCC: Oromo Cultural Center, SPS: Seattle Public Schools, KCLS: King County Library System, TPL: Tacoma Public Libraries, LIHI: Low Income Housing Institute.

Site Host	Partner Org(s)	Type	Region	Year
Filipino Community Center	FCS	LTE Cell Site	Seattle	2021
Garfield High School	SPS	LTE Cell Site	Seattle	2021
Franklin High School	SPS	LTE Cell Site	Seattle	2021
KCLS Skyway Library	KCLS	LTE Cell Site	Uninc. King County	2021
UW Tacoma GWP Building	UW	Backhaul	Seattle	2021
UW Harborview Medical Center	UW	Backhaul	Seattle	2021
SurgeTacoma Coworking Space	TCN & Surge-Tacoma	LTE Cell Site	Tacoma	2021
Oromo Cultural Center Masjid	OCC	LTE Cell Site	Seattle	2021
Nickelsville CD Village	Nickelsville	WiFi User Site	Seattle	2021
LIHI Southend Village	LIHI	LTE User Site	Seattle	2022
Nickelsville Northlake Village	Nickelsville	WiFi User Site	Seattle	2022
Tacoma Public Library Main Branch	TCN & TPL	LTE Cell Site	Tacoma	2022
Westin Building	SCN Volunteer	Backhaul	Seattle	2023
Progressive Skyway Village	TSTF, LIHI	WiFi User Site	Uninc. King County	2023
LIHI TC Spirit Village	TSTF, LIHI	WiFi User Site	Seattle	2024

additional technical details [168].

Upon granting SCN its first funding, King County grant administrators commented that in addition to the low-cost budget, what made the proposal attractive to them was its exploration of LTE and CBRS, seen as a timely area of innovation and interest for broadband development

within industry and government. Moreover, the project seemed appropriate for an academic team, whereas most other funded proposals had been from well-established, service-providing nonprofits proposing less risky programs, such as device distribution. However, over the course of the project, the chosen technology and the conditions of its implementation placed constraints on the infrastructure's ability to provide community benefit in the following ways:

1. *High cost per user bandwidth for LTE.* In the 2020 market, SCN faced high price points for LTE eNBs (\$3500 USD-over \$10000 USD), CPEs (\$150 USD-\$1000 USD) and newer smartphones (\$300 USD refurbished) supporting the CBRS band, as well as bandwidth constraints from the (Category 4) LTE eNB and CPE radio layer protocols. This limited our total end-user bandwidth per sector to around 100 Mbps download and less than 10 Mbps upload speeds: lower performance than cheaper, more commonly used fixed-wireless hardware.
2. *Low-end hardware.* Due to the cost-based radio hardware choices described, each LTE site is underbuilt for distributing its upstream bandwidth, which is typically a gigabit fiber connection. In 2023, the LTE eNB model initially deployed also reached "end-of-life" for manufacturer support, and SCN will soon need to upgrade every cell site to a newer model at double the cost to receive security patches going forward. Furthermore, over the past few years, the mini-PC hardware running the core network software at each site has failed at four of our initial five sites, and SCN has frequently had to enact emergency replacement procedures.
3. *Rushed site selection.* The requirement to spend the initial grant money between October and December 2020 to rapidly deploy the first three sites reduced the long-term potential for benefit. The time pressure led SCN to select sites and coverage areas based mainly on existing partner readiness and rapport, without thoroughly understanding coverage needs or demands in those neighborhoods. For example, one LTE network was deployed at the

single-story Oromo Cultural Center, resulting in a correspondingly small coverage area. Luckily, a later-recruited THV user site was just within wireless range via a non-line-of-sight link, but the service is correspondingly slow (at 60 Mbps) and shared by around 40 residents. However, if not for this limited LTE site, THV residents might not have Internet service or the access devices SCN provided.

The choice of DIY, open-source LTE technologies for the physical infrastructure has presented mixed benefits and drawbacks for participation in the resulting CoP, on one hand making the learning curve steeper for newcomers, but concurrently revealing the inner workings of the technology to depths they might otherwise never see. We describe these tradeoffs below.

1. *Steep learning curve.* It has been difficult to train any LTE technicians among participants (DS and volunteers alike) outside the research lab beyond basic troubleshooting techniques, such as rebooting a site's mini-PC if a network outage occurs. Novices in computing especially struggle to work with open-source software running on less-familiar Linux servers. Creative curriculum design for these topics is an area of future work.
2. *Career benefits.* SCN has facilitated uniquely deep and hands-on experiences with cellular technologies for dozens of computing students both inside and outside the University. Several SCN students and volunteers, after impressing technical job interviewers with their understanding of LTE, have been hired into local companies, such as F5 and Starlink. I have also gained extensive embodied experience deploying particular cellular hardware, and has been hired to train technicians in other settings.
3. *Open-source and research contributions.* SCN's participation strengthens the open-source CoP around the use and development of LTE, producing guides and materials that other CNs (including NYC Mesh) have used. This CoP also supports work conducted in the research

lab on innovations in community cellular technologies, including decentralized roaming between sites and open-source eSIM infrastructure, which would allow end-users to join SCN's network without having to swap other carriers' SIM cards out of their phones. The latter could enable a future where independent cellular networks can fill gaps in patchy urban coverage.

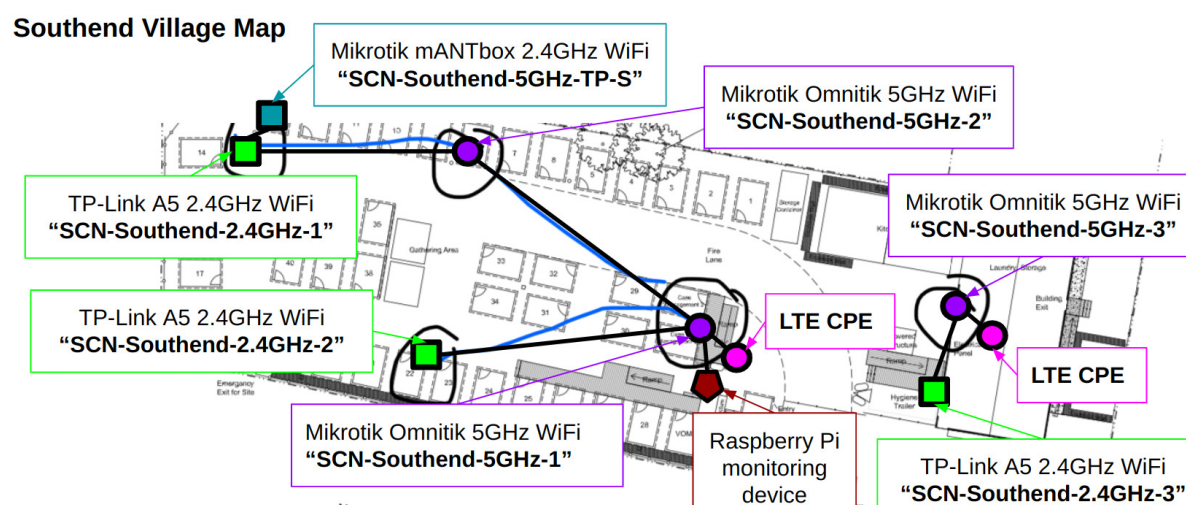


Figure 3.2: LIHI Southend Village network map.

Fiber Backhaul.

Upstream internet connectivity for many of SCN's sites is another critical resource choice that has created technical constraints. Recurring service fees (such as for Internet access) are typically not covered or are only partially covered by one-time grants, threatening SCN's sustainability. Through a City Internet initiative, SCN can request no-cost gigabit Lumen home fiber connections (within city limits) directly from the City IT to share via their community wireless sites. This has been particularly helpful for serving THVs, regionally popular transitional housing that shelters around 20-40 unhoused individuals in private one-room sheds with shared kitchens and bathrooms. The most efficient way SCN has found to provide Internet service at THVs is to install robust

site-wide WiFi, connected to the fastest wired or wireless upstream internet (“backhaul”) they can acquire for free. Unfortunately, in a surprising number of cases, including the Southend THV (Figure 3.2), affordable, high-speed ISP wired connections cannot be purchased through typical channels. Commercial ISPs may not initially recognize these assumed-temporary housing plots as home addresses. Though some cases have been mitigated by working directly with the City IT office, some addresses are still deemed unserviceable. Thus, the Southend Internet connection is provided via two LTE CPEs receiving service from the SCN cell site at the nearby Cultural Center, as described in Sec. 3.5.4. At some other sites, access to fiber backhaul is provided via a point-to-point wireless link from a UW building (such as one link from Harborview Medical Center to Franklin HS).

We note the UW’s crucial role in establishing SCN’s access to this City-based Internet access agreement through a network of relationships. In summer 2020, my advisor was contacted based on his academic reputation by a City Strategic Advisor for Broadband. Interested in SCN, she ultimately connected us to a City Wireless Advisor who championed the project with the City IT, resulting in the agreement and an additional Pilot Project grant that established two new sites with local public schools.

An important consequence of this backhaul contribution has been the administrative complexities of sharing a commercial ISP connection. For example, over the course of a year, one LTE site experienced repeated service restrictions affecting the whole user base due to punitive Digital Millennium Copyright Act (DMCA) [193] policies. The copyright complaints were always the result of a single user seeding torrents of the same pirated game file despite multiple warnings SCN posted to all users of the site after these outages; this user likely lacked knowledge of a torrent program running in the background on their own or a visitor’s computer.³ Finally, SCN received

³The site’s Senior-heavy demographics and the seasonality of violations (roughly aligning with winter and summer holidays) suggested that perhaps a student would come to visit grandparents, unknowingly running a torrent program on their laptop while on their grandparent’s WiFi.

an automated “final notice” from the ISP and had to switch the site onto a slower emergency mobile connection until the issue was administratively resolved months later.

In response, SCN is redesigning its core network to tunnel traffic to a VPN gateway at the local Internet Exchange, enabling use of its own IP address space so the community-governed CN can enact its own DMCA policies as a carrier. While a VPN was initially not implemented to prioritize network speed, protecting user privacy and quality of service has provided an impetus for the engineering change. Within a month of the most recent shutoff, a small group of volunteers speedily proposed, coordinated, and deployed a volunteer-donated server in a donated Internet Exchange rack space as a core network router. While this solution has so far proved difficult for the volunteers to set up and maintain, it has become a much-valued opportunity for participants to learn hands-on and produce open knowledge about the opaque and “behind-the-scenes” workings of ISP core networks.

3.6 Discussion

3.6.1 The Community Learning Network Model

Through our ongoing action research and documentation, we contribute a living example of an infrastructuring model for a community of practice and “learning commons” centered around the deployment of community network infrastructure, which we term a “community learning network” (CLN). While functioning as a network commons for users, the CoP and its outputs have become a knowledge commons, and opportunities to build and maintain the technical infrastructure have become a commons for hands-on learning. We thus far explored how participants and their modes of participation have shaped community outreach and network site recruitment, teaching, governance, and technology choices, including network software and hardware. Here, we discuss further considerations and challenges for CLNs.

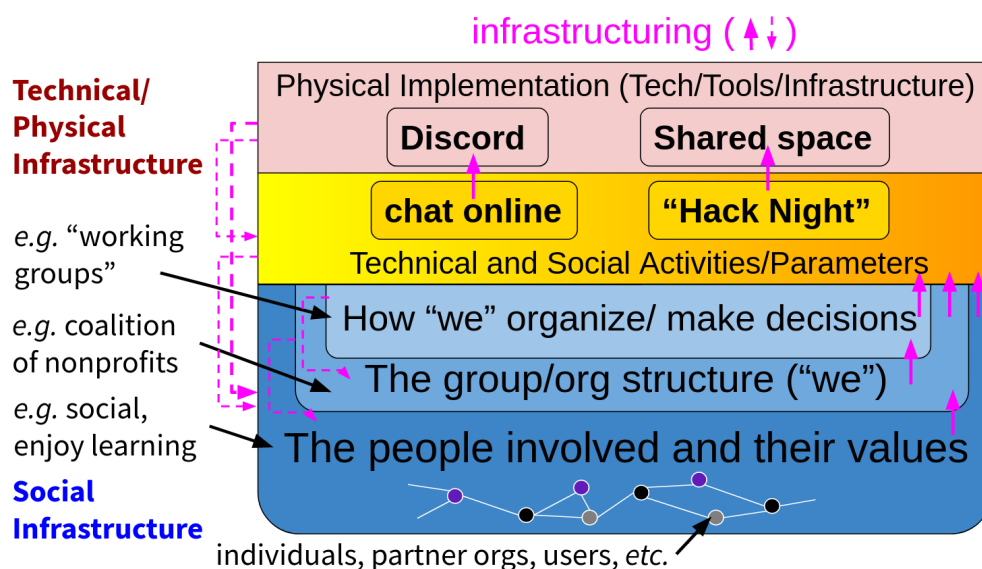


Figure 3.3: (Read from bottom to top) The social and relational infrastructure of SCN (bottom blue half) underlies technical (yellow) and social (orange) activities, and ultimately technology and tool design/choices (red). Pink arrows represent infrastructuring processes (styled solid for upward layering, dashed for downward feedback).

An Infrastructuring "Stack"

Figure 3.3 offers a descriptive framework of how social infrastructure can provide the foundation for the technical and physical infrastructure that gets deployed in SCN. It contributes a mechanistic model and examples of the processes by which participants of grassroots or "bottom-up" [72] CNs can build and shape technical infrastructure.

The bottom layer (dark blue) shows the network of participants, including their beliefs and values as well as relationships they hold, such as community partnerships, affiliations, and personal friendships. Built from that (medium blue) is the operational entity and model, in SCN's case a community project supported by non-profits and educational institutions, which structures how participants present the "we" of the group both internally and externally. Above (in light blue) are governance and work processes that structure group activities and decisions in the context of the

Figure 3.4: Examples of how specific elements in lower layers of SCN’s infrastructure “stack” lead to specific technology and tool choices (especially software). Layers are color coded as in Figure 3.3, turned clockwise for readability.

People & Values	Model: Volunteer-based nonprofit	Decentralized technical “Working Groups” with variable membership	Internal Team Communications	Discord/Slack
			Internal Documentation	Google Team Drive
			Internal Meetings	Discord/Zoom, Google Calendar
			Internal Management of Help Requests/tasks	OSTicket, email lists
	Missions: education, providing internet service, access to knowledge	Open to general public participation	External Input for Help Requests	Google phone number, public email address
			Publicize Community Events	Meetup, Facebook, Instagram, email lists
			Maintain External Documentation	Open-source Public Website (on Github)
	Model: Grant funded	Grant deliverables managed by volunteers	Network Monitoring and Reporting	LibreNMS + custom scripts
	Mission: providing internet service	Collaborative volunteer site management	Network Status Alerts	LibreNMS + Discord alerts
	Mission: education; grant funded; nonprofit	No user fees or regular income; technical volunteer managed	Self-Hosting Internal Web Services	Azure Cloud VMs
Getting Free Nonprofit Computing Resources				
	Model	Practices	Activities	Tools

organizational structure.⁴

As an example, volunteer work practices such as SCN’s self-organized, decentralized “working groups” (light blue layer) require transparent online chat driven by the organization’s collaborative multi-partner structure (medium blue layer) as well as values of inclusiveness and education (dark blue layer), resulting in the use of a public Discord server. The layer above shows the activities SCN participants organize (ranging from technical-focused in yellow to social/organizing-focused in orange), including monthly meetings, weekly work sessions, Hack Nights, socials, installs,

⁴We note strong parallels between these bottom layers and the first two of three iterative steps of Freirean participatory communication theory, described in Ghoshal [101]—(1) *Forming a collective identity* and (2) *Mobilizing toward collective action*. We observe that these iterations happen dynamically as people continue to join the group, organize new activities, and (3) *Engage in reflexive dialogue* (the third step) via online chat.

and trainings. These activities result in deployed technical artifacts, tools, and other physical manifestations (light red layer), such as shared physical space in community centers. While only the formation of top layer might typically be seen as technical infrastructure building or deployment, this framework conceptualizes the construction of all layers as well as the movement between them as contributing to the form of engineered products.

We also observe feedback across layers from top (red) to bottom (blue). For example, it becomes easier to recruit people to the bottom layer who already align with group preferences (such as those who can use Discord), which can reinforce current group composition. Another important example is the feedback from regularly sharing space at community centers, e.g., visiting the Filipino Community Center rooftop cell site to perform technical site maintenance, or co-hosting community-building events such as “Hack Nights” in their makerspace. Both involve learning and technical activities in a social setting, which build trust and strengthen SCN’s working relationship with FCS members. In Figure 3.4, we offer further specific examples of deployed infrastructure based on choices at different layers (turned clockwise to a left-to-right orientation for readability).

Dynamic Infrastructure.

We note that the CLN’s goals of DIY and openness to hands-on work by non-experts, combined with its resource-constrained non-profit context, can result in infrastructure that is more dynamic or changeable and in some ways less robust than a typical ISP’s. Due to time, labor, or financial constraints, engineering dilemmas (such as those imposed by contributed resources) may sometimes lead to “ad hoc” or temporary solutions, cobbling together assemblages of low-cost, DIY-friendly, or general-purpose tools, as discussed in Chapter 3. Other grassroots-engineered socio-technical systems (such as open-source software) may also optimize for prioritizing use of other open-source projects as well as participation over stability or performance, representing a special case of infrastructure that shifts and potentially breaks more frequently than usual. How-

ever, we argue that such shifts represent development, engagement, and learning opportunities. As long as this tradeoff is acceptable to the system's end-users, e.g., because services are free or come with other benefits, the model becomes viable. In future work, we intend to present more detailed designs for an open-source, modular technology stack and technical infrastructuring practices that maximize network stability despite this dynamism, which can be appropriated and remixed by other CNs.

Power and Transformation.

We highlighted how the CLN, framed as a TSI, proposes to transform power relations by creating spaces for innovative social interactions that change socio-material reality. In SCN's case, these interactions are the building and maintaining of an equitable Internet access infrastructure (the socio-material reality) in a DIY and community-collaborative manner, and the spaces in which they occur are the sites of participation (digital or physical) created by the CLN. This builds on an intention to undermine an inequitable dominant paradigm and "hegemony" [30] of connectivity as commodity, which leads to cases where physical infrastructure may be present or close by, but the terms and cost of use make it inaccessible for some. Like other TSIs, CNs seek to "build civic capacities to think differently, to challenge assumptions and norms, and to articulate new ideas and visions" [99] about connectivity and technology infrastructure.

From feminist theory, we agree with Lorde that "the master's tools"—in our case the skills and knowledge of computing and wireless networking—cannot dismantle "the master's house"—existing infrastructure, tools, and commercial frameworks for connectivity, including power and knowledge imbalances that exclude some members of society. However, we propose a new agenda for exploring whether we can teach and learn from the master's tools in service of designing our own tools as we work together to build new houses—infrastructure and community—from which we can find respite from the old. As Bates explains, Gramsci's hegemony can be overcome only

by “building a new order” that replaces the old, “organizing a new society and creating a new culture” [30] in the context of the TSI.

Our findings highlight dilemmas TSIs face when attempting to leverage the power-over of sponsor institutions, whose resource contributions they need to help combat broader societal power structures, while not overly depending on them. This mirrors the simultaneous necessity for TSIs of finding “institutional homes” (Proposition 7 of Pel et al.’s framework), while also “reconfiguring the broader institutional logics” of dominant institutions and of the wider socio-material context (Proposition 9) [200]. In the sections below, we briefly outline possible ways to reconfigure the academic context in which this work is housed to reflect the centrality of participation we observed.

3.6.2 Reconfiguring Participation

Many researchers have proposed the use of *values* to inform technology design [94] and the use of *participatory methods* to involve intended users [259]. Others have shown how developers can embed values and political choices directly in technical artifacts, e.g., the repairable, open-hardware LibreRouter designed for CWNs, described as “*a distillation of principles, values, techniques, and practices, as a whole, not only the device, but the whole proposal...*” [97] A step further, *participatory action research* (PAR) proposes to begin initial ideation for research with community participants to forefront their values and needs in projects and resulting artifacts. We do not claim our work to be PAR because the values and intentions of the researchers and other SCN community mobilizers took precedence during project inception. However, we propose a different goal: knitting collaborative working relationships and encouraging bi-directional dialogue between community members and technology designers or builders across typical social and economic boundaries, and manifesting power-with through collaborative action. Like Freire, we believe that such two-way dialogue is necessary for “true humanization” that can disrupt power imbalances between these groups and

act as an infrastructuring process from which other initiatives such as PAR can grow. For example, technical projects could engage in pedagogical work to integrate members of marginalized or excluded groups into the social fabrics, work processes, and discourse of technologists, giving them power to participate directly in technology infrastructuring. Explicit teaching and mentorship would be necessary to onboard participants into technical CoPs, but the knowledge once gained could empower them to understand and join other technical processes in the future, working against structural exclusion. Conversely, we also propose that developers could be invited for dialogue or to contribute valued collaborative work in the physical spaces and environments of marginalized people for whom they design, which could build rapport as well as empathy and understanding of their use cases. This community-building approach seeks to subvert dominant design and research paradigms assuming distinct categories of developers and users.

We acknowledge that given the lack of transparency around development in the technology industry and the selection practices gatekeeping formal academic institutions, “third place” or civil society spaces such as CLNs may be the easiest context in which to build these types of working relationships around technology. Thus, future work remains to make such voluntary “invited spaces” like SCN more accessible and inviting to those who start initially outside or on the margins of the community of practice, such as CN users. For example, we have shown how some SCN participants enter through more specialized identity-based organizations such as BBR and FCS, which Cornwall suggests “provide the terrain at the margins from which marginalized people can organize,” [68]. Gaventa adds that “real change” occurs “when horizontal alliances are built across these spaces,” as SCN aims to do by building power-with through the shared context and activities of the CLN [98]. Thus, we propose that institutions with power and resources to contribute to action research focus on allocating resources for participation from marginalized groups, especially in ways that build direct “mesh”-like relationships horizontally across organized groups.

Finally, for more traditional technical work contexts, we propose our method of personal process journaling as a tool for ethical technology and infrastructure design, to help track the decision-making processes involved in producing infrastructure. Like any journaling-based or autobiographical research, this approach requires sincerity, transparency, and honesty, which we acknowledge are difficult in certain contexts. For example, for-profit corporate entities might be less amenable to such employee-initiated documentation when their technical choices do not strongly adhere to publicly beneficial values and goals. When academic researchers design interventions for the outside world (or for themselves), we propose this kind of journaling to document the multifaceted, often personal and positional factors around design choices for historical reflection and analysis.

3.7 Conclusion and Takeaways

Since the Covid-19 pandemic, the SCN action research project has been able to meet some Internet connectivity needs in urban areas where some residents cannot access affordable broadband. We present the “Community Learning Network” model it has generated, which combines a community of practice and a hands-on learning commons through grassroots, participatory, and DIY infrastructuring processes. Within this framework, participants and their values shape the CN’s social and relational infrastructure as well as deployed technology artifacts, building power-to and power-with. However, the infrastructure remains subject to power relations with institutional contributors, the effects of which must be mitigated through further infrastructure analysis and action.

We propose transforming participation in technical infrastructuring to prioritize community empowerment by establishing participatory communities of practice, relational “mesh” networks, and “humanizing” dialogue engaging technology builders, learners, and users as a primary goal rather than as side benefits or spillover effects of research. We note that the perspective of the

researchers, used in conjunction with qualitative analysis of CN participant interviews from SCN and NYC Mesh, contributes critical information and depth of knowledge about the processes and decisions underlying the work. We encourage engineers and technologists to likewise engage in personal process journaling or field notes as a tool in ethical technology and infrastructure design to track decisions and values that become embedded in engineering processes.

Chapter 4

| Leaves |

Participatory Design of IoT in Self-Managed Tiny House Villages

Abstract

In tiny house villages, land ownership, the local regulatory environment, and management affect how residents use and modify infrastructure, including how they deploy and engage with technologies. Differences between public and private land ownership directly impact the regulation and infrastructure possibilities for tiny house villages, and historical and current zoning of land shapes the types of social problems that the community must navigate. These factors affect the dynamics for residents once the villages are operational. This chapter forefronts how different land ownership, zoning and management frameworks influence residents' lived experiences, creating both constraints and opportunities for deploying networked sensor technologies in support of communication, physical security, and shared infrastructure governance. Through a

series of participatory design workshops and visits with residents of two tiny house villages, we identified how residents balance privacy and security concerns when considering sensor design and deployment. We find, for example, that residents impose constraints on their designed sensors for the group’s protection, such as a strict ban on camera-based visual or audio surveillance and a preference for local as opposed to cloud data storage. They also identify opportunities for diverse sensors and actuators to improve village accessibility and alleviate resource sharing tensions. Our findings deepen the CSCW research agenda by examining parameters for successful IoT interventions among low-resourced urban groups experiencing housing precarity.

4.1 Introduction

Homelessness, a “...fundamental lack of long-term shelter deemed adequate and sustainable for individuals seeking housing resources” [257], is on the rise in North American cities. In the last decade, the homeless population in the United States (US) has surged, peaking in 2022 (with 2023 yet to be counted). The 2023 Annual Homeless Assessment Report (AHAR) to Congress estimated that on a single night, 653,100 individuals in the United States (two in every 1,000 people) experienced homelessness. Washington (WA) was identified as one of four US states with a higher number of unhoused individuals compared to other states [235], and WA’s King County (home of Seattle) mirrored this trend, with over 7,600 people unhoused on a given night according to a 2022 Point-in-Time (PIT) estimate (and over 13,300 including sheltered homeless) [21]. Furthermore, the AHAR highlighted that approximately 59% of the homeless population was located in urban areas. The scale of this crisis invites novel housing solutions.

In the Pacific Northwest of the US, Tiny House Villages (THVs) are a type of emergency shelter commonly used to bring people indoors, providing short-term relief. Small, easy-to-construct standalone sheds are used as rooms, akin to individual hoteling as a shelter solution; the private units provide lockable personal space and allow families and pets to stay together, unlike many

other shelter models [131, 247, 248]. Villages of these “Tiny Houses” provide transitional housing for people while they seek permanent housing, addressing an insufficient supply of affordable, low-income or permanent supportive housing in the context of rapid gentrification, historically restrictive zoning, and slow timelines for permanent housing construction. However, due to the same conditions (e.g., market, policy, and environmental) that curtail supply, public or contributed land for these types of shelters is extremely limited.

This multi-disciplinary work explores tensions in bringing “IoT” or “smart” home and city technologies into the context of urban homelessness and housing insecurity through collaboration with THV residents living in Seattle, WA.

The past decade has seen an explosion of research on and deployments of smart city infrastructure, ranging from technical innovations in sensing and mapping to uses in governance and activism to analyses of surveillance and discrimination [19, 62, 148]. A core issue and common thread is that large-scale IoT initiatives are consistently designed, planned, and implemented top-down by powerful actors (e.g., city governments or corporations), with insufficient community ownership and oversight over data collection and management. Further, concurrently proliferating “smart home” technologies, where individuals install sensors and automation in their homes, encounter similar challenges regarding data privacy and consent due to cloud data processing, storage, and sale practices common across the tech industry. A plethora of commercial IoT products now exist with varying technical affordances, such as smart doorbells with cameras for monitoring, lights with a programmability layer, plugs that can automatically power devices on and off, and myriad others. At best, these technologies are an awkward fit with low-resourced communities, often marketed as high-end accessories for luxury homes. At worst, they can cause users to feel actively targeted and threatened, such as when data is sold to third parties or leveraged against users by law enforcement.

This research aims to enable THV communities to iteratively co-design and implement their

own “smart village” sensing systems with as complete ownership as possible. We engage with villages that are self-managed by formerly unhoused residents who collectively organize for political advocacy. In this multi-resident context, sensing and automation exist in a middle ground between city- and home-scale IoT, offering novel applications and opportunities for community cooperation and technical innovation. Through an ongoing partnership with the Seattle Community Network (SCN) [168], a mutual-aid group that builds free WiFi and internet infrastructure in THVs, we use participatory design workshops to ground iterative installation and user feedback cycles to design appropriate technologies for this context. In doing so, we explore opportunities and limitations of leveraging community-driven sensing systems to support resilience, collective politics, and data sovereignty in contexts where people experience housing *precarity*, i.e., a state of persistent insecurity.

We find that self-managed THVs struggle with precarities in their housing infrastructure based on underlying insecurities faced by their residents as well as a collective lack of ownership and agency in their land use arrangements. Ultimately, infrastructure changes require approval by governing authorities and land owners, as in the top-down smart city scenarios we sought to avoid mimicking. Through participatory methodologies, we see how residents impose constraints on their designed sensors for the group’s protection against these precarities, such as a strict ban on camera-based visual or audio surveillance and a preference for local as opposed to cloud data storage. They also identify opportunities for diverse sensors and actuators to improve village accessibility and alleviate resource sharing tensions. We note the crucial importance of privacy to mitigate the impacts of local power dynamics and the often controversial trade-offs between privacy and security. Finally, we discuss additional open design problems and opportunities for IoT in low-resourced, self-managed communal settings like THVs and other shelters with similar constraints.

4.2 Related Work

4.2.1 Homelessness and Informal Housing in the U.S.

Homelessness and housing instability encompass a diverse range of experiences, both temporally (transitional, episodic, or chronic) and spatially (e.g. living in vehicles or tents, “doubled up” with other people, etc.) [171, 191]. While extremely varied, experiences of homelessness are broadly associated with “a series of heightened risks and threats related to health and well-being” [257]. These can include heavy policing [240], disability [34, 81], mental illness, poverty, violence, harsh environmental conditions, discrimination, and inadequate access to basic needs such as healthcare and transportation; individuals experiencing homelessness face higher mortality rates [234]. Climate justice research has characterized homeless populations as among “frontline communities” for experiencing harms from climate change [6, 90]. Furthermore, select groups, including BIPOC, pet owners, non-U.S. citizens, members of the LGBTQ community, and individuals with a history of justice involvement are shown to be disproportionately affected by homelessness [89].

Sanctioned encampments are one intervention tentatively embraced by some service providers and local governments, where land access is secured through agreements with land owners and/or governments [196, 88]. In the Pacific Northwest US, these encampments typically have some level of infrastructural provision for electricity, water, and waste management in place. People can live in encampments for longer periods of time without needing to vacate premises during the day, as is typical in shelter systems, or move from site to site in order to avoid sweeps by police [103]. Shelter structures at these encampments can include vehicles, tents, other self-made constructs, or—as is the case at the sites included in this study—“Tiny Houses,” prefabricated structures that provide individual sleeping and storage space accompanied by shared bathrooms and kitchens [71], detailed further in Sec. 4.4.

Table 4.1: A summary of Ostrom’s design principles of Common Pool Resource (CPR) governance [198], adapted from [153].

CPR Principle	Summary Description
1. Clearly defined boundaries	The boundaries of the resource and those allowed to use or “appropriate” it are defined and enforceable.
2. Congruence between rules and local conditions	The way the resource is actually used is reflected in any rules applied, and those rules are responsive to changes in local resource conditions.
3. Collective-choice arrangements	Most users impacted by operational rules can participate in rule modification.
4. Monitoring	Monitors can track use and are accountable to local users or are local users themselves.
5. Graduated sanctions	Punishments for breaking rules are contextual and flexible given the seriousness of the offense.
6. Conflict-resolution mechanisms	Inevitably arising conflicts can be resolved quickly and at low cost.
7. Minimal recognition of rights to organize	The rights of users to organize and self-regulate are not challenged by external authorities.
8. Nested enterprises	If the CPR is part of a larger system, activities are organized in multiple layers.

4.2.2 Precarity and World-Building

Discussion of homelessness and informal housing can be usefully contextualized within a broader examination of urban precarity. Beyond the meaning of the English word *precarity*, describing insecurity or vulnerability to uncertain conditions, the concept of precarity in sociology and economics first emerged to describe conditions of poverty, and later evolved to refer to forms of labor outside guarantees of permanent contracts characterizing classic Fordist economics [169]. Butler expands the meaning of precarity beyond economic concerns; she argues that all human existence is defined by a certain level of precariousness, which she defines as the inherent vulnerability of bodily existence [55, 54]. While accounting for how class and labor statuses unevenly distribute vulnerability across populations [113, pg. 336], her interpretation also allows for a more multifaceted exploration of how other factors (e.g., age, race, and gender) produce and mediate conditions of vulnerability [9]. Butler’s conceptualization of precarity as a social and

political arrangement leaves open the possibility of creating new arrangements that more equitably distribute vulnerabilities, as our work explores.

Recent work has highlighted precarity as a pervasive and global condition that has been greatly expanded through the shift to neoliberal economics. Berlant [38, pg. 192], for example, even describes precarity as the “dominant structure and experience of the present moment.” Despite the ubiquity of precarious conditions, there remains a special relationship between precarity and urban spaces. Notable for this chapter, scholars have described spatial practices – such as practices of possession and dispossession – as important factors in the production of precarity [25, 201]. Scholars in urban studies have long associated cities with precarity, pointing to ways in which city life produces “unique challenges in terms of vulnerability, uncertainty, and risk” [56, pg. 285]. Campbell and Laheij [56] are particularly interested in understanding how precarity may actually encourage individuals to strive for the improvement of urban spaces, thereby serving as a “condition conducive to world-building and social transformation” [56, pg. 285]. Other scholars have similarly described precarity as providing the conditions for the emergence of a politics of refusal (e.g., [182]) or as inspiration for the design of more resilient cities (e.g., [9]).

In this chapter we see our participants’ collective governance and advocacy strategies as examples of tactics for producing new ‘worlds’ out of precarity. We investigate whether new innovations in sensor and IoT technologies can further enhance world-building. For example, in the context of managing constrained shared utilities, we consider whether and how sensors might enable the strategic use of Ostrom’s principles for sustainable governance of Communal Pool Resources (CPRs), summarized in Table 4.1 [198]. We also see opportunities for a generative “politics of refusal” on the part of THVs, whose residents protect their data privacy through the refusal of certain sensors and of sending data to cloud-based IoT platforms. As a collective and as individuals, they intuitively adopt and mobilize the concept of “data sovereignty,” broadly defined in literature and common discourse as “meaningful control, ownership, and other claims to data

or data infrastructures” [57]¹. Taken together, these examples help to highlight the opportunities, challenges, and limitations of leveraging technologies to address precarity. In doing so, they establish the foundation for a more expansive CSCW research agenda around urban precarity.

4.2.3 Smart Cities and Home IoT

Research and implementation of “smart city” and IoT technologies are often driven by visions of leveraging networked sensor data to better understand and intervene in the conditions of city life [33, 31, 32], or to monitor social and economic indicators of interest [162]. For example, real time data on local conditions, from traffic disruptions and crime to pollution, can be fed into automated analyses and visualizations to provide city managers with urban dashboards and other governance tools [163]. Proposals for smart city applications in Barcelona in 2015 included features that addressed homelessness directly, using plans for improved wireless connectivity for advanced mapping and tracking of homeless people and their needs or providing direct donations to them online [177].

However, this vision of the future can represent an unprecedented dystopia for marginalized and underserved populations. A wide and rapidly growing literature on AI ethics acknowledges countless missteps by AI solutions and practitioners, some egregious, that reinforce existing negative social biases such as racism and misogyny [36, 87, 190, 147]. Scholars point to the ways that smart technologies undermine privacy [47, 161, 52] and encourage the adoption of instrumental rationalities that can limit alternate views of local politics [162]. Whitney et al. recounted how activists opposed a San Diego smart streetlight deployment because it was funded and implemented in a top-down fashion that did not consider resident input. The project failed to fulfill its promised sensing functions, and if it had functioned, it would have promoted data centralization and surveillance that would have mostly benefited the police. The chapter

¹and more specifically applied to Indigenous sovereign nations: “the right of a nation to collect and manage its own data” [206]

argues for “a robust, regulated, and community-informed technology acquisition process” for municipal deployments, which we believe participatory design (PD) processes with citizens would promote [256]. Heitlinger et al. framed their PD project focused on urban agricultural communities in London and a public seed library with connected environmental sensors as enacting a “right to the smart city” [123]. Iaione et al. [130] further proposed that an “Internet of Humans” governance structure would be necessary for just city IoT, framing technical and other infrastructure as urban “commons,” described further in Sec. 4.2.2.

Researchers have also examined implications of IoT and smart home devices for households in areas such as security of cloud-based sensors (including user perspectives [264], collaborative decision making [86], and others), but also the interaction between these devices and upcoming AI innovations [195]. While these projects often address questions of how to increase participation, they nevertheless remain shaped by hierarchies that give marginalized communities little control over sensor systems and the data they produce [31, 45]. Our work seeks to change the dynamics for implementing these technologies for THVs via participatory design and deployment with collectively organized resident-managers.

4.2.4 User-Engaged and Participatory IoT Design

Researchers from diverse fields, including human-computer interaction, ubiquitous computing, and assistive technologies, have conducted varieties of user-centered design research in IoT for both home and smart city use cases; however, we draw primarily from studies that explore PD to facilitate empowerment and involvement of stakeholders in technology innovations that affect them [259, 155, 94], close in subject or spirit to our work. Kozubaev et al.’s PD workshops in Atlanta advised a large public housing agency on the use of smart technologies in a new multi-family senior living facility. They noted that “merely adding smart devices into an environment fraught with regulation and precarity created anxiety” among residential participants. They reacted

positively to the idea of residents being able to monitor their own health and safety or to allow family members to receive health-relevant personal information, but they had apprehensions when the data was accessible or actionable by outsiders. They also did not want any voice or video recording to occur [165]. In the self-managed THV setting, the power dynamics may be very different from this externally managed senior housing setting, but we identified parallels concerning the THV residents' anxieties about regulations and installation of infrastructure based on an underlying lack of ownership and housing security. Geeng et al.'s qualitative study of IoT in non-precarious shared housing revealed tensions between residents with potentially complex or changing relationships over time regarding control and access of data [100]. In contrast, Jenkins's exploration of IoT designs for intentional cohousing residents found interesting new applications for group coordination and personal benchmarking against average communal participation metrics [149], also considered by our THV residents. Like the participants in Asad and Dantec's PD study of smart applications for urban cycling infrastructure advocates [18], our participants found potential uses of data for public and neighborhood advocacy around their living conditions.

There exists a small body of research at the intersection of participatory technology design and housing-unstable contexts. Dantec's "community resource manager," a communications system iteratively co-designed and deployed with management staff in a women's homeless shelter, allowed residents to post to public message boards and send "private" messages to the staff in a manner sensitive to management hierarchies and different "publics" at the shelter. Residents "would not necessarily identify as part of a 'homeless' public, eschewing the stigma of homelessness and more readily self-identifying as individuals overcoming adversity," highlighting the complexity and diversity of experiences with homelessness as well as the social isolation and stigma they may expect to experience [170]. Finally, Halperin and McElroy's first-person reflexive ethnographic work examining technology developed for advocacy against housing precarity, where researchers are participants in the advocacy organization AEMP [110], echoes our own use of participant

observation as researchers involved with the Seattle Community Network (SCN).

Accessibility Research

Another rich area of human-centered IoT research to which we draw connections is the development of assistive technologies to allow people with mobility or other access challenges greater independence. In the realm of accessible smart cities, there is work on proximity-sensing IoT technologies using RFID to enable virtual interaction (for mobility-impaired people) or audio-description (for visually impaired people) with objects, e.g., in “Smart Shelves” for shops and libraries [209]. However, most studies focus on smart home scenarios where individuals with disabilities are living alone or with limited assistance from caretakers. “Ambient assisted living systems” have proposed using data-intensive monitoring sensors, including wearables, cameras, and location tracking, as well as machine learning algorithms to estimate residents’ activities or mental and physical health; these designs clearly prioritize personal safety and system responsiveness over data privacy or freedom of choice [112, 225].

Acceptability and usability have been explored among elderly and disabled users for smart home technologies, including control modes (such as voice or smartphone remote control) and automation of configurations (such as lights, window blinds, thermostats, and appliances) [183, 174, 202, 199]. The smart home needs of vision-impaired residents were significantly different from others, involving descriptive features such as voice-based labels and speaking refrigerator contents [174, 75]. However, there were similarities between the preferences of elderly users [202] and people with Multiple Sclerosis [108], who disliked having tasks automated away that helped to provide a sense of purpose, routine, or agency, or put them in social contact with others. In engaging stakeholders with diverse needs in our PD process, it has been helpful to keep these accessibility applications of sensing and IoT in mind.

4.2.5 Community Networks and “DIY” Infrastructure

Seattle Community Network (SCN) [168] is a local volunteer-based community organization that works with THVs and other underserved groups to build and maintain free Internet access infrastructure. In THVs, SCN deploys village-wide WiFi, connected upstream to City or other grant and nonprofit-supported Internet connections, trains users on its operation and maintenance, and provides ongoing support. SCN installed the Nickelsville CD Village’s WiFi in 2021 on a 100 Mbps 4G LTE connection, upgraded it to a gigabit fiber connection in 2022 once the service became available, and has performed several equipment upgrades as needed with some voluntary assistance from village residents. SCN installed the Nickelsville Northlake Village’s WiFi in 2022 directly on a gigabit fiber connection since the service was already available, and has performed repairs and upgrades as needed. These interactions and connectivity infrastructures provide the substrate for our implementation of IoT devices in this work.

Community Networks (CNs) [143] are small-scale Internet access networks, unlike traditional commercial or nation-scale ISPs, that are commonly owned, operated, or managed in a local, cooperative- and community-focused manner. CN research explores questions of economic feasibility and business models [23], power consumption [120], repair [146, 97], edge computing [188], and others that are also relevant to networked sensor technologies. Our research extends this work to the domain of THVs, another type of community shared infrastructure. The research team’s prior research experiences with CNs have informed some project methods as well as expectations, including gender norms in technology use and adoption [41], opportunities for resource sharing [153], and potential issues with federated data models [114]. Garrison et al. [97] and other CN work demonstrates the value of building and repairing core IT infrastructure in a participatory fashion with community.

Closely tied to CNs is the concept and political ethos of Do-It-Yourself or “DIY,” commonly involving hands-on implementation and ownership of tools or infrastructure [80]. DIY brings

infrastructure into the foreground via the process of building, which makes it visible to builders and those who interact with the build process. As theorized by Star, Graham and Thrift, and Jackson in their studies of infrastructure, breakdown, and repair [238, 104, 137, 136], when successfully maintained, technical infrastructure achieves a degree of invisibility. We can conceptualize the lack of infrastructure as an extreme “broken-world” scenario, where the infrastructure’s function and social dependencies (such as repair personnel) required to maintain it must all be built up from scratch. However, this initial nothingness also offers some freedom from barriers to entry for DIY ownership and maintenance since preexisting or formalized technical infrastructures may come with standards or requirements, e.g., for specialized expertise or certifications, financing, legal requirements, or certain physical and psychological abilities, to maintain without excessive danger, difficulty, or liability. Non-professionals can often design and build infrastructure that meets their needs and is within the scope of their skills and resourcefulness to maintain, in addition to sometimes extending and repairing professionally installed infrastructure, as demonstrated in less formalized settings [12, 145], though the success of this activity can be mixed [243, 96]. The IoT technology interventions in this chapter are part of a larger DIY infrastructure ecosystem that includes our community wireless network.

We note that other researchers, such as Kaziunas et al., have framed such unusual or workaround solutions provided outside of standard infrastructure as “precarious interventions” and as “care work” [156] implemented in response to broken systems that fail to provide services (in their case, health care). In this chapter we note examples wherein the Nickelsville THVs’ basic needs such as water can be met only in the “infrastructural shadows” due to structural conditions such as low financial resources.

4.3 Methods

Participatory design (PD) is a methodological approach that includes end users in design processes. It has its origins in trade union projects meant to include workers in the design of better workplaces [44, 185, 27], but it has since expanded to applications ranging from designing technologies and information systems [237] to decolonizing pedagogies and creating educational justice [164, 26, 111]. Core values of PD approaches include the advancement of democratic practices, the empowerment of end users through design, mutual learning by expert designers and participants, and the recognition that end users can lend critical insights to the design process [43]. When practiced effectively, PD methods have several advantages over more expert-driven design. Not only do they leverage user insights to design solutions that are useful, but the process itself gives users feelings of ownership over the solution that make those solutions more likely to be adopted. PD can be particularly useful in designing solutions for communities that are often excluded from expert-driven design processes. In this project, PD can help incorporate the lived experiences and knowledge of those experiencing housing precarity into the design of new technologies.

Our primary data collection method included two PD workshops at each of two THVs, conducted with 13 residents in total. The workshops were implemented as the first step in what will be a longer PD process that engages these villages in the co-design of sensing technologies meant to support their everyday lives. This research is also part of a broader engagement between the project team and the THVs. Prior to hosting the workshops, team members worked with the Seattle Community Network to install wireless network infrastructure in each village. Implementation of these networks both provided the technical infrastructure necessary for IoT sensor development and built trust between the research team and residents. Engagement of residents through the installation of WiFi and later the initial sensor prototypes also provided team members with rich observations of and insights into their needs and perspectives. Participant observer field notes from my IoT installation activities with residents and conversations during subsequent site visits

are also used to triangulate and validate analyses of workshop data.

The first pair of workshops was held at Nickelsville Northlake Village in January 2023, and the next pair at Nickelsville Central District (CD) Village in June 2023, with parallel processes used for each village. Prior to the workshops, the research team first attended a community meeting to request permission to hold the workshops and then worked with village leadership to identify convenient workshop times. The workshops were advertised in advance, held in a community space within the village and open to all residents. There were four masculine-identifying and two feminine-identifying participants at Northlake (coded N1-N6), and four masculine-identifying and three feminine-identifying participants at CD (coded C1-C7). All but two attended both workshops at their village.

At the beginning of the first workshop, the research team introduced themselves, described the purpose of the project, and went through an informed consent process. An initial activity then invited participants to respond to several prompts, which asked them to reflect on (1) things they wished technology could do for them, (2) notable experiences with sensors, (3) challenges that their community is facing, and (4) ways in which technology might help to address those challenges. Participants were asked to first respond to these prompts in writing, and they then shared their responses with the research team, facilitating a full group discussion of these responses; the aim of this discussion was to identify needs and challenges that could be further developed into ideas for sensing technologies, resulting in a list of possible solutions for discussion at the second workshop. The research team performed a rapid qualitative analysis of field notes in between workshops to identify the primary challenge-solution pairs described by participants. Results were presented back to participants at the second workshop, and the remainder of that workshop was used to identify further design criteria for developing technology solutions to identified challenges.

All workshop sessions were audio recorded, and these audio recordings were later transcribed. At the end of each workshop, participants were provided with research subject payments in

recognition of the time and knowledge they shared with the research team. Members of the research team have subsequently returned to the villages to implement initial prototypes of some of the solutions identified and plan to iteratively solicit feedback at community meetings, making adjustments over time.

The research team performed a thematic analysis of the qualitative interview data [48], an inductive approach that involves reading through data to identify patterns that can be generalized into more abstract themes. Thematic analysis also requires the use of reflexivity, the examination of how one's own experiences and feelings shape the process of data interpretation, to mitigate the risk of introducing bias into the analysis. To further minimize the effects of individual biases, two members of the team separately engaged in open coding of workshop transcripts using the software *Atlas.ti*. This was a bottom-up coding process in which each researcher labeled quotes with relevant thematic codes, such as “data privacy” or “communal living tensions.” After both had completed an initial round of open coding, they shared the results with one another and the broader team. The team collated similar codes and discussed differences in codes until reaching agreement and producing a final code book. They also discussed the relationship between the codes and grouped them into potential higher level themes. The two researchers then used the final code book to re-code the transcripts, after which the full team met again and reviewed and revised themes into broader second-level themes through axial coding. All researchers collected the quotes associated with the broader themes identified and used them to write this chapter.

4.4 Context: Tiny House Villages

A standardized definition of what constitutes a tiny house does not exist [250]; the type and size of small houses may vary, and the term remains elusive [228]. In the U.S., a ‘Tiny House Village’ (THV) refers to a constellation of small dwellings, each encompassing a modest area ranging from 100 to 400 square feet [257, 51]. These housing clusters are alternatively known as micro homes,

tiny homes, dignity villages [257, 51, 229], or micro dwellings [250]. Today, THVs are promoted in multiple states as affordable housing alternatives (temporary or permanent) for individuals experiencing homelessness [250]. For instance, Dignity Village in Oregon, recognized as the first THV in the U.S., was established in 2000 with the intent of offering a housing solution to the unhoused in Portland [184, 67]. Oregon and Washington, especially receptive to tiny houses, have collaborated with local governments to create and designate THVs as viable, affordable, and rapid housing for the homeless. More broadly, they represent a form of “decommodified housing,” which Colburn and Aldern describe as housing stock maintained outside of commodity markets and their pricing pressures [61].

Despite their known affordability, sustainability, mobility, and communal orientation, THVs, whether built on wheels or foundations, face many challenges. These include institutional and regulatory barriers, such as strict state and local zoning, building, and housing codes [249, 250, 229]. The non-standard nature of these dwellings also complicates financing options [249] and conflicts with local restrictions on minimum footprint [250]. Detailed insights into zoning and building code requirements for these developments are provided in [250].

4.4.1 Tiny House Village Ecosystem in Seattle

The Low Income Housing Institute (LIHI), a large regional low-income housing non-profit, runs the majority of THVs in Seattle. As of January 2024, there are 18 LIHI sites across three counties in the Puget Sound region. In 2019, LIHI reported that the ten existing LIHI THVs had served around 1000 individuals that year. THV residents had a 34% exit rate to permanent housing compared to 4% and 21%, respectively, for basic and service-enhanced congregate shelters[131]. LIHI residents are identified through the King County Coordinated Entry system via in-person intake and triage at local walk-in offices (Regional Access Points). While these villages may use democratic governance practices such as weekly meetings to encourage personal empowerment,

management and authority structures are still top-down in the interest of keeping the environment “low-barrier” for residents. LIHI also provides supportive services, such as case management and mental health counseling.

Other shelters in the region have long-standing traditions of self-management and governance.² One is “Tent City 3,” a tent encampment with about 60 residents, supported by the nonprofit organization “Share/Wheel,” which receives temporary permits to occupy a given location for three to ten months at a time before having to relocate [226]. Our research is conducted in collaboration with Nickelsville Seattle, a small housing advocacy nonprofit that currently operates two resident-managed THVs; its relationship to LIHI is described below.

4.4.2 Nickelsville

Nickelsville is a 501(c)(3) nonprofit composed of a set of communally self-managed, rent-free, permanent cooperative housing “villages” for people transitioning out of homelessness. Nickelsville began in 2008 as a self-organized homeless encampment established on public land in response to sweeps by then-Mayor Greg Nickels. Having grown to 170 residents at its peak, they partnered with LIHI for help with case management and opening new locations. Participants described that in these early days [N4:] “*Nickelsville was helping set them up [(with the THV model)].*” However, over subsequent years, some villages ultimately objected to LIHI and city management practices, breaking away and establishing their own organization. After several forced relocations due to population growth, management challenges such as crime, and waves of public opposition or support, two Nickelsville locations currently remain, Northlake and Central District (CD), each containing around 15-20 households [189]. These are the communities we work with in this chapter.

²We note that Dignity Village in Portland, the first documented THV, is also self-managed [184].

Nickelsville Self-Governance

Nickelsville stresses the importance of communal self-governance and participation over top-down management. From their website, “Nickelsville’s goal is not only to survive homelessness, but to help solve homelessness while living in an empowering, self-managed setting” [189]. Each village is led by an elected “Triad” consisting of a Bookkeeper & External Coordinator, Arbitrator, and Head of Security, as well as a number of smaller elected roles such as Intake Coordinator, Kitchen Coordinator, and Infrastructure Master. The Nickelsville Central Committee (NCC) is open to members from all villages and the broader public and meets weekly, making decisions relevant to Nickelsville as a whole.

Membership at Nickelsville

Residents are encouraged to consider their village to be “family.” While each new member is encouraged to have a personal timeline for moving out into permanent housing, they do not receive external pressure to reveal it to others or leave before they are ready. At the time of the research study, the longest stays of current residents had been about two years. To join a village, prospective residents call the number of that village to join its wait list. When there are open spots, the Intake Coordinator calls back and interviews people from the wait list, who are then further evaluated by village and NCC leadership. A hard requirement is that they must already be drug free since all villages maintain strictly drug- and alcohol-free environments. Residents must also attend weekly village meetings and earn a minimum number of monthly “credits” for service activities. These may include weekly three-hour security shifts, village cleaning and upkeep, attending NCC meetings, neighborhood “litter busters,” serving hot food and toiletries on Sundays with a partner nonprofit, “Stop the Sweeps,” and political advocacy, such as attending City Council meetings on housing issues, where they are encouraged to make public comments. The villages have strict policies against speaking directly with their neighbors or land owners about village

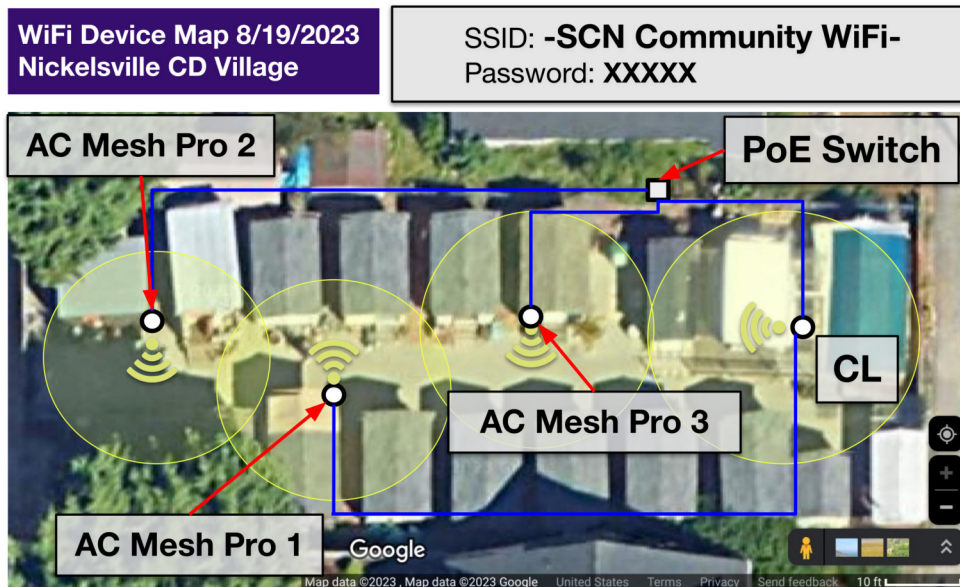


Figure 4.1: Nickelsville CD WiFi map, showing the village layout via a satellite-view image (Google Maps). Photo credit: Seattle Community Network

issues to prevent external interference with decision making and to limit individual liability.

4.4.3 Building a Tiny House Village

The first Nickelsville one-room wooden tiny houses built at the original encampment site in 2008 provided “small, simple, sturdy sleeping structures” with basic insulation and electricity for each resident [189]. Affordable to construct at around \$2,500 USD each and easy to maintain or move as needed, their square footage falls under the threshold for requiring construction permits. However, their spare, lightweight design is harder than standard homes to heat and cool efficiently, leaving residents more exposed to the elements. New village plans are permitted by the King County Regional Homelessness Authority (RHA) and City of Seattle Human Services Department (HSD), after which Nickelsville must put up public community notices and hold a public meeting to solicit neighborhood feedback before establishing a new village.

Local organizations often donate individual houses, either pre-fabricated or built by residents

and volunteers, to the villages. Thus, the dominant costs for building new villages are typically water and sewer lines, ranging from \$15,000-60,000 USD, followed by electrical wiring. Their installation and setup are often non-standard or improvised for these unusual plots of land, with specific terms for designated-temporary use, as described further below.

Land Use and Construction Limitations

Both CD and Northlake Villages have land use and construction limitations that give rise to core challenges when living in and managing the villages.

Northlake. Northlake Village is located on public land owned by Seattle City Light, the City's public electric utility company, in an industrial and maritime-zoned neighborhood (Code IC-65 (M)) [60]. No ground disturbance or ground coverage (such as of paved walkways or ramps) is allowed for construction because of the infrastructure buried under the village, which may require immediate access by the utility company at any point. Residents report that the mainly commercial neighborhood's relative emptiness at night and the village's direct adjacency to a large parking lot attracts crime, described in Sec. 4.5.

Central District. CD Village was built on an otherwise empty plot in a gentrifying residential neighborhood (zone code NR3) that generally allows detached single-family houses and attached/detached accessory dwellings. The village is permitted under Municipal Land Use Code Subtitle III Section 23.42.054 [1], specifically regarding "transitional encampments" on property "owned or controlled by a religious organization;" their faith sponsor is the Kadima Reconstructionist Community, a progressive Jewish nonprofit that supports local mutual aid initiatives, and the land owners are members who live across the street. The municipal code reflects Nickelsville's particular history of building some of its first THVs on church-owned land and their subsequent political advocacy to survive as an institution. One of their primary concerns is that they could be asked to move because of neighbors complaining to the City, unhappy about the intrusion into

their single-family neighborhood, as detailed in Sec. 4.5.

4.5 Results

Sensor co-design workshops and iterative prototyping revealed infrastructural precarities that both villages experience. We found that residents face resource constraints related to availability and cost of utilities, exacerbated by the utility infrastructure's ad hoc and outdoor construction. An increased resident population density compared to the expected number (often just a few households) on a given land plot can add to resource pressure on both utilities and appliances, as do the challenges of collective governance of these shared resources.

THV residents are constantly engaged in infrastructuring work to counteract these precarities, including both internal communal management practices and external community advocacy. They rely upon resident participation and "DIY" maintenance for this work, based on commonly expressed values of autonomy and sustainability. However, it can be challenging to navigate this participation with individuals' various capacities, boundaries, and accessibility needs. The PD process reveals social tensions, such as trade-offs between individual privacy and security.

Despite their infrastructuring work, because residents are designated as temporary emergency occupants, they have neither the well-understood occupancy rights of home owners nor the protections for tenants. The villages face differing external threats based on their land situations, including legal liabilities and neighborhood social dynamics that threaten their existence. These physical and social challenges constrain the design and building of infrastructure and accompanying sensing technologies. While their differing land situations produce different precarities, the villages' common situation, experiences, and governance result in a sharing of concerns, solidarity, and advocacy practices that work to combat precarity. We examine these topics in more detail below.

4.5.1 Precarity of Utilities: Water and Power

We now explore the villages' challenges with water and electrical power, which reveal infrastructural precarities and communal management tensions.

Resource Constraints

A core challenge shared by both groups is the ability to keep utility costs as low as possible. Residents do not individually pay for their utilities; Nickelsville pays for them collectively via public grants and private donations, and these finances are constrained. (Prior to these grants, residents paid \$90 USD a month per house for utilities.) Some residents feel that outside funding decreases individual accountability and efficiency: “[C7:] *nobody really knows where exactly in the details of it or whose pocket it's coming out of. ... if it's coming out of your pocket, you're going to respect it more. That's just nature.*” This structure reinforces residents' narrative of the village as transitional housing and the expectation or hope that they will move on. Several participants called the village a “stepping stone:”

[C2:] I think people want to make this their own little house. It's not. You're still homeless, you know. Somebody else is paying your bill, and we just need to be grateful for what we have. ... This is a stepping stone to get into your own home, and you cannot make it your own home because somebody else is paying your bill. And when the bills start to get higher and higher, that's when they start coming down and saying, hey, what's going on?

We observe that in exchange for the lack of individual financial burden comes a reduced sense of individual ownership and permanence. Residents have anxieties about inviting criticism from those inside and outside of Nickelsville who pay for their utility usage. As a political advocacy organization with a public presence, Nickelsville and its residents must hold themselves collectively accountable to a broader public community (including the City) that supports and observes their

activities, helping to solidify and validate their existence. Thus, during the workshops, residents expressed internal accountability to collective values such as energy efficiency and being “*eco-friendly*” (N6) or “*going green*” (C6). These values likely promote more mindful practices and consequently reduced usage.

Ad hoc, Outdoor Construction

Both villages struggle with electrical and water systems being under-provisioned or insufficiently hardened for the outdoors environment. Installations of village infrastructure are generally ad hoc, i.e., not built from a standardized, heavily tested design. This occasionally results in insufficient scaling of infrastructure. For example, Northlake’s electrical system is [N5:] “*not wired for [a stove and an oven like the CD village]. So all of that has to be taken into account when you do anything here because we don’t have the same breaker boxes.*” Northlake also has [N5:] “*a tankless hot water heater that is designed for a normal house, not for 20 people,*” which causes erratic heating and cooling during showers. One winter, Northlake residents went without water for one and a half weeks because of frozen pipes, which were caused in part by the outdoor installation of pipes without insulation. It is clear that such issues stem from resource constraints.

According to residents discussing an ongoing village build process, new Nickelsville THVs are built for a twentieth the cost of the newer LIHI villages, which at \$1.6 million USD provide electrical infrastructure to accommodate an air conditioner in each tiny house, a full kitchen, and modest multi-unit laundry room for a village size of 40 or more households. According to a Nickelsville resident (but unconfirmed by researchers), utilities cost \$150/day per house at LIHI villages, compared to \$20/day per house at Nickelsville.

We note that LIHI currently has 18 operating THVs throughout WA state; each iteration, customized to the land plot used, is a chance to standardize and update the construction and design for robustness. Currently these plans, designs, and best practices are not available in a public way

that could guide other non-profits, and we propose that the THV ecosystem could benefit from the treatment of this knowledge as “open source.” Despite upgraded designs, a recent visit by the researchers to the newest LIHI village on Lake City Way revealed the full-time employment of an on-site infrastructure manager with an electrical engineering degree to deal with local maintenance and fixes, highlighting the anticipated difficulties. Costs to install and maintain this more robust planned infrastructure may be prohibitive for smaller organizations without adequate funding.

Greater Need for Detailed Knowledge and DIY Maintenance of Infrastructure

We find that the ad hoc living infrastructure at THVs, while faster and cheaper to build than other housing, requires more active management and resources to maintain than typical permitted housing structures due to their non-standardized setup and outdoor environment. We encountered circumstances where residents needed a detailed understanding of their utility infrastructure and its sources, which was often not documented, to troubleshoot specific problems or add sensors.

At the CD village, residents mentioned frequently (every few days) tripping circuit breakers, which they initially thought was due to overconsumption. However, this proved to be a knowledge and maintenance issue. When the SCN team came to install initial sensor prototypes at Nickelsville CD, the breaker for the shower lights and heater had tripped and would not reset; an SCN volunteer familiar with electrical work noticed that all of the village circuits were installed with GFCI protection (required by electrical code for outdoor circuits), which meant that any faulty electrical appliance or moisture causing current to leak to ground would cause the breaker to trip. After conversing with residents, the volunteer hypothesized that after the bathroom heater stopped working, condensation on the lights allowed current leakage to ground. He found and repaired the heater fault, which fixed the breaker issue.

Though Nickelsville has a handyman to call when needed, his labor is too expensive to use

as frequently as maintenance is needed given the organization's financial constraints. Thus, the village always turns first to a resident, i.e., their "Infrastructure Master," who attempts to handle the problem. We note that this level of maintenance can be difficult to DIY since it requires more than a typical resident's (or community's) expertise and knowledge of how the infrastructure is built and functions, and could potentially lead to costly mistakes.

We observed similar challenges for the villages' water systems. Due to the prohibitive costs of adding a new dedicated water line to the neighborhood's clay piping, the CD village water is piped in from an outdoor spigot on a neighbor's house via an insulated hose buried underground between the two properties, adding a layer of precarity via potential failures at other households. In one instance, [C5:] *"Our water completely turned off at ten o'clock at night. We found out the reason was because somebody turned off the water from the main site completely by accident. And then it came back down in the morning at eight o'clock, but [all night] there was no water for people to shower, flush your toilet, nothing like that."* This neighbor's water is now shared with an accessory dwelling unit in addition to Nickelsville CD, which affects water pressure. A workshop outcome was a planned installation of a water flow, temperature, and pressure sensor for shutoff alerts located at the water source in the neighbor's yard (because after multiple days of investigation, neither our team nor the residents could find an accessible entry point for the water pipe on the village side).

In contrast, Northlake has its own water main and meter, hooked up to temporary trailer-style portable bathroom and kitchen modules similar to some recently built LIHI THVs. However, residents described water quality problems where they have "[N5:] brown water" or "[N5:] small flakes, almost like pepper" every three to four months. One resident purchased bottled water because the tap water "[N2:] made me sick for a while. . . . Once we stopped using it, I was no longer sick." Some cited possible "[N4:] backlogs" of contaminated water in the past due to misconfigurations of their water hoses and trailer hookups, highlighting that specialized knowledge is often needed



Figure 4.2: Nickelsville Northlake brown water sample, collected by residents and shown to researchers in Sep. 2023. Photo Credit: ANON

to correctly install and troubleshoot ad hoc infrastructure.

Village leadership contacted Seattle Public Utilities to test the water, which returned inconclusive results and an unsatisfying explanation of annual fire hydrant testing causing the brown water (which occurs more often than annually). If the brown water is due to fire hydrants, we note unusually frequent hydrant accesses by the fire department in this neighborhood, perhaps due to its industrial uses. However, the source of contaminants remains an open question after many months. This poses a significant quality of life problem that would likely not persist in a neighborhood with large numbers of homeowner residents pressuring the utility company or City to resolve the situation.

4.5.2 Personal Health and Accessibility

Nickelsville residents have to account for each other's accessibility and health needs in the communal setting, occasionally in tension with their need for communal participation and DIY. Their

solidarity around shared understandings of homelessness makes them uniquely well positioned to do so. Many mentioned underlying health precarities such as disability, echoing the fact that people with disabilities are statistically over-represented among homeless populations [34, 81], at 51% in King County according to the 2022 PIT count [21].

Residents of the CD village, in particular, expressed risk aversion with respect to making changes to their housing situation (even installing sensors) because they believed the entire village could be asked to leave with 30 days' notice (NCC leadership later informed the researchers that this is untrue—only the religious sponsors or landowners can require them to leave). Those who cited risks to health seemed most strongly concerned about offending their neighbors and losing their housing:

[C5:] If we are asked by any of our neighbors, we have 30 days to pack up these houses and everybody else within 30 days. Nine times out of ten we don't have another place to go...I'm not going back to Tent City 3...I can't be cold because of my health issues. There are several other people here that can't be cold because of their health issues.

We note the particularly severe consequences for health and safety of being disabled while unhoused:

[C2:] being older and homeless and more disabled, I guess the fear of upsetting anybody, the neighbors, it scares me to death, because I can't live on the streets again. ... So, for me, it's just I don't want to ruffle any feathers. I just want to go back in my little house I have and be safe and not have to worry about somebody coming in to beat me or beat my dog, because that's where I was at.

We further explore perceived housing insecurities due to neighborhood social tensions as well as lack of clarity around their policy status in the sections that follow.

Accessibility

Residents know and consider each other's accessibility needs as much as possible in DIY infrastructure work, even outside of their weekly community meetings. At the sensor install, we asked one resident to test out a newly installed automatic gate closer to make sure the weight of the gate was acceptable. She took care to call over and test it with one particular resident with mobility issues whom she knew would have the most trouble.

However, both villages are constrained in terms of the accessibility accommodations they can make due to their construction restrictions. Participants from both groups stated that they would have liked to install more accessible walkways and ramps, but neither village is allowed to dig to install anything permanent on or under the ground in the CD site due to not knowing the depth or locations of already buried infrastructure on the plot, and in the Northlake site due to Seattle City Light's uses for the land (Sec. 4.4). Thus, both villages installed and maintained gravel paths, which do not readily accommodate mobility aids such as wheels.

At Northlake, the group also strives for full communal participation of three hard-of-hearing residents (one fully deaf and two using hearing aids). On their weekly required security and gate monitoring shifts, hard-of-hearing residents cannot hear a typical auditory doorbell or knocking at the gate, and residents occasionally have to “*jump fence*” to get inside. Northlake workshop participants insisted on sensor data reporting with both audio and visual elements to accommodate hard-of-hearing residents, such as a loud noise and flashing lights when doors are left open by accident. We further discuss these design considerations in Opportunities and Challenges.

These discussions also surfaced the issue of accessible group communications with hard-of-hearing members, who are expected to participate equally in group discussions, e.g., community meetings for decision-making and voting. One resident can sign in ASL and another can read lips, but a third cannot hear or speak. As N4 described, “*We're self managed. So one of the big things is...being able to give feedback on proposals that we're making...And so, this isn't gonna get*

made without their input, without their consent...” While note-takers are assigned for their benefit, complex nuances and cross-talk are often lost in translation. Another explained that they try their best to be inclusive but still struggle, e.g., reach the limits of commonly available automated transcription technologies:

[N5:] It can be a little bit difficult trying to write things down and make sure that they fully understand what's being written down, you do the best you can... They're trying to have it so that [we] speak into something and it shows up, say on a screen, so that during our meetings, [the hearing impaired members] can follow along. We do include them. And I don't know how easy it would be to follow along. If you have other people cross talk, or if [N4] is speaking and then I'm interrupting, how does that go in?

We note that accurate automated speech-to-text transcription in complex group settings is still a challenge in computing and an application area that would improve social participation for hearing-impaired people both in THVs and elsewhere.

Addressing inclusivity along different lines, participants at both villages also noted that not all community members have access to web-enabled devices. They proposed that the security resident on duty should be the primary point of contact to receive alert messages (e.g., SMS texts) generated from sensor data on a daily or weekly basis because they are assigned a village-owned phone for their shift and would be ready to take action if necessary. However, some proposed that texts should go to NCC leadership directly since they have the greatest authority and knowledge to make infrastructure decisions. These policy-based considerations are discussed further in Sec. 4.5.3.

Quality of Life and Mental Health

Several participants brought up mental health as a challenge in the village, though they did not go into specifics. We now focus on broad themes and challenges we identified around quality of life

and emotional well-being and how these are related to the villages' land or housing precarity.

We find that residents of both villages often feel socially discriminated against based on their experiences with homelessness. However, both also emphasized feeling grateful for their situation and not expecting luxuries, which we explore further in Sec. 4.5.4. Meanwhile, we see other impacts on quality of living based on differences in both built and social environments between the villages.

Discrimination and Antagonism. Both villages described common public misconceptions about them. A Northlake participant mentioned hearing “[N5:] *a drug guy who literally said this is Tweaker Central. And we're like, what are you talking about? ... Yes, A lot of people associate homelessness with with drugs, drugs and mental health, that's across the board. ... [N4:] we run clean and sober.*” Others in the neighborhood perhaps do not know the Nickelsville policy of remaining drug and alcohol free. The participants mused that in addition to broad stereotypes about homeless people, mistaken impressions may arise due to non-residents who deal and use drugs in the large commercial parking lot beside the village, a prominent feature of the historically industrial and maritime-zoned neighborhood.

Residents described the parking lot as “[N5:] *a place that the RVs will go and park for months at a time. And they're not the people that you want hanging out here.*” Inconsiderate parking lot users often cause noise pollution that affects residents' sleep quality. People spend time in their cars late at night, sometimes playing music with the bass turned up and setting off fireworks, activities that would typically be considered unacceptable in residential neighborhoods. One participant felt unsafe because [N6:] *“I have a window that faces right up against [the fence]. And I mean, there's people that come out late at night and they just sit there with their car running.”* They were especially frustrated by what they called [N4:] *“a mega bass concert:”* [N6:] *“It's- no boy, no. No. Rude. Rude... You can see [our] houses right here.”* This problem is exacerbated because the tiny houses are constructed outdoors, with less sound insulation than typical homes.

In contrast, Nickelsville CD is located in a rapidly gentrifying residential area, where neighbors occupy a higher socio-economic class. Here as well, neighbors' treatment of residents has an impact on their emotional health, constraining their behavior and affecting their sense of security about their housing in different ways. One resident felt that their neighbors did not want them around, describing when his truck had been towed from the street in front:

[C4:] their issue comes from their condition, from how they see the world. If you're not well to do... then you are in a category that people don't want you around. You could be a good person ... They towed my truck. I paid three hundred and some dollars to get it out. I had to put a note on it, and the note read, "I'm not really a bad guy, if you want to talk to me, we could talk about it, and I could move it if that would make you happy. You don't have to call the cops on me because we can talk about it, and I could move it or whatever. We could work together." ... Like last week, I went and cut their grass... the thing is that we're trying to get along with them, but they can't soften up enough to see.

The group called a few particular neighbors [C6:] "a great challenge," citing multiple noise complaints to the City in the past. They proposed that noise sensors might provide "[C6:] some ammunition at least" against false accusations. Residents have made lifestyle changes to accommodate the complaints, not knowing if they were true:

[C6:] One of those [noise] sensors would help quite a bit. ... every time [one resident] goes somewhere, she has to take her dog. She's got to go to work and all these places...

[C7:] it's not the noise itself; it's just because they can say something and mess with us.

There were concerns that even with the sensor data, the neighbors would find other things to complain about because they were always looking for faults.

Gratitude. Despite these challenges, CD residents greatly appreciated kindness and human connection from neighbors through donations or even casual interactions, such as being hired

for manual work. These welcoming interactions with neighbors likely reduce anxieties about Nickelsville residents' precarity in the neighborhood:

[C6:] Yeah, there's some really good people around here. Really good neighbors. They bring food. I'm talking about some of them take the time to cook the meal then bring it. I do yard work for a few of them. So, I get to know them a little bit more personally and stuff, and they are good people.

[C3:] Their recognition of you too is important.

People are known to experience considerable social stigma and isolation when unhoused, and in their appreciation of basic friendly recognition, we note contrasts participants draw with rougher circumstances they may have come from. The neighborhood dynamics in some ways echo the historical experiences of racial minorities attempting to move into and desegregate majority White neighborhoods. Though in general the CD village encounters much less hostility and violence than in those racially motivated cases, it appears that less hostility is needed to destabilize them due to the substantial legal precarity of their presence on the land.

Both villages also emphasized gratitude for their physical infrastructure, with all its limitations. A Northlake resident insisted that the village did not need luxuries, perhaps as a value: *[N5:] We don't need a modern village. This is a homeless village, and we don't need fancy—very basic.* A CD resident expressed:

[C2:] from where Nickelsville was in 2013, electricity, what's that? Wi-Fi, what's that? ... there was no such thing as a refrigerator. A light, there was no such thing as a light because you know. You have port-a-potties. You were issued a garbage can to put your food in. You could only have dry things because of the rats. The rats were this big. ... Our dryer is not working right now. Okay, I understand, but that's not a right to have. It's a privilege and a luxury to have that. ... It's just really hard for me to understand, you

know, getting all this new technology when it's like nobody has to do this for anybody.
We should be grateful for what we have, just a little bit.

This attitude was especially pertinent to appliances and technology, including the proposed IoT sensors, which were initially considered a luxury. We note the strong difference between their attitude and that of renters, who are explicitly encouraged to bring problems with their large appliances to landlords; in turn, landlords are in most cases required to make repairs.

4.5.3 Legal and Policy Status

While the villages' status in public policy as emergency and temporary housing has thus far made it possible for them to be allocated land in a decommodified way, the rules around this status combined with their resource constraints make it more difficult to build and improve their own infrastructure, limiting their DIY capabilities. Despite their lack of a policy framework or occupancy rights, village residents essentially carry the same responsibilities and liabilities as homeowners but without the housing security and other benefits. For example, one mentioned that their kitchens (and those of other emergency shelters) must comply with local codes or risk being shut down: [N5:] *“we do have to follow the county health rules here for our kitchen... you pass or fail. Tent City 3 failed miserably.* Their village layouts and gates are also regularly inspected by the City Fire Marshal.

Not all residents are familiar with the many rules that must be followed and their associated consequences, as evidenced by the initial misunderstanding in CD village about the risk of being asked to leave by their neighbors (Sec. 4.5.2). For DIY infrastructure modification, we see again that detailed knowledge is crucial—not only of the infrastructure's physical configuration, but also its policy environment and regulation. Villages go through upper Nickelsville management to approve any changes, worrying about violating the terms of their land use. As one CD resident put it, they have [C2:] *“to make sure it's okay within our contract [to install sensors] because this*

isn't our property... really what I want to stress is I don't want- if we get [an alarm] coming out with 'back gate is open,' [the owners are] going to be going, 'What in the world is that? That's not your property. That's not your decision.' ”

4.5.4 Managing the Commons

In light of the self-reliance and communal responsibilities their housing situation requires, participants had important concerns about the reliability and maintainability of the IoT sensors and automation. While most expressed excitement about the technology, they also considered possible advantages of alternative human management or policy solutions to their infrastructure problems. Discussions revealed internal communal living tensions between residents, including conflicts in opinions, desires, and actions that impact sensor design. Notably, residents are not necessarily all living there because they prefer life in large communal settings, making tensions especially important to alleviate. We found places where sensors could help with communal pool resource management and places where they must be limited for people's privacy.

Arguments for Human Solutions

We often heard from residents that they preferred self-reliant or human rather than technology-based solutions to their problems. Some cited a general conservatism around changing their working village systems for fear of disrupting their situation, as in Sec. 4.5.2. Others were hesitant to be saddled with technologies that might fail and need maintenance beyond their abilities: *[N4:] we like to be as self-reliant as we can. We might not have the mechanical aptitude to keep that up to date. I just don't want to have a pile of really expensive components, most [without] usability after a year.* Some anticipated developing bad habits from expecting automation, such as leaving faucets running *“[C7:] for like 15 minutes”* in bathrooms that are not automated, expecting them to turn off on their own. A few felt that being able to live without automation should be a default mentality

and learned skill, especially given that utilities are paid for by others, which they believed should necessitate respectful and restrained usage:

[C2:] it was drilled in from the time that you're walking, if you're cold, you put a coat on. You don't turn up the heat because Mom and Dad pay the bill. You don't pay the bill. ...If you don't turn the light off, you get your butt turned back around and you turn that light off. ...if technology wasn't around, people wouldn't even know how to live.

Given the failure rate of electrical appliances in the village (such as the broken bathroom heater and clothes dryer we encountered), the residents' DIY responsibility over them, and the more challenging outdoor setting, we note that being able to live gracefully without any given technology for a period of time could be an important element of emotional resiliency.

Finally, some residents expressed a reluctance to assume the additional responsibility of having to respond to sensor readings since there are already many self-management duties in the village. A few participants wondered, *[C2:] "Who is going to take responsibility for all these little sensors, or all the data? What are you supposed to do, you know?"* One posited that *[C7:] "It's a lot of stress when you've got to deal with all that stuff."* An important design consideration not to have sensor readings introduce stress or burden without commensurate benefit into the residents' lives, *e.g.* by reporting false positives or bothering people who cannot do anything about a given problem with alerts. For example, displaying sensor alerts if the Nickelsville CD water flow is cut off may be most effective in the neighbor's house, where it can notify them to check if they have shut off the wrong valve by accident. Automated actuation in response to sensors may reduce this burden, but only if reliable and maintainable.

Relieving Internal Tensions

An interesting category of design considerations revolved around tensions caused by the communal sharing of infrastructure. For example, Northlake participants recalled a situation when a careless

or even potentially malicious former resident repeatedly cut power to the refrigerators and caused everyone's food to spoil: [N5:] *"We've had people here that literally will cut the power off to the refrigerators just to affect everyone else... So no one is allowed in the breaker box. This happened in the kitchen where the surge protector was shut off. Nothing is locked... I mean we don't typically have issues with it, but we did with her."* Northlake residents proposed a sensor-based alert for when power is out in the kitchen to avoid this problem, looking to smooth over consequences rather than assign blame despite this bad-faith experience with a former resident.

Participants also wanted sensors to help them avoid unintentional mistakes with infrastructure that could affect others. For example, both Northlake and CD participants suggested sensor alerts for when the refrigerator door is left ajar, a common problem in both villages. At CD, their older refrigerator was frequently left open by people in a hurry while cooking, whereas a new one with a built-in beeping door alert greatly reduces the problem. Inspired by this, both villages proposed similar open sensors for their front gates. We highlight the added difficulty of maintaining infrastructure and appliances (especially older or ad hoc ones) in heavy-use shared settings where the increased number of users creates many opportunities for damage, wear, or accidents in addition to group accountability challenges.

In general, we see a culture of forgiveness, understanding, and solidarity within and between the villages that facilitates resource sharing and the use of rules such as access restrictions to protect each other against liability. Some participants used familial terms such as [C1, C5:] *"family"* or [N3:] *"brothers"* to refer to other Nickelsville residents. At the same time, when brainstorming freely about "what technology could do for them" at the beginning of the first workshop, one Northlake participant joked that they would want a [N3:] *"free private apartment so you're not sharing with some asshole,"* the levity softening implications about the real tensions of sharing.

One major tension is the need to respect individual autonomy and privacy even while protecting group interests. A Northlake resident explained the philosophy:

[N4:] in our community the way we set it up, we really tried to avoid having too many eyes in individuals' private choices and lives. So yeah, I realized that I was kind of spearheading to monitor every house if it wasn't for that.

[N5:] I knew that you weren't singling out my air conditioner.

Participant N5 had purchased an air conditioner³ during the heat wave two summers ago because her house cat had almost died, and people had complained about her power usage. *[N5:] "But it's a life or death situation. And so I don't want anything to read what I'm using."* In this case the participant expressed fear of group judgment based on sensor readings, which when made public could either absolve (as in the noise sensor case above) or incriminate monitored individuals and constrain their freedom of choice. While we note that electricity usage data could be made privately visible only to each house resident, we can imagine how the mere availability of the data in such a close-knit communal setting could result in social or political pressure to share it unless there are explicit policies against doing so. Even so, the benefits of surrendering data privacy might in some cases outweigh the risks, for example, where a noise sensor monitoring on a group level could protect the village from external neighborhood power dynamics that threaten the stability of their housing. The questions of whom sensor data empowers and for what benefits are critical to design decisions about both data collection and sharing for IoT devices.

We notice that Ostrom's theory of Common Pool Resources [198] can be applied to shared utilities such as electrical power in THVs. Resources are constrained and can be used up or spoiled by individual appropriators. The group of appropriators is generally limited to residents and can theoretically exclude those who do not use resources cooperatively. Sensor and actuator systems could be used to prevent people's mistakes from having too much impact and to help with resource regulation in other ways if desired by residents. However, one important tenet of Ostrom's CPRs

³Many Nickelsville residents have jobs and income sources they rely on for food, daily necessities and comforts, and to save up for moving out.

is that there should be sanctions for the misappropriation of resources, which can be done only by monitoring against rule infractions. However, in this case the need for privacy stands in tension with monitoring.

4.5.5 Privacy and Power Dynamics

Security camera data (video and audio) were types of data that participants were generally not willing to collect. This opinion was widely shared despite physical security and safety being a top-of-mind concern for residents of both villages, whose outdoor grounds are bounded by only a fence (that is regularly jumped), which necessitates security guard shifts at all times. We perceive that this type of data, even contained within the village, could give residents too much power over each other for their comfort, a preference stemming from a history of abuse of camera data from previous organizational management.

Physical Security

At the time of the design workshops, both villages had encountered recent instances of “fence jumping” that brought security and safety to the group’s attention. At Northlake, non-residents had been jumping the fence to use the showers and bathrooms, which residents had decided must be left unlocked for their quick access. At CD, after a recent burglary at a neighboring house, the burglar had opportunistically jumped the fence into the village to flee and was caught because the Nickelsville security on duty had promptly called the police. Participants at both villages mentioned times when the front gate had been accidentally left open or unlocked, sometimes overnight, and proposed both light and sound-based alarms for gate status.

We note especial security concerns due to the environment surrounding the Northlake village, where “[N5:] [*the police*] don’t come down here. Even if we call.” She recounted calling the police when someone had been shaking doors trying to enter both the village and a restaurant across the

street, and they never arrived. She explained the difficulty of obtaining public services such as police and ambulances in terms of the built environment, which we again recall as a consequence of zoning and land use histories: *“(in the construction zone next door) they’re still building but there’s nobody there. They’re closed. Nobody lives in that house. I don’t think people realize that there are people that live out there. And then you’ve got this wide open parking lot that you can easily escape (after committing a crime).”*

In addition to external risks, a few residents described having had safety concerns inside the village in the past. A CD member had heard of individual rooms being broken into before his time, though he did not feel in danger of it now. Another at Northlake described having recurring panic attacks due to problematic former residents coming to her door in the middle of the night. She had asked to install [N5:] *a camera out there that literally faces the fence. The only way anyone would be seen is if they’re on my porch, and [the leadership still] said if you do that you will be barred [from living here].* While N6 expressed support for N5 by suggesting a re-vote on the policy, the consensus remained to respect the “no camera” rule and implement motion sensors or other non-camera options.

No Cameras

Nickelsville maintains a strict policy of disallowing monitoring cameras in their villages. Longer term members currently at Northlake described that when they had been under LIHI management, staff would use camera feeds to listen in on private conversations to justify evicting residents, or even to [N4:] *“enter the village, knowing that leadership wasn’t in the village, and start to say, ‘We’ve got to do this’...kind of usurping them democratically”* to control village decisions. Once under their own management, Nickelsville had [N4:] *“decided not to allow cameras pointing into the village.”* Participants at CD village agreed that even cameras recording the street outside the gate could be problematic because it still allowed someone to track who was going in and out:

[C2:] *“Who is going to be watching that camera?...I wouldn’t want everybody else to know what I’m doing, and when I’m coming, and when I’m going.”* One resident described this kind of monitoring as being “[C1:] *really in jail.*” Even without the top-down management, the villages still have internal tensions and power dynamics, akin to any family or small town, that could be shifted by privacy-impacting technologies.

The consensus preference for THV sensor designs was to use motion sensors and alarms as lower-fidelity evidence or as subtle deterrents for crimes: [C4:] *“[With a sensor alarm] we don’t know who it is, but we know somebody was there around that time...Say the door’s beeping and somebody is trying to come in, maybe [they] might not want to, because it’s beeping. Somebody might hear it and just walk off.”* This way, no one could be personally identified or tracked unless there was an incident, in which case the residents would collectively investigate further.

4.5.6 Public Advocacy Using Data

Both villages saw opportunities to share sensor data publicly as a form of advocacy and positive social contribution, in some cases worth the trade for data privacy. One Northlake participant said “[N4:] *I think 90 percent of [the data] should go online*” and specifically noted water sensors as a chance to *“be involved in the wider discussion nationwide about water quality and water property.”* Another resident saw monitoring water quality as [N5:] *“being neighborly”* and *“paying back the community”* for their support: *“if we find that there’s an issue, it is at the taxpayers’ expense because taxes go toward those things...It holds [the City] a little more accountable.”* Further, they felt that making the data public to mobilize popular and political support would be more effective than just informing the City themselves: [N5:] *“the City would be more apt to act if it’s common knowledge versus, ‘Oh, yeah, we’ll get [to] it’ because homeless people are a lower priority. And I think that the reaction would be better if it was in public, or everybody was aware.”*

After years of organizing, the Nickelsville communities have developed deep knowledge and

strategies around political collective action to combat their neighborhood challenges and housing precarities. Sharing sensor data related to public goods such as water and other environmental variables could be a strategy to increase their housing stability by providing value to their neighborhoods as well as increasing their public visibility as a whole.

4.6 Discussion: Challenges and Opportunities

While our THV participants broadly believe IoT and sensing technologies hold promise in improving infrastructure in their community, we identified a number of factors that constrain appropriate designs as well as areas of interest ripe for future innovation.

4.6.1 Ownership and Resources

Precarity surrounding the THVs' permissions and particular terms of existence on the land, as well as resulting limitations on what they can build, has been an important constraint in our work. We note that IoT devices typically require minimum levels of infrastructure reliability to function, which might be difficult depending on the underlying infrastructure limitations unless the devices are appropriately designed or hardened to deal with the conditions (for example, outdoor or off-grid use cases). Unfavorable terms of land use may also include potentially finite timelines for occupancy, or even uncertainty around whether such timelines might be enforced in the future. Thus, we propose that *portability, non-destructiveness, and ease of installation and removal of smart devices could be features of interest* for THV communities. These qualities together are not guaranteed for many sensors typically installed by homeowners, e.g., sensors for measuring total water flow on a whole-house (or village) scale, which usually involves modifications to plumbing. One can imagine less invasive monitors using other physical properties, such as sound, to measure flow through a pipe (e.g., ultrasonic flow meters with clamp-on transducers, used in industrial settings). While such sensors may exist for specialized and industrial uses, they are

currently cost-prohibitive for these resource-constrained THVs and require further research and development.

We also found that enacting ownership via infrastructure building can crucially require knowledge and expertise. For example, while the CD village's land owner may have allowed digging on their property with perfect knowledge or documentation of the infrastructure underground, without this it was deemed too risky, underscoring the importance of understanding underlying infrastructure as part of ownership. *There is also much room for sensors themselves to be made more usable by laypeople without specialized expertise.* To illustrate, during prototyping, we found that there are simple, off-the-shelf per-circuit power monitoring sensors similar to commonly available handheld current meters that need only to be clamped around the outsides of wires, but these are optimized for wiring directly into electrical panels for power, and not friendly to install for novices without electrician skills.

Further, we see *ripe opportunities for hands-on technical education and learning using IoT and sensors*, a strategy long adopted by educational platforms such as Arduino to teach basic programming and hardware prototyping. While our project does not go so far as to teach programming, we have seen through our repeated engagements with residents, including on-site build days and a public weekend hackathon, that tinkering with and installing user-friendly IoT devices can be a low-barrier-to-entry exercise that encourages basic familiarity with both computing technology and village infrastructure, and it can engage teams of people of many experience levels in problem solving together. The installation processes have made utilities infrastructure more visible to village residents and encouraged them to develop their household DIY skills, which can be invaluable in these resource-constrained living settings.

We note that the THV environment already cultivates development of these skills by providing “training grounds” with real break-fix scenarios for practice, as described in repair literature [146, 97]. While DIY knowledge can be considered digitally more accessible than ever (such as via

online demonstrations on YouTube), this is crucially dependent on Internet access, another layer of infrastructure that cannot be taken for granted.

How to address the root problem of ownership is an open question, related to that of resource limitation among the housing-precarious. Community land trusts, such as the nonprofit Homestead in Seattle, work to combat neighborhood displacement by providing alternative routes to home ownership for low-income applicants, holding land at low prices that must be resold under the same conditions in perpetuity. This particular solution is designed to help single families build generational wealth, not for transitional groups seeking emergency shelter; however, such policies could be adapted to fit nonprofits intending to operate long-term shelters like Nickelsville.

Even with the existing restrictions and red tape of conditional and permitted land use, it is clear that the THVs' permission to exist and occupy their space for the long term is the most basic and crucial need for the residents' sense of stability. With adequate resources, ingenuity, and community support, THVs' infrastructure has been reliable enough to meet crisis needs where land would otherwise lie fallow. As our participants pointed out, *installing environmental sensors reporting public data could turn the villages into valued informational infrastructure for their neighborhoods and the City and support their case for continued existence there*. The data may also help increase their public visibility, making them harder to remove without public notice. We believe that such creative and cost-effective solutions for rapid and emergency housing should continue to be explored and supported since there will always be a need for decommodified, dignified, and socially supportive shelter environments.

4.6.2 Collective Living

As urban housing needs grow, supporting the management of dense or shared communal living arrangements among groups of people will become increasingly important. *Appropriate and functional implementations of sensing and automation could make communal resource management*

smoother and more efficient, as pointed out by participants regarding the advantages of beeping refrigerator doors, automatic gate closing and locking, and other conveniences that minimize the effect of accidents. We also note an exciting potential for new sensor-based functionalities to contribute towards collective resources managed as Communal Pool Resources where desired, as introduced in Related Work. *Sensors could be used to support monitoring of current resource conditions and encourage or enforce rule following*, particularly relevant to rules 1, 2, 4, 5, and 6 of the list in Table 4.1.

However, we find that Ostrom-style CPR management may not always be desired or appropriate. In the case of power usage at Northlake, participants felt communal monitoring would hinder individual freedom of choice to an unnecessary extent given that power over-usage did not seem dire. We note that sensors, by design, can uncover and respond to physical realities that humans might not notice or be able to quantify on their own, so *care must be taken to balance fidelity of measurement with privacy*. Ostrom's rules tip the balance towards higher fidelity and transparency, asking individuals to commit to following collective rules even over personal interest, and requiring group accountability to that commitment. In return, governance structures must allow users to modify the rules in a bottom-up fashion based on real and transparent resource conditions shown by the data (via rules 3, 7, and 8), to ensure the rules are fair and users are willing to be held accountable to them. However, in private living environments, bringing sufficient information about people's specific activities into the open to allow this degree of accountability may raise discussions in the "public" of the village that residents are not comfortable with, depending on habitual levels of internal familiarity, openness, and trust. If sensors break, report misleading data, fail to trigger expected automations, or produce burdensome labor (e.g. in responding to alerts), they may also increase community tensions.

In LIHI-style managed THVs, effective home automation could decrease management labor needs or improve communications between residents and staff as in the case of Dantec's Commu-

nity Resource Manager. However, in these cases, we note that sensing infrastructure deployed top-down by management would likely reproduce and ossify existing power hierarchies, rules, and constraints based on the context and purposes for which they were designed, not necessarily according to residents' preferences [258]. (For example, all LIHI villages are equipped with CCTV monitoring.) The participatory and consent-based nature of our sensor design and installation processes with Nickelsville, especially in promoting shared knowledge and understanding of the deployed technology, importantly means that *it can be uninstalled or shut down by residents at any time.*

4.6.3 Privacy and Security

We are struck by how strongly the 'no-camera' rule was held by participants despite their concerns about village physical security and safety and the obvious security gains (both to us and to participants) of video monitoring. Participants from both villages playfully described other modes of intrusion deterrence that could work well enough, such as mock cameras or alarm lights and sounds. Design studies of smart and automated homes in other contexts, such as among elderly and vulnerable populations in assisted living, have revealed similar preferences against cameras except in the case of especially debilitating medical conditions [202]. Thus, we acknowledge that residents might have different preferences regarding video surveillance in communal settings given higher perceived threats to safety or lower internal trust of other residents. These nuances are exactly why we believe *participatory and collaborative methods are crucial for just smart and sensing installations in communal settings.*

We also see opportunities for *improved transparency and granularity of data sharing and storage*, especially compared to the often inscrutable privacy policies displayed to users upon IoT device installation. Many participants expressed an intense desire to understand what data is collected about them, both from our proposed sensors and latent technologies such as their mobile phones,

who it would be made accessible to, and how it might be used. These questions were repeated for other sensors discussed, with multiple levels of data sharing (personal, village, external, public or online) and the potential utility of sharing at each level. Though individuals had wide-ranging preferences about what they cared about keeping private or sharing, *the group consensus was to prefer storing all sensor data locally on-premises*, echoing concepts of data sovereignty also preferred by other marginalized groups in strategic protection of their own interests [206].

This preference has informed our choice of the popular open source platform Home Assistant [126] for initial prototyping. We have found so far that few off-the-shelf smart sensors and platforms natively meet the groups' needs, typically exfiltrating data to the cloud. There is room to imagine *rigorous standards for IoT products for explaining data retention and sharing policies*, such as the clear "Data Privacy Nutrition Labels" which were proposed by security researchers as early as 2009 [159, 160] and adopted in 2020 by Apple [204].

4.6.4 Accessibility and Inclusion

Accessibility issues can become a management challenge and a cause for communal tensions when people have differing and competing needs that are not all met. We propose that *larger living groups will need more diverse and multi-modal affordances for sensors and actuators to accommodate differently abled members*. For example, for poor water quality Northlake village members recommended visual alerts, such as a red light (already common in water filter sensors), text messages with descriptors such as "brown," instructions such as "Don't use. Boil your water first," or even haptic buzzers and beep sounds. The extensible Home Assistant platform will help us add a wide variety of off-the-shelf actuators such as lights and speakers to respond to sensing elements via scripted automations. Finally, we note an *open challenge to improve live speech-to-text transcription for group settings*, e.g., via innovative machine learning algorithms, to make multi-speaker group discourse more accessible for deaf or hard-of-hearing individuals in

community forums or “town hall”-style settings.

Interestingly, we notice that our communal THV settings share many of the same values, concerns, and goals regarding IoT design as addressed in assistive and health monitoring research. We found strong shared values of self-reliance and autonomy among THV residents, echoing the traditional emphasis of accessibility research on enabling greater independence and autonomy for people with disabilities. Challenging this, some recent work has favored social interdependence and relationship building as alternative values [37, 108], also mirroring the Nickelsvilles’ strategic reliance on social support from community, policy support from government, and financial support from both. We see both housing-unstable and accessibility research communities doing the work of building a patchwork of strategies, independent and interdependent, for stability and solidarity from a place of precarity and vulnerability. Meanwhile, there is also a disproportionately high overlap between unhoused people and those with disabilities or physical and mental health conditions, meaning that individuals’ personal sensing, health monitoring, and smart appliance needs, as well as their data privacy and sovereignty needs, are likely to have overlap, as well. Therefore, we anticipate many *opportunities for fruitful cross-pollination between assistive or accessible technology research and design in support of the unhoused.*

4.6.5 The “Missing Middle” Scale in Sensing

Finally, throughout the initial prototyping following our workshops, we noticed a *relative lack of ‘mid-size’ (or ‘village-scale’) IoT platforms and sensors with appropriate affordances for our group size, privacy needs, and data transparency levels.* Despite the robust body of sensors available for both city- and home-scale IoT, most off-the-shelf products did not meet THV needs. To illustrate, wireless doorbells, a ubiquitous example of the home-scale, typically work via Bluetooth, with insufficient range for the village’s size and outdoor setting. Commonly available ‘smart’ camera doorbells also do not meet the community’s privacy needs. Thus, for our light-up doorbell, we

had to construct a simple but custom ZigBee-connected button with flashing light. Similarly, like the ultrasonic flow meter above, industrial sensors made for large infrastructure are often wildly cost-prohibitive; a smart water quality monitor was found at over \$5000 USD and did not integrate into any known platforms. We have turned to DIY options, such as outfitting simple sensors' analog outputs with additional hardware that can wirelessly report state to our Home Assistant integration. This “missing middle,” or relative lack of village-scale and communally oriented sensing infrastructure, invites significant future work. Technical questions about how to efficiently scale ‘home’ IoT to larger group settings or inexpensively scale down ‘city’-scale solutions will be paramount. Design questions, as discussed above, will include data privacy and security as key concerns. We also believe *questions of collective governance* (e.g., how should we respond to sensors, and what if the sensors are wrong?), *accessibility* (e.g., how can we make the sensors work for everyone?), and *data transience* (e.g., what happens to the data once a person moves on?) are equally interesting and will be a focus of ours going forward.

4.7 Conclusion

While IoT design may be of limited use in directly addressing the housing crisis, we have identified potential ways for IoT to support THV residents' quality of living in their built environment, and support their housing stability by improving neighborhood standing and public advocacy through data sharing. To collaboratively design and install our sensing solutions, we have made visible the infrastructure underlying our intended technologies to both ourselves and the residents participating in the design choices. This infrastructure crucially includes issues of land ownership and arrangements surrounding its use. We find that the challenges in context (i.e., related to ad hoc infrastructure, resource-sharing and collective living, accessibility, neighbors' perceptions, security and privacy) faced by THV residents lead to a rich set of design opportunities addressing a “missing middle” between city- and home-scale IoT.

Chapter 5

Concluding Thoughts

As the Affordable Connectivity Program (ACP) and other pandemic-driven digital equity programs wind down, communities nationwide will have to implement resilient solutions for maintaining equitable and affordable connectivity and technology access. Through this action research thesis, I created an operational model for non-profit, educational *community learning networks* serving Internet access to low-resourced and marginalized communities for free. The Seattle Community Network project fosters a community of practice including volunteers, trainees, and nonprofit partners who expand and maintain our infrastructure, working in public online; among them are local engineers, students, open-source hackers, activists, and many others. I see this and other CNs as contributing to community-based ecosystems of care, providing support for Internet and technology users who would otherwise fall through the “seams” in patchy infrastructures described in Chapter 2.

5.1 Loose Threads

5.1.1 Community Pedagogy

This thesis argues for creating structural change by empowering participants in technical communities of practice through effective, hands-on pedagogy, especially for those who would not otherwise have access to typically gatekept technical activities and skills. Over several years of training Digital Stewards and others in community networking, I have observed that hands-on learning experiences within a persistent, supportive, and socially fulfilling community structure can be the linchpin for continued motivation, retention, and participation.

I also propose that more in-depth pedagogy in advanced or hidden infrastructure topics is needed to bring participants at the margins of these CoPs into positions of greater power and ownership over their computing and network technologies. For example, CNs in Tribal nations could leverage hands-on learning environments for these topics to achieve greater network sovereignty [79]. Such environments are often gate-kept within the tech industry behind expensive certifications, degrees, or bootcamps. For example, both hardware and software for foundational Internet functions such as core routing and BGP are expensive and poorly documented, requiring expertise, long hours, or enterprise support to debug. Open source technologies such as our research group's LTE core network software[224], while not strictly needed for the operation of community networks, can enable a deeper levels of DIY and hands-on engagement than proprietary technologies, and become a powerful pedagogical tool. Revolutionary but outdated toolkits such as Commotion focused on a particular (mesh) network architecture and open-source firmware which is now unmaintained, though their community engagement tools remain relevant and useful [213]. There is currently a dearth of modern, accessible, free, and open-source learning materials for computing applications centering social justice (like CNs), rather than hobbyist, commercial, or purely educational uses; this is a lost opportunity for attracting equity and justice-minded people

into technical fields.

Of particular relevance to the ICTD and technology for social change communities, I claim that effective and sustainable “technology transfer,” where non-developers of a technology intervention take over its long-term maintenance, requires enough pedagogy and/or relational infrastructure for the non-developers to gain entry into communities of practice with developers or expert users (for example, even remotely via online forums or open source repositories). This can allow them to problem-solve and find help for issues as well as to grow their confidence by helping others.

A Call to Action Research

Finally, building on Chapter 2’s observations that individuals can mediate institutional power, I offer that graduate students’ intersectional positionality can allow them to occupy important liminal roles in bridging together powerful academic institutions and vulnerable local communities with which they wish to do action research. Like other members of well-resourced organizations, they maintain access and adjacency to a wealth of knowledge (e.g. through expert, library, and technical resources), networks of other well-connected academics, and other benefits. Meanwhile, with financial circumstances more similar to those of unskilled workers, vulnerable to fluctuations in funding and advisor support, they may be more able than other academics to empathize with marginalized community members’ constraints and precarious livelihoods. When engaging in human-centered research, graduate students are often on the “front lines” interfacing with participants, and thus have a degree of direct control over the way research is conducted and data is produced, which they can mediate with their ethics. While still subject to top-down hierarchical decision making within research teams, they are simultaneously not seen as powerful or officially representing universities in the same way that professors are, leaving more room for subtle subversion of typical academic values and incentives (such as those favoring aggressive publishing rates over time spent on robust engineering, or pursuing academically interesting designs over

those most needed). I call on and encourage graduate students (especially those blessed with stable funding and supportive advising relationships) to claim power by designing and implementing their own research “DIY” so that it reflects their core values—to build community partnerships, collaborations, and other relational infrastructure; to seek funding for their ideas if needed; and to find or create the communities of practice that will sustain their continued growth and flourishing.

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APPENDIX A

Chapter 1: Area Profiles

These area profiles of the study sites in Chapter 1 were co-authored by Philip Garrison, John Andrew Evangelista, and Josephine Dionisio from the research team, and published as an addendum to the CSCW paper.

A.0.1 Introduction and Methodology

The study was conducted primarily in three sites along the coast of Aurora Province, Philippines: Dikapinisan, Dibut, and Diotorin. In order to more justly represent these places in our writing, we held one group discussion in each site to learn about the place. Groups quickly drafted a statement to introduce their town to a foreigner, and after they presented, we asked questions about the place to cover topics they did not highlight at first. Then, from translated transcriptions of these discussions, we heavily edited and reorganized their words into a multivocal “profile” of each area (unlike usual quotes, we have taken liberty to reorder phrases and sentences, and we have omitted the standard ellipses) which tries to represent the site from the perspective of the people who live there. What follows are the resulting profiles, interspersed with some of our interpretation.

A.1 Dikapinisan

We live simply, and we are peaceful here. People from Barangay Dikapinisan are welcoming even to people not from our barangay and people we do not know. We respect each and everyone of us. Here we experience that no matter their title or standing in life, even if you’re someone very important, the people don’t care. Everyone is very much welcome. There is no discrimination. The very first people [in Dikapinisan] were the Dumagats and the Agtas. [Now], most of us are not minorities.

We are rich in fresh vegetables and fishes from both fresh water and sea. We have fresh air here. We have produce, like bananas, coconut, taro, and vegetables, that we sell outside. Our food is also simple. Most of us here have crops growing around our homes. Those are the things in Dikapinisan that we can be proud of.

Back then [when we were children], we really live only on sweet potato, banana. We often ate only those. Life was hard back then. In those times, we were able to survive just from what the fields could offer, and from the river.

Mothers stay at home while most of the fathers are in the fields. Livelihood here in our community also includes our husbands going to the sea [to fish] when the sea is good like this. Most of us here also catch fish in the river. Most of us here have our own land. It is up to you how to make it productive. If you invest in farms, specifically in coconuts, that is for life.

Although farming and fishing are the mainstays of life in Dikapinisan, some people find outside employment. Particularly when typhoons make living in Dikapinisan difficult, people will get jobs in nearby towns, for example in construction. Many people from Dikapinisan have moved to other countries for work as *balikbayans*, part of the global export of Filipino labor.

When they brought the cell site here, it was a huge thing for us. It's really a very big help because instead of going outside to send money to our children [who study outside of Dikapinisan], we can simply send it to shore and our children can wait for it there. If we need something from outside, instead of going outside to call, we can call from here; before, we sent letters. Most of us who are present here have husbands who work outside, working as construction workers. Now, from here we can just call them. Just from that we have saved a lot already.

The nearest signal to Dikapinisan, besides the VBTS site, is in Baler and another similarly distant town. Residents of Dikapinisan are eager to get internet access in their village to contact relatives and use Facebook.

There was logging before. Based on what we remember about logging, it was depressing. There were a lot [of companies] before. [Logging started] around the '70s. In 2000, there was almost none. Around 2010, all of it stopped. We are now able to keep our trees safe.

If we are badly hit by a typhoon, all of us here really have no source of income. [The main effect of logging was] flood. We were almost wiped out. It's because there are no more roots that control the soil.

When they [companies] saw that there were branches all over the main waterway of the river, they should have cleared it. [When a typhoon came], instead of the water passing, these [debris] blocked the way. The water, then, found other exits. They

didn't have any concern with cleaning up or pity for the citizens in case of a calamity. It's as if they didn't care about it because they don't live here.

A barangay can become very developed but if we, the residents, would be wiped out that development would be useless.

Our respondents recall logging starting in the early 70's, during the US-backed dictatorship of Ferdinand Marcos. Use a citation to connect logging and neocolonialism. This extractive industry created what is now perhaps the largest threat to Dikapinisan: severe flooding caused by typhoons, unstable soil, and altered drainage systems.

A.2 Dibut

In Dibut, our residents here have Dumagat roots [tubong Dumagat]; that is the tribe. Our cultural norm was more tribe-like in the beginning, always migrating. We have two leaderships, the tribe and the barangay, but they still have proper communication and solidarity with each other.

Dibut was offered by [President Manuel] Quezon as the land of our ancestors. The only ones with the right to till the land [in the ancestral domain] are those with *dugong* Dibut [i.e., Dibut ancestry]. Those who are Tagalog are not allowed. We should not give out our ancestral land because it should be for our children. Not just for today, but also for the generations to come.

Around 1972, Dibut was recognized by the government as a barangay, and in 2005 the Dumagat indigenous people got an official title to much of the land in Dibut. The vast majority of people living in Dibut are Dumagat.

We live peaceful lives because we live prosperous lives here. Our people live harmoniously. We are also religious people. We actually have five churches here, and every Sunday, we go to our churches.

Our primary occupations are fishing, farming, and anything else that is profitable. From September until March, we are usually in the farms, planting coconuts, bananas, and sweet potatoes. We sell [banana and coconut] outside, but we cannot complain to [the produce traders] because the price and profit is set beforehand. This had been the cause of our problems and is why the farmers are on the losing side. Now, our product prices are quite low, but we are still grateful that we have something to cook.

The reason why we do not get jobs is because of the lack of education. A percentage of [the children] need to graduate to be able to work with machines. But we cannot finish school because of the lack of income.

It is uncommon for people to leave Dibut for work, but there are a few who do, and some who work overseas. The school in Dibut goes up to grade 6, and starting in grade 7 students leave the village to go to boarding school.

When there was no VBTS yet, we would go to several places just so we can do important calls. But today, at least, we can make immediate contacts if needed. That is why technology is beneficial. [Before], there were no signal here. You had to climb the mountain; as soon as you get higher, there would be signal from Smart.

In the nearby mountains, people could get internet access well before the VBTS project and had cell phones to do so. People would climb the mountain to contact family in other towns or overseas.

We have a clean environment, which is one of our important characteristics. We have a rich forest, because most of our areas here are still virgin forests with large trunks. Barangay Dibut is proud to firmly stand for the trees, despite whatever calamity we face, because these are God's treasures.

The type of logging that uses vehicles started around 1986 to 1987. It was totally stopped in 1995, with an ordinance that prohibits logging at the mountain front. There are areas where if there are no more forest trees, erosion and flash floods become more hazardous. But we tend to our land here.

We are also proud to have bountiful oceans, just like we are proud to have built our fish sanctuary. We tend to it in order to protect the corals inhabited by fishes, because once these corals are destroyed, the fishes will leave.

A.3 Diotorin

Our lives are simple here. Diotorin is quiet and fun. The whole community possess a strong and healthy communication with each other. That's why everybody has a healthy relationship with one another. There's still what we call *bayanihan* [roughly, communal work]. This old value has not been forgotten.

This place is very small, yet we wanted you to know that we have different sorts of people here. There are Tagalog people, Bisaya, Bicol, and we also have our minorities, Dumagat and Lumad. The first people here were the Agta. It's very diverse.

Our foods are fresh, and bountiful as well. During *Amihanin* [the rainy season], our livelihood becomes more difficult. The farmers will come back to the mountains [instead of the sea] to start and plant crops again. A problem here are the big buyers outside. We cannot argue about how [exports] are priced; their prices are standard. That's why normally, many people have no money. Because of that, it's hard for us to buy or get food, and we end up eating bananas. The city is very far. Sometimes, we're

not eating rice. The problem here is money. How will our children study if we have no money?

In an event when the boat cannot get to Baler due to the strong sea current, our children suffer, walking through this mountain. That's the sacrifice of our students. If we only have a proper road, perhaps, it would be a great relief for each of our citizens here. Everyone wants a road. From there, we can have improvement in all of our products.

Cellphones are big help in this place. Somehow, we can contact with each other despite the distance, the circumstance. Through calls we can easily have a conversation.

It is important to people in Diotorin to help each other in the tradition of *bayanihan*, which can include helping people park boats, carry houses, recover after disasters, or various other tasks.

Almost everything here was established by the locals, who mostly dedicated their lives for this place. A number of people practice slash and burn [*kaingin*]; however, many of us have done it in the lands we do not [formally] own. These lands are controlled by the big landowners. How did it happen that they got a land title? Perhaps it was done under table. Usually [the municipal government] asks people to certify that they are the owners of the land, but they did not ask us to do it. How about us, poor people, who struggle for our future? For our family? One day, the lands we till will be grabbed by whoever the owner is. That's our other problem here: if the time comes, they might treat us as mere trash, displaced in our own island. That's why it's our other request. We're grateful for your system as it made us happy and hopeful that you [the researchers] might help us in this matter.

The biggest threat to the people of Diotorin is that their land will be taken by big landowners who have secured legal rights to their land without ever having lived there. Some people working their land for up to 20 years have found that the local government gave out the title to someone else.

APPENDIX B

Chapter 2: SCN Community Governance

This Appendix presents a snapshot of community governance, work processes, and technical tools used by SCN in 2024, as well as some of the narratives behind their adoption and use.

B.1 Monthly Community Meetings

Monthly community meetings on Zoom for all current and prospective participants (modeled after NYC Mesh’s monthly meetups and Quintana Libre’s monthly *reuniones* [97]) began in December 2020 after a wave of new volunteers joined (see Sec. 3.4.3). Official meeting notes since January 2021 are stored in a public Google Shared Drive. Since 2022, this meeting has been held hybrid with an in-person component.

B.2 Visioning Documents

A “Mission, Vision, and Values” statement for the SCN website was spearheaded in March 2021 by an undergraduate volunteer and an external community member experienced in grassroots governance. This became an important public reference for attracting value-aligned participants, partners, and funding. Members also adapted a “Code of Conduct” from NYC Mesh and wrote a team onboarding guide and Slack channel guide (now used for Discord). A few community members attempted an organization chart involving partner organizations and nonprofits, but our collaborations were too fluid at the time to formalize before we had any infrastructure to manage together.

B.3 Work Processes

Working groups were initially modeled after those in NYC Mesh. These were expected to operate in an autonomous and decentralized fashion, set their own agendas, allow open membership, communicate in public on the Slack chat server, and meet as needed at their own pace. However, these groups often lost direction or steam without leadership to provide goal setting or task delegation. Many disengaged and drifted off without well-defined responsibilities, in-person events to build relationships, or critical mass to keep new directives and activities bubbling up. After a near complete turnover of volunteers between mid-2021 and mid-2022, exacerbated by the dominance of undergraduate volunteers and their cyclical graduation, I began to check in on projects regularly and ask all volunteers to adopt stronger documentation practices to maintain organizational memory. All technical working groups were asked to provide public documents on the Shared Drive and regular updates at a weekly 30-minute virtual “stand-up” meeting or at a separate public work session if needed.

Due to my depth of historical context around the network and held relationships with important community partners, the I currently perform “project manager” roles for other technical participants. I help coordinate work between teams and flags issues that are urgent, e.g., those affecting the reliability of internet service at user sites. However, as other participants have gained seniority, context, and ownership within the organization, they have begun to assume more of these onboarding and coordination roles for their own projects or tasks.

B.4 Community Building Processes

Volunteer recruitment drives have been performed regularly through non-academic organizations since 2022, including a local in-person “hacker” conference and a local contingent of the Recurse Center [246], resulting in more stable community participation. SCN also aims to strengthen community partnerships by fostering more densely connected interpersonal and working relationships amongst SCN volunteers, Digital Stewards, and community partners. The return of in-person activities to some extent after 2022 has facilitated learning and relationship-building events such as a monthly “Hack Night,” occasional outings and dinners, and weekly amateur radio study sessions in addition to the weekly technical stand-up and monthly community meetings. Organizing enjoyable group activities remains a core priority for me, though it can be challenging due to time limitations and geographic, lifestyle, or interest differences between members.

B.5 Community Roles and Authority

The newest approved community governance document, inspired by conversations with NYC Mesh members in 2022, outlines mechanisms for collective power to set agendas and spend money on projects. A 5-9 seat “Community Board” is elected up to four times per year from a set of “voting members” or “leads” who have contributed to 10 or more technical or social working

groups, gaining community trust and context. (This was adapted from NYC Mesh’s 10-install requirement to become an “install lead,” which I had observed in 2019). The Board sponsors and approves member-proposed projects, monitors current project statuses, and approves spending for projects over \$50 USD. Board members must attend community meetings and remain responsive to email or chat communications about decision making. As governance infrastructure, the Board gives its members a means to shape and publicly claim SCN as a project, particularly valuable for community partner organizations.

B.6 Communication Tools

An important factor enabling appropriation in the learning commons is how upcoming technical tasks and “To-Do” items are communicated and coordinated, which presents an ongoing challenge. SCN’s initial vision (modeled after NYC Mesh’s Slack) was to organize all participants and activities, including user technical support, over a single online platform to encourage transparency and open collaboration between volunteers and other partners. As explained below, this has proved impossible due to a need for diversity in communications practices for different participant groups. For other software, many values and design tensions competed for precedence on platform choices:

- Commercial software is often convenient and fast to adopt, and requires less maintenance.
- Free or low-cost enterprise services are often available for nonprofits.
- Self-hosted or home-built Free and Open Source (FOSS) options align with values of openness and education (allowing community members/students to learn by deploying them), but operating costs include labor, costs of cloud compute if required, and potential downtime.

B.7 Online chat platform

As in many other CNs [97, 101], SCN’s need for always-on communications independent of volunteer capacity (especially during network outages) has so far trumped a principled preference for a FOSS or self-hosted platform. The community initially adopted Slack, a popular chat tool in the technology industry with a free tier, organizing features such as topic-based channels and threading, and both computer and smartphone-based usability to maximize accessibility. The volunteers additionally use mailing lists and the Meetup platform for event announcements and interfacing with the public. About 2 years into the project, SCN switched from Slack to Discord (a direct competitor with very similar features) in response to feedback from community partners that they were already operating on Discord, and it would be unacceptably difficult to learn and follow yet another chat platform. SCN implemented a software bridge to pipe messages to legacy Slack users who missed the transition but could return later to find out about it. Still other community partners have insisted that we pipe Discord messages to email in order to reach them, which is a technical project currently in the works.

B.8 Diverse and accessible contact methods

SCN has needed to integrate a diversity of communications channels, including traditional voice calls and text, due to its focus on digitally excluded groups. Many current or potential network users are not comfortable with online chat platforms such as Discord or even with online form-filling, so SCN's Google Voice number remains their primary means of reporting outages or requesting network enrollment. Between volunteers and other participants with uneven availability collaborating to provide service, there is not typically a person available to pick up the phone or field requests immediately. As a result, the group is working on integrating a more fully featured phone and issue ticketing system that can pipe user requests asynchronously to Discord or email for volunteers according to their needs. In future work we hope to formalize these tools as modular components of a technical organizing "stack" for providing public volunteer-based resources.

B.9 Network monitoring and management

We are currently testing and building on the following software:

- Redmine or similar issue tracker for managing user help across decentralized volunteer activity
- LibreNMS, an open source SNMP aggregator with alerts for device and link monitoring, and data collection (e.g., RRDTool, Prometheus, Python scripts), needed for performance or usage reporting for nonprofit grants
- Ansible or other tools for automated configuration tracking and management
- Wireless systems based on remote configuration management (e.g., Unifi or Omada) to facilitate smoother WiFi network deployments led by less experienced trainees or students
- A cloud VM provider or self-hosting on owned hardware for software deployments (both used)

The work to integrate these functions into a system that promotes effective network maintenance and responsiveness is ongoing and will require additional software components. We later intend to publish runbooks or lessons on budget building, community outreach (such as email or phone scripts for soliciting site partners), and templates/flow charts for responding to user help requests, forming the basis for a CN curriculum. Such guides, like a replicable site bill of materials, could also become information infrastructure to support future training activities and deployments. Training for all technical aspects of SCN management in the future will also require more advanced, full-stack technical labs for a wide range of networking and radio topics.

APPENDIX C

SCN Seattle Report 2022

Also found at <https://bit.ly/scn-seattle-report-2022>.



Seattle Community Network (SCN) CBRS-Based LTE Internet Access Project City of Seattle Report 2022

Based on a collaboration between:

Local Connectivity Lab (LCL)
University of Washington (UW)
Seattle Public Schools (SPS)
City of Seattle Internet For All

Esther Jang, *Local Connectivity Lab*
Yoshiaki Sono, *SCN Volunteer*
Cody Harris, *SCN Volunteer*

Table of Contents

I. Introduction and Summary	195
II. Core Network Infrastructure	197
A. LTE Access Network Technology	198
B. Installed Sites	199
1. SPS School Sites	199
• Garfield High School & Nickelsville CD Village	199
• Franklin High School	205
2. Other Seattle Cell Sites	209
• Filipino Community Center	209
• Oromo Cultural Center (OCC) & LIHI Southend Village	212
3. WiFi-only Sites	217
• Nickelsville Northlake Village	217
4. Non-Seattle Cell Sites	219
C. Network Monitoring and Response Strategy	219
D. Quantitative Network Metrics	220
1. Data Usage	220
2. Network uptime/availability	222
3. Number of people using the network	225
4. Network Speeds	226
III. Capacity Building Programs	227
A. User Device Program	227
1. Recruitment	227
2. Recipient Demographics	229
B. Training Programs	230
1. Volunteers	230
2. Adult Training and Employment	232
• Adult Digital Stewards	232
• EEC-WA Connect WA Broadband Technicians	232
3. Youth Engagement	235
• Youth Digital Stewards Program 2021 & 2022	235
• Supporting SPS Students' Connectivity	237

IV. Qualitative Findings: Impacts and Opportunities	238
A. Working with Tiny Home Villages	238
1. Broadband Needs	238
2. Device needs	238
3. Volunteer Engagement	239
B. Major Challenges	239
1. ISP DMCA Policies	239
2. Maintaining Infrastructure at Community Centers	240
3. Overall costs	241
C. Conclusions	241
1. Addendum: Continued Network Data Collection	242
Appendix C.1: Network Map	242
Appendix C.2: Additional Graphs	243

I. Introduction and Summary

This report seeks to document the Seattle Community Network (SCN) community-based Internet connectivity project as an evaluation and proof of concept of the use of Citizens' Broadband Radio Spectrum (CBRS, or "LTE Band 48") dynamically licensed radio-frequency spectrum to power an LTE access network for low-income and vulnerable populations. The project was initially funded by the King County Digital Equity for Marginalized Adults Grant early in the Covid-19 pandemic to help improve connectivity for Seniors, Homeless, Unemployed, and majority Non-English-Speaking folks, and later also funded by the City of Seattle IT to expand our scope to students. Our goal was to serve these groups in higher-need neighborhoods through collaborations with existing community institutions such as schools, libraries, community centers, senior centers, and Tiny Home Villages. High-speed Internet connections at these host institutions are shared out to local neighborhoods via one or more LTE cellular access points (called "eNodeB" or eNB) on their rooftops, supported by open-source cellular core network software commonly deployed for networking research projects at the University of Washington (UW). During 2020 and 2021, the City of Seattle IT further supported the project by providing access to Lumen connections for community host institutions, and set up a collaboration with Seattle Public Schools locations Garfield High School and Franklin High School to establish 2 additional Internet access sites on their rooftops for the Central District and Mt. Baker neighborhoods, respectively.

Our initial conclusions are that this connectivity strategy is not generally and immediately scalable to cover all homes within Seattle. Due to the challenges and costs of setting up the community collaborations and meeting technical requirements to install the LTE cellular equipment on rooftops, so far there are only seven LTE cell sites spread over areas ranging across Seattle, Skyway, and Tacoma with coverage areas limited to at most 1-2 miles from the access point, in addition to a few WiFi-only sites with coverage limited to the service location (such as a single Tiny Home Village). Further, the low density of access points results in low signal strength and speed at many locations, and we cannot ensure consistent wireless coverage of every residence within our coverage areas. Given the current policy environment where low-income people within Seattle can get subsidized Internet access from commercial service providers, there are typically better options for day-to-day connectivity. However, we have had some success in providing a baseline level of broadband access at specifically targeted locations such as Tiny Home Villages near our LTE access sites where other ISP options are not available. In conjunction with our network service we have also established a holistic technology access and capacity-building program including device delivery and training, which we believe has positive knock-on effects independent of the specific network technology used.

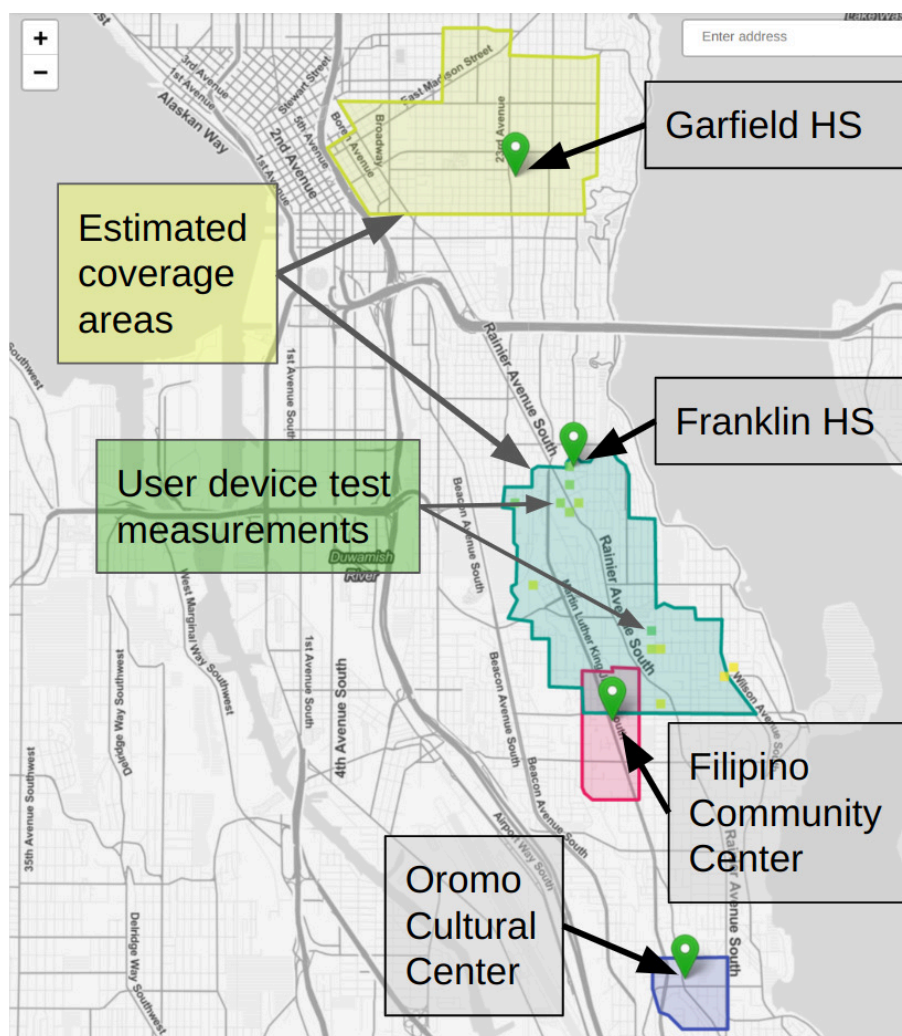
Our CBRS LTE sites currently meet people's needs within their scope as a *neighborhood-wide, limited-bandwidth fallback connectivity option*, especially for *public or semi-public shared spaces without other low-cost or free options* (potentially analogous to public water fountains, electrical outlets, restrooms, etc). They support essential applications such as messaging, email, Internet-based calling and a limited amount of video calling. Importantly, access to this network does not depend on the inconsistencies of house by house or street by

street availability and pricing via commercial ISPs, and can also remain available as a backup if hyper-local ISP connectivity is knocked offline (e.g. on a street level). The hardware SIM card required to access the LTE network also makes it easy to focus our currently limited bandwidth on our especially vulnerable user populations. However, more openly-accessible higher-bandwidth services will still be necessary in the future to support increasing Internet usage.

SCN's immediate goals include expansion into unlicensed wireless and wired access technologies where possible to increase the bandwidth available to our users, as well as more emphasis on provision of local WiFi access networks using fiber (e.g. Lumen) backhaul where available. For everyday accessibility, we have found that low-income and vulnerable people still need the convenience, openness, and wide compatibility of WiFi, especially those that support older (e.g. 2.4 GHz-only) devices. They also still need access to newer devices as well as help setting them up, as device vendor-locked online account ecosystems and login/authentication procedures continue to increase in complexity.

In the future, we will continue to develop SCN as a nonprofit "teaching network" towards digital equity goals. We aim to make internet infrastructure more publicly visible and accessible, build meaningful relationships between our many local high-capacity tech and university workers with our local high-need groups, and connect all participants with computing knowledge, resources, and our networking community of practice at the level they need to improve their lives and professional prospects. We will also continue to develop, operate, and collect data on our network for ongoing and future evaluations of Internet access and needs over the coming years. For more information on the Seattle Community Network project and our 501(c)(3) nonprofit the Local Connectivity Lab, please visit our website at <https://seattlecommunitynetwork.org/>.

II. Core Network Infrastructure



Map of Seattle SCN Sites and estimated coverage areas (an optimistic basis for further testing)

A detailed network diagram of the Seattle SCN sites (with IP addresses removed) is provided in Appendix C.1.



FCS Site Antenna Mast

A. LTE Access Network Technology

Each LTE “cell site” includes an outdoor commercial LTE access point (called an “eNodeB” or eNB) on the rooftop of a community building, controlled by a generic (indoor) commodity computer running the open-source LTE “core network” software package “open5gs” (<https://open5gs.org/>) used for networking research at the UW (used by our own package [CoLTE](#), or Community LTE). The CBRS licensed channels are requested as needed by the radio equipment to a national FCC database regulating the spectrum use, for which the Spectrum Access Service (SAS) database front-end is provided by Google at no cost based on an existing research collaboration with the UW. The specific models of eNB (Baicells Nova 233 and 436Q) and LTE sector antennas we use (at around \$4-5K per set, on the lower end of the commercial price range and most commonly used for wide-area rural coverage) typically result in a coverage area of up to 1-2 miles with patchiness depending on terrain and obstructions, and can support up to a max of 96 simultaneously connected LTE devices with up to 114 Mbps download speed/14 Mbps upload speed. Due to the small scale and low-power hardware used

at each cell site, the expected max power budget of each site is well under 200W, making the electricity cost affordable for community host institutions.

Where possible, the project also provided the host institution with a gigabit Lumen fiber connection through the City of Seattle’s Internet for All initiative to provide “backhaul” or “upstream” Internet connectivity for the cell site and for local use, though ultimately the full capacity could not be distributed via our LTE networks due to radio hardware limitations. At Franklin HS where this was not possible, the UW provided our backhaul through a wireless link from Harborview Medical Center. In the coming year we intend to distribute the remaining bandwidth at our sites via other types of wireless access networks.

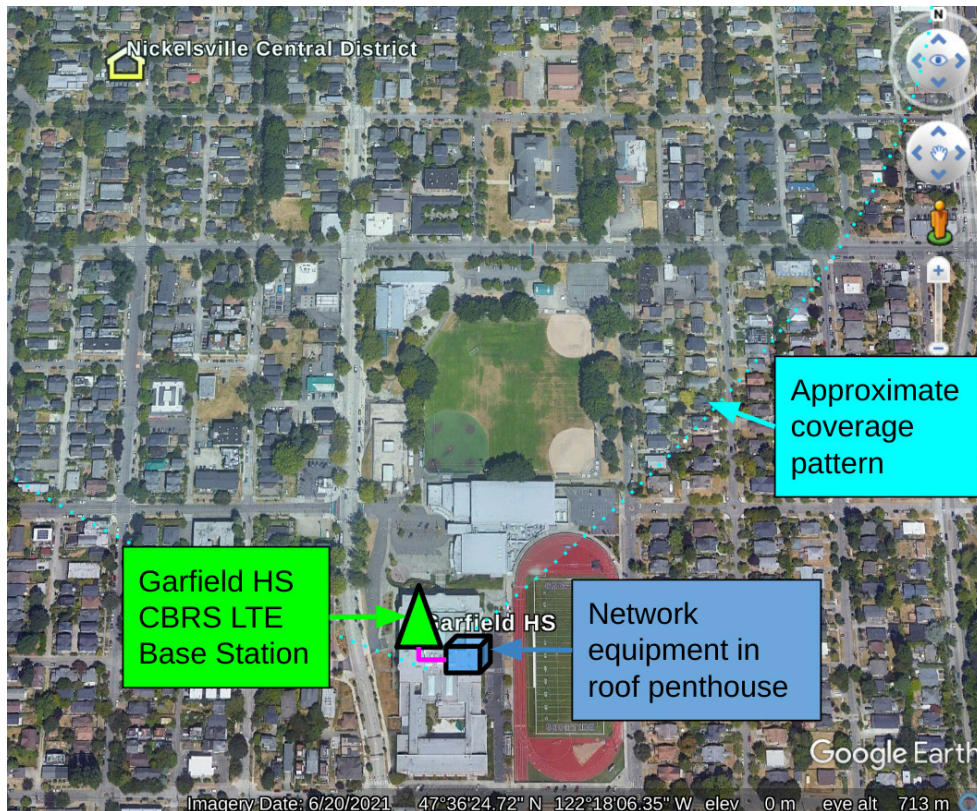
Each distinct LTE connection requires a custom SIM card for our network and a CBRS band-supporting phone, hotspot device, or other “Customer Premises Equipment” (CPE) LTE access device. As only newer smartphone devices (2019+ models) support Band 48, we planned a free device delivery program for enrolled users, described further in the “User Device Program” section below.

B. Installed Sites

1. SPS School Sites

- Garfield High School & Nickelsville CD Village

The Garfield cell site, installed in 2021, points a wedge-shaped coverage area NW into the Central District towards the Nickelsville Central District (CD) Tiny Home Village user site, which had already been recruited as a potential user group in 2020.



Garfield High School Site Map



Garfield High School Antenna Mast During Installation



Fully Constructed Outdoor Antenna Mast at Garfield High School



View from the Garfield High School Antenna Mast

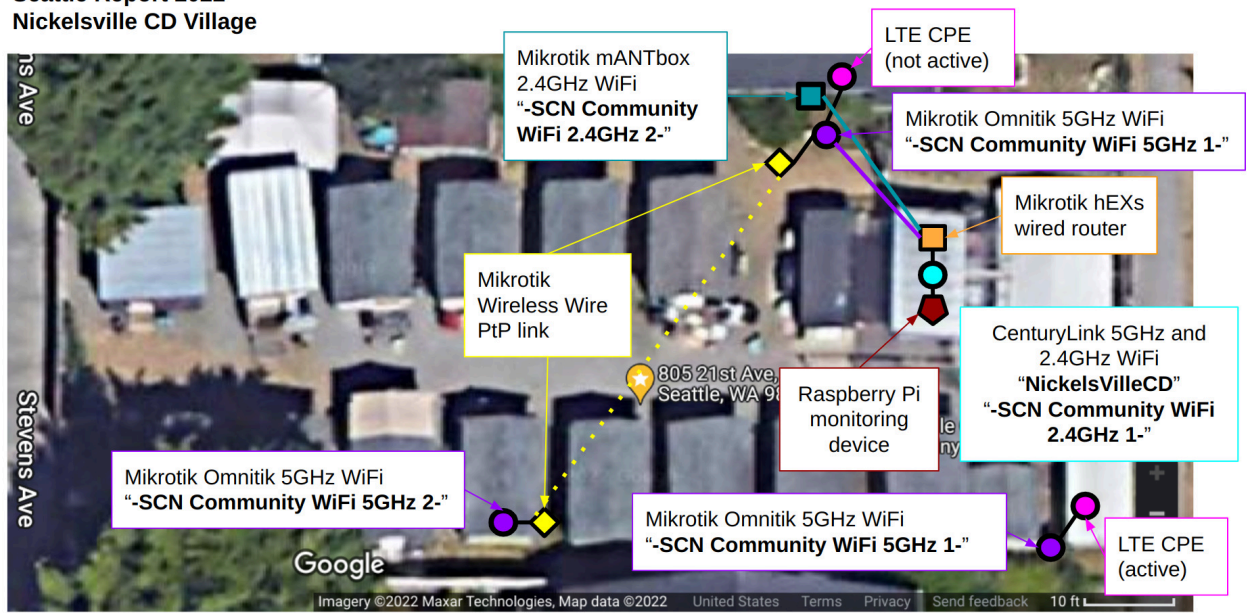
The Nickelsville CD Village WiFi network was installed in April of 2021, consisting of three LTE CPEs attached to our cell network along with 2.4 GHz and 5 GHz WiFi networks distributing that connectivity throughout the village.



Nickelsville CD Village resident mounting CPE and WiFi equipment on his unit (for power)

In Summer 2022 we found that Lumen gigabit fiber service finally became available at the Nickelsville CD house plot address, and we requested it to be installed as a free Internet for All connection. In December 2022, we reconfigured our local WiFi network to use that faster connection, leaving only one LTE CPE online as a backup connection with future plans to configure failover to LTE if needed.

Seattle Report 2022
Nickelsville CD Village

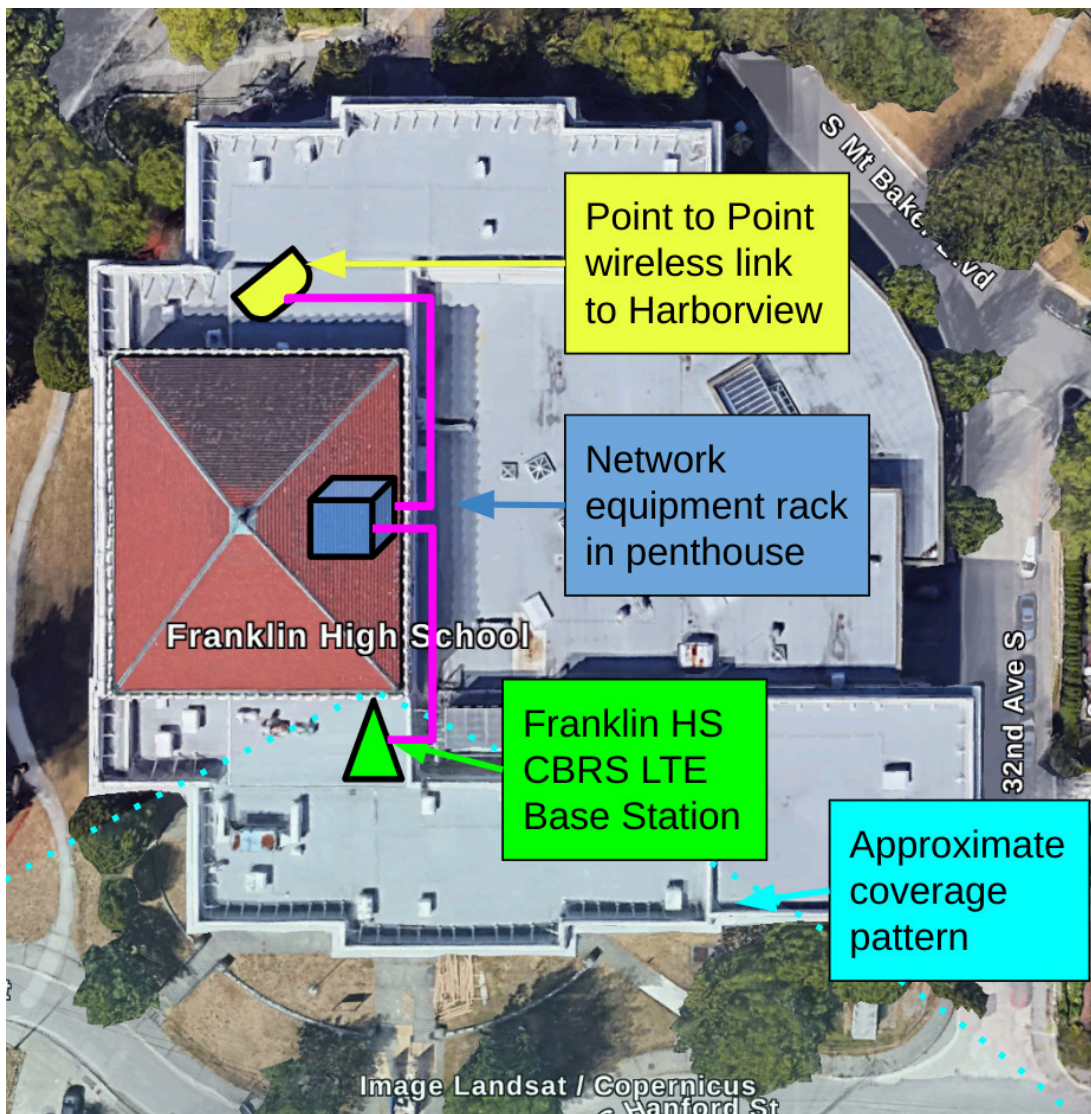


Updated Nickelsville CD network map after 12/22 upgrade



Lumen Fiber and SCN Equipment at Nickelsville CD Site After Fiber Upgrade

- Franklin High School



Franklin High School Site

The Franklin High School cell site, also installed in 2021, points a wedge-shaped coverage area South towards the S Mount Baker and Columbia City neighborhoods. Due to lack of availability of Lumen gigabit fiber, backhaul connectivity is provided via an unlicensed 24GHz wireless Point-to-Point (PtP) link (Ubiquiti AirFiber24) from the UW Harborview Medical Center, which provides around 750 Mbps simultaneous upload and download capacity.

Despite the promising high location and vantage for coverage, the Franklin High School site does not yet have users due to lack of initial success with partner outreach to low-income housing and community organizations, and insufficient volunteer capacity in the area. We have performed coverage testing and measurements in preparation for continued outreach in this area (visible on our coverage map above and online), which we hope to increase in 2023 via our new Digital Stewards hires.



Franklin High School Site Antenna Mast Construction



Harborview AF24 (PtP wireless radio)



Franklin AF24 (PtP wireless radio)

2. Other Seattle Cell Sites

- Filipino Community Center

The Filipino Community of Seattle (FCS) Community Center on Martin Luther King, Jr. Way South near the New Holly neighborhood was our first cell site, installed in 2020 with the first cohort of our Adult Digital Stewards training program. The coverage area points NW towards the Katharine's Place low-income housing complex, where we have connected a handful of home CPE users and the public community room.



FCS eNB Sector 1 (now turned to face the opposite direction, NW)

After our initial installation, FCS completed the construction of a taller second building next door, the Filipino Community Village (FCV) senior living center, where we expanded the network with a second cell site pointing South. We have also connected several FCV Senior residents who are otherwise not able to afford in-home WiFi.



FCV eNB Sector 2, pointing South



FCS User Home Device Installation



Home CPE at User's Residence

- Oromo Cultural Center (OCC) & LIHI Southend Village

The Oromo Cultural Center cell site was established in late Fall 2021 as the result of a strong partnership between the OCC Board and one of our Adult Digital Stewards trainees, Adam. Though the roof is not very high, the strength of the

community there, ease of working with the institution, demographics of the neighborhood, and availability of a Lumen fiber connection made it a reasonable choice.



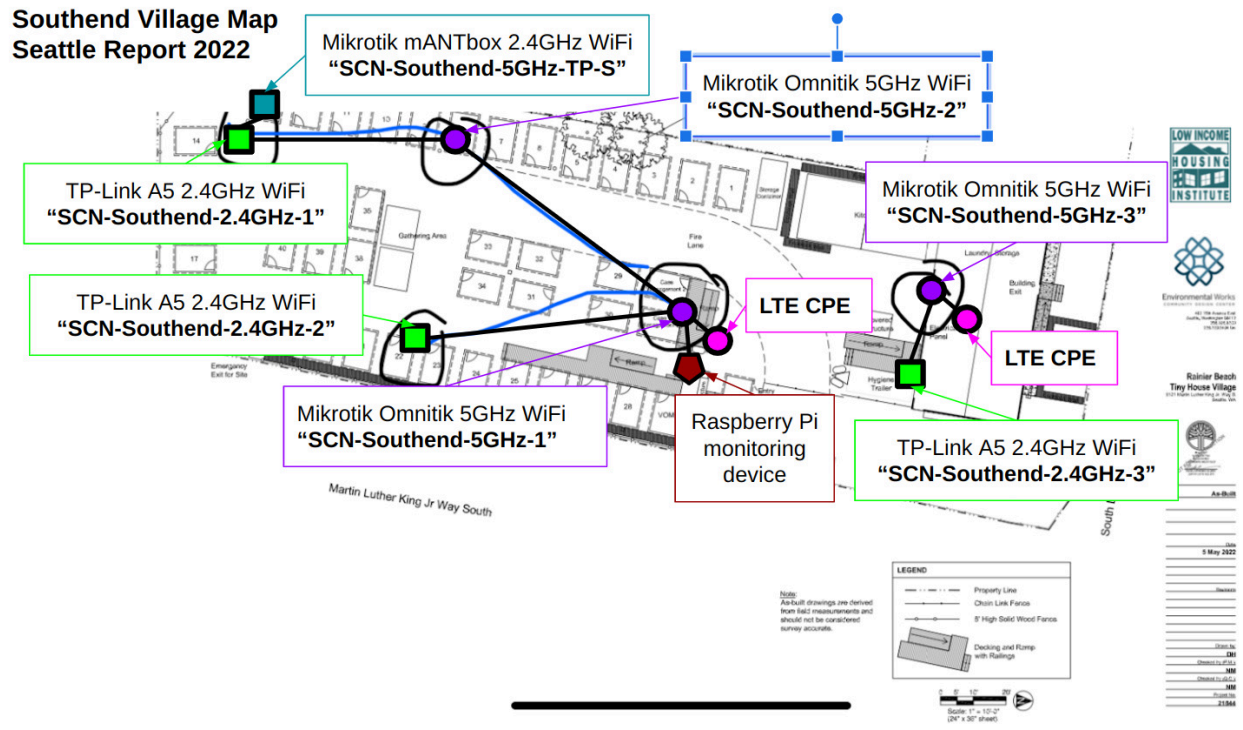
Close-up View of OCC Cell Site Antenna Mast



OCC Cell Site

The Low Income Housing Institute (LIHI)-managed Southend Tiny Home Village was recruited as a user site in early 2022 after initial coverage testing at another nearby LIHI location (Othello Village) the previous year yielded too low signal reception to

pursue further. Two CPEs and an associated WiFi network were installed in Fall 2022 a few months after the village was opened. Soon after, a Southend Village resident with a prior professional background in wireless networking and IT, Kent, joined the SCN Discord as a volunteer. He has been actively helping to improve the configuration of the network, test new equipment, and coordinate tabling visits with the leadership and the rest of the village as a way to continue using his networking skills.



Southend Village Site Map



Network Equipment Installed at the Southend Village Site



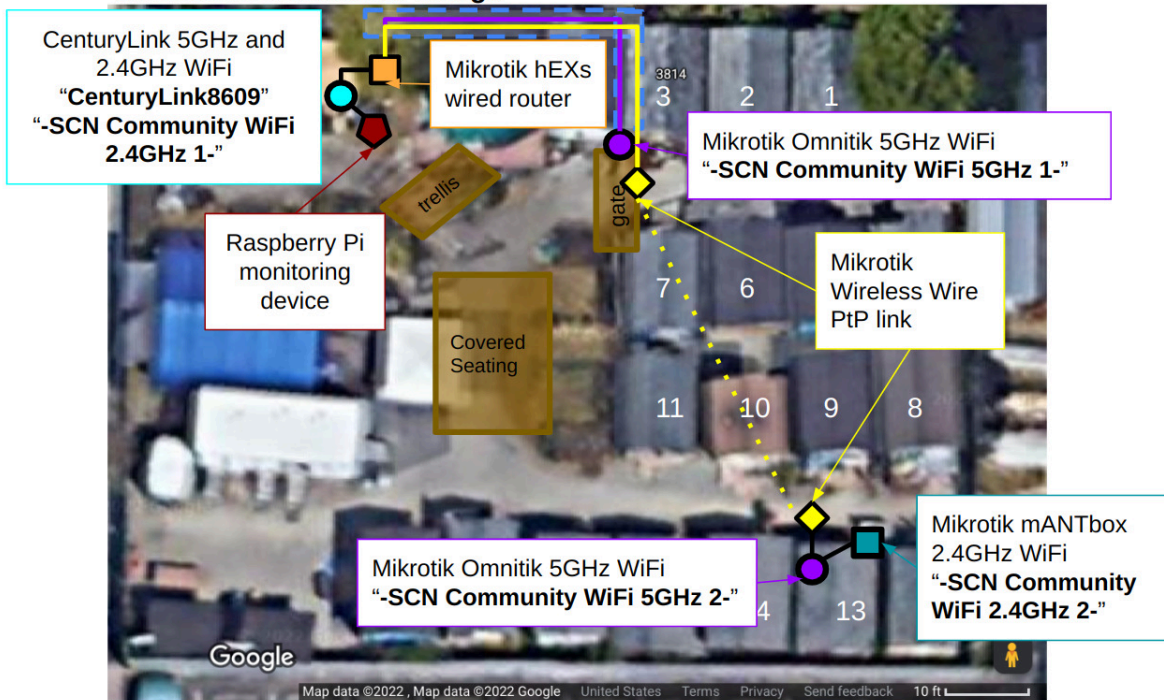
SCN Volunteers at the Southend Village Site

3. WiFi-only Sites

- Nickelsville Northlake Village

The Nickelsville Northlake Village was recruited by the Nickelsville CD Village leadership in 2022 soon after the Nickelsville CD site install and device delivery, as the Nickelsville organization has at least one shared staff member (Jarvis). While the Northlake install seemed stalled for a few months due to the lack of a nearby LTE cell site, Lumen gigabit service became available at the house plot address for Northlake around the same time as for Nickelsville CD, and the two connections were requested at the same time. The Northlake location was initially designed as a WiFi-only site, where the main task was sharing the WiFi network throughout the village rather than the main security desk where the network was installed. In early Fall 2022 we initially installed two outdoor WiFi-mesh access points which showed degraded performance later on in the winter due to weather and a newly built Line-of-Sight obstruction in the center of the village. In December 2022 we upgraded the WiFi network with a PtP link and new cabling to improve performance.

Seattle Report 2022
Nickelsville Northlake Village



Northlake Village Site Map



Northlake Village WiFi and PtP Wireless Equipment Mounted on Tiny Home



Northlake Village WiFi and PtP Equipment Mounted on Gate

4. Non-Seattle Cell Sites

- King County Library System- Skyway Library
- SurgeTacoma Coworking Space
- Tacoma Public Library Main Branch

C. Network Monitoring and Response Strategy

SCN is primarily a volunteer-built and maintained network with a best-effort service policy. The public SCN Discord server is used as a central hub for communications and coordination of all network activities involving both volunteers and users, modeled after NYCmesh's use of Slack in the same way. The FCS and Southend locations have each had one active resident user reporting service issues with

immediacy on the #support channel on Discord, where volunteers typically respond within a few hours. We also have email lists for both volunteers and users of each site, used for announcements about service and outages. We maintain a VOIP phone number and help@seattlecommunitynetwork.org email address for inquiries and help requests, listed on flyers and stickers on installed equipment. We occasionally get service inquiries to the phone number or email address (around 1-3 per month), but our most successful user recruitment has been via higher-density housing and living groups such as Tiny Home Villages.

For the past two years we have maintained a once weekly in-person SCN Community Technology Help Desk at the FCV Senior Center on Fridays 3-5pm, where new users could sign up for network service and ask for help with other technology needs (computer setup, etc). Other local prospective users and new volunteers were also successfully referred there as an in-person onboarding and service location. After the first few months of the Help Desk, the Filipino Community Center used its Digital Navigator funding to hire the volunteer lead of our Help Desk, Jonathan, as a permanent Digital Navigator staff member. Over time, the Filipino Community Center IT has been able to use our learnings and feedback from the Help Desk about the Seniors' needs to tune their digital training and support offerings. Due to decreasing demand, we recently decided to discontinue our FCV Help Desk in favor of less frequent on-site pop-ups at local Tiny Home villages such as the Southend Village.

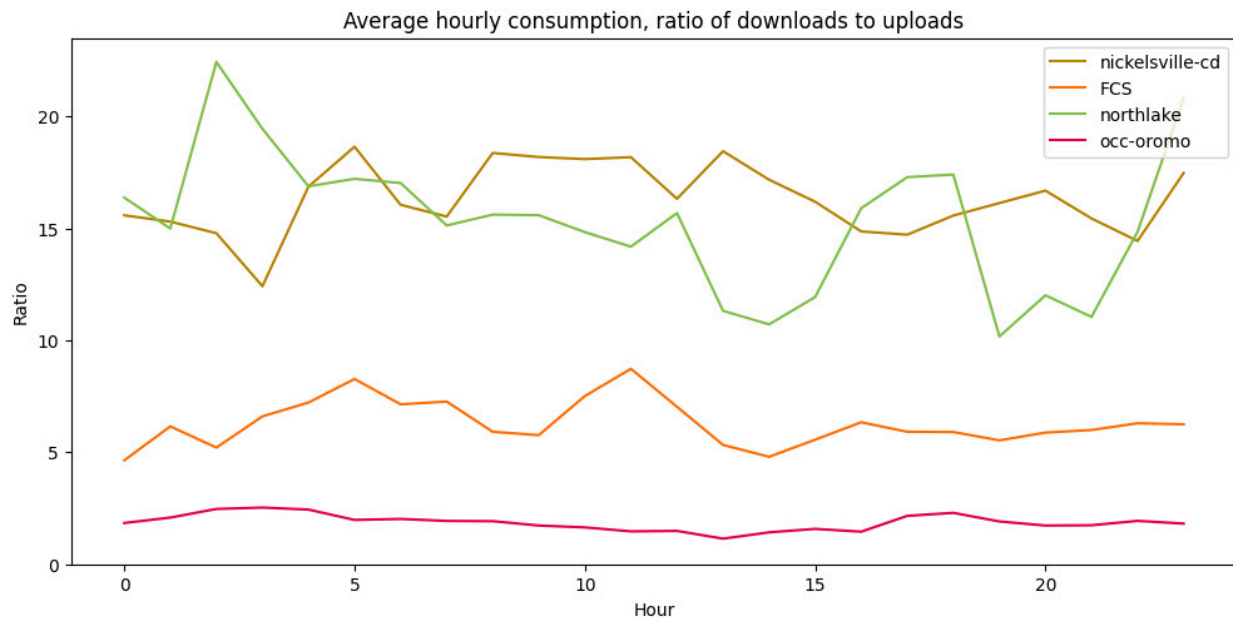
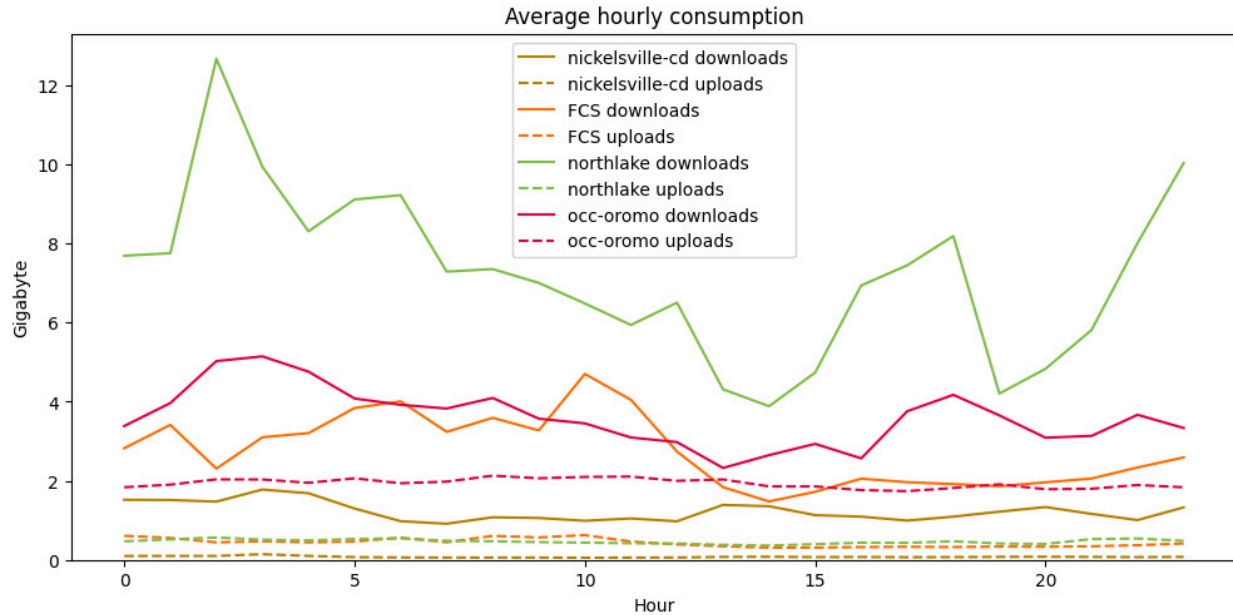
In response to challenges of scale over the past few months, we have been working on improved strategies for remote network monitoring while maintaining user privacy. We currently use the LibreNMS open-source monitoring software hosted on a cloud server connected to SCN via a management VPN, with SNMP reporting from all of our network devices that support it. Our device enrollment is still incomplete, but we are improving our tooling and processes for this in the immediate term. Due to our privacy policies, we will not enroll any privately owned end-user home equipment (including CPE and WiFi routers) into our monitoring system (unless expressly requested to do so).

D. Quantitative Network Metrics

Data on network metrics were collected through our LibreNMS SNMP aggregator instance running on Azure cloud from devices with SNMP capability.

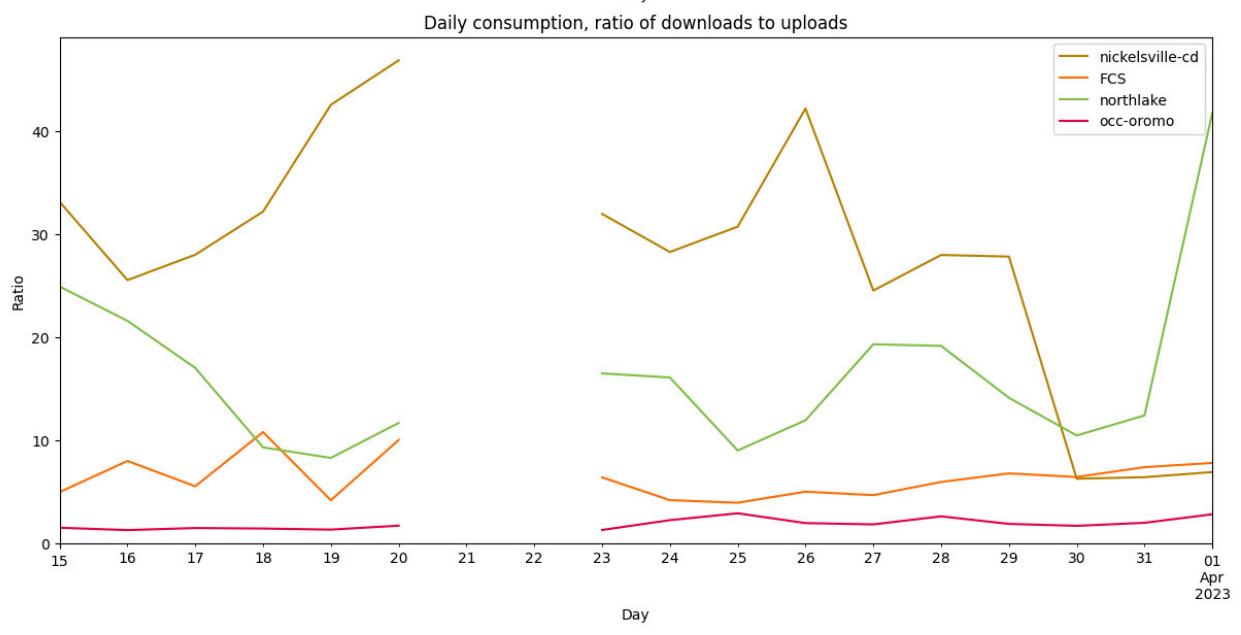
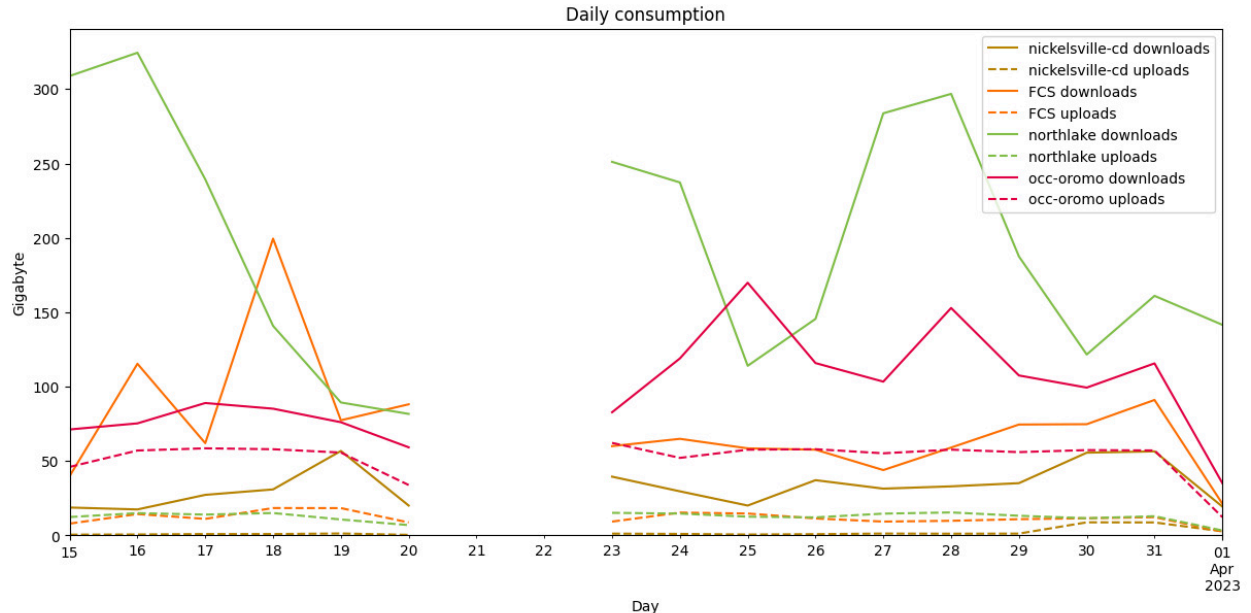
1. Data Usage

The first graph below shows an average of hourly data usage (in GB) over the course of the day (uploads and downloads separated), averaged over March 15 through March 31st 2023. The second graph shows the ratio of downloads to uploads over the same time span. The graphs display data from the LTE cell sites with active users (FCS, and OCC-Oromo serving the Southend Village) and the two Nickelsville sites with fiber connections (CD and Northlake). See Appendix C.2 for disaggregated per-site graphs.



Data Consumption and Download/Upload Hourly Averages

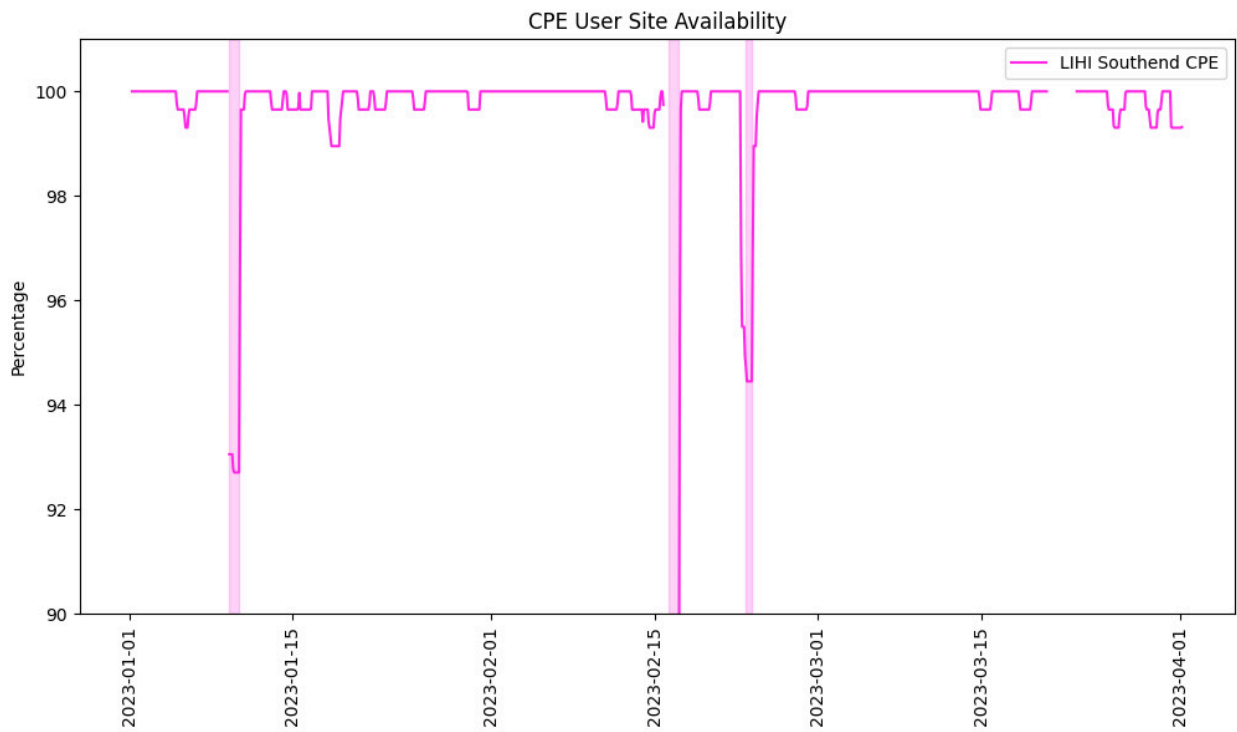
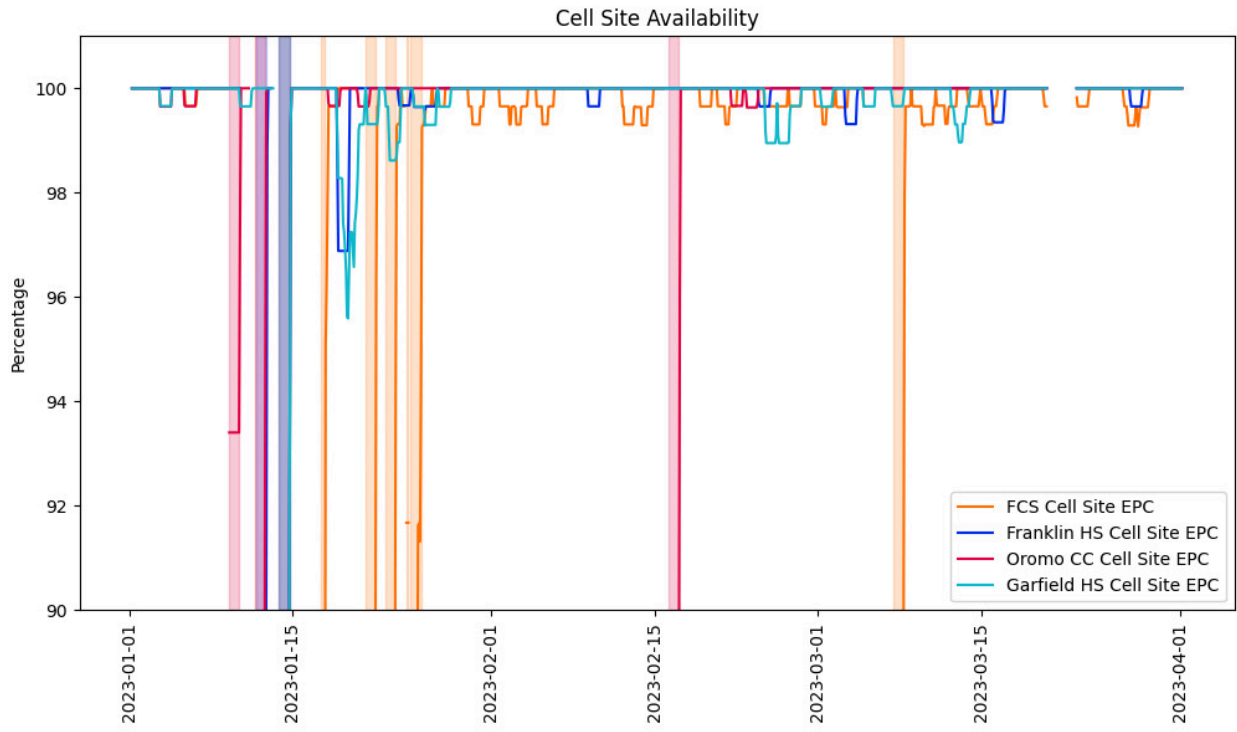
The graph below shows daily data usage (in GB) for the same network sites and date range as above, with uploads and downloads separated. The gap in data from March 20th to 23rd is due to an unusual multi-day outage of our measurement server. The date range is constrained to the last 15 days because the consumption data from the preceding months had been heavily impacted by bandwidth-heavy speed tests we had been running to monitor the network. The below data is representative of the users' network usage without the speed tests running. We provide the full usage data from the past three months (including the speed tests) in the Appendix.

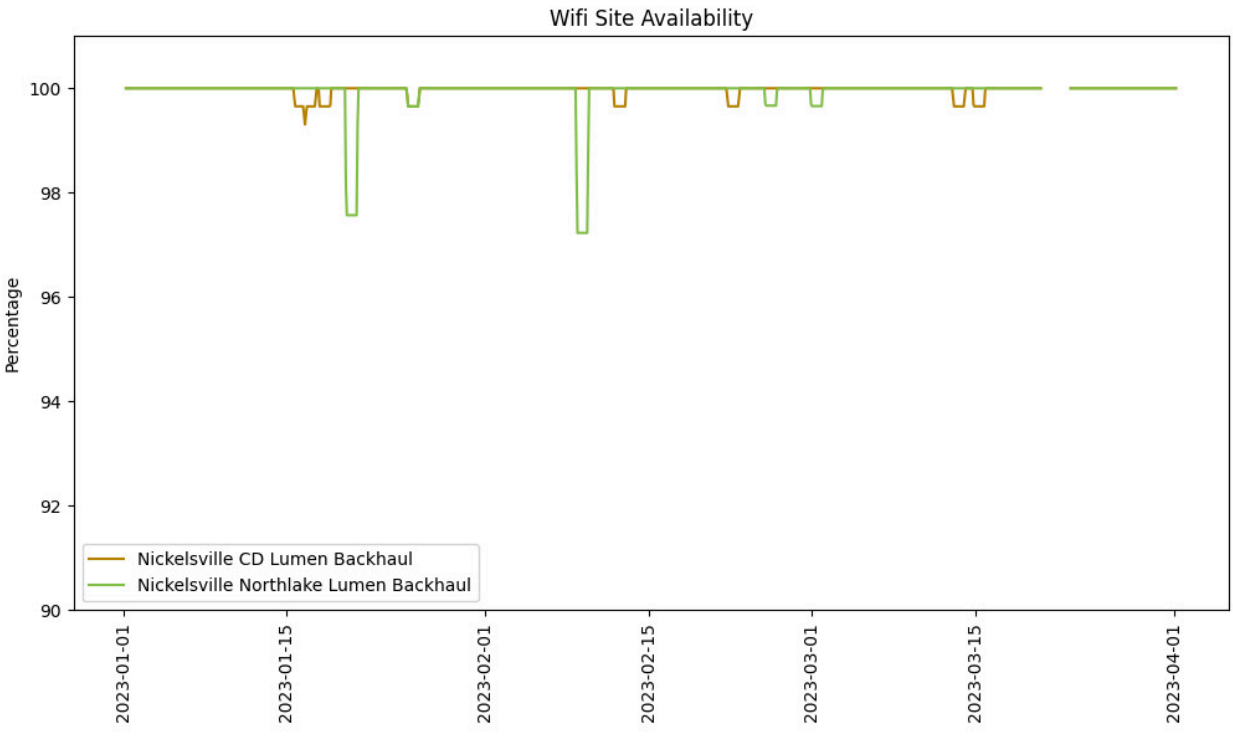


Daily Data Consumption

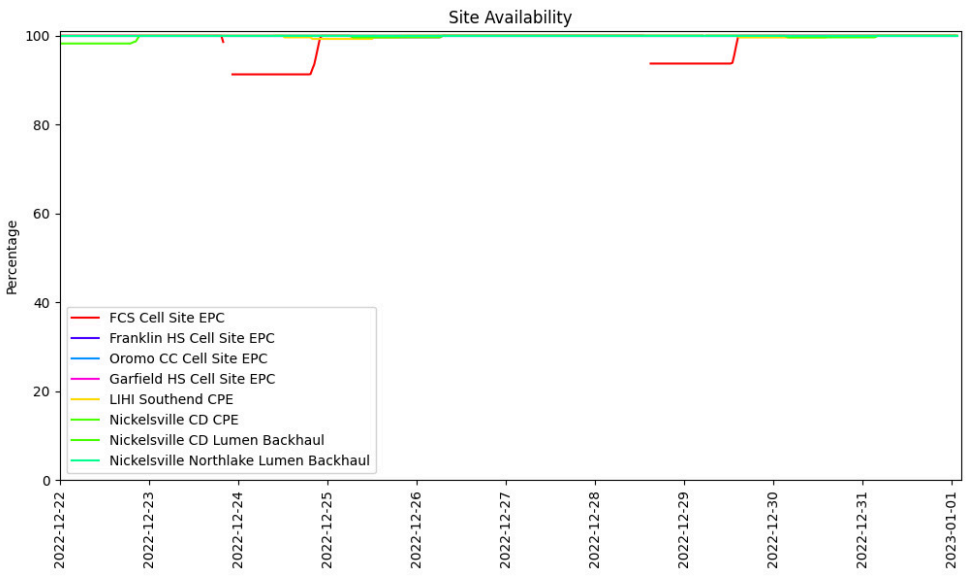
2. Network uptime/availability

The plots below show (1) the availability of SCN LTE cellular sites, (2) user sites connected via CPE (LIHI Southend Village is served by OCC-Oromo), and (3) user sites connected via fiber (“WiFi sites”). Light-colored bands on the graphs indicate days where availability was less than 95%. Availability is measured by device responsiveness to pings from our online Azure Cloud-based LibreNMS server. The gap in data from March 20th through 23rd is due to a measurement server outage.





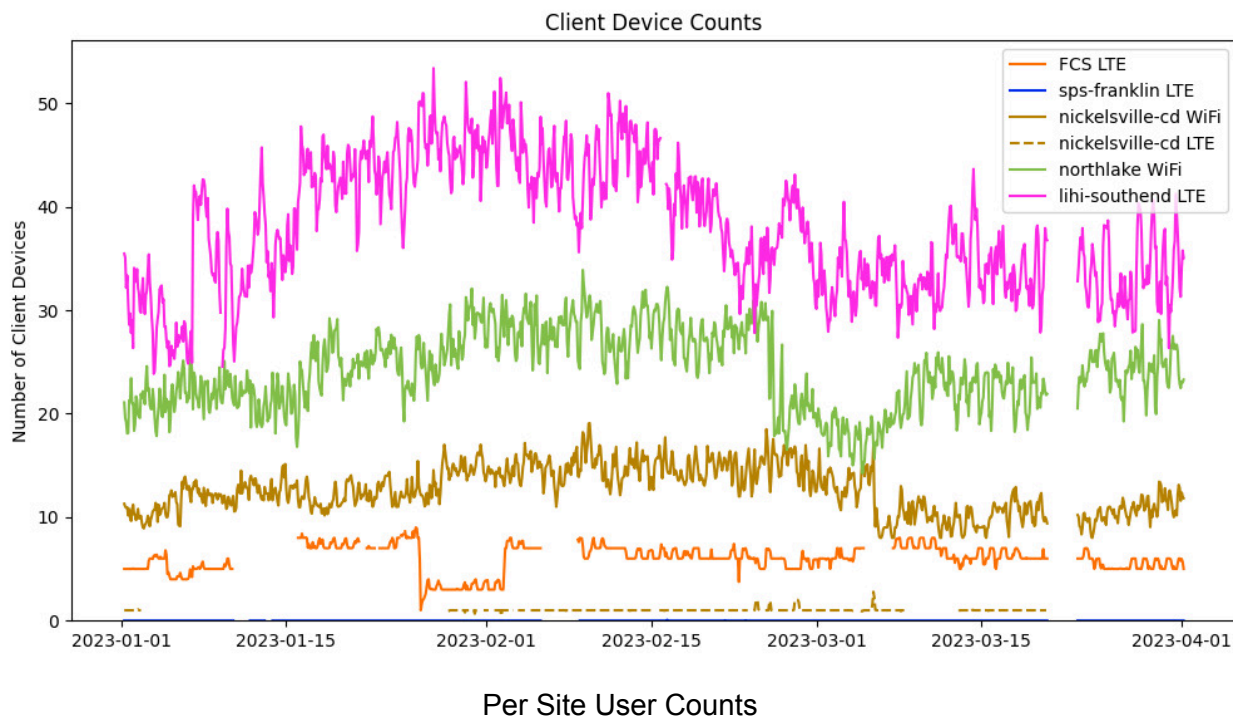
The graph below shows site availability in late December 2022. On 12/23/22, the Filipino Community Center site had been switched from Lumen fiber onto an emergency T-mobile 5G Home Internet mobile broadband hotspot backhaul (at around 100-300 Mbps download/12-20 Mbps upload) with lower reliability, due a Lumen’s DMCA policy restriction described in Section IV-B. This situation was resolved and Lumen service was restored in January 2023.



3. Number of people using the network

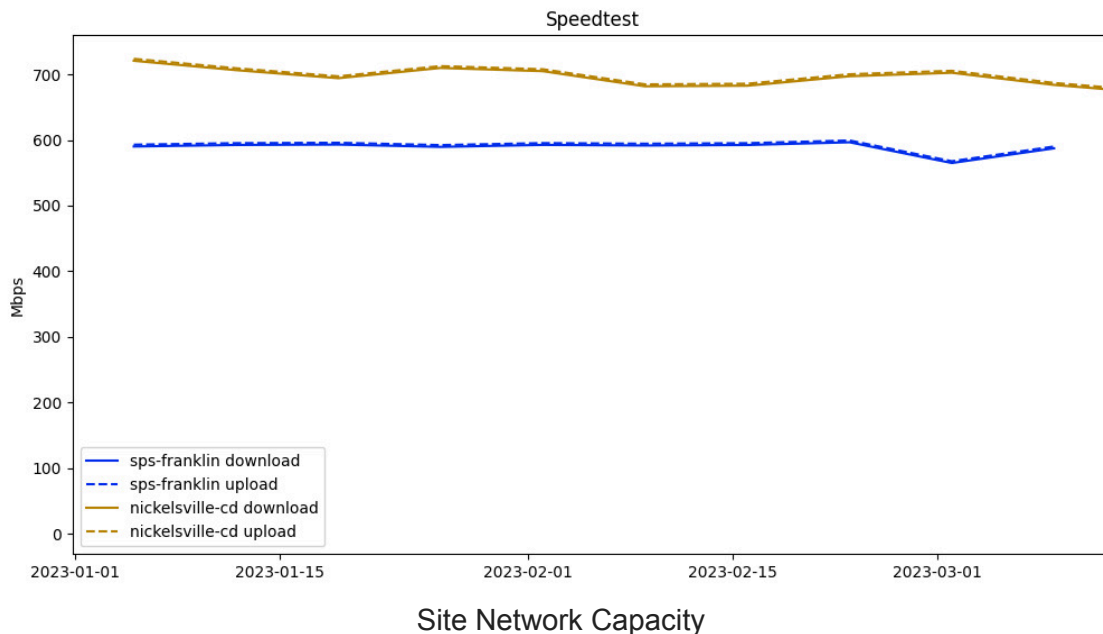
The graph below shows the number of client devices on the network at each SCN site.

- Southend Village has the most residents and a SCN WiFi network that allows all WiFi devices to connect, resulting in a high device count.
- Nickelsville CD Village has both Lumen-backhauled WiFi and LTE-backhauled WiFi networks. On 12/21/22 we switched all but one of the CD Village's local WiFi networks onto the gigabit Lumen backhaul to increase the bandwidth available throughout the Village, shifting the majority of users onto the "nickelsville-cd WiFi" count.
- The "FCS LTE" user count shows only the number of LTE CPE (one per household). For example, the FCV Senior Village Lobby, Katharine's Place Community Room, and individual households are each displayed as a single user, though they each serve multiple people. The number of attached CPE also appears to fluctuate due to the presence of a new eNB base station at the same site that is not tracked in our user count measurements, to which close by CPE occasionally shift based on signal fluctuations.
- Due to the move of Nickelsville CD Village from LTE to a wired connection, the Garfield High School LTE site currently does not have users attached. The Franklin High School LTE site also does not have users, and further outreach and recruitment is ongoing.



4. Network Speeds

The following speed test data were collected starting in late December based on iperf3 tests run every 30 minutes between two of our Seattle network sites (Nickelsville CD on Lumen and the UW-backhauled Franklin High School LTE EPC) and a measurement server on Azure. We include these as representative samples of a Lumen-connected site and a wireless backhauled site (via a PtP Ubiquiti AF24 link), each providing a maximum upstream capacity of 1 Gbps. Due to data collection errors, our LTE user site (such as Southend Village) speed tests are not represented here. Experimentally, users at Southend Village are typically able to get 30-50 Mbps download speeds and around 5-10 Mbps upload speeds.



We later found that these iperf3-based speed tests largely under-represented the amount of bandwidth available to users on popular websites, even as compared to other speed test tools. For example, recent speed tests at the FCS site (on T-mobile 5G Home Internet backhaul) using the Ookla Speedtest tool yielded 100-150 Mbps while our measurements using iperf3 yielded only 13 Mbps. This is partially explained by our Azure cloud server not having as much throughput capacity and availability as Google and other popular websites. In the future, we will revise our speed test tooling to collect data that more accurately reflects the user experience at each site.

A Note on CBRS LTE Signal Strengths:

For our network sites backhauled over LTE, a main driver of network speed is LTE signal strength received at the end-user CPE. Continuous collection of CPE signal strength data has not yet been implemented due to device limitations; however, manually collected test data points are available on our coverage map (linked above). CPE signal strengths are often low on our network because planning for user sites has

been mostly ad hoc; cell site locations were selected opportunistically, with certain service areas (e.g. Southend Village) not in existence at the start of the pandemic.

Signal strengths at Southend and Nickelsville CD, both of our Tiny Home Villages with CPE, are in the -115 to 120 dB range, with correspondingly lower than optimal data rates (30-50 Mbps down). However, even at these low signal strengths the speeds are fairly consistent, perhaps due to low wireless interference on the less-occupied CBRS band. Signal strengths are much better for FCS network users at -80 to -90 dB, since the residences are close to the tower, with some users consistently able to get 70-90 Mbps down.

III. Capacity Building Programs

A. User Device Program

SCN's ongoing user device delivery program was initially necessary to provide CBRS-capable devices to individual home (CPE) or mobile users. We provided users the choice between a mobile smartphone with 4G LTE Internet service and hotspot capability on our network or a WiFi-capable small laptop with a Baicells 4G LTE CPE device and TP-link dual-band home router for home WiFi. In 2020, the LG G8 ThinQ and Google Pixel 4 (Verizon Unlocked versions) were the two commonly available refurbished CBRS-capable phone models we were able to procure in bulk, at \$180-320 each. While the phones were comparable in price and features, we found that the Pixel 4 is more compatible with other networks and allows more flexibility in switching service providers if needed.

1. Recruitment

In conjunction with establishing WiFi networks at Tiny Home Villages, low-income housing, and other semi-public community partner locations where users could also bring their own WiFi devices, SCN held pre-announced presentations and semi-regular tabling events where we signed eligible people up for devices who needed them. Eligibility criteria was based on our King County and City of Seattle grants (for Seniors, Homeless, Unemployed, and majority Non-English-Speaking folks, and later SPS students). We also worked with the KCLS Skyway Library, FCS, and Skyway local businesses on flier design and distribution.



Seattle Community Network

Community-based Internet access for everyone
Supported by King County and the City of Seattle

Local community-run 4G LTE Internet

Like Xfinity but owned by a **volunteer-based community nonprofit**.

Do I qualify?

Ongoing Internet service is free for:

Low-income families of students, adults ages 65+, houseless folks, unemployed adults and non-English-speaking adults. There is a **suggested monthly donation** for others.

Self-certification only.

If you qualify, you can receive **free home WiFi or a mobile phone** with Internet only.

How it works:

Internet access is **based from community centers** (including the KCLS Skyway Library).

Coverage for around **1-1.5 miles** from these locations.

You can **either receive a phone, or home WiFi** if our 4G network reception is available at your home.

Our SIM card goes inside the device.

Visit seattlecommunitynetwork.org/ourSites.html for details and tinyurl.com/SCNcoverage to see coverage areas.

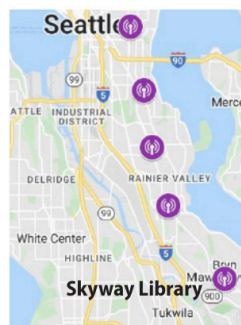
How to sign up:

Option 1: Email us at lcl@seattlecommunitynetwork.org with your name and contact info.

Option 2: Call or text (253) 655-7221 with your name and contact info.

Option 3: Fill out the **interest form** online: <https://tinyurl.com/SCNuser>

Option 4: Come **in person** to the *Filipino Community Center, Fridays 3-5 pm.*



Contact lcl@seattlecommunitynetwork.org to sign up.

To learn more, visit our website seattlecommunitynetwork.org or follow the **Local Connectivity Lab** on social media @SeattleCommNet on Facebook, Twitter, LinkedIn, and Instagram!



Seattle Community Network Recruitment Flyer

In Fall 2022, we were additionally able to reach a few SPS students through a Garfield HS librarian who typically fields student hotspot requests, who we met for in-person training using our coverage map (<https://coverage.seattlecommunitynetwork.org/>) to determine service availability. We are planning to make a more concerted effort to recruit high-school youth from Franklin and Garfield High Schools over the coming year.

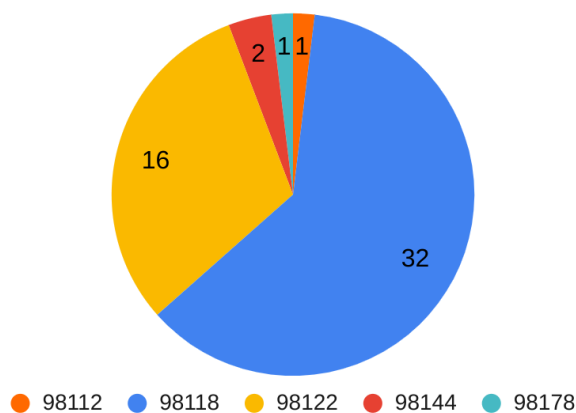
Via our combined user broadband device budgets from the King County and City of Seattle grants, we were able to procure 38 laptops and 42

smartphones, of which 52 devices (36 laptops and 17 smartphones) have been delivered, signed, and attested for (with an additional 2 laptops recently delivered but without paperwork collected yet). We immediately noticed that the majority of demand was for laptops (and specifically not Chromebooks) despite their WiFi-only capability and having technically less monetary value than the phones, especially among Seniors. More findings are detailed in the Qualitative Findings section below.

2. Recipient Demographics

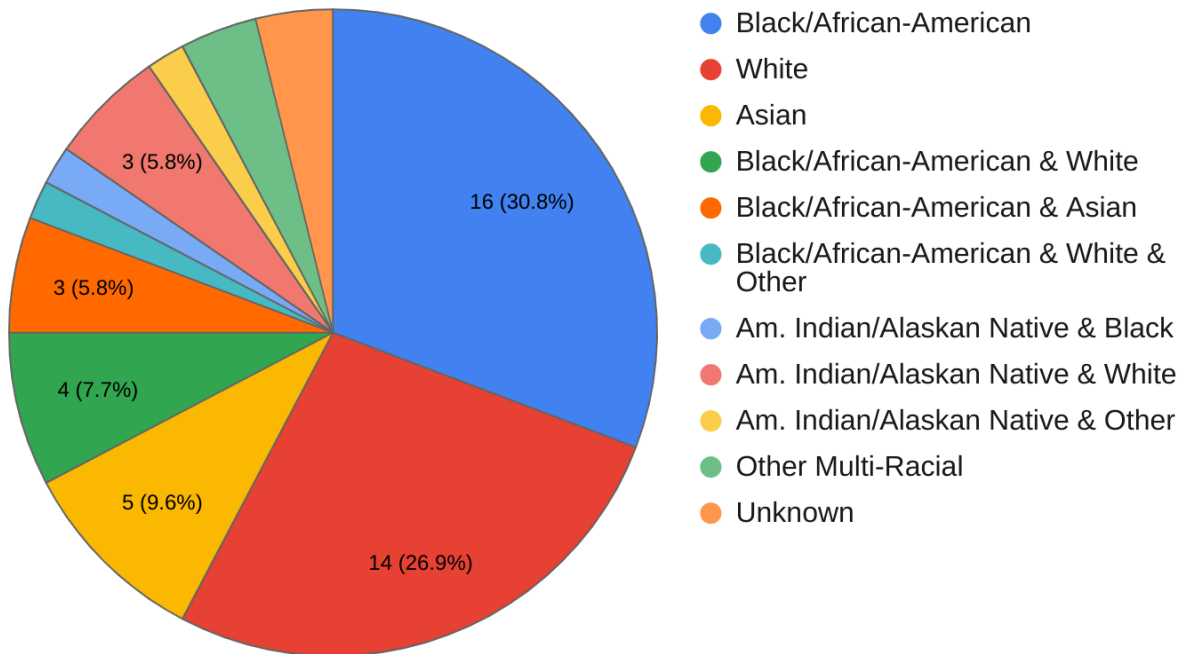
Total Device Recipients	Senior	Homeless	Unemployed	Primarily Non English Speaking	SPS student
52	14	31	30	3	2
100%	27%	60%	58%	6%	4%
Phone Recipients Only					
17	1	11	9	0	2
33%	6%	69%	56%	0%	13%
Laptop Recipients Only					
36	12	20	21	2	0
69%	34%	57%	60%	6%	0%

Device Recipients by Zip Code



Target Group	Laptop	Phone
	12	1
Senior	92%	8%
	20	11
Homeless	65%	35%
	21	9
Unemployed	70%	30%
	11	7
Homeless & Unemployed	61%	39%
	36	17
Overall	69%	33%

Device Recipients by Race



B. Training Programs

1. Volunteers

For the past two years, SCN has maintained around 10 very active volunteers at any given time, with an additional ~10 less active volunteers and a growing community presence. This group currently includes around 5 longer-term UW Computer Science PhD, Masters, and Undergraduate students in the ICTD research lab (<https://ictd.cs.washington.edu/>), mentoring a fluctuating number of more temporary students. Occasional opportunities arise such as a “Community Networks” Software Engineering Capstone Class ([link](#)) in Winter 2022 which involved an additional 15 CS students in SCN projects. One of SCN’s core missions includes facilitating connections between university people and resources with the broader Seattle community. An especial goal has been to bring UW engineering student mentors and instructors into our Youth Digital Stewards (YDS) STEM education program for local youth (detailed below). This coming January we will also be onboarding our first Seattle Central College (SCC) intern through their Service Learning program for course credit.

Many general SCN community volunteers are former tech workers in between jobs when they join, motivated by the digital equity mission and looking for technical learning experiences to expand and develop their skills. Of 6 currently active technical volunteers who were unemployed when they first joined, 2 are now employed and cited SCN work on their resume. Some cite

changing interests within engineering, or wanting to continue skill development while not being ready for the demands of paid work for personal reasons (as in the case of one of the Tiny Home Village resident volunteers).

Volunteer Adults		~24
General community members (Currently Active)		~10
	All to date	~35
	Tiny Home Village Residents	1
University of Washington (Currently Active)		12
	Students	6
	All to date	~35
	CS Capstone Software Engineering Class	15
	Other Researchers & Staff	6
Seattle Central College (Currently Active)		2
	Researchers	1
	Interns	1

2. Adult Training and Employment



Adult Digital Stewards 2021

- Adult Digital Stewards

This program started as a primarily virtual, stipended training course in Spring 2021 with an initial cohort of 8 students recruited through our partner organization the Black Brilliance Research Project (BBR). Two students have since been hired into more permanent SCN and digital equity-related roles (one as a FCS Digital Navigator and one as a BBR Digital Steward Coordinator). There are additionally three current Adult Digital Stewards trainees through BBR's community partner The Silent Task Force (TSTF) who are undergoing on-the-job training.

- EEC-WA Connect WA Broadband Technicians

Our partner organization the Equity in Education Coalition Washington (EEC-WA) supports a wireless broadband networking and IT job training program for formerly incarcerated folks run by Kris Larsen at FCS called the "Connect WA Broadband Technicians" class. The class intends to train a team to support rural and Native Tribal WA areas with broadband access. Starting in August 2022, the first cohort of five adults recruited through our mutual partner organization Fresh Start participated in the class, and had their first three on the job training experiences with SCN. These included community teaching events such as our

monthly SCN “Hack Night” where they set up their first PtP wireless link and in more recent months have taught youth how to crimp ethernet cable, participated in the Tacoma Public Library Main Branch cell network install, and performed a local wireless site survey at Park Place Assisted Living. After more training this year, they have installed wireless access networks for low-income housing complexes in George and Quincy, Washington. The success of the hands-on learning experiences provided by SCN highlights its role as a “teaching network” for broadband work within the broader community. A new EEC-WA cohort will start in early 2023 with our continued collaboration.



EEC-WA Connect Broadband Technicians 2022



EEC-WA Connect Broadband Technician Performing Site Survey

Employed Adults		16
Adult Digital Stewards		
	Trained 2021	8
	Trained 2022	3
	Currently Employed	4
	Silent Task Force	3
	Tiny Home Village Residents	1
	Black Brilliance Research Project	1
Other Active Participants		
	Connect WA Broadband Technicians	5
	Filipino Community Center	2
	Community Researchers (UW and SCC projects)	5

3. Youth Engagement

- Youth Digital Stewards Program 2021 & 2022

The Youth Digital Stewards (YDS) STEM education program started in the Winter of 2021-2022 as a virtual-only, stipended 13-week after-school program with eight students. There were three hours of class per week in total, plus three weekend 3-hour field trips to SCN sites and other network-relevant locations over the course of the program. The goal was to train local South Seattle students in computing and networking skills to stimulate their interest in both technology and helping their communities, aiming towards both future impacts and potential immediate involvement in SCN activities. After the cohort one student remained involved with SCN and became employed by BBR for occasional roles in teaching support.

Youth Digital Stewards	
Trained 2021	8
Trained 2022	20
Current Volunteers	6

In Fall 2022, through our partners BBR and the Breakfast Group (BG), we ran our second YDS cohort fully in-person as an 8-week after-school program with 20 enrolled students plus a few more unofficial attendees. We had three hours per week of classroom time plus six 3-hour weekend field trips, including visits to SCN network locations, public SCN events such as our monthly “Hack Nights” where we work together on projects, and other educational experiences such as trips to networking research labs, companies, local makerspaces, and museums. While we had intended to run the program at Garfield and Franklin High Schools, due to chaos around scheduling during the teachers’ strike in early Fall, the best location BG was able to arrange was the Rainier Valley Leadership Academy (RVLA) near the Othello neighborhood, a short walk away from our FCS site. Most of the students ended up being based at RVLA, with one additional student from Renton High School and another from Garfield HS. For this cohort we had 14 volunteer instructors leading classes and field trips, including four current UW students, three BBR collaborators, and six additional SCN community volunteers. Around six YDS students responded in the end of class survey that they wanted to continue working with SCN and began attending SCN volunteer events, such as tabling for device delivery at the LIHI Southend Village at the end of this year.



Youth Digital Stewards 2021 Cohort



SCN Hack Night with 2022 YDS Cohort

- Supporting SPS Students' Connectivity

For future YDS cohorts, we are looking for more internal support to establish a presence at Garfield and Franklin High Schools, where we have the best potential for hands-on learning experiences with our installed network infrastructure. We expect the impact of these learning experiences to be greater overall in the SPS student community than our network service, for which we have gotten limited requests so far. Our Garfield HS librarian contact inquired about six students, of whom three were in the coverage area. Two students received smartphones with our service, and the remaining one had been in LIHI temporary housing but moved within a few weeks to a place outside our coverage where they no longer needed access. While SCN provides unique and valuable learning opportunities along with our connectivity strategy, we recommend that students with connectivity gaps need an ongoing hotspot program that can provide them access immediately wherever and whenever they need. The T-Mobile "Project 10 million" hotspot program and others during the pandemic was able to largely support this need, but now that those programs have ended, these students are again without the support they need.

IV. Qualitative Findings: Impacts and Opportunities

A. Working with Tiny Home Villages

1. Broadband Needs

- One of our main findings is that outdoor WiFi network propagation is a huge problem in Tiny Home Villages, regardless of whether or not a fast upstream Internet connection is available. Any significant distance from the user to the nearest WiFi access point (AP), especially if the AP is an indoor router sending signals through multiple walls, slows down the speed a great deal. For example, we recently discovered that a set of three Google Nest indoor mesh WiFi nodes was being used to distribute WiFi throughout the LIHI Progressive Skyway Village. The 700+ Mbps Comcast for Business connection becomes less than 1 Mbps on the opposite side of the village, crawling to unusable speeds. Our next scheduled install will be at this village, upgrading the WiFi network for more equitable distribution.
- Older 2.4 GHz WiFi standards are still extremely important for providing service among homeless populations, who are often using much older broadband devices which may not support newer WiFi bands and standards.
- Connectivity in the Villages is especially crucial for supporting upward mobility, as many people are attending school or trying to get jobs. Watching YouTube and having Zoom calls are useful and necessary activities for learning, and require usable network speeds (3+ Mbps accessible to each resident at any time). We recommend that a baseline level of reliable, immediate public connectivity at the best speeds currently available should be provided in Villages as a stopgap in all cases, and upgraded regularly when possible.
- Where local commercial ISPs such as CenturyLink, Wave, and Comcast Xfinity are available, a single high-speed wired connection may be bought by the village and distributed via a Village-wide WiFi network to provide this baseline of access. This can be the most reliable option for Village-wide access, and should be implemented where available.

2. Device needs

- For device delivery programs, we found that laptops were generally preferred as broadband devices over smartphones (about 2:1). However, there was evidence that phones are the more basic need. Most people we encountered had working phones already (even if older or hand-me-down models, for example with only 2.4GHz WiFi support), and those who

expressed not having one at all typically chose a phone over a laptop. Furthermore, occasionally we encountered people in the villages who additionally needed help getting connected to free or low-cost phone plans as they had no idea these existed.

- Chromebooks were less desirable due to the inconsistency of Internet connectivity in homeless people's lives.
- Our device delivery program was initially implemented in an ad-hoc manner via tabling-based sign-up that did not reach every resident, and did not guarantee availability of specific device types all the time. In one instance at LIHI Southend Village, we found that there was some existing conflict around prior broadband device theft and sales that was then aggravated by interactions around our program. We realized that working more formally with Village management to sign up residents would have reduced uncertainty around device availability and resulting potential for conflict. In general, we recommend that management organizations such as LIHI simply provide standardized broadband devices or facilities with the residences to reduce unnecessary conflict over resources for a critical utility.

3. Volunteer Engagement

- We found that providing both volunteer and paid opportunities for residents at Tiny Home Villages was important for engagement in different cases. One resident explicitly expressed not wanting the demands of paid work but preferred a volunteer role as a chance to refresh his technical skills; in that role, he has provided excellent contributions and maintenance of the network. In a different Village, another resident with a technical background has also provided excellent contributions in the initial network planning steps for their network, but explicitly stated that due to current financial constraints he would be unable to continue working without a paid role (which we made sure to establish before any more work was done).

B. Major Challenges

Our LTE-based pilot as initially imagined encountered a number of major challenges, and would need major adaptations in order to work at scale.

1. ISP DMCA Policies

Open networks can be challenging to operate and maintain. Over the past few months Lumen has restricted our service several times at the FCS network due to Digital Millennium Copyright Act (DMCA) complaints received as the result of a user seeding torrents on the FCS network (always the same pirated game file). Due to some technical problem on

Lumen's side the complaint emails have never reached SCN. Last week we received a "final notice" from Lumen, so just in the past few days we have had to switch the FCS cell site onto a slower emergency 100-300 Mbps T-mobile 5G Home Internet connection until the problem is resolved. The violations have continued happening despite repeated warnings to the FCS user community, but the seasonality of violations (winter and summer holidays) suggests the culprit could be a student coming to visit grandparents at the Senior Village and unknowingly running a torrent program in the background on a laptop on their grandparents' WiFi. It is unlikely that grandparents would be able to detect this and warn their relatives. The temporary solution we have implemented for now to address Lumen's complaints is a custom firewall on a fully managed and configurable SCN router replacing Lumen's, as well as a VPN for our cell network's traffic.

2. Maintaining Infrastructure at Community Centers

- Site acquisition for our network has been extremely challenging, and would be difficult to scale without concerted effort and collaboration from public institutions such as schools and libraries. Establishing effective network sites has required slowly building trust and partnerships with individual community organizations fulfilling a number of requirements:
 - (1) Located in target neighborhoods, with a potential user base living nearby (within wireless coverage range)
 - (2) Access to high points ("vertical assets") on buildings they own. Ownership can be particularly important for permission to mount outdoor equipment and make other building modifications. For example, although the local nonprofits ALTSpace, SE Seattle Tool Library, and many tightly managed low-income housing complexes wanted to support the network, they were prevented by the building owner or other management rules from placing equipment on their buildings.
 - (3) Access to high-bandwidth Internet connections to share with the community
- Access control has been a challenge, as community centers such as FCS are often closed and locked on weekends, and require security protocols in neighborhoods with significant crime. For emergency or short-notice volunteer access in future, we have realized that keeping network equipment in secure cabinets on the outside of locked buildings could be an advantage.
- Despite the challenges, it has been a worthwhile opportunity to use these institutions' assets to benefit their local neighborhoods. Community networking activities can provide excuses for

high-touch technical, collaborative work that facilitates relationship building and teaching, for example Hack Night and YDS.

3. Overall costs

Making LTE networks accessible and convenient for users has been relatively difficult and expensive given the current CBRS device ecosystem, where only specific newer models of smartphones support Band 48, and the price point for CPEs (\$150-\$1000) is much higher than for comparable commodity radio hardware due to economies of scale. As CBRS-capable phones become more common, we are considering options for using eSIMs which would allow people to join our network with their device in addition to using their carrier SIM. Conversations with the team deploying the New York Public Library (NYPL)'s CBRS pilot project have revealed similar learnings about the device ecosystem.

C. Conclusions

Our ongoing Seattle Community Network wireless project has been able to meet some broadband needs in areas where commercial connectivity options are currently unavailable, such as the LIHI Southend Tiny Home Village. Where wired (especially fiber) commercial connectivity options are available, they can be a more reliable and affordable option, especially for delivering much-needed shared internet connections to Tiny Home Villages. However, harshly enforced ISP DMCA policies endanger the sustainability of shared community internet connections where residents' low digital literacy could result in external abuse or unintentional misuse of the network; community or organizational tech support to help resolve these cases with ISPs is likely to be needed. There is still an unmet need for ongoing mobile hotspot programs for low-income families of students and community members living in areas without affordable and fast commercial internet options or the extremely topography-limited wireless coverage offered by our network.

Installing physical infrastructure based at community centers, libraries, and other partners (such as LIHI, Nickelsville, and the Filipino Community Center) has sometimes been challenging due to building and permission-related constraints. The more autonomy and physical ownership of the space an organization has, the easier they have been to work with. However, working with them on outreach has been instrumental in allowing us to reach vulnerable people in need of connectivity.

SCN continues to provide successful hands-on educational and outreach programs using the installed infrastructure, as well as a device distribution program where we have found largely a need for laptops and some need for phones among houseless and Senior residents. We recommend that Tiny Home Villages and other community locations for vulnerable and marginalized groups

should maintain or give residents public computing devices for internet access available for their personal use, to avoid issues of resource scarcity and conflict over technology.

1. Addendum: Continued Network Data Collection

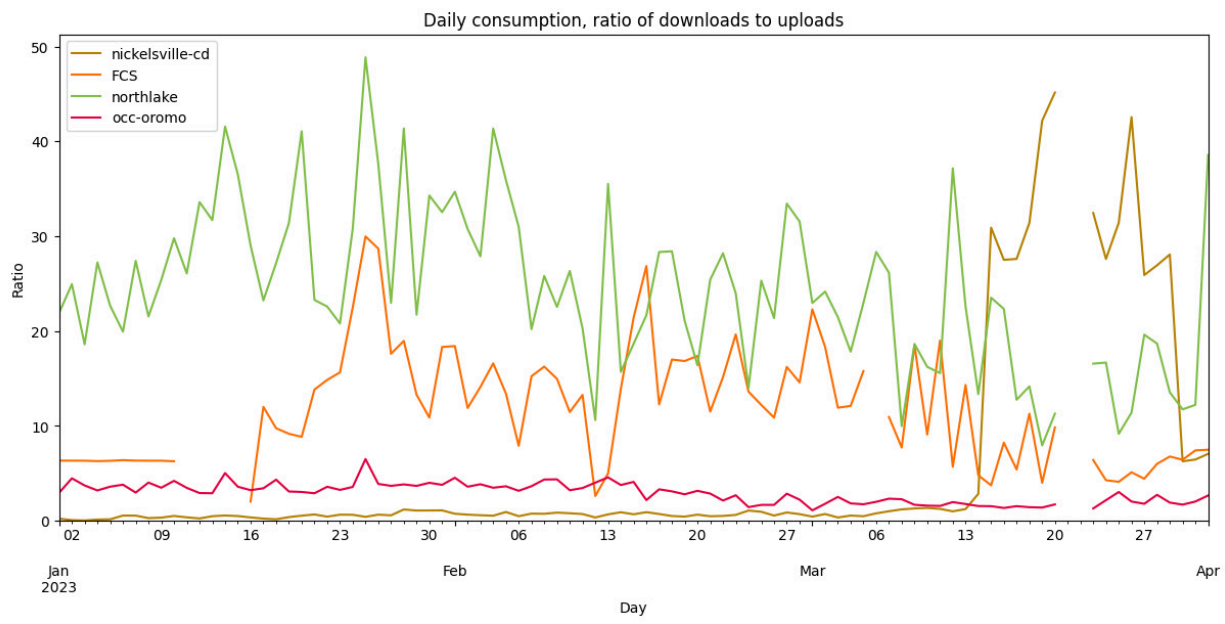
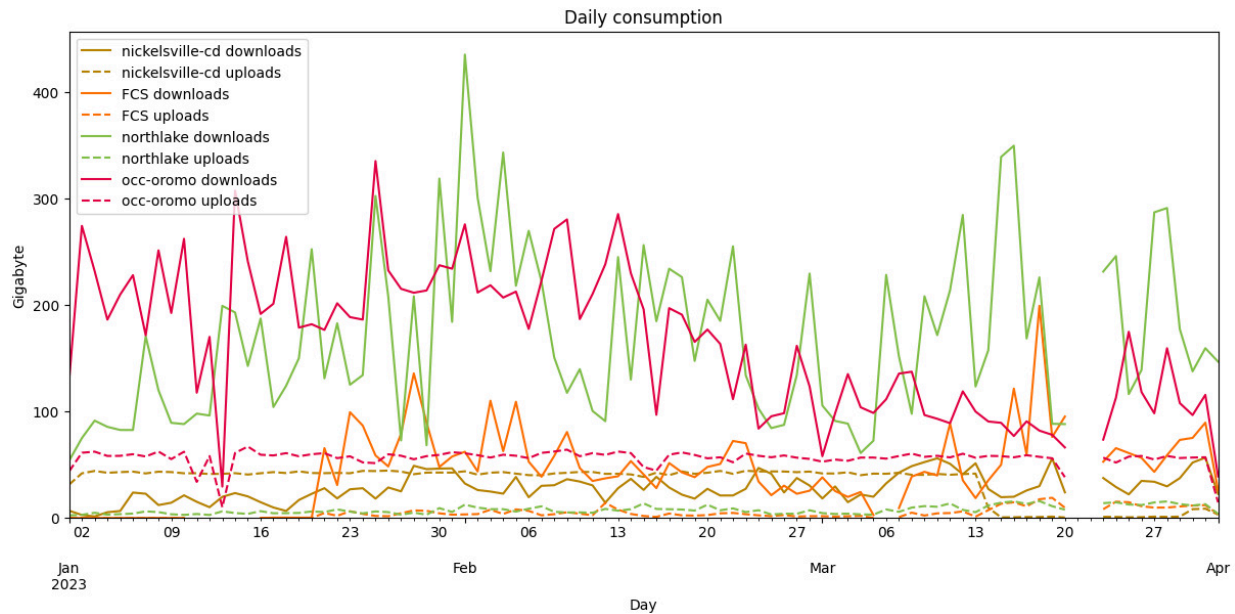
Due to only December 2022 network utilization data being available for the year end report, data collection has continued through March 2023, showing graph data through Q1-2023.

Appendix C.1: Network Map

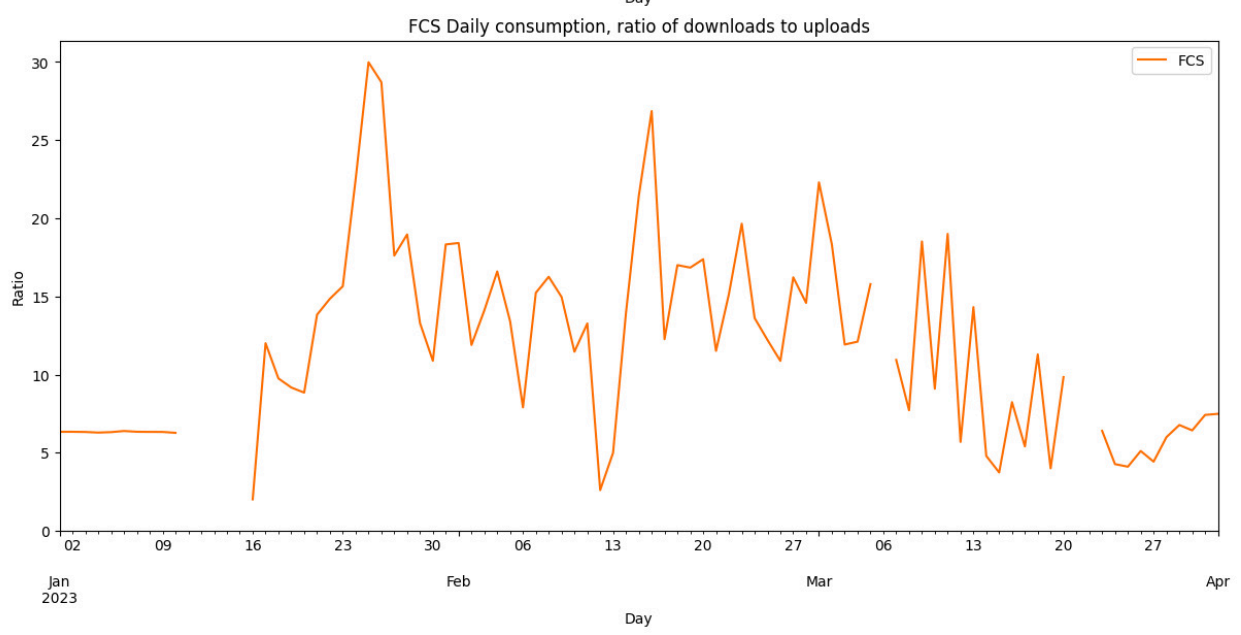
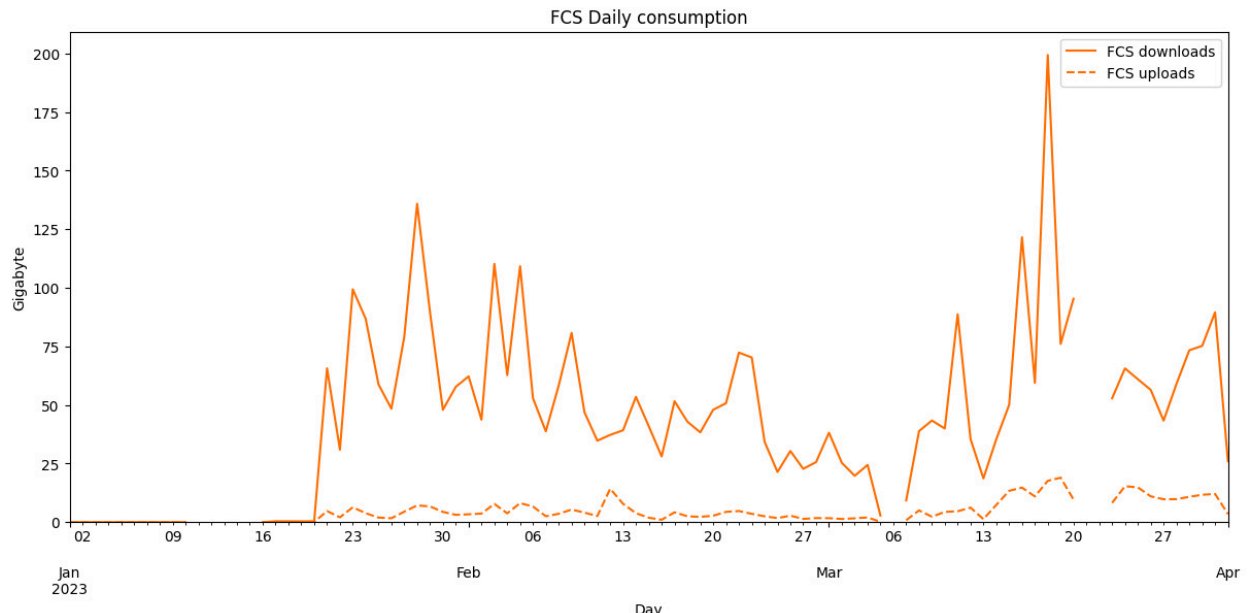
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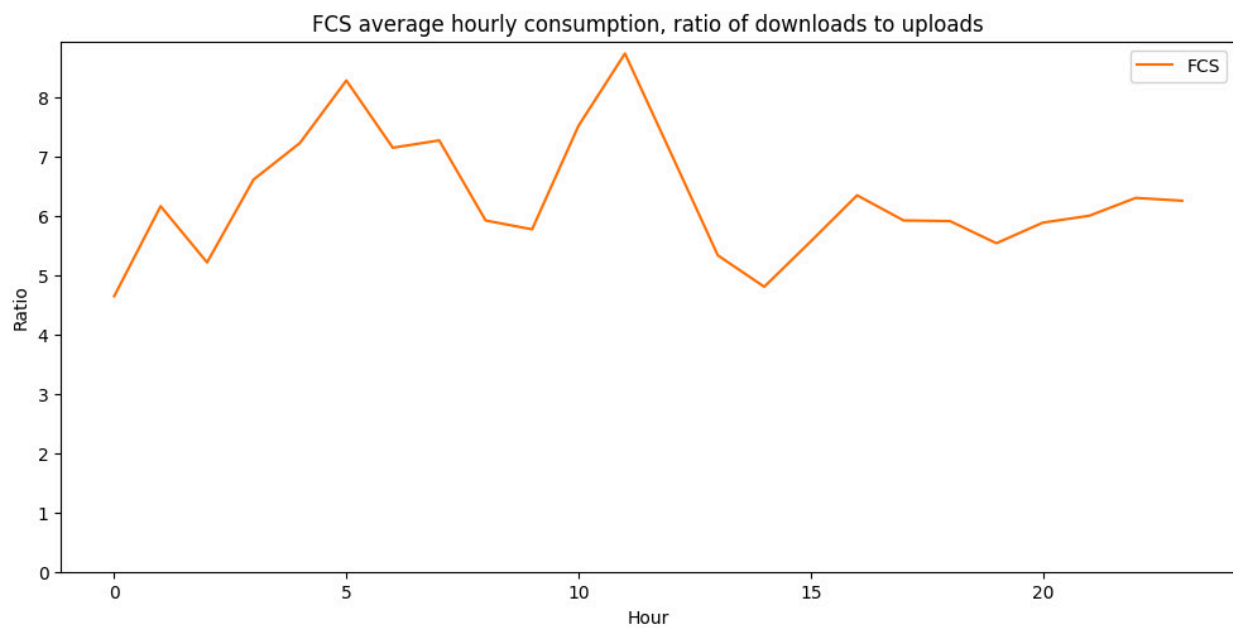
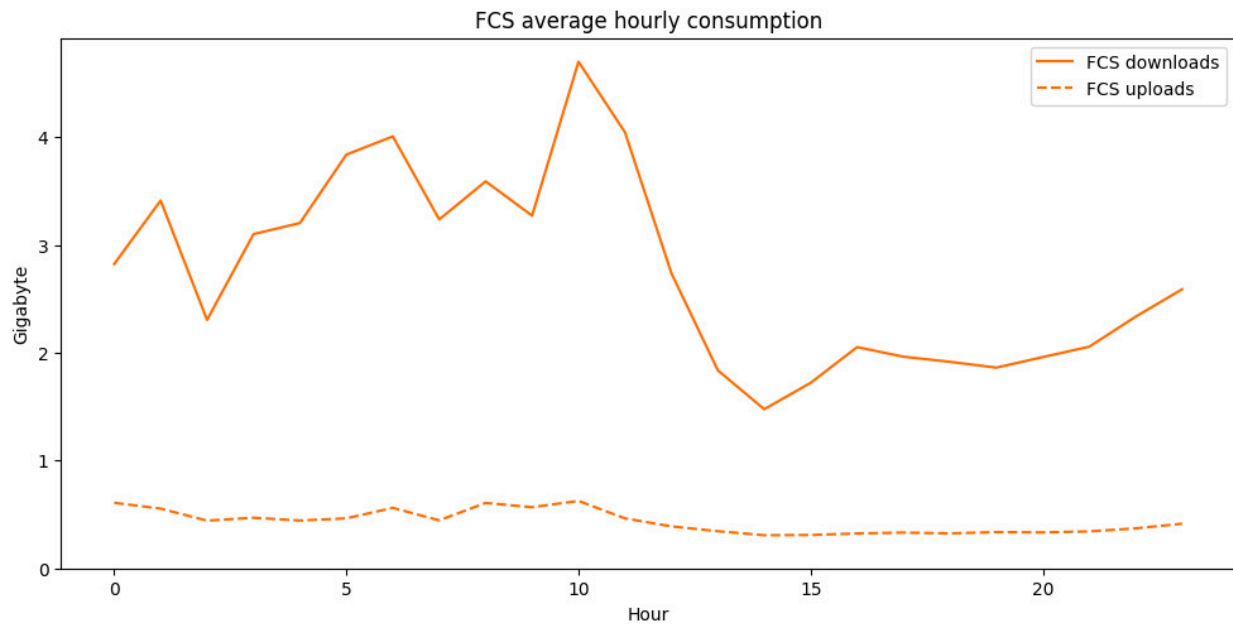
Appendix C.2: Additional Graphs

1. Combined plot of daily data use and ratio of downloaded to uploaded data from January to March 2023 per site. Note that upload metrics at Nickelsville CD were noticeably affected by speed testing until March 14th, and at OCC-Oromo (representing LIHI Southend Village) until present, and do not reflect actual user upload activity. Downloaded data amounts are not believed to be affected. See further below for individual site plots.

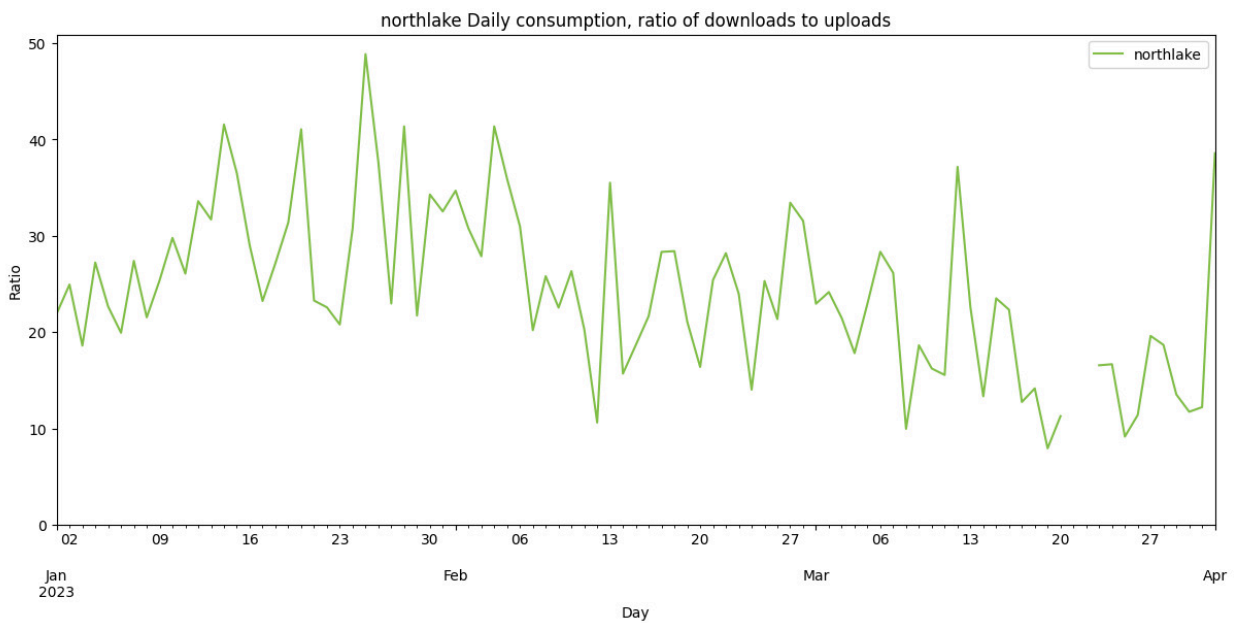
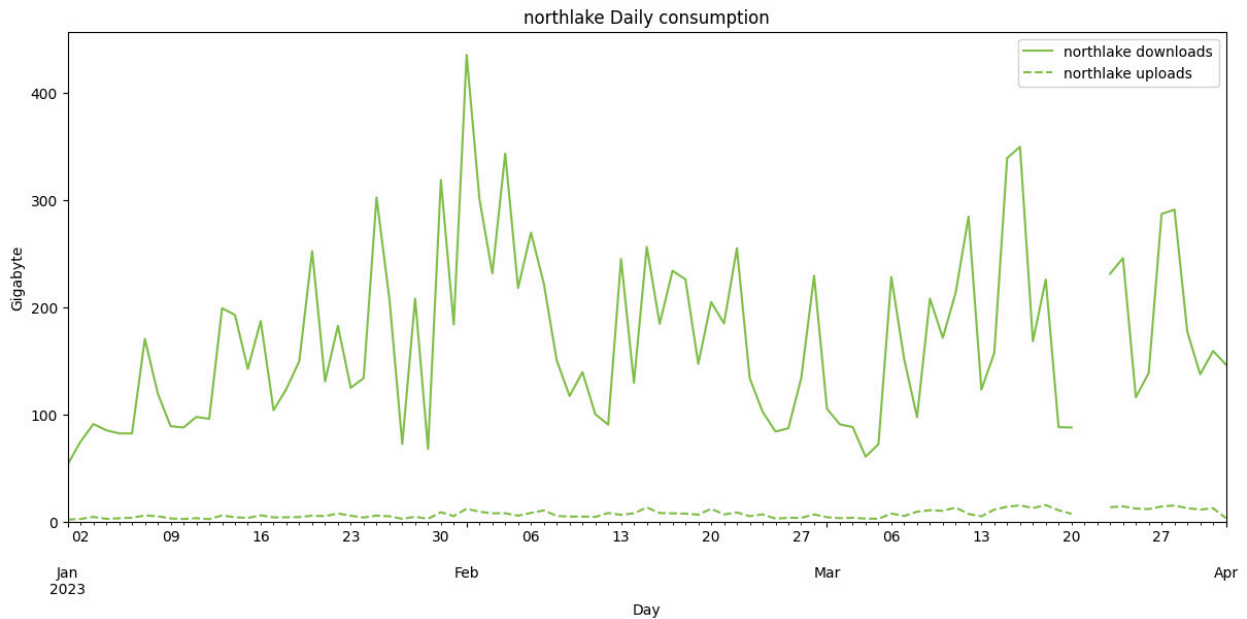


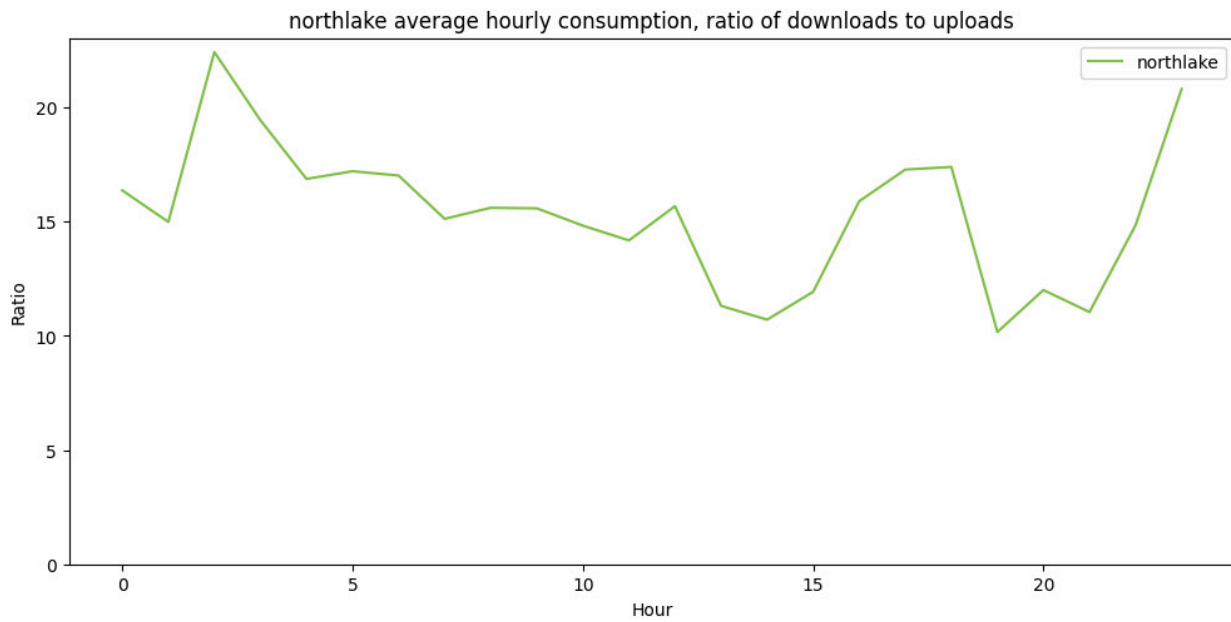
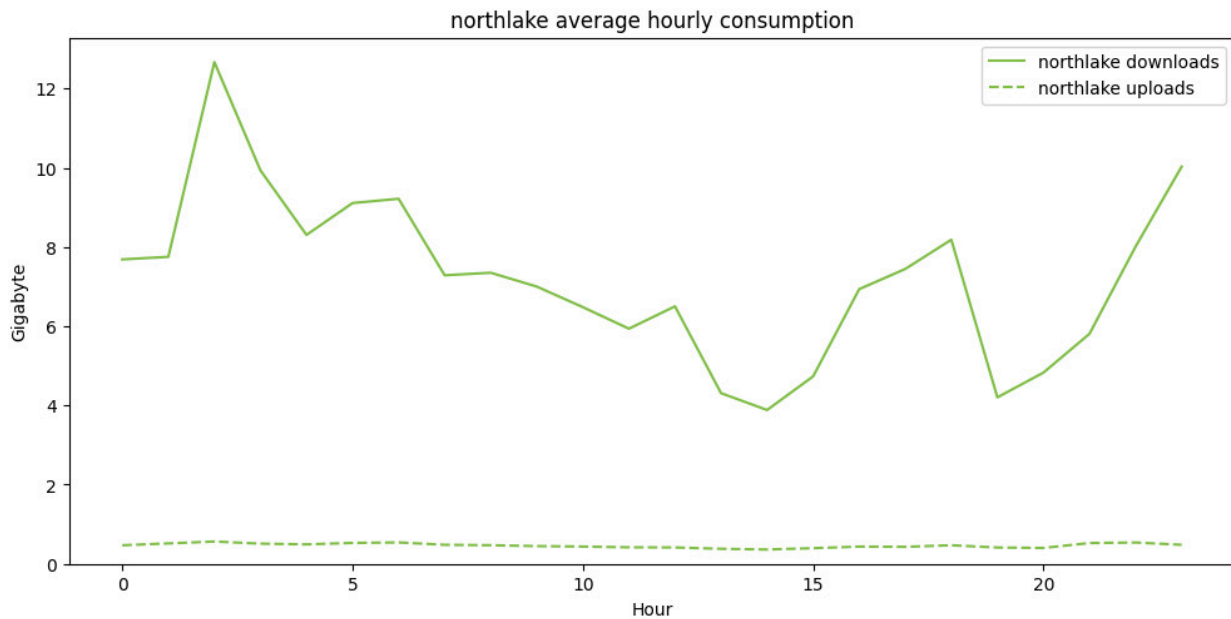
2. Filipino Community Center (LTE site) - Daily usage and download to upload ratio.
Note that valid data starts in late January, when the LTE EPC (core network) hardware was replaced due to a hardware failure.



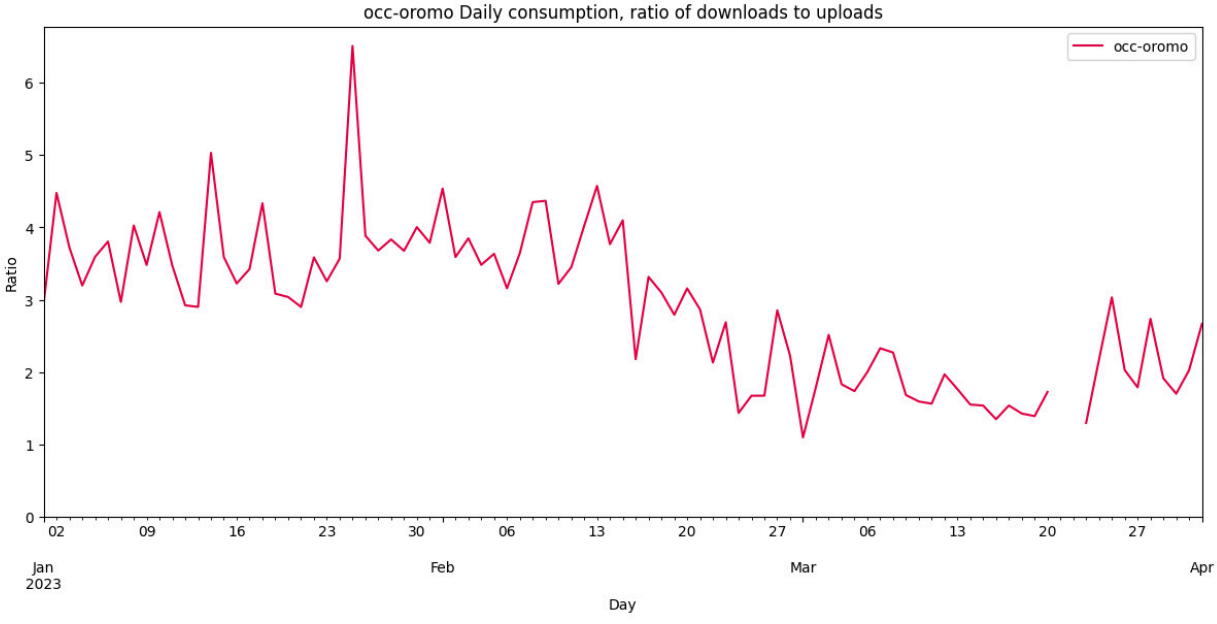
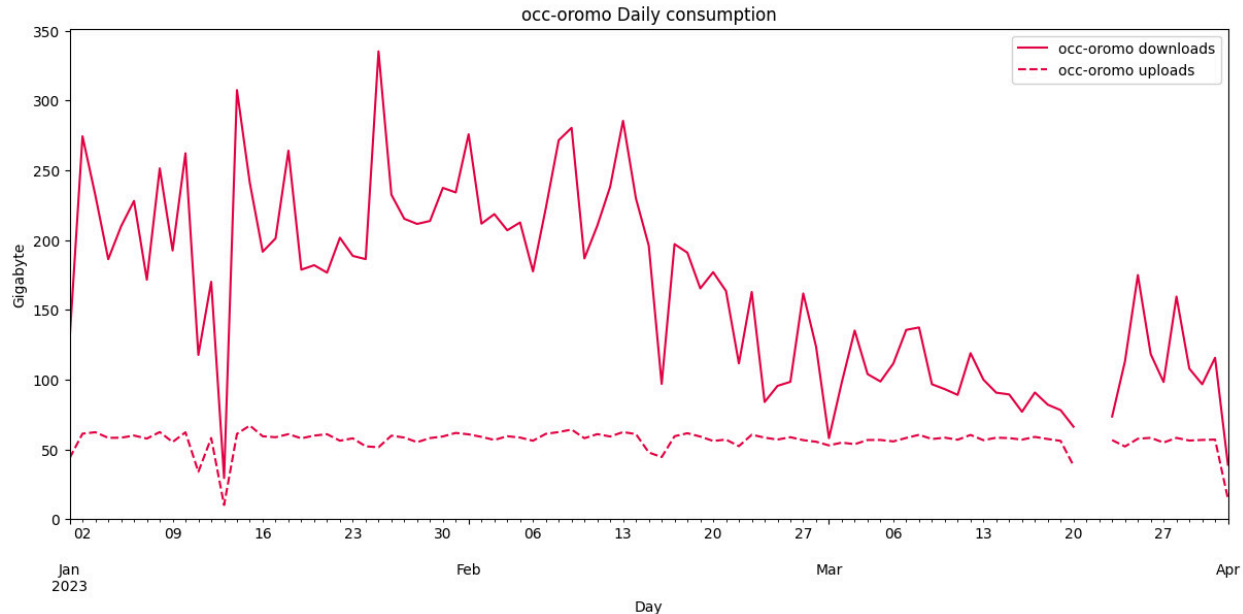


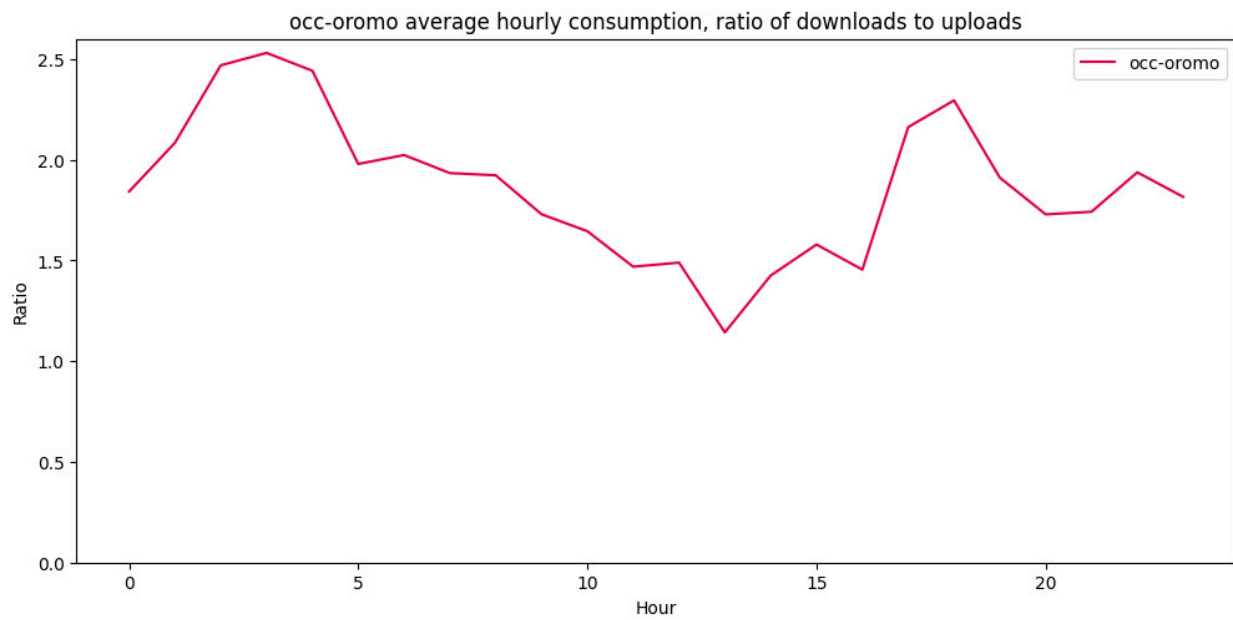
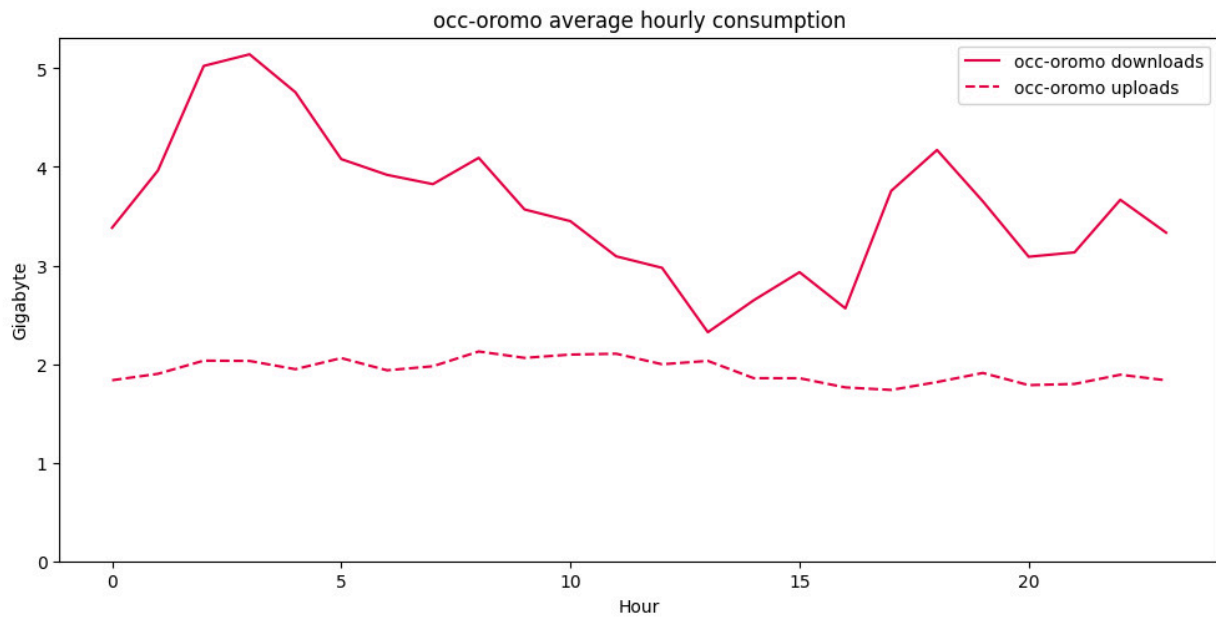
- Nickelsville Northlake daily usage and download to upload ratio from January to end of March 2023. Nickelsville Northlake uses Lumen fiber backhaul and WiFi access points.



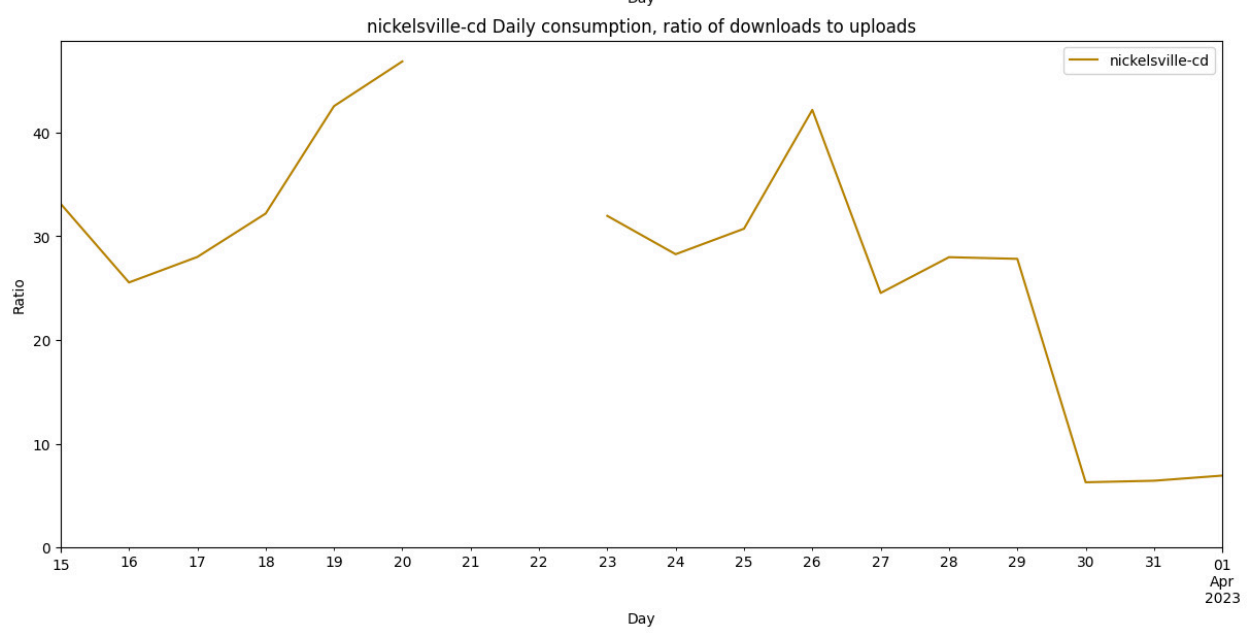
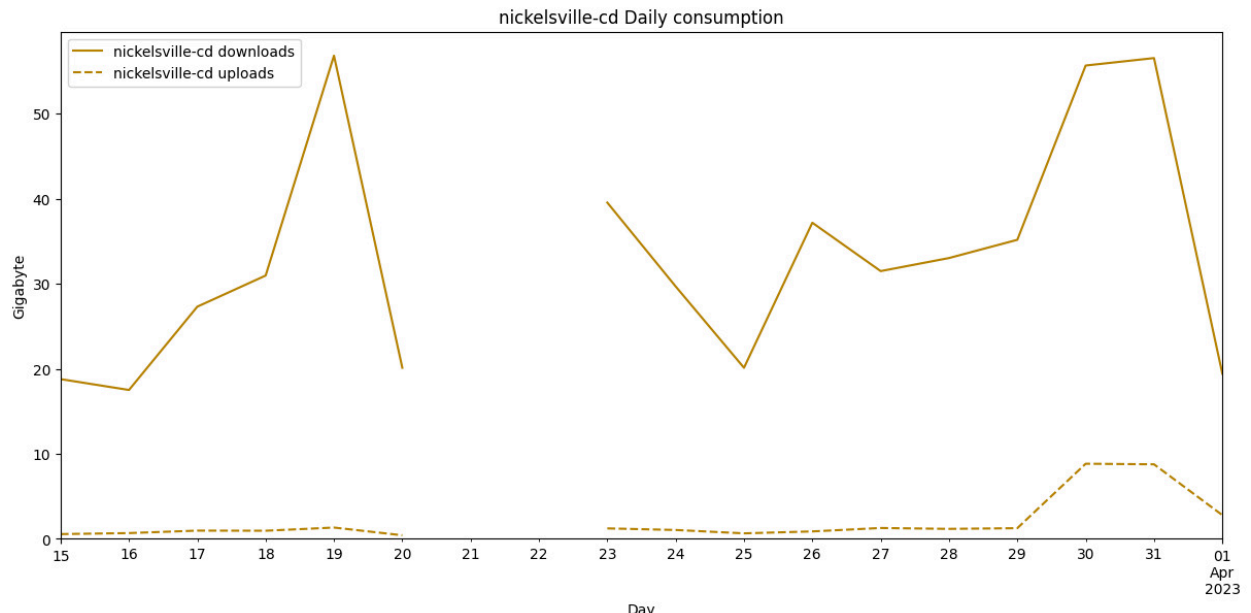


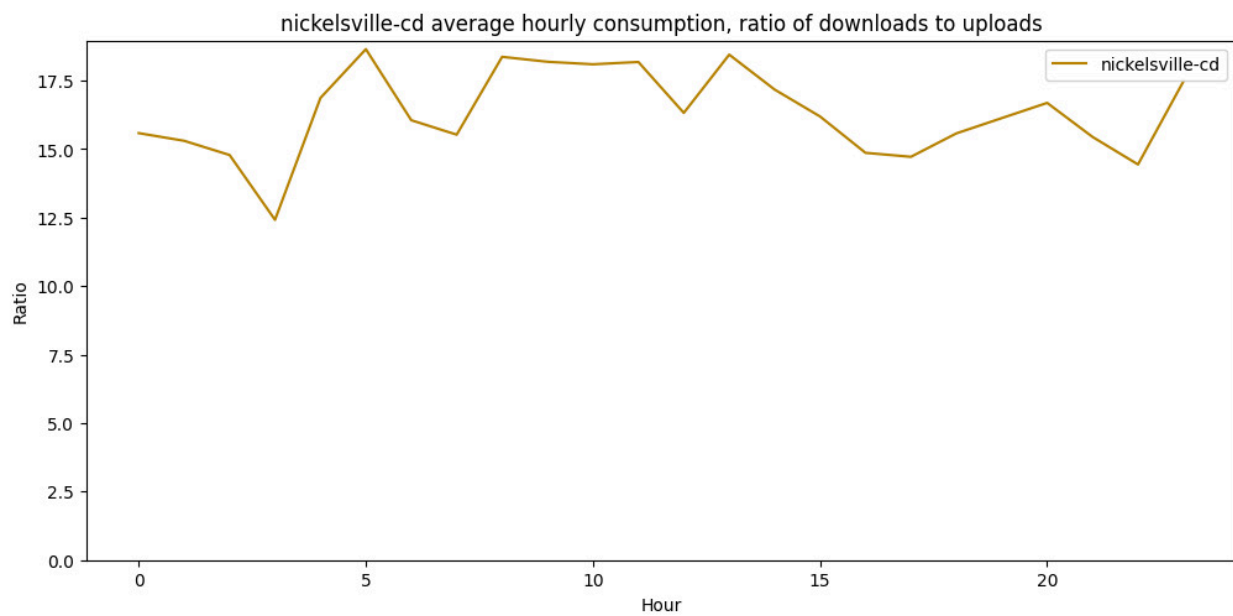
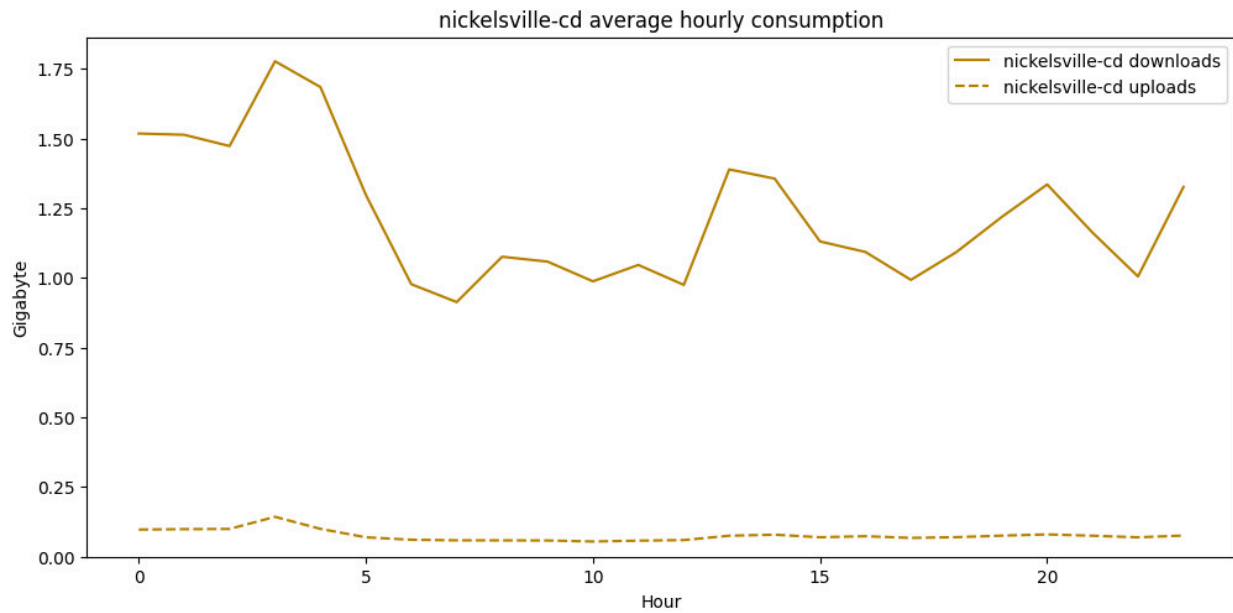
4. Oromo Cultural Center (LTE site) serving LIHI Southend Village - Daily usage and download to upload ratio. Note that the upload data metric and ratio metrics have been affected by speed testing and do not accurately represent user data consumption.



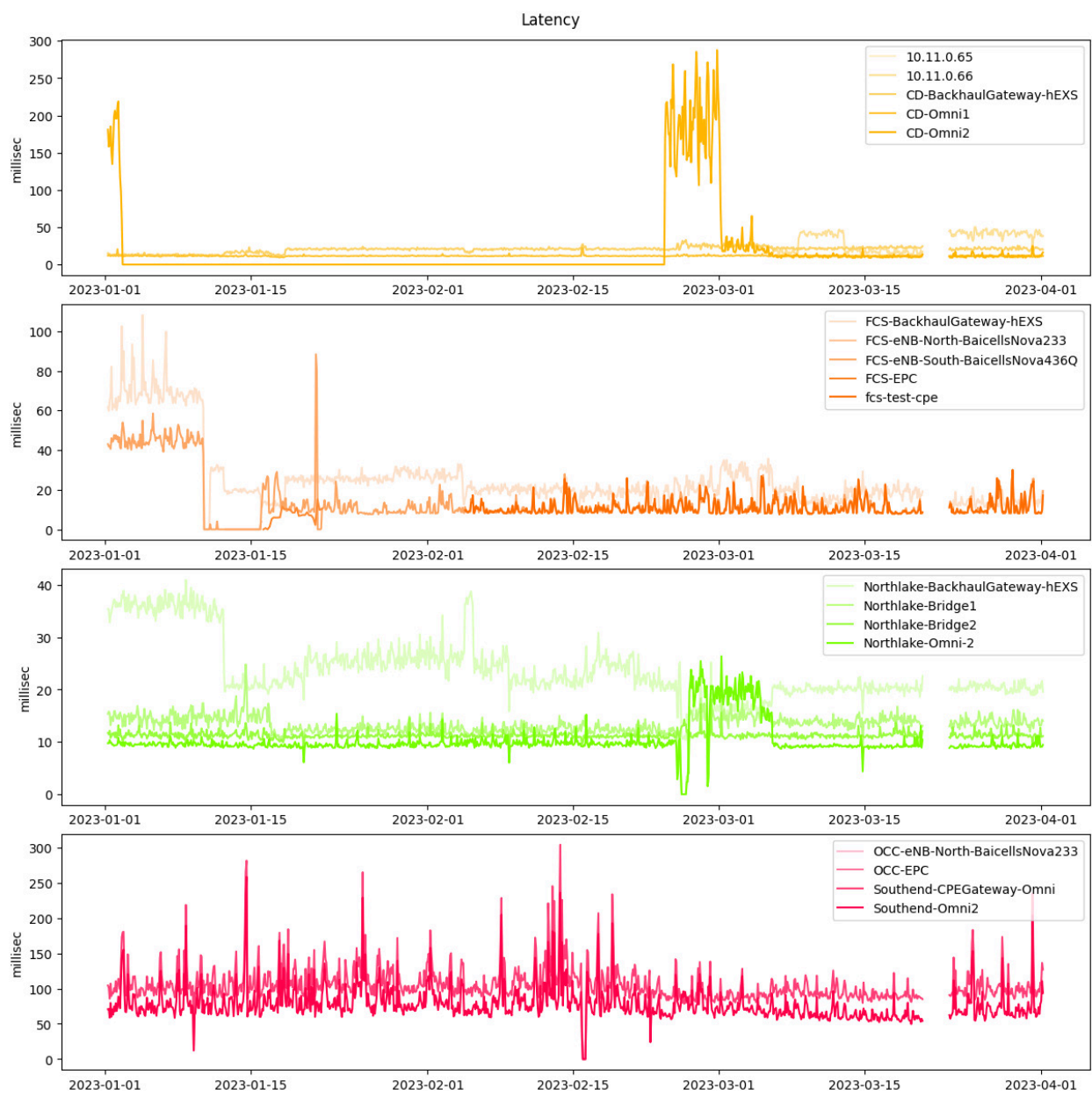


5. Nickelsville CD Village served by Lumen fiber backhaul and WiFi access points - Daily usage and download to upload ratio. Note that these metrics begin in mid-March. Earlier data was inflated by speed tests and did not accurately represent usage, so it has been excluded. Hourly averages are based on the data recorded since mid-March.





6. Latency measured from the SCN metrics server (Azure-hosted) to equipment installed at the Nickelsville CD, FCS, Nickelsville Northlake, and OCC-Oromo sites.



APPENDIX D

CN Roadmap

The CN Roadmap is attached to the end of the document in printable booklet form (double sided, center stapled). An in-order screen version can be found at <https://bit.ly/cn-roadmap-web>.

Vita

Esther Jang is a PhD student in Computer Science at the University of Washington in Seattle. Her research addresses both rural and urban community networks, and especially how communities of practice can build and sustain technical infrastructures. She has installed community networks in Tanzania, the Philippines, Mexico, and various states around the US. She founded and organizes the Seattle Community Network (SCN) project, which builds community-owned and maintained Internet access infrastructure to support digital equity in Seattle and Tacoma. She serves as a Director at the Local Connectivity Lab, a 501(c)(3) nonprofit focusing on technology research, deployment, and teaching in support of community networks around the world. She has been a technical networking instructor for the Tribal Broadband Bootcamps since 2019. In her free time, she is an avid jazz singer and plays often with the vibrant local swing community. Website: <https://estherjang.com>.

The Community Network Roadmap is a tool designed to help communities create their own broadband network solutions for connectivity. From community organizing, to network planning, building out the network, technical training, organizational stability, community inclusivity and accountability, and growing the network into a long term, sustainable enterprise, this roadmap offers a comprehensive guide for the community network development process.

The Community Network Roadmap was made possible with funding from the Social Sciences and Humanities Research Council of Canada (SSHRC).

For more information contact:

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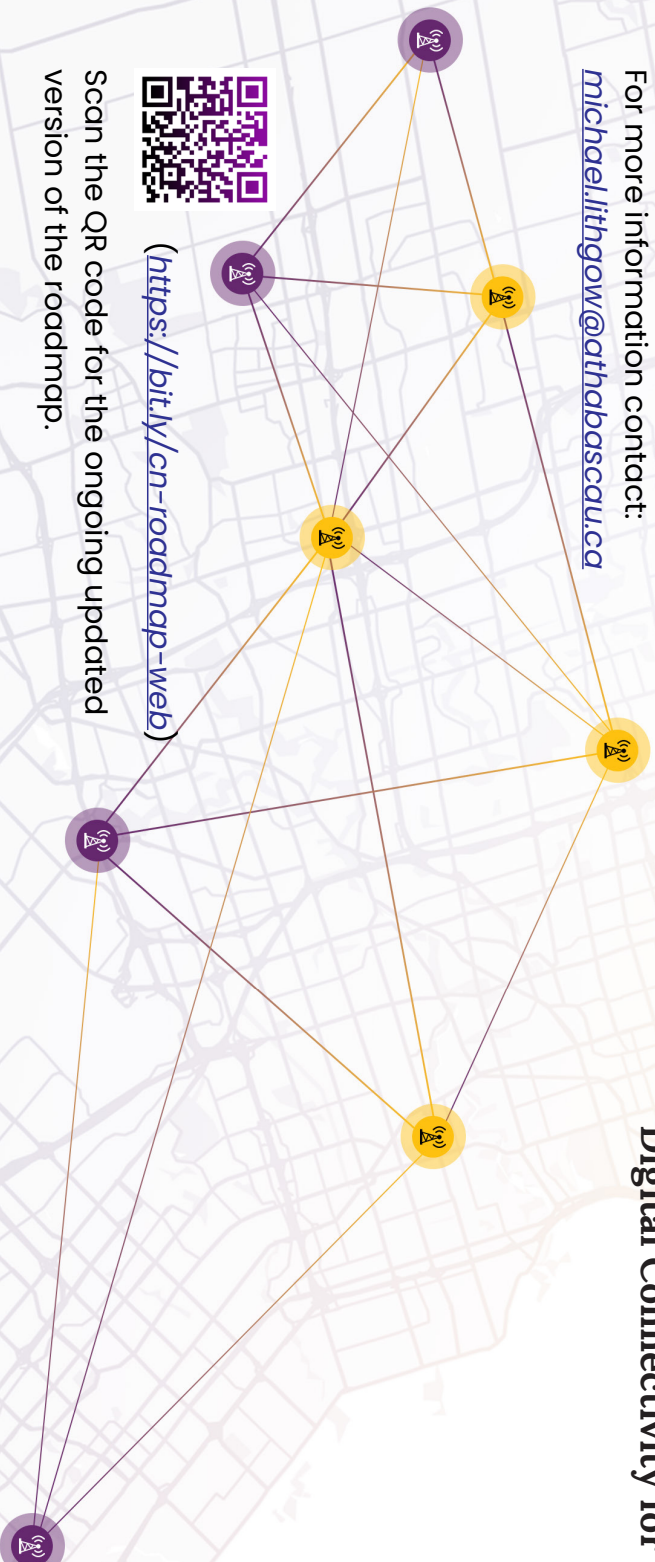


(<https://bit.ly/cn-roadmap-web>)

Scan the QR code for the ongoing updated version of the roadmap.

Community Network Roadmap

A Guide for Building and Maintaining Digital Connectivity for Your Community



ACKNOWLEDGEMENTS

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and the many other community networks around

the world who have informed and inspired us in

the making of this guide. Special thanks to our

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Thank you to the University of Washington, especially the members of the Information and Communications Technology for Development (ICTD) Lab; the Local Connectivity Lab; Internet Society; Institute for Local Self-Reliance; Network Startup Resource Center; and other organizations who provide resources, support, knowledge, and advocacy on behalf of community networks as a whole.

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2023

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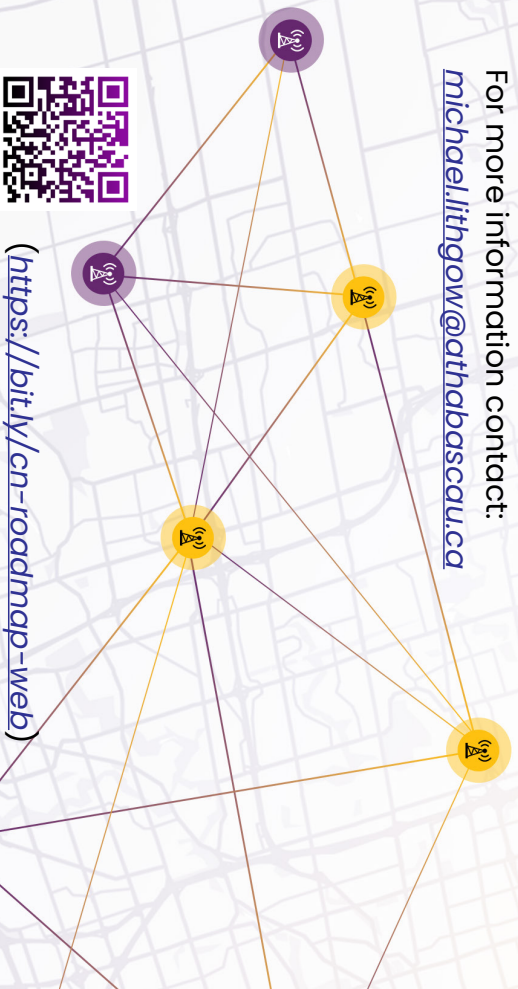
(<https://creativecommons.org/licenses/by-nc-sa/4.0/>)

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HOW TO READ THIS ROADMAP

You can either read the Roadmap from beginning to end or choose a topic and explore.

The Roadmap is organized by our sense of how a community network gets created, step-by-step, but each topic area can also be explored separately depending on your needs.

The information in the Road Map is organized in two ways: Building the network, and Maintaining the network.

- Photo by Ted Balmer on Unsplash (<https://unsplash.com/photos/a-grassy-field-with-trees-in-the-distance-Vjbu1QWHJg>)/image cropped from original (The Prairies image on page 10)
- Photo by Sveta Fedarava on Unsplash (<https://unsplash.com/photos/aerial-photography-of-brown-and-green-fields-vIar8eIdQjg>)/image cropped from original (Rural Areas image on page 10)
- Photo by Kristijan Arsov on Unsplash (<https://unsplash.com/photos/green-mountain-under-white-clouds-during-daytime-BBYNDZFEI3A>)/image cropped from original (Mountainous Regions image on page 10)
- “Black and White Abstract Painting” by Tima Miroschnichenko (<https://www.pexels.com/photo/flight-landscape-bird-people-5725589/>)/removed background and edited color from original (Map on page 12, 13)
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- “Arctic Village– Prudence Macleod” by PrudenceMacleod is licensed under CC BY 2.0. To view a copy of this license, visit <https://creativecommons.org/licenses/by/2.0/?ref=openverse>. / image cropped from original (Northern Communities image on page 10)
- Photo by Juan Rojas on Unsplash (https://unsplash.com/photos/city-skyline-under-gray-cloudy-sky-during-day-time-VWwK2bgug_Q) / image cropped from original (Urban Centers image on page 10)

The **Build** sections focus on the kinds of information and tasks particularly relevant to starting your network. There are many things to consider in the planning and building of a first network, and these sections are designed to help you think your way into developing and executing a successful community network plan.

The **Maintain** sections focus on longer term considerations. Once the network is up and running, there are different kinds of problems that can arise and need to be considered and planned for – tasks and matters aimed at keeping a community network operation sustainable and stable over time.

Both ways of thinking about a community network are important. But of course, one comes before the other. Use the guide in a way that is relevant to your situation.

Note: Click on the links in the document to view them, as copying and pasting may introduce some errors.

CONTENTS

01. INTRODUCTION	8
Community network (CN) benefits & challenges	11
Examples of Living Community Networks	12
02. TEAM BUILDING	14
Community Outreach & Sustained Engagement	14
IT & Network Administration	16
Identify community needs	18
Leadership and Organizing	20
Organizational Structures	22
Equity, Diversity and Inclusion	24
Policies and Regulations	25
Establishing Community Support	26
Governance and Finances	30
03. PLANNING A NETWORK	32
Glossary of Technical Terms	34
Technical Planning	36

Additional Resources

- “Learn” pages for technical networking topics maintained by Network Startup Resource Center (NSRC): <https://nsrc.org/videos>
- Learning resources for US Tribal ISPs: <https://tribalresourcecenter.net>
- Global Community Networks Discussion Forum: <https://communitynetworks.group>
- Crowdsourced Community Networks Learning Resource List (Please Comment): <https://bit.ly/cn-resource-list>
- ISOC Spectrum Policy Brief: <https://www.internetsociety.org/policybriefs/spectrum/>



Scan the QR code for the ongoing updated version of the roadmap.
<https://bit.ly/cn-roadmap-web>

- Community Networks (2018) Association for Progressive Communication & International Development Reserarch Centre: <https://www.apc.org/en/pubs/global-information-society-watch-2018-community-networks>
- Neighbourhood Network Construction Kit: <https://communitytechnology.github.io/docs/cck/>
- Community Networks: <https://communitynets.org>
- TakNet (a community network in Thailand that combines mesh network and TVWS technologies): <https://blog.apnic.net/2019/07/01/>
- ISM bands: <https://en.wikipedia.org/wiki/ISM>

How Community Networks Work	38
Network Relationships & Maintenance	40
Wireless Coverage Area Analysis	44
Strategic Planning	46
Assess existing infrastructure	48
Choosing the Right Technology	50
Design a Pilot Network	56
04. BUILDING THE NETWORK	58
Community Support	62
05. FREQUENTLY ASKED QUESTIONS	64
06. REFERENCES	72
Additional Resources	75
Credits and Attribution	76

01

INTRODUCTION

Community networks (CNs) provide access to **affordable, reliable digital network services** that are designed and operated by the local community. Community networks emphasize technical solutions for specific local needs, **community member control** over decision making, community participation and skills training.

Communities all over the world are designing, building and operating their own digital communications networks. Community Networks can be found on every continent, some as small as a few households, others like the *Guifi.net* in the *Catalan region of Spain*, with tens of thousands of network members.

Community networks are an effective way to get digital networking and the Internet into communities that otherwise would not have access.

Chapter 2

- Community Network Readiness Assessment Course (Internet Society): <https://www.internetsociety.org/learning/community-network-readiness/>
- Community Networks Training Webinar (Internet Society): <https://www.internetsociety.org/events/indigenous-connectivity-summit/2021/trainings/community-networks-webinar/>
- Community Networks Learning Repository: <https://cnlearning.apc.org>

Chapter 3

- Lesson 6 – Designing a Network – Aug 1: <https://bit.ly/ds-lesson-designing-wireless>
- Line of sight Image Reference: <https://www.crows-nestbb.net/how-it-works.html>
- Inventory the Neighborhood: <https://communitywireless.net/docs/cck/planning/inventory-the-neighborhood/>
- Google Earth Pro: <https://www.youtube.com/watch?v=ad7bMGPPDwc&list=PLZ1cQ-uIX-TA7Nkhde5XfUFLCEBfUjBktoX&index=6>

06

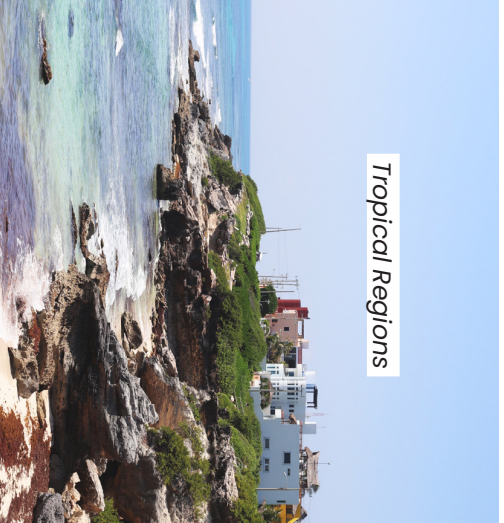
REFERENCES

Chapter 1

- Guifi.Net: <https://guifi.net/en>
- Rhizomatica: <https://www.rhizomatica.org>
- Zenzelini.Net: <https://zenzeleni.net>
- Freifunk.Net: <https://freifunk.net>
- New York City Mesh: <https://www.nycmesh.net>
- AlterMundi.Net: <https://altermundi.net>
- Wireless for Communities: <https://wforc.in>
- Seattle Community Network: <https://seattlecommunitynetwork.org>

SCN volunteers working
on Skyway Library cell
site install in 2021





Tropical Regions



Northern Communities



Urban Centers



The Prairies



Rural Areas



Mountainous Regions

Community
Networks thrive in every kind of landscape; their low cost and reliability are common reasons why people appreciate them.

Many community networks cultivate a culture of DIY to encourage people to solve their own technical problems or work with their neighbors on local issues, activities which can solidify the practice of collaborating as well as help users acquire technical knowledge through experience. We recommend a shared communications platform where network members can reach out to the group for help and status updates. It can be crucial to recruit and maintain (often through continuous teaching and training) a large enough community of technicians, be they fellow users, employees, volunteers, or other. Especially invaluable are those who are reliable, responsive communicators, even when remote, and who enjoy helping others with their problems. Also invaluable are those with flexible schedules who are ready and eager to spring into action, and can shift other obligations around to prioritize network emergencies (e.g. people between jobs, those with flexible work—from home jobs, elders who are retired, students on summer break, etc.). While in-person site visits are sometimes needed, remote support over the phone or chat can often be just as effective and necessary, and provide those with limited mobility meaningful ways to participate. See [Chapter 2, Leadership and Organizing section \(page 20\)](#) for more strategies on maintaining sustainable membership, processes, and communications.

the ebb and flow of people's capacities and changing life circumstances.

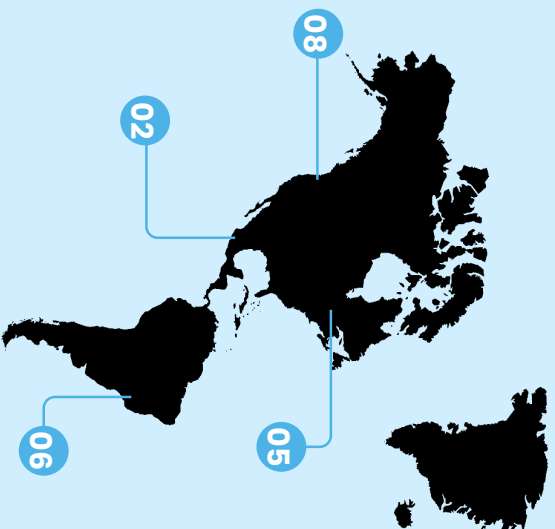
You should establish realistic boundaries and reasonable expectations among users for how quickly problems can be resolved based on your available resources. For example, in a free, non-profit, volunteer-based network, you may have a member agreement that new joiners sign stating that services are provided on a best-effort basis, and outlining the user's own responsibilities to help maintain their own node. To support this, you will want to have robust troubleshooting resources online, on paper, and/or through workshops. Users who pay for Internet access will typically be more demanding. For a well-maintained and functional network, a realistic time estimate is the equivalent of at least one person contributing a full-time job's worth of mental and physical energy to the project. This can be shared by a few leaders contributing smaller amounts of time and energy, as long as they are well organized, committed, and work well together at sharing responsibilities and accountability. Passion and conviction among the network mobilizers are important, but these alone are not sufficient. It can be tempting to rely too heavily on individual "all-stars," but these members can also have their own needs to care for and their own limitations. Reliability and resilience depends on broader team capacity building and participation.

Community networks present numerous benefits alongside a set of challenges.

Advantages: The advantages of community networks include affordability, reliability of services, capacity building (technical skills training), meeting neighbours and building relationships, community independence, shared costs, collective ownership, local content, digital inclusion, community solidarity, data privacy and security, economic investment that stays in the community, and having a digital network that is responsive to local needs.

Challenges: Community networks require time and effort on the part of network members—solving technical problems, decision-making, financial management, network planning and growth, and sustainability planning all demand attention from community members. Sharing responsibilities is a key path towards long-term sustainability.

Digital networks might be inaccessible for many reasons: The infrastructure may not exist, or if it does, it is unreliable and/or unaffordable; commercial providers and policy-makers may not prioritize local community needs. Community networks can address all of these problems.



Examples of Living Community Networks

Community networks thrive globally, with numerous flourishing examples. Tapping into the experiences of other community network organizations can provide valuable insights for planning and running your own network. With hundreds of successful community networks out there, a wealth of knowledge awaits.

These are just a few examples of the many living community networks around the world. If you would like to add your network to a repository of community networks, please fill out this form and we'll get in touch with you! <https://bit.ly/globalcn>

donation, pay-what-you-can, or sliding scale model for user contribution. Networks can also operate using a hybrid or tiered approach—for example, offering a free limited bandwidth service and charging fees for faster or more data capable services. You may also want to consider asking members to contribute labor, time, skills training, or other alternatives which can be just as valuable as money in a community network's operations. See [Chapter 2, Governance and Finances section \(page 30\)](#) for more on financial sustainability and organizational models.

How much work / how much time does it take to run a community network? What about my work / life balance?

Finding work/life balance while running a community network is an important and common question, especially if there is a small core team running the network compared to the total number of users or the geographic reach of the network. Operating critical infrastructure that people depend on can feel overwhelming at times, and can realistically take up as much space in your life as you let it. When network outages happen, users may urgently need assistance. It is up to you as a group to establish sustainable community practices for providing that help without overburdening or burning out any members. The network should remain resilient to

your community's culture, language, and history that students can access from connected locations, such as their school, library, or home. You can also share resources from the Internet through an intranet network, thus reducing Internet access fees. You can often run an Intranet for very low cost, and you don't have to pay or charge money for these services unless you want to. You do not have to connect an Intranet to the wider Internet (e.g. make your website available to the rest of the world), unless you want to. You can provide both an Intranet and Internet service in your community at the same time.

Will the network be free for community members or should we charge a fee for access?

The pricing structure is up to you. Charging fees for access is a valid way to encourage member "buy-in" and commitment, keeps income flowing into the network to cover operational and maintenance costs, and can keep network operators accountable for the quality of service they provide. However, some communities may choose to focus their network projects on serving those who cannot afford to pay for access, pushing them towards a nonprofit model where they do not charge users. These networks may need to constantly fundraise from external sources to cover unavoidable maintenance costs. Some networks operate on a suggested



01. Guifi.Net

<https://guifi.net/en>

02. Rhizomatica

<https://www.rhizomatica.org>

03. Zenzelini.Net

<https://zenzeleni.net>

04. Freifunk.Net

<https://freifunk.net>

05. New York City Mesh

<https://www.nycmesh.net>

06. AlterMundi.Net

<https://altermundi.net/>

07. Wireless for Communities

<https://wforc.in>

08. Seattle Community Network

<https://seattlecommunitynetwork.org>

02

TEAM BUILDING

Community networks are as much about people as they are about technology. It is people who will decide what technologies to use, how to deploy them in the community, how to maintain network operations and how to grow the community network to serve local needs.

Community networks are often started by a small handful of interested and dedicated community members, sometimes as small as two to five people. A core element is a shared sense of determination to solve their local connectivity problems.

Community Outreach and Sustained Engagement

Consider the core skills and knowledge required for creating and sustaining a community network: leadership and team—building, IT and network administration (i.e. managing computers and routers), community outreach, training, conducting

Do we need to incorporate a company or organization to run a community network?

No, you don't. However, incorporation may help you in the long run for things like raising and holding funds to support your network, advocating politically, hiring people, and establishing a public presence. For example, having registered nonprofit or cooperative status may help with specific types of funding or financial management. We would encourage you to build your team and community, letting your shared values and goals shape the organization you incorporate. See [Chapter 2, \(page 14\)](#) for more on organizing your network.

Intranet v. Internet: Which is better?

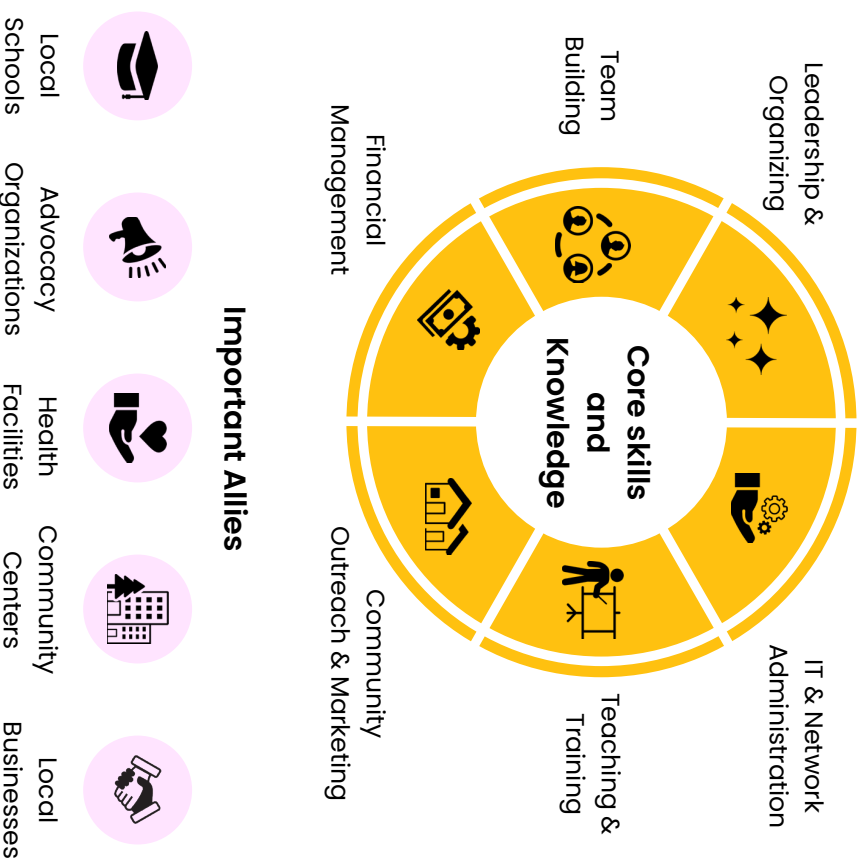
It depends on your goals! If you are interested in connectivity to the outside world, accessing remote websites, information, and services such as WhatsApp, Google, and Facebook, you will need access to the Internet (also known as backhaul). You will typically (but not always) have to pay for this kind of “upstream” connection that can carry your data anywhere in the world. In contrast, an Intranet is a local network that can connect different places or machines inside your physical community (via wireless or wired links). You can use the Intranet for sharing resources and data internally—for example, you can host a local website about

and ranging sensing technologies used to measure elevation data), with which you can easily run a “viewshed analysis” to find out what you can see from a given point, i.e. to map.

What are some good strategies for getting community members involved and on board?

Community networks, like any community-building initiative, benefit from activities and structures that bring people together regularly in rewarding and enjoyable ways (think clubs, sports teams or religious establishments). Social events and cozy gatherings, planning and decision-making meetings, and skill share or work sessions all have their place in an ecosystem of support and collaboration. It can be helpful to give participants goals to work towards, and a way to “buy in” or commit to joining the network, whether through building and installing their own node, or through working towards membership via a series of completed trainings or tasks. To gain more public community presence, classic outreach and publicity techniques such as door knocking, canvassing, and handing out or mailing fliers to tell people about your initiative can also be effective. Use outreach to bring people to in-person meetings where they can meet the community and see for themselves what joining the network will look like.

workshops and financial management. Schools, local businesses, community centers, health facilities, advocacy organizations can be **important allies** when developing a community network. Reach out to stakeholders in the community who can share some of these skills, either by participating in network planning or offering workshops.



IT & Network Administration (Online Learning Materials)

Technical networking skills can be more specialized. There are people (and learning resources) available on the Internet specializing in community network building.

Below is a list of resources and organizations.

Training interested community members and finding community members already familiar with digital network technologies are both excellent strategies.

01. Community Network Readiness Assessment Course (Internet Society)

<https://www.internetsociety.org/learning/community-network-readiness/>

02. Community Networks Training Webinar (Internet Society)

<https://www.internetsociety.org/events/indigenous-connectivity-summer2021/trainings/community-networks-webinar/>

03. Community Networks Learning Repository

<https://cnlearning.qpc.org>

small “WISPs”) can be orders of magnitude cheaper than licensed and simpler to manage and configure, but can have other drawbacks such as vulnerability to interference, weather-dependent performance, or potential to run out of spectrum. See [Chapter 2, Governance and Finances section \(page 30\)](#) for more on cost considerations, and [Chapter 3, \(page 32\)](#) for technology options.

How hard is it to learn the technical skills required to run a network? Where can I learn them?

It depends on the technology you’re using! Learning by hands-on experience is by far the best way to learn networking, however different technologies will also have very different learning curves. But the basic skills required to set up and run a local network can be learned by both adults and youth with access to resources and tools, time and patience. See [Chapter 3, \(page 32\)](#) for on different technology options for CNs and to access further learning resources.

Where can I access topographical maps of my region for network planning?

Many modern computer-based mapping tools such as Google Earth Pro come pre-loaded with satellite-based and other types of topographical data (such as LIDAR, which means Light detection

05

FREQUENTLY ASKED QUESTIONS

Is building a community network expensive?

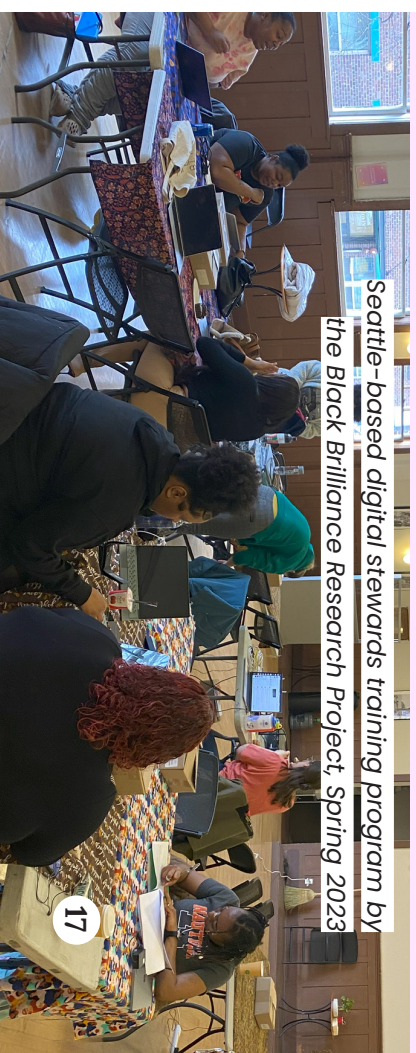
Building a community network does not have to be expensive. You can even build a community network without money, making use of donated labor and resources you might already have in your local environment such as old routers, e-waste, open-source software, and repair or construction skills. However, these more “scrappy” options may require more knowledge and experience to implement. The costs will also depend heavily on the technology you choose. For example, fiber-optic networks can be extremely expensive to build, but can provide faster and more reliable network service in the long run with fewer maintenance costs. Unlicensed wireless frequencies and equipment (marketed for

Maintain

Building long-term community resilience requires capacity building.

To help community members get the necessary skills required to keep the network running, consider facilitating **regular workshops in all areas of network operations**—community-building and outreach, network administration, governance and leadership, financial management, and technical troubleshooting.

Attend community events, set up an information table where you can demonstrate equipment and answer questions, and/or host a community BBQ. The network’s survival over the long term will depend in part on maintaining, renewing and expanding interest and support from community members. A **community presence** can also help to grow the network. Teamwork not only strengthens the network but also creates a cooperative vibe in the community, promoting a shared goal of local growth and staying connected.



Seattle-based digital stewards training program by the Black Brilliance Research Project, Spring 2023



Identify community needs

When building support for a community network, understanding the different needs of different community members is essential.

Where is coverage needed?

What are the barriers to access?



Cost?



Reliable Service?



Access to a computer or smartphone?



Digital literacy skills?



Content Language(s)?

Understanding the full range of community needs helps with designing a community network that the community will find helpful and support.

A communications platform can help community members coordinate fun community-building and feel-good events as well as solve problems, which can improve network sustainability and resiliency. Community networks are built on human relationships, and maintaining those relationships should be encouraged as a priority. Use the network as an excuse to build community, and the community as the foundation to build and expand the network.

At the same time, it can be a powerful learning experience for people to troubleshoot and resolve their own problems when possible, rather than immediately asking for help. Encourage an ethos of DIY, knowledge sharing and contribution. Consider establishing norms/practices of thanking, commending, or rewarding people publicly for sharing and documenting DIY activities or solutions to problems, or for helping others resolve their problems. The communications platform can be used to help facilitate this.

Community Support

Create and offer workshops for new members that provide technical training, introduction to the network and its operations, identify different ways of participating, explain responsibilities and expectations. Ensuring community participation is one of the most important strategies for the long term success of a community network.



Establish a communications system/platform for network members to share experiences, plan, discuss problems, offer assistance and solutions. Examples of popular communication solutions include: Slack or Discord forums, discussion forums, WhatsApp message groups, etc. Choose something that is accessible for most community members.

Community needs are never static

Accessibility will likely change over time (for example, changing Internet service prices or changing locations of where ISPs have deployed transmission towers, cable or fiber), as will people's expectations of what kind of service they need (e.g. speeds).

The more that network design and operation can reflect real community needs, the more likely the network will be supported by diverse community members.

Population demographics in a region may vary. It is essential to **maintain procedures for integrating and on-boarding new people**, as well as maintaining or expanding your community-building activities. These considerations can also help to expand your physical network.

Leadership and Organizing

As community networks are locally owned, you will have many decisions to make: Where to build the network, what equipment to use, how to manage costs, where and when to organize community events, how to sort out problems, what kinds of workshops to present and how often, policy decisions, etc. The community network will require a system of decision-making (or governance) that is transparent, inclusive and accountable to the broader community.

Accountability is crucial: Who will ensure tasks get done and be responsible for how the network is created, its operations and impacts? The governance structures you implement will also depend on how many people are involved. Find a decision making structure that makes sense for the group you are working with. The network will require decision-making in many different areas. If it is a small group, one organizing committee might make sense. But with a larger group, consider setting up a committee structure to encourage members with particular strengths into relevant conversations.

Key areas of decision-making include community outreach/support, technical design & build, capacity building/workshops, troubleshooting & network maintenance, finances & legal considerations.

Establish a 'steward' or 'referente' system which encourages more technically knowledgeable network members to help others set up nodes and troubleshoot/learn to troubleshoot.

Develop a troubleshooting self-help archive to keep text and/or photo or video records of solutions to common technical problems. Encourage members to document their technical problems and solutions in the archive.

Some examples:

- Create a community wiki that members can add to as problems arise and solutions are found.
- Share troubleshooting stories in real time through a communication platform, for example a Slack, WhatsApp, or other internal chat group.
- Have members take photos of technical problems & solutions (before/after), and post them somewhere with text describing their problem and how it was solved.
- Create videos showing how problems are solved, and post them somewhere accessible.

Here are some key tasks when building the network:

01. Determine the location for nodes and/or access points
 02. Obtain necessary permissions and access
 03. Obtain routers, nodes, transmitters, software, and tools
 04. Install nodes
 05. Conduct network testing
 06. Optimize network performance
 07. Troubleshoot and resolve issues
- Once the initial network is up and running, consider organizing a community event to announce the network and invite community members to join.

Even when your network has reached a level of organizational maturity, how easy is it for new people to come in and have their voices heard, for them to participate in decision making and feel that they have a meaningful impact on the community? This can be key to **keeping new people engaged** after the initial spark of inspiration which causes them to join or come to their first meeting.

What happens when very active users, volunteers, employees, or contributors leave the network or move away? Are there processes in place to turn their **roles and responsibilities** over to new people, as well as keeping documentation to help with **knowledge retention** and transfer? Are there processes for roles to be redefined or recognized and reallocated? Are people elected into leadership roles via **democratic processes** that feel fair (how-ever formal or informal)?

Sometimes forcing turnover (via term limits etc) can be a good idea for establishing these turnover processes concretely and not just in the abstract, even if it seems unnecessary at any given moment.

Build

Organizational Structures

Leadership roles can be helpful. Consider establishing leadership roles for community outreach & new member recruitment, volunteer coordinating, technical design and build, capacity building/workshops, finances & legal considerations. Leadership roles can be linked to committees to create small teams of **problem solvers** in specific areas.

Weekly helpdesk at Filipino Community Center

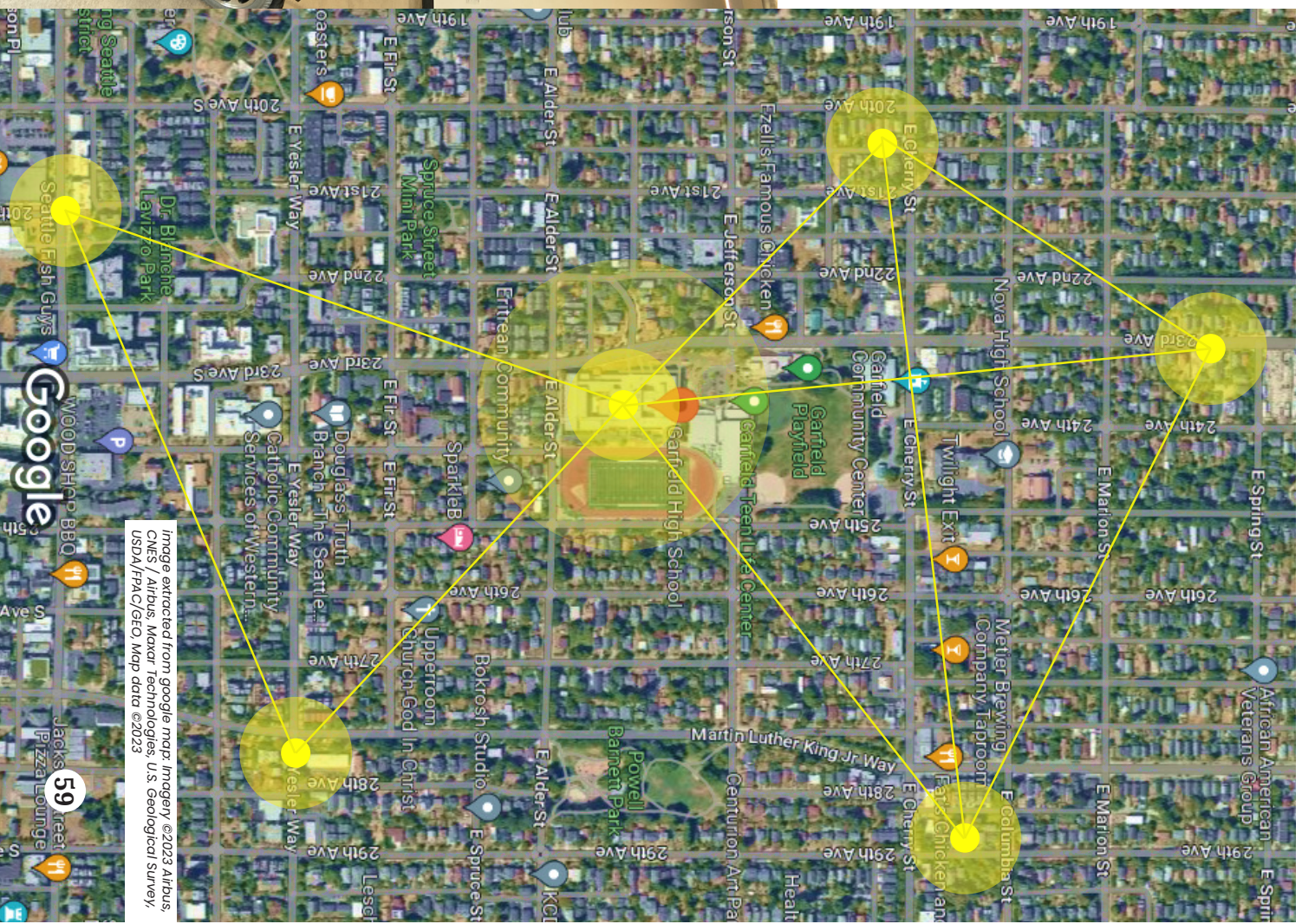


Image extracted from google map, Imagery ©2023 Airbus, CNES / Airbus, Maxar Technologies, U.S. Geological Survey, USDA/FPA/C/Geo, Map data ©2023

04

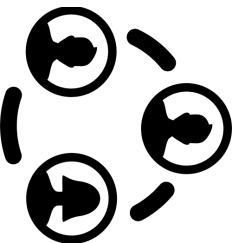
BUILDING THE NETWORK

After putting the team together, establishing rules for inclusive and accountable decision-making, mapping and designing a workable network design that incorporates topographical and infrastructural limitations and advantages, it is time to build the network. **Consider building a pilot network first as proof of concept.** A pilot network is a much smaller and simpler version of the network you ultimately hope to build. A pilot network may only have a few nodes to begin with, a chance to learn about and to try new technologies, troubleshoot problems, and get familiar with technologies before inviting the public to join the network.

Consider **succession strategies** for key roles in the network. How will wisdom and knowledge be shared and passed on? How will key roles be replaced if someone moves or decides to step down? Consider an under-study or assistant framework where no one is working alone, and someone is always in a learning position, i.e. **ongoing capacity building with every position.**

Regular governance meetings are important for community and team building as well as infrastructure upkeep. They are a chance for network members to air complaints, make suggestions, and maintain accountability and a steady pace of progress. They are an important way to ensure transparency and fairness in decision-making. They are **a strategic way to prevent problems**, to address problems in a timely way, and to take advantage of opportunities. Regular governance meetings, even when the network is not being actively set up or growing, help stabilize network operations over the long term.

Equity, Diversity and Inclusion



Consider who the decision-makers are and questions of **equity, diversity and inclusion**. Who could be invited into the decision-making process that might otherwise be excluded or forgotten?

Are the decision-makers representative of and respected/loved by the community? You can think of representation in terms of gender, class, ethnicity, socioeconomic background, sexual orientation, etc. Still, of course, humans are more than demographics; these are certainly not the only important features.

Diversity is strength—the more allies you have in the community who are willing to sit at the same table and work together, the better the network’s chances for long-term sustainability.

The long-term feasibility of a community network will depend in part on addressing ongoing issues of maintenance and upkeep in a timely way. Consider creating longer term strategic plans for sustainability, including strategies for:

01. Ongoing awareness/evaluation of changing community needs
02. Network expansion to serve new areas / new users Equipment upgrade costs & planning
03. Maintain and build relationships with owners of infrastructure as the network expands
04. Capacity building and knowledge sharing

Design a Pilot Network

Working with the information gathered and decisions made in response to the network planning questions, design a feasible pilot network. Ensure:

01. Transmitters/repeaters/nodes have line-of-sight as required
02. Permissions for transmitters/repeaters/nodes locations are obtained
03. Appropriate tools & equipment are available
04. You have technical know-how through outside expertise, instructional content and/or community members.

Policies and Regulations

Identify the policies and regulations that affect the network—municipal, regional, and national. What are the **telecommunications rules and regulations**? In Canada, the Canadian Radio–Telecommunications Commission (CRTC) sets digital network rules and regulations. In the United States it is the Federal Communications Commission (FCC). Most countries have a regulatory agency that sets communications policies. Find out what rules and regulations apply to community networks and internet service providers.

What kind of an organization will run the network? Will it be incorporated as a not-for-profit? Small business? Community organization? What rules and regulations, filing requirements, taxation, and insurance will be required?

Maintain

Once you know what rules and policies apply to your community network, you may find that some work against the network's interests. Consider trying to have the rules changed. Are there policies that might help it thrive? Where it makes sense, you can build relationships with elected leaders and telecommunications officials, and advocate for policies that benefit community networks. You can find a global wiki and community of support at <https://policy.communitynetworks.group>.

Establishing Community Support

Inclusivity and diversity are essential to the long-term health of the network.

Build relationships with community members.

Y Make it easy for people to get involved.

↻ Create procedures for bringing people into the organization; consider pairing new members with a more experienced community member (i.e. a network mentor) to help them learn about the organization and how it works.

i Be attentive to how different individuals want to participate.

✂ Create opportunities for skills learning through hands-on direct experience and/or workshops.

Establishing relationships with other community networks may be an effective way to get help when you need it. Reach out to one or more of the networks listed in this document or any community networks nearby. Introduce yourself and your project. Share experiences, wisdom and resources as appropriate.

Resources

- 01.** Community Networks (2018) Association for Progressive Communication & International Development Research Centre.
<https://www.apcc.org/en/pubs/global-information-society-watch-2018-community-networks>
- 02.** Neighbourhood Network Construction Kit.
<https://communitytechnology.github.io/docs/cck/>
- 03.** ILSR Community Networks
<https://communitynets.org/>
- 04.** TakNet (a community network in Thailand that combines mesh network and TVWS technologies)
<https://blog.qpnic.net/2019/07/01/>
- 05.** ISM bands
https://en.wikipedia.org/wiki/ISM_radio_band



TV White Space (TVWS, Unlicensed)

spectrum: TVWS is an option most commonly used in rural wireless networks to cover long distances (often with lower bandwidths, in the tens to low hundreds of Mbps). TVWS transmitters utilize unused television spectrum to send signals. TVWS systems can be mesh networks or point-to-multipoint distribution networks. One advantage of TVWS is that you do not need line of sight to make network connections due to the use of low frequencies (470 MHz–790 MHz). **Lightly licensed spectrum:** In the United States, the Citizens' Broadband Radio Service (CBRS) spectrum at around 3.5GHz is another option, sometimes desirable because unlicensed bands can have a lot of interference (less of a problem in rural areas). To legally install devices in this band, you need someone with a **Certified Professional Installer (CPI) license**, which you can get by taking an online course/exam for a fee. You also need to pay for a subscription to a national database called a Spectrum Access Service (SAS) for spectrum coordination (usually a few dollars per device per month).

Keeping track of successes and achievements is vital for sharing the network's story with other community members, potential funders, policy-makers, and so on.



Reach out and check in periodically with your partner organizations or network members, e.g. once a month, to make sure their needs are met.



Keep a record or log book of accomplishments.



It is also important to recognize the contributions of individual community members.



Use celebrations to acknowledge and reward hard work and to invite new community members into the network.



Keep complete documentation of all employed equipment and infrastructure (such as login passwords, photos, and what is plugged into what). Define and use access control practices to keep this info out of the wrong hands, but make sure it's always available to the right people who are responsible for maintenance.

Online Community

Establish social media platforms or channels where community network participants can share information, concerns, experiences, ideas, technical information and solutions to problems. Examples include WhatsApp, Discord, slack, etc.

Physical Events

The sense of camaraderie among network participants should be more than just work oriented. **Have fun!** Hold regular social gatherings—BBQs, shared meals, outdoor/indoor games, clothing swaps. Informal gatherings like this can be invaluable ways for people to share information, network, meet others in the community, and build relationships.



SCN Social Picnic 2021

28

If using wireless technologies, what frequency spectrum/type of radio should we use?

ISM ISM band (Unlicensed) spectrum:

ISM radio bands are radio frequencies allocated internationally for industrial, scientific, and medical (ISM) purposes. These include the 5GHz and 2.4GHz frequency bands typically used by WiFi, and a 900MHz band often used for low-bandwidth communications such as sensor networks. These are the most common bands available for wireless ISP gear. PTP wireless radios are also available in 24GHz and 60GHz, more dependent on line of sight due to their higher frequency. The ISM bands are by far the cheapest options for wireless equipment.



Most networks in the world have a hierarchical structure (like an upside-down tree) which route data to, from, and between the users (the leaves) through a “core” network (the branches and trunk). This can make routing simpler, more predictable, and higher performance (faster), sometimes at the expense of disaster resiliency. Examples include simple **access point networks** such as a standard high-power WiFi AP installed on a roof that anyone’s laptop can connect to, or a **point-to-multipoint** (PtMP) 4G LTE network distributing internet access to hotspots throughout the community. These access points can then be connected “upstream” (ie. linked together at a place in the network that is before users access data) to a core router via physical or virtual (e.g. VPN) network links if you want to combine them into a single network sharing one backhaul (like building branches from leaves to a shared trunk), but this is not strictly necessary for basic internet connectivity. Other examples are **GPON (fiber) networks** (ie. Gigabit Ethernet passive optical network, a point-to-multipoint network technology that delivers broadband access to the end user via fiber optic cable).

Consider annual or semi-annual events inviting the broader community into the community network conversation. Ask how well the network is serving needs: where is it succeeding, where is it falling short, who needs access but does not have it, and what are the issues and concerns being faced by community members?

Consider creating ongoing, accessible opportunities for regular feedback. Incorporate feedback into decision-making processes.

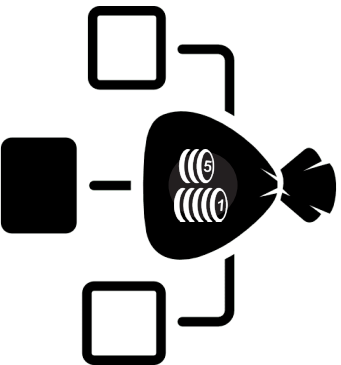


SCN Hack Night at the Filipino Community Center

Governance and Finances

Community networks require money to build and maintain.

Consider how money will be handled for the network organization: Who will be entrusted to manage finances, i.e. a treasurer? Will you open a bank account for the network with multiple signing officers? How will you raise money? (e.g. grants, user fees, membership dues, fundraising activities like Bingos, bottle drives, bake sales, etc.). If there are user fees, who will collect them? What if members are late or don't pay?



Explore what kind of organization will run the network procedures in your region. Reach out to other, similar organizations or pro-bono legal services for guidance.



Mesh networks can grow incrementally and in an ad hoc way, with little coordinated planning: as new users join the network, the new nodes increase the network's coverage area and resilience. If one node breaks down, network traffic is rerouted automatically through alternative paths. Examples of software and firmware that support mesh functionality include **LibreMesh**, **Quick Mesh Project**, and **OpenWRT**. This firmware often needs to be installed on off-the-shelf routers, which is typically a fiddly but doable process. An alternative is **LibreRouter**, an open hardware project where network nodes are designed with both hardware and software optimized for rural community mesh networks, but these devices are not yet legally certified to operate in many countries. There are other ways to configure mesh networks without open source software, which still requires a small amount of centralized coordination (**NYC Mesh** is an example, with very good documentation available online).

Choosing the Right Technology

There are many different technology options for community networks, each with their own strengths and challenges.

Here are some common choices community networks are presented with:

Mesh or hierarchical network structure?



Mesh networks can be an affordable, accessible option for some community networks, especially those interested in **open source technologies**. Each user maintains a network “node” that acts as an internet connection to other users (connected with wire or wirelessly to one another). Imagine a network structured like a fish net, with nodes at the crossings. Typically all nodes are the same (i.e. in equipment, configuration, and maintenance), which can be helpful for developing a shared knowledge base and community of practice.

Longer-term financial planning for community networks requires planning for unexpected technical failure and replacing equipment, technological upgrades, tools and supplies, crowd-sourced funding strategies, grant writing strategies, and other sources of revenue generation.

Consider creating a committee or group to think about longer-term network goals and visioning. Create space and time outside of addressing day-to-day issues for long term planning.

The people doing long term visioning should be well informed of day-to-day network operations to ensure continuity and strategic planning.

03

PLANNING A NETWORK

Community networks can be created with different technologies, but they all share the key goal of carrying data from one location to another, whether through wired cables or wireless signals transmitted through the air. It might be from household to household (as in a mesh network), or it might be from a more centralized transmitter to multiple households and users (as with an Access Point).

The key steps are:

01. Obtaining an Internet connection or “backhaul” if desired
02. Sharing this signal to one or more locations in the community.

It is important to continuously look for opportunities to **build relationships with owners of useful existing infrastructure**, such as local backhaul providers, utility companies, people with rack space (i.e. server and data storage capacity) in IXPs or data centers, local tall building owners, and community resource hubs operating for public benefit such as schools and libraries.

You may also be forced to move sites over time, for example:



Due to future or ongoing construction that might create line-of-sight obstructions, the sale of a building.



Increased backhaul costs.







Changing community relationships, sponsorship agreements, etc.

Assess existing infrastructure

Note that “site acquisition,” or finding and getting access to places to host equipment, can often be the hardest and/or most expensive part of building a community network. It typically takes the longest time and can depend heavily on community relationships and personal connections, especially on a low budget.

As you develop your network design, identify existing infrastructure that you can use:

-  Is there existing backhaul in the community?
-  → Where is the closest IXP?
-  What information infrastructure is available locally (if any): telephone poles and lines, cable television lines, fiber–optic cables?
-  What land locations might be important for your network design? What buildings?



SCN volunteers installing LTE network at Franklin High School in Seattle, 2021

Glossary of Technical Terms

Backhaul: This will be the internet connection coming into your community and shared via your network.

There may be multiple sources or locations for backhaul in your network. Each backhaul connection may look different– it could be a fiber–optic cable coming into your building, a wireless point–to–point link on your roof (described below), or an ethernet port on your Internet Service Provider (ISP)’s router.

Access networks: This is the part of the network that connects your end users to their backhaul (source of internet). They can be wireless (e.g. WiFi or cellular) or wired (e.g. cable or fiber to the home).

Access Points (APs): These are special nodes that share network access with many users from a single point, creating “access networks.” Cellular towers and WiFi routers that a smartphone uses to connect to the internet are all different types of “access points.”

Captive Portal: Sometimes called a Splash Page, a captive portal directs any user of a particular network to one particular webpage. The user is required to view and interact with this webpage before they can access the network.

Data Centre: Organizations who provide centralized data storage services for one interdependence,

- Will you use software for automated **network monitoring or data collection**? Compatible software may depend on specific features of your network devices, e.g. their supported firmware (such as OpenWRT, compatible with **OpenWISP**) or monitoring protocols (such as **SNMP**).
- Are there high points that are very hard to access in your network design, for example mountain tops or telecommunications towers? Will you **need to hire** a certified tower climber to maintain this gear, or is there someone reliably available in your community who can do it?
- Will two people or organizations on either side of a link be able to **maintain good working relationships** and procedures over time so they can repair their link if it becomes disconnected (even several years after being installed)?
- Is there a plan for **replacing damaged gear**, e.g. after lightning strikes? How about gear at its “end-of-life” for manufacturer security updates? What upgrades will you prioritize?

Incorporating New Sites and Equipment

You may later be able to acquire new sites with better vantage points for wireless gear.

- How will you integrate new locations, members, and equipment **both physically and organizationally** into your network?
- Can equipment at a site be moved if needed?

Strategic Planning

Network Expansion and User Base Planning

Sometimes it can be hard to predict who will be interested in joining, which can make coverage area planning hard. More community engagement and planning ahead can make this easier, but be ready to adapt the network to a changing user base. Ideally, when you plan your network you want take into account possible future users to make any expansion more efficient and easier.

- Do you have a good idea of where future users are located, i.e. community members who one day you may have to reach with the network?
- Do you have a **plan for growth/expansion**?

Supporting Network Reliability and Maintenance

Every link you establish (especially wireless) will need to be maintained by you or other members over time. Ensure that each new link or piece of equipment is explicitly “on someone’s radar” with a plan for maintenance and monitoring, even if that person is just the DIY end-user themself.

- How will you or other community members be informed when a link fails or decreases in effectiveness, e.g., if wireless point-to-point antennas become misaligned due to strong winds? Do you have **backup communications channels**?



autonomous management, and growth.

Middle Mile Network: Middle Mile Network describes Internet infrastructure that links together “last mile” (i.e., local) networks to the wider Internet through regional networks and service providers.

Point-to-point (PTP) link: A connection (usually wireless) between just two devices (point A to point B). These links tend to use very tightly focused directional antennas, such as parabolic dishes, that have to be aimed accurately at each other.

Point-to-multipoint (PtMP) network: A network (typically wireless) connecting one point with several others (for example, an AP and multiple end users). These antennas tend to look very different, for example like flat panels or wider horns, so that their signal can be spread across a wider angle in space to communicate with multiple devices at once.

Virtual Network: Virtual networks are networks created with software and hardware to emulate physical networks by linking together a specific group of devices and users, for example a large company who creates a virtual private network (VPN) to create secure and efficient data flow among its employees.

References: Lesson 6–Designing a Network–Aug 1:

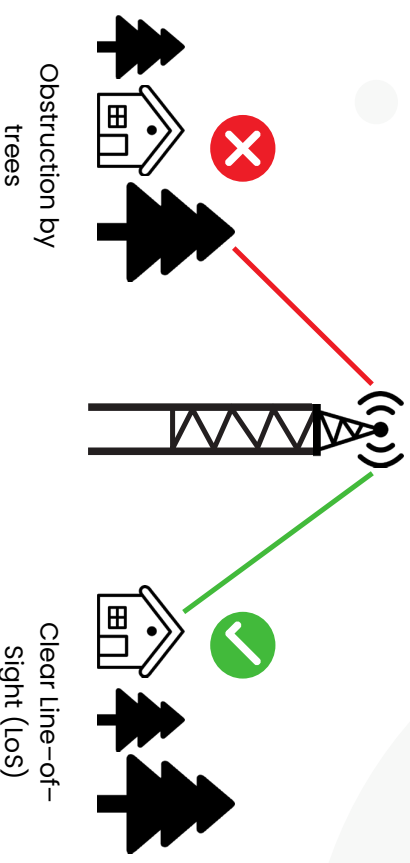
<https://bitly/ds-lesson-designing-wireless>

An important consideration for community networks is the question of **tiered access**. Will everyone in the community have the same access to the network, or will the network offer tiered services; that is, different services depending on the level of commitment or engagement. For example, a community network can offer limited free services for everyone in the community with certain restrictions such as band width, time or usage, and unlimited services for network members who volunteer or pay fees, etc.

Technical Planning

Planning your network will require gathering information. Here is a list of questions to guide your planning:

01. Intranet v. Internet? If access to the Internet is an integral purpose of your network's operation, where will you source backhaul?
02. What is the geographic territory that you want the network to reach? Where are the users, and what network speeds will they require for their everyday use?
03. Which radio technologies and radio frequencies to choose for your community network? WiFi, TV White Space, etc. This may depend on



Line of sight Image Reference:

<https://www.crowdsnestbbn.net/how-it-works.html>

Try drawing a map of the region you are hoping to reach with the network, showing relative heights of features in the area. You can use free **topography data and mapping tools** such as Google Earth Pro to run a “viewshed analysis” to see what LOS looks like from any given point.

References:

- Lesson 6 – Designing a Network – Aug 1!
- <https://bit.ly/ds-lesson-designing-wireless>
- Inventory the Neighborhood: <https://commotionwireless.net/docs/cck/planning/inventory-the-neighborhood/>
- Google Earth Pro: <https://www.youtube.com/watch?v=adZbMGPPDwcw&list=PLZ1cQ-uIXTA7nkhdf5XU-ELCEBfUbktoX&index=6>

Wireless Coverage Area Analysis

Designing and planning a network means thinking about both where network nodes should physically be installed to cover the intended user population, who owns the land, whose buildings are in strategic locations, how signals can be moved from one part of the community to other parts.

Wireless connections often rely on **line-of-sight (LoS)**, i.e. data can only be sent if the transmitter and receiver nodes can visibly see each other without obstructions between them. This means an understanding of regional topography is needed to design the network.

- Where are your backhaul connections physically available, and where are your intended users located?
- Where are the high points and low points in the community?
- How will you get signals to low-lying areas if needed?
- Are there trees, mountains or buildings between intended nodes that have to be worked around or added to the network?

local regulations and licensing available to you, as well as cost for equipment and operation, and complexity of the install (such as power requirements).

04. For wireless networks, you will likely need line-of-sight (LoS) between nodes if you are using high radio frequencies (upwards of 1GHz). If so, what topographical features must be taken into consideration in planning node locations?
05. Who do you need permissions from for access to backhaul sites or high points? For mounting equipment on these structures or land?
06. Do you have the required technical know-how and/or tools to build and install network equipment? Who in the community has the technical know-how and any required licenses (such as for electrical work)? Who outside of the community can you ask for help? What training opportunities are available?
07. Open source or Paid services? While popular among CNs for their DIY spirit and low cost, open source ecosystems are ever-changing. If you anticipate needing lots of outside technical support, low-cost commercial options may better suit your needs. It will help to stay up-to-date about both types of options.

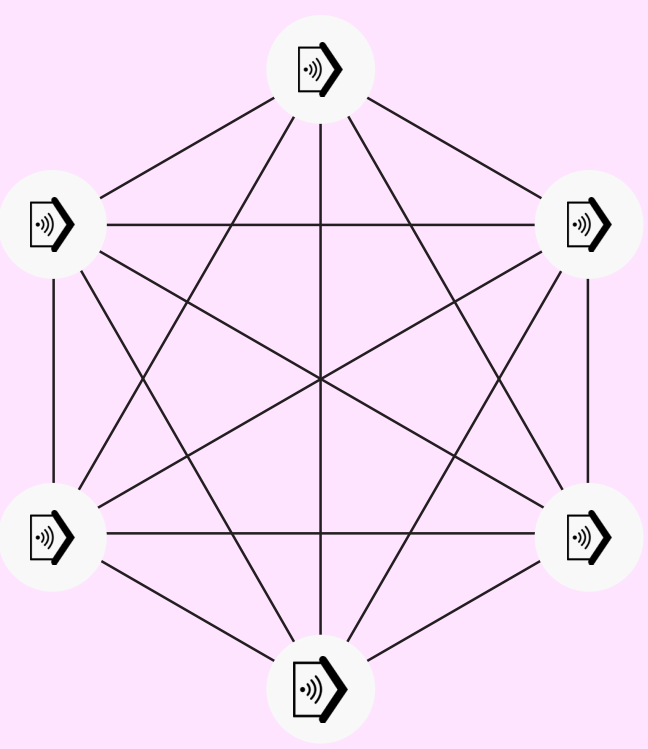
How Community Networks Work (Technical Primer)

You can think of wired networks as hoses carrying water, and wireless networks as sprinklers or spigots for the water. Wired networks such as fiber-optic, cable, or ethernet will often be higher performance (faster speeds) than wireless networks, and (depending on how rugged the implementation, for example whether conduit is used for wires) will often be more resilient to the elements and easier to maintain. However, wireless networks can be much cheaper when starting out, because you need less equipment and physical material to cover a large area with network access. Low-end wireless equipment will typically need to be upgraded sooner and go out of date faster due to the changing expectations of users, their devices, and web technology.

Wireless networks (such as Wifi) are also how your users will probably ultimately use the internet access, so they will be necessary in the end.

become a pain point, because “standard” commercial network equipment configurations and firmware often do not support mesh networking functions. Special and often open-source firmware may have to be “flashed” (i.e. uploaded manually onto devices). See our Resource Guide near the end of the Road Map for open-source network software suggestions.

Mesh Networks



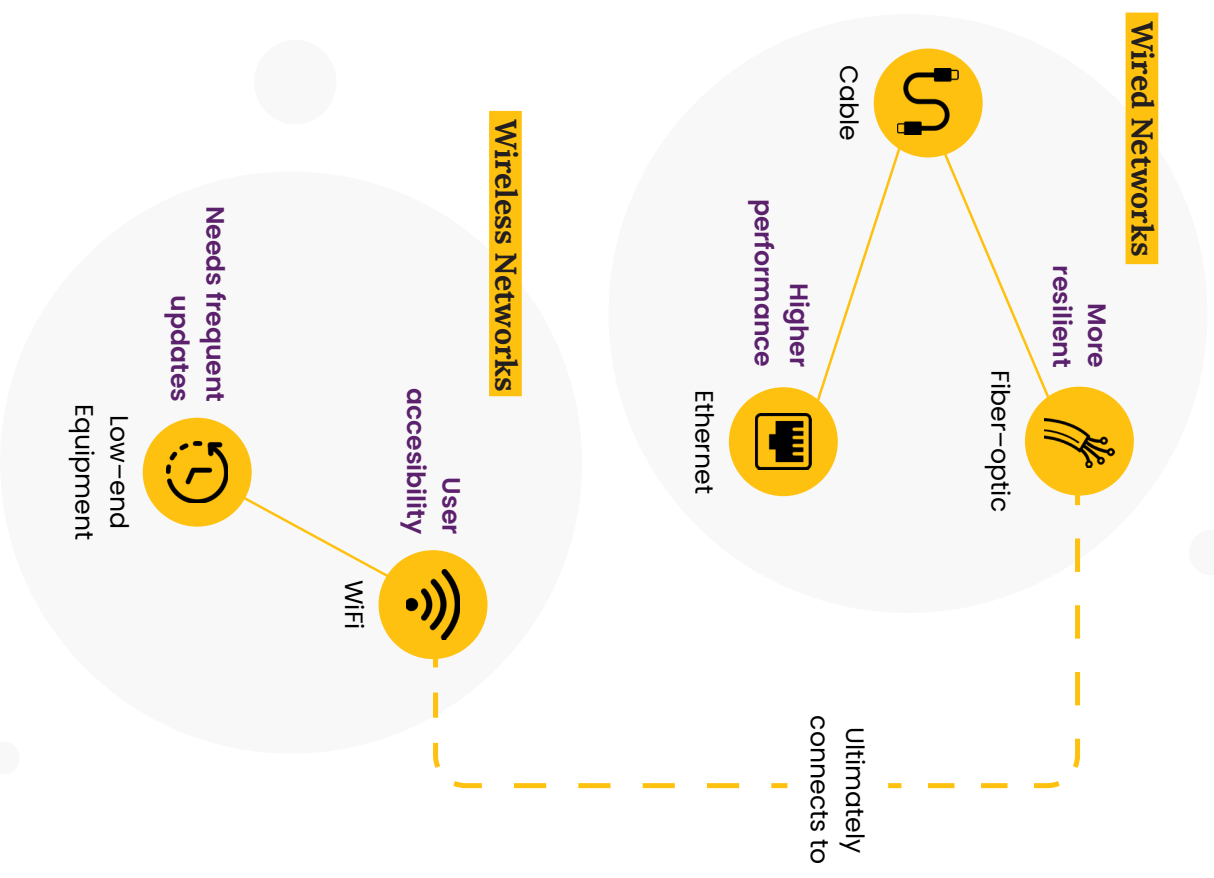
Example of full mesh network topology



How will users communicate and get help if there is a network outage?

Set up protocols and signage (such as stickers on equipment or printed forms/signs) for how users will reach out for help, troubleshoot, and keep track of information such as their WiFi passwords and equipment locations. Manage their expectations for how they will be helped, by who, how quickly, and how independent they are expected to be. You will likely want to exchange contact info, and set up member **agreements and terms of service** for new users to sign. Many networks also depend on automated recurring payments (often structured as suggested donations), and/or expectations for recurring participation or labor from their members as part of the membership model.

If you have a **mesh network**, new nodes' connectivity will come to depend on nodes and people that joined the network before them. The interconnectedness created by a mesh network structure can be a strength for community maintenance, as the nodes' physical interdependence can knit relationships together. However, the physical topology of a mesh network may be more fragile and require more frequent physical labor to keep up and repair. The maintenance of the firmware or software may

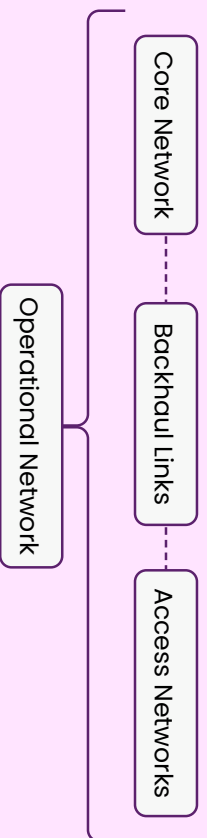


Network Relationships & Maintenance

Every piece of equipment you deploy, as well as the location you deploy it on (and the corresponding relationship and logistics that give you access to that location), will need to be maintained for the continued operation of the network.

Make sure you have good communicators on your team who are ready and willing to maintain and strengthen community relationships over time.

Your network will consist of one or more following components: a “core network,” “backhaul links” for your nodes, and “access network. All of these may incur operational costs and require maintenance.”



Backhaul links or “upstream” internet service are typically paid for on a recurring basis, unless you have an ongoing donation of a certain amount of bandwidth through an ISP, university, or other institution. **Look for support from regional middle mile service providers** who often operate as nonprofits for the benefit of research and education.

These agreements are easier to get if you have equipment located in a data center or **Internet Exchange Point (IXP)** that ISPs connect to.

If your backhaul is provided through a **wireless point-to-point (PTP) link**, you may need to rent or access donated roof space as well as electricity to support your equipment.

Your equipment may also need maintenance, for example if it gets damaged or knocked out of alignment by weather (frequent in some areas). Be sure to establish processes, human roles and responsibilities (including skills training if needed), and expectations for this maintenance.

Access network equipment such as WiFi routers will also need ongoing power, space and mounting locations/permissions, and maintenance. **Users will need support over time** with troubleshooting or updating their access networks, so think about how they will reach you and other network members (e.g. via phone number, email, WhatsApp, or other communication platforms). It may help to set up a “captive portal” (or splash/landing page) for public or guest access networks (often offered for non-members) that help spread information about your community network and limit “hogging” of network resources by non-members via time or bandwidth limits.