

“The Network Is an Excuse”: Hardware Maintenance Supporting Community

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The global *community networking* movement promotes locally-managed network infrastructure as a strategy for affordable Internet connectivity. This case study investigates a group of collectively managed WiFi Internet networks in Argentina and the technologists who design the networking hardware and software. Members of these community networks collaborate on maintenance and repair and practice new forms of collective work. Drawing on Actor-Network Theory, we show that the networking technologies play a role in the social relations of their maintenance and that they are intentionally configured to do so. For technology designers and deployers, we suggest a path beyond designing for easy repair: since every breakdown is an opportunity to learn, we should design for accessible repair experiences that enable effective collaborative learning.

CCS Concepts: • **Human-centered computing** → Empirical studies in HCI.

Additional Key Words and Phrases: community networks; communities of practice; repair; ICTD

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1 INTRODUCTION

A growing movement of ICT users and designers promotes community-run telecommunications networks as a way to address connectivity challenges [35] and support local self-determination [6]. Belli defines community networks (CNs) as “collaborative networks, developed in a bottom-up fashion by groups of individuals that conceive, deploy and manage the new network infrastructure as a common good” [6].

Our setting is a group of CNs in Córdoba, Argentina that collaborate with our research partner, the AlterMundi Civil Association, a prominent community networking organization. AlterMundi promotes community development through the creation of networking technology, such as the open-hardware LibreRouter [16]. For AlterMundi, CNs are a step towards the “right to co-create the Internet”: the right not just to access telecommunications, but to build one’s own infrastructure and to control one’s own online interactions [15]. Indeed, a persistent challenge expressed by our interviewees is how best to broaden engagement by CN members in the design, creation, and maintenance of networking technology.

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The Human-Computer Interaction (HCI) community has begun to explore how technicians around the world learn to repair electronics [3, 25, 29] and the role technical artifacts play in community building [12, 34]. Laypeople contribute to repair of these CNs, and their participation is shaped in part by material aspects of the networking technologies.

Early work on CN maintenance suggests improving fault diagnosis to facilitate novice repair and identifies a need for educational approaches to supporting CN repair [45]. Indeed, simply designing devices to minimize repair fails to ensure that devices are readily repairable in their context of use [39]. In this case, the networking technologies are designed and configured by members of the CNs and of AlterMundi to nurture an accessible repair community of practice, suggesting one such “educational approach.” Using the fact that every breakdown is an opportunity to learn, the CNs try to support broad participation in repair. We contribute to the new, small body of scholarship on the sociality of repair and maintenance of community networks in the Global South, a set of writing with shared interest in demonstrating the complexity of the connections between the materiality of CN hardware and participation in CNs [9, 14, 29].

For implementors of new CNs and for organizations supporting CNs, we observe that a primary challenge is building and nurturing a community of learners. To better understand how material objects mediate cooperative work, we use Actor-Network Theory to analyze how community-run networking technology encourages and affords different kinds of community engagement. The purpose of this case study is to document how networking technology can be used to address a community network’s need to building a novice community of practice based on repair and maintenance of network hardware.

2 RELATED WORK

2.1 Community ICTs and Community Networks

Community network literature generally focuses on costs and impacts of newly deployed information and communication technologies (ICTs) [e.g., 20, 46]. Such perspectives overlook questions related to the development process itself, including links between appropriate technologies, cultural contexts and technology designs, as well as questions of long-term sustainability [1, 2, 18, 31]. Numerous researchers have advocated for more interdisciplinary and contextually grounded approaches to community ICT research [19, 24, 32, 33, 41, 48, 49]; however, little interdisciplinary research addresses both ICT artifact design and “the subtle interaction between the ICT artifact and the context” [49].

2.2 Actor-Network Theory

Actor Network Theory (ANT) is a framework for interpretation that understands the social world as the unstable product of a network of alliances, interactions, and controversies among actors—human and non-human [30]. In the interest of explaining social ties, ANT looks at how actors act on each other and how certain relations are made durable by non-human actors. This makes ANT an attractive framework for studying telecommunications networks since it helps us consider the materiality of technical infrastructures in tandem with human action [43, 47].

ANT has proven helpful in examining the creation of community ICT networks beyond simple explanations of success and failure based on measurements of impacts [21, 42]. Further, it is useful in revealing dissonance between results stimulated by external development decisions and the needs of local communities [4, 37], and has been embraced by some researchers as a framework to overcome simplistic understandings of how to bridge the digital divide [40].

Though wireless mesh networks include many parts, we treat networking technology as a single actor, *not* as an actor-network. We use the term “network” in three ways: in the ANT jargon

actor-network, to refer to the *networking hardware* that makes up a wireless mesh network, and to refer to a *whole community network* (CN): the hardware, the people who identify as members of the network, and the relationships between them. For example, Quintana Libre is a CN. The network in the second sense is an actor that shapes and is shaped by the relations and associations that comprise the community network in the third sense.

2.3 Communities of Practice

Wenger’s now-classic theory of *communities of practice* is a social theory of learning that identifies knowledge and knowing as participating competently in valued enterprises. A “community created over time by the sustained pursuit of a shared enterprise” in which practices have been adjusted to “reflect both the pursuit of [the enterprise] and the attendant social relations” is a *community of practice* [50, p45]. For Wenger, the ultimate goal of learning is the *social production of meaning*, which is continually negotiated through the dual processes of *participation* and *reification*: participation is direct interaction between people, and reification is the production of artifacts (e.g. tools, documentation, methods, lesson plans) to organize participation. But, this is not a strict human/non-human dichotomy, and thus it is a natural pairing for ANT; Wenger writes, “the duality of participation and reification suggests precisely that, in terms of meaning, people and things cannot be defined independently of each other” [50, p70].

We use this case study to argue that lay members of a CN can participate in a community of practice focused on learning to maintain networking hardware (with some expert support). In this paper, such a community of practice includes (1) a broad group of members with little to no prior experience with telecommunications technology maintenance, and (2) collaboration between lay members on the technicalities of maintenance. We posit that nurturing a novice community of practice can anticipate breakdown and facilitate repair.

2.4 Repair and Design

Amid HCI’s focus on creation and design, repair and maintenance scholars have centered repair as a crucial part of technology use, since everything breaks eventually. This turn is what Jackson refers to as “broken world thinking.” Writing on the sociality of repair has elaborated the many connections between repair work and repairer’s social worlds. For instance, Houston and Jackson argue that repairers rely on both local (walking distance) and global (online) knowledge networks [23], and Jang et al. point out how repairers depend on relationships with parts suppliers, emphasizing the role of trust in those relationships [29]. This approach has borne critical analyses of divisions in who does which maintenance work. For example, De Wilde describes how women are expected to do cleaning work [13], and Bidwell describes how women are expect not to climb CN towers [8]. Similarly, Crooks describes how in the absence of structured support for classroom technology, the troubleshooting of iPads in an LA public school fell to unpaid student labor [11].

The literature about digital device repair commonly finds it important because of sustainability issues [25, 26, 28], an important perspective given the proliferation of electronic waste and the exploitative labor practices of rare metal mining. Houston’s work that interprets digital device repair as care expands our ability to appreciate the labor of repair through attention to repairers’ personal and emotional investment, and it calls on ICTD scholars to attend to the ethico-political commitments of their/our work [22, 23]. Recent work by Rifat et al. dexterously engages both the e-waste and care considerations [38]. In this paper, we further extend this appreciation of repair by focusing on the social relations repair supports.

To make that argument more precisely, we lean on de Laet and Mol’s work, translating their arguments about the Zimbabwe Bush Pump to the world of telecommunications [12]. They write that the Bush Pump’s need for maintenance “*constitutes* its community.”

After all, if pumps are to be successfully maintained, some degree of organization and division of responsibility are needed; the community needs to assume joint ownership and so affirm itself as a community. And so with a Bush Pump – or any other standard pump – the community acquires a piece of equipment that it subsequently enrolls in its efforts to organize and form itself.

In a direct parallel, Section 4.1 documents social relations made durable by the maintenance needs of the networking technology.

Throughout maintenance and repair literature, particularly in HCI, there is a general admonishment to “design for repair,” but it is not yet well understood *how* we might design for repair. Rosner and Ames developed a crucial critique that “breakdown and repair are not processes that designers can effectively script ahead of time” [39]. They point to failures to repair the XO laptops of the One Laptop Per Child program as evidence that the design of a device itself, or even a device and its attendant documentation, is insufficient to ensure that it will be maintained. Among complicating factors they identify are *repair infrastructure* and user *expertise* (as we will see, both are aspects of local context which AlterMundi nurtures through their design processes and collaborations with CNs).

If repair cannot be baked into a device, technology designers interested in repair must direct their efforts to the contexts of use and maintenance. Houston and Jackson responded to this critique with a call for device manufacturers to “intervene in the aftermarket” [22], echoing Jackson et al.’s earlier call for manufacturers to develop connections to local “repair worlds” [27]. Jang et al. gave a more detailed suggestion for how such “aftermarket” interventions could work by schematizing a “repair ecosystem” [29]. So far there is no documentation in the literature of a digital device manufacturers’ or designers’ attempts to engage with local repair communities. Our paper describes how the AlterMundi technologists relate to a novice repair community of practice, presenting initial evidence of how such connections can work.

Our focus on unpaid novice repair contrasts with the usual focus on paid experts (e.g. Orr’s original study at Xerox or the cell phone repairers of Dhaka [3, 36]). This raises some natural questions which we leave to future work: how can device manufacturers connect to professional repair worlds? and to what extent are AlterMundi’s strategies particular to the unpaid novice repair context?

3 METHODS

3.1 Collaboration and Topic Selection

This research was conducted as a partnership between AlterMundi and academics from the U.S. and Canada. We decided to collaborate based on our shared interest in documenting how successful CNs work in order to support the community networking movement. This paper is just one academic expression of that goal.

3.2 Sampling Rationale

We first chose to investigate the Quintana Libre (the CN in José de la Quintana) network because of its relatively large number of members and network nodes, around 70 households. We then expanded our data collection to three of the other four CNs created in partnership with AlterMundi in Córdoba province, Argentina: La Bolsa Libre, La Serranita Libre, and Anisacate Libre (marked in Figure 1). Each CN is named after the town where it is located.

We identified interviewees through AlterMundi, recruiting CN participants in as wide a variety of roles as possible. We interviewed technologists who design networking equipment (4), people with official responsibilities in their networks (4) (e.g. collecting money), people trying to restart

non-operational networks (4), people responsible for network hardware they mounted on their homes (12), and enthusiastic network users (15). In total we conducted 13 interviews with 15 people: 5 women and 10 men. Table 1 provides more detail.

3.3 Conducting Interviews

Interviews were semi-structured. Topics included how CNs are maintained, financed, used, designed, and governed. Though Nicolás Pace is a co-author on this paper, we interviewed him as part of this study in his capacity as a technology designer, community animator, and member of AlterMundi.

All authors conducted the interviews together. Interviews were conducted in a mix of Spanish and English, with Nicolás Pace translating. The English portion of the interviews was transcribed for analysis. Interviews lasted roughly 45-90 minutes. Participants are identified by their real names, at their request. Data collection for this study was approved by the Athabasca University Ethics Review Board.

3.4 Data Analysis

We present a snapshot of a few specific CNs at one point in time, centering our analysis on the wireless mesh networks themselves to reveal how networking technology mediates others' courses of action. In Latour's 2005 re-articulation of ANT *mediation* is a key concept, referring to an actor's mobilization to act in response to being acted upon [30]. For example, when a swarm of wasps builds a nest inside a router, the router mediates the wasps' action by *stopping* the flow of data packets moving through it.

The first author analyzed the interview transcripts. The interview with Nicolás Pace was coded first with an open coding, and then these codes were synthesized into a small set of high-level codes reflecting this ANT-based interest in understanding the role of the networking technology as an active participant in CN sociality. Specifically, the coding scheme focuses on courses of action mediated by networking technology and the actions of the technology mediated by others. This set of codes was then used to code the full set of transcripts.

3.5 Validity & Limitations

Since we have only interviewed a subset of CN members, we necessarily present a partial view of experiences in the CNs. Our sampling strategy—seeking a diversity of roles—was our attempt to make the most of limited time to conduct interviews. Relationships between CNs and those who are not involved is a ripe area for future work. In particular, people who have left CNs would provide a valuable complementary perspective.

Our analysis employed multiple rounds of coding as part of a process of rereading transcripts and revisiting audio recordings to ensure the account is faithful to our interviewees' perspectives. Following ANT, in the analysis we try to understand how research subjects construct meaning, since this is an integral aspect of understanding how actor-networks emerge and are sustained.

As an additional check on the validity of our results, the bulk of the analysis was conducted without Nicolás Pace. He read through early drafts and corrected any points in conflict with his

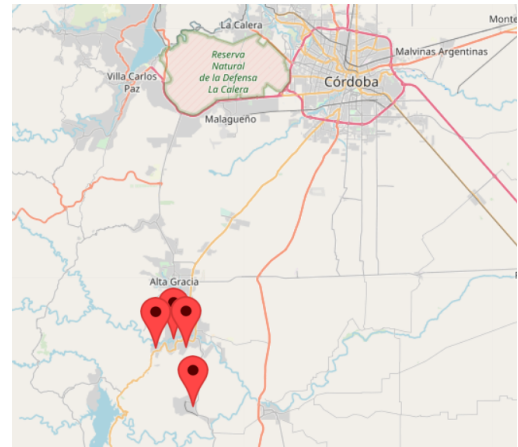


Fig. 1. Research sites in Córdoba province, Argentina (from OpenStreetMap).

Name	Gen.	Affiliations	Roles
Gio	M	AlterMundi (AM)	AM tech developer, visiting
Nicolás Pace	M	AM	AM tech developer, long-term visitor
Martin	M	Anisacate Libre	Network member
Walter	M	Anisacate Libre	Network member
Alajandro	M	La Bolsa Libre	Network member
Natalia	F	La Bolsa Libre	Network founding member
Marcos	M	Quintana Libre, AM	AM tech developer, resident
Florencia	F	Quintana Libre, AM	Network <i>referente</i>
Jessica	F	Quintana Libre, AM	AM & network founding member
Nicolás Echániz	M	Quintana Libre, AM	AM & network founding member
Daniel	M	Quintana Libre, AM	Network founding member, early admin
Virginia	F	Quintana Libre, AM	Network founding member, early admin
Manel	M	Quintana Libre	Involved network member
Soledad	F	(Quintana Libre)	Potential new network member
Leandro	M	La Serranita Libre	Network founding member

Table 1. Interviewees by gender, CN/AlterMundi affiliations, and CN involvement. “Early admin” role refers to procuring initial bandwidth and managing finances for the Quintana Libre network, respectively; these roles have since been distributed among others.

understanding as a very involved member of AlterMundi. These corrections were minor (but important).

After writing a draft of this paper, we met with participants again to assess the validity of our interpretations (a form of member check). We invited all of our participants and conducted a small group discussion online with the few who were available to meet. We described both our descriptive findings and our interpretations, and we discussed two main questions: whether the interpretations fit their understanding and what feedback they have about how we are representing their communities. The response was quite positive, with enthusiastic support for the interpretations we were least certain about, and we learned more detail about how these issues are continuing to play out.

4 FINDINGS

4.1 Relationships Constitute the Community of Practice

It's a social relation thing. That's the most important part of the network. It's not Internet... The network is an excuse. That's what I understand... and why I am part of it. For sure, there are more points of view, but that's what I think. —Manel

For some interviewees, the CNs are an excuse to build community relationships. The networks bring together people of different backgrounds who have different goals for the CNs by prompting and reinforcing a variety of relationships, which in turn constitute the groups as communities.

The CNs are communities of *practice*; we identify their practices as participating in the relationships discussed here. To the extent that these are repeated practices and named relationships, they reify meanings that people bring to them, such as the importance of Internet connectivity or the productive challenge of collaboration. To participate *competently* in the community of practice is to plan, talk about, and do maintenance with others.

A number of concrete community strategies emerged.

4.1.1 Workshops. Quintana Libre runs workshops to introduce new people into the network. At the workshops, participants together assemble new roof-mounted nodes that manage the mesh networking protocol (while standard commercial routers installed inside users’ homes are used as WiFi hotspots). Previously, AlterMundi’s recommended way of assembling a node was to purchase a specific commercially available router, open up the case and weatherproof it, and install a new antenna. That model of router they used is no longer produced.

AlterMundi has designed and manufactured an alternative—the LibreRouter—which, among other differences, does not require weatherproofing. However, Florencia told us that this means the future of the workshops is uncertain.

For every [workshop] there is a coordinator, and all the people that want to build their own routers build their routers, their nodes. Now, with the LibreRouter, that you don’t need to build it, now we need to think. What collective dynamic do we build around the joining action so those people that will join understand what [a community network is], acquire the knowledge to manage it, and also assume the commitment to sustain it?

Florencia identified that some characteristics of their group (e.g., shared understanding and commitment to sustaining the network) are reproduced by these workshops. Without the need for assembling routers, she seeks a way to replace their valuable social functions.

La Bolsa Libre holds workshops too, and Alajandro sees them as playing an important social role: to “reinforce the importance of being together,” which he sees as political, “a way of resist[ing] this right-wing struggle.” Though these workshops also teach technical skills, it’s the social pedagogy of learning to build community and solve problems collaboratively that Alajandro emphasizes.

4.1.2 Collaborative Maintenance. Among our interviewees, novices doing maintenance are usually supported by someone else, such as neighbors who have done a similar task, or an expert in another town. Jessica explained how these mentoring relationships can begin at workshops or other CN meetings.

[In the workshops,] sometimes, [people have] organized collaborations like, “Oh, so you live in that house that I can see from my window. Well, if you will manage your node this Saturday, when I can go there and help you.” So, they meet each other, they help each other, just because they live in the [same area].

The collaborative work of maintaining the network brings people together and forms social ties. Those ties, in turn, support maintenance. Martin, a member of La Bolsa Libre, maintained a node connecting to the neighboring town of Anisacate, and would work with Juan (a pseudonym), who managed the other end, to solve hardware problems. Martin told us that when there was a major connection problem, he and Juan did not have the right relationship to be able to communicate and perform a repair.

This link that was broken—it was providing internet to Anisacate—has never been fixed, and it’s something—It might be something simple, but there was no communication that helped. . . .It’s not about having the number or to be able to call someone; it’s the bond that makes the communication possible.

However, Martin clarified that it’s not just that the human relationship was unable to support the relationship between the routers—the technical link failing also weakened the social bond.

[W]hen we have the link, we talk to [Juan] almost every week. Like, we have a fluent relationship with, like, a friendship, you know. When the link went down, we stopped talking. So the network in a way was facilitating a social relationship. The other way around too, but the network was making that happen.

Studying the Cuban CN SNET, Dye et al. also observe that maintaining connections between nodes depends on social relationships—she describes how a pair of users were disconnected from the CN because the owner of the node they connected to was uninterested in supporting the technical link and was able to exclude them due to their lack of “social influence” [14]. We discuss inclusion/exclusion in our case in more detail in section 4.4.

In La Bolsa Libre, the backhaul antenna connects to another antenna on a mountain a few kilometers away.¹ A few months before our interviews, a storm had knocked the mountaintop antenna out of alignment. Since then, the CN has been disconnected. In our interview with Alajandro, we discussed plans to realign the antenna. The research team was initially eager to join in the repair to contribute positively to the network as participant-observers; however, upon learning that the La Bolsa Libre community had already organized themselves to conduct the repair, Nicolás Pace told us not to join.

If you have too much technical knowledge, you can affect negatively the community. If we [the research team] go—if you come with me and we go on Friday to the mountain—we would be preventing for them [the members of the network] to go to the mountain and deal with it. So. And they were already organizing. . . . It’s a healthy mechanism.

According to Nicolás Pace, repair is an opportunity for learning; realigning this antenna is not just a social activity, but a challenge with pedagogical value. CN members *learning* to repair was understood to contribute to long-term network operation as much as, if not more than, the repair itself. If we intervened to simplify the process, we would be denying them a chance to exercise their technical problem solving capacities and expand their experience.

4.1.3 Assemblies and Reunions. In order to coordinate the repair of the mountaintop antenna, members of the La Bolsa Libre network planned a reunion event—a barbecue—for the upcoming weekend. Having not met in a while, the group would use the CN as an excuse to strengthen important social bonds. By organizing the barbecue around the CN, La Bolsa Libre’s members actively constitute themselves as a community despite their network’s current dysfunction.

This finding also echoes a comment from one of Dye’s participants in their investigation of the Cuban CN SNET: discussing the in-person meetups of the CN members, Alejandro (Male, 65) says “The most important thing about SNET is the relationship between all users” [14].

Quintana Libre members hold regular assemblies to make collective decisions about the network, such as managing membership and collecting money for repairs and upgrades. Jessica explained:

Jessica: You have to ask for help if you can’t solve [your problem] yourself. [For] people who . . . don’t feel [the] confidence to say, “I have a problem,” . . . we decided in [the] assembly . . . that people have to come a new [assembly] and a new workshop of the meeting to ask for . . . reentry.

Nicolás Pace: They have to be resocialized.

Like the La Bolsa Libre barbecue, these regular meetings help to constitute Quintana Libre as a community. Further, they are used to maintain norms and expectations, to “resocialize.” Resocialization through assemblies is used to re-establish, in Wenger’s terms, *mutuality of engagement* in response to people not *participating competently*.

4.2 Motivations are the foundation of relationships: What people want

Investigating some of the same community networks, Bidwell identified an important distinction between “members whose families had lived locally for generations and newcomers who moved

¹A *backhaul* connection is a link between a local network and the greater Internet. Another long-range wireless link connects the mountaintop antenna to the Internet via the University of Córdoba, which allows use of their excess bandwidth.

to the area during its gentrification in the past decade” [8]. These two groups often give different meanings to the network. She writes, “Newcomers more often related the CN to political commitments... In contrast, members whose families had lived locally for generations... tended to relate the CNs to affordable connectivity.” In our study, interviewees value the CNs for many reasons; e.g., communicating with loved ones, activism and community independence, or professional/economic use. From these, we identify affordable connectivity and political vision as two parallel modes in which desires about the CNs are produced.²

4.2.1 Affordable Internet. When Daniel moved to José de La Quintana, he was CEO of a telecommunications company. He wanted Internet service at his house and was working outside with a gardener when a representative from the local Internet Service Provider (ISP) came by. The representative described the new infrastructure the ISP would have to install to reach Daniel’s house and quoted a price triple what Daniel knew it actually costs. At that moment, the gardener interjected, “Why don’t you go to see these hippies? They have Internet that’s free and super-fast.” From there, Daniel quickly became heavily involved in Quintana Libre.

Like Daniel, most of our interviewees want a CN because they want connectivity and local alternatives are generally slower or much more expensive. In Quintana Libre, the monthly fee for using the network is ARS 100, about USD 1.5, significantly less than commercial Internet costs. The other CNs are similar. Members of Quintana Libre who cannot afford that price can instead support the network with their labor. Jessica, a co-founder of AlterMundi, described the economic situation:

[I]t’s not a high-income place. But anyway, people usually have some kind of cellphone data connectivity which may be not permanent. Like they pay for it daily.

The desire for affordable connectivity is distinct from the collective vision discussed next, but these are not mutually exclusive: many interviewees express both desires.

4.2.2 Collective Problem Solving as Political Vision. AlterMundi operates on principles that support and encourage open source technology and local community effort to combat digital exclusion [5]. They view local collective responses to problems—whether global, local or regional—as the most strategic for community survival.³ CNs fit into this vision as both a solution to the problem of communications and as a catalyst for building community relationships, expanding capacities for collective problem solving in general. Nicolás Pace explained:

A dream is to create this empathic territory where communities will start helping each other. Because it’s not [AlterMundi’s] call to help everyone. Our call is to prepare a fertile ground for everyone to be able to do it. ... We [all] directly or indirectly made the communities be vulnerable and be unsustainable and be in danger because of climate change and be dependent on global consumerism... If the communities grow in this empathy, there will be more hands involved in the process of making this [problem solving] happen.

Further, Nicolás Echániz, a co-founder of AlterMundi, described the organization’s goals as being in competition with individualist and capitalist models of service. “[T]he social economic organization here [in Argentina] is an individual capitalist [structure], so that’s I think also a problem [for us].” In contrast, he recounted the relative ease of organizing in a Cuban community he visited to discuss potential CNs, due to robust existing practices of collective action there.

[T]he first meeting [about a CN] was already 70 people from every organization. ... It’s a completely different landscape... social organization. ... They had to set up... one kilometer

²After writing about the distinction between affordability and politics in an earlier draft, we were delighted to find that Bidwell had independently found the same distinction.

³CNs are similarly motivated in other parts of the world, e.g. the “vision-based organizing” of the Equitable Internet Initiative [44].

run of electricity poles and cable, and it was... organized or led by the [state-run] company, but the people dug the holes and brought out the poles and fed the workers [at] each house in that kilometer during 10 days. ... It was not like, "Oh, this was something new." It's common sense. ... They were doing this to bring electricity to one house.

Just as prior experience facilitated the Cuban CN's inception, many of our interviewees hope that experience with CNs will develop capacities for starting other communal projects. Manel, a member of Quintana Libre, identified this inspirational power of CNs: "the relevance of these community networks is that they open a future that is not the official one."

This vision of broad participation in collective work is aspirational; in Córdoba, AlterMundi encountered barriers to collective action rooted in local histories. Argentina has a tradition of local service cooperatives for providing utilities (water, gas, electricity, etc.), which are democratically managed but with delegated responsibility. Nicolás Echániz explained:

The difference [compared to community networks] is that the workers are workers—are hired. People don't go fixing the electrical and water network... I think that for us having this mindset in Argentina about community services, cooperative services, has to do with people understanding quite easily the idea of having a community network. But then, when you start explaining "but you won't be calling the guys from the cooperative to come fix your node. You will fix it yourself," that is a step forward.

In the service cooperative model, the community of practice would be a small group of trained professionals. But in AlterMundi's CN model, it includes a wide range of local novices in addition to some experts. The focus on broad participation illustrates that this vision is about a desire to be in community; this is the community that the CNs are an excuse for.

To achieve broad participation, CN members hold one another personally responsible for maintaining "their node" at their own residence, with support from others.⁴ Manel explained this method of fostering responsibility:

Someone can come and just tell me, "I don't find the problem [with the node]; I've [tried] this." ... If they have done nothing, then no one will pay attention to that request. If they tried and they failed, someone will come and will help.

In other words, people should first try to fix their hardware with their own knowledge, and then ask for help; this practice is a mechanism by which people are held responsible for their piece of the communal infrastructure, a *relation of mutual accountability*, in Wenger's terms.⁵

4.3 Network hardware as actor: What the network wants

The CNs face some trouble: despite the sociopolitical vision that many members share, non-participation lurks around every corner. Networking technology offers some affordances for collaborating with those who do not necessarily share that vision. In particular, it can (1) recruit and excite new people, (2) motivate people to take care of it, and (3) permit multiple readings of why the CNs are valuable.

If networking hardware is the central object of concern, ANT encourages us to ask (1) what/whose actions does the network mediate? and (2) what are the network's actions, and who mediates them? Networking hardware *connects* users' devices and other Internet-connected devices. It *supports* people in communicating with their friends and family. It *allows* children to spend all afternoon on

⁴Because these networks use a mesh architecture, they are primarily composed of a router with one or more antennas mounted on each member's home. A family living together could have one node that is theirs to care for; in other communities with denser populations, the ratio of people to nodes might be higher.

⁵Manel actually rejects the term "responsibility" here because it might suggest coercion: "There are none responsible... Everything is voluntary."

YouTube. Sometimes, it *stops* connecting people to the Internet. And in these situations, it *needs* to be repaired. It also *needs* to be installed, to be upgraded, to be designed.

Soledad, a friend of a Quintana Libre member, visits her friend’s house regularly to connect to the Internet. She was sitting on a chair outside her friend’s house with her laptop, when, as she tells it:

One of the neighbors passed by—he’s building his house—and he stopped with his truck, shocked, and asked [me], ‘you have Internet here?’ And [I] shared with him what the network is.

In this sense, networking hardware *recruits* people into getting involved, raising curiosity and starting conversations: first with Soledad (who is planning to become a member herself), and then with the neighbor. Similarly, Martin related that the network gave him an excuse to talk to neighbors he sees only rarely.

[T]here are other neighbors behind me, around 50 meters, and I was just talking to them. ... The topic allowed me to get in touch with a neighbor I see not too often because they work in Córdoba. Because I have my antenna here, it was easy to get to [discussing] that.

Martin used the physical presence of the antenna to start a conversation about the CN. Thus, it is not just the idea of the CN but the material network hardware that is used to recruit. Indeed, we used the conversation-starting ability of antennae in our data collection: we conducted most interviews in the interviewees’ homes, and, during or after the interview, we would often go to see their antenna.

La Bolsa Libre had been disconnected from the Internet for months, but Alajandro described their ongoing desire to repair their backhaul antenna on the mountain.

[F]ive and a half of the families are on vacation. So it’s very, very difficult to [get] all together and have a reunion and go to [the] mountain to do the work... I think this Sunday we have a reunion. And then I think we will go to the mountain... and do that thing.

Despite, or perhaps because of, the antenna’s prolonged state of disrepair, the networking hardware still “*seduce[s]* people into taking care of it,” to use a phrase of de Laet and Mol’s (emphasis added) [12]. The network does not act alone; rather, it is made to act. The seductive power of the technology is produced jointly by people’s desires for connectivity and for a communal project, the storm’s chaotic ability to de-align antennae, and the decision to use that particular link for backhaul.

Finally, the networking hardware facilitates participation by people who interpret it differently. Manel describes the main difference in how people understand the CNs, echoing Alajandro’s view (from 4.1.1) that the workshops are political.

People don’t usually understand what it means to be social, the communal part. So, they came [to join the network] because they know it’s... cheaper... It’s harder [to get connectivity] because they are in a rural area. There are many motivations. But [to] understand what it means—that’s why the workshops are there, so [that] people understand that it’s not a service.

The workshops are used actively by Quintana Libre to inculcate in new members the community-minded ethos and emphasis on broad participation. But even for some core members of the CNs, connectivity is the goal. Daniel has been a member of Quintana Libre and AlterMundi since their beginnings; here, he explains his focus on connectivity.

Having or not having Internet is more or less autonomy; it doesn’t matter where the Internet come[s] from. ... It’s not that the community network will give autonomy to the community; Internet gives them autonomy.

Thus, it is possible for those who understand the CNs as primarily for connectivity to collaborate with those driven by the sociopolitical vision for the CNs. Crabu and Magaudda, in their study of the Ninux.org CN, found that, “often participants’ involvement began on a mere technical level, but soon started intersecting with political views and practices rooted in leftist and in part anti-capitalist movements,” suggesting a similar flexibility [10].

The hardware, the focal point of the CNs, is a flexible object in that it can permit these multiple interpretations. Despite their disagreement on the meaning of the network, Manel and Daniel could have a productive discussion about the direction in which the antenna of a new node should point, and they share goals such as including more people in the CN. Collaborating on technical issues is a common ground for all involved; this facilitates *mutual engagement*—one of Wenger’s three dimensions of practice as the property of a community.

4.4 Social and technical protocol: The question of power

Anyone can join the CNs if they are within range of a wireless signal, and novices will get help if they are ready to take some responsibility for their node, as indicated by Manel in section 4.2. In practice, however, failing to carry out one or any of these expectations alone has not proven grounds for exclusion. There also needed to be technical failure. Jessica and Nicholàs Eshániz described the sole case of eventual exclusion that we came across, and how the person had installed a connection to the Quintana Libre routers without officially joining the CN.

Nicolás Echániz: *This guy has a client device pointed at our node, which is open.*

Jessica: *He... made that helped by our neighbors.*

Nicolás Echániz: *Yeah, he was helped by our neighbor here*

...

Jessica: *And [the priest] talked to me, and he asked [to] be part of the network, and I told him, “Okay, you have to come to the meeting,” ... and I think that it was too much for his Lefebvrism.*

Nicolás Pace: *He would have to face all the members of the community.*

While the community member had expressed interest in joining and had found a way to connect to the CN without permission, he did not attend any meetings. Eventually, his hardware broke down.

Jessica: *We didn’t disconnect him, but when... his node was*

Nicolás Echániz: *Hit by a lightning or something.*

Jessica: *Yes. Nobody wanted to help, so he [was] disconnect[ed], because—*

Nicolás Pace: *And the network didn’t pay for a replacement, [though usually] the network pays for replacement hardware.*

In this telling, the action of the lightning and networking technology are foregrounded: it is the technical breakdown which occasions his disconnection from the CN. Simultaneously, we see other actors - the other CN members - who did not want to help and decided not to pay for replacement hardware. The priest’s (lack of) participation failed to produce in the other CN members the desire to help repair, and thus he was unable to take advantage of the collaborative mechanisms that others rely on to keep their hardware functional.

Jessica identified four levels of participation in the Cordoba networks: (1) core and ongoing active participation, (2) people who participate when asked, (3) people who only participate occasionally in small ways (4) as described above, people who contribute no labor. Jessica’s four levels of involvement directly parallel Wenger’s four levels of involvement in a community of practice: (1) core, (2) active, (3) peripheral, and (4) outsider [51, p57]. So-called outsiders violate the relations of mutual accountability that shape the joint enterprise of the community of practice. In fact, this standard of “being responsible to others by not making their lives more difficult” has been

identified as a relationship of mutual accountability in prior work [50, p81]. Jessica used the term “leech” to describe the nonreciprocating community member, a term which legitimizes the others’ unwillingness to help the “leech”—this is a discursive component to CN inclusion.

Non-payment of ongoing costs for covering CN operations and non-performance of volunteer services did not prompt disconnection from the CN. Instead, the regulating mechanism for CN inclusion was a combination of technical network function and the willingness of CN members to assist with maintenance. In the case described above, when the “leech’s” node needed repair, no one came to help with the repair because he was not participating in the CN. Broken social protocol combined with technical failure ended the relationship.

We observed two kinds of protocol at work defining network operability. The technical operation of a digital network requires each node to comply with the LibreMesh standards. Inclusion in the event of technical failure—when LibreMesh standards fail to be met—requires compliance with social protocol. Recruiting help when your node breaks requires accepting the terms of mutual accountability on which network functionality depends. Network functionality encompasses both kinds of protocol agreement: technically, between nodes and socially through collective assistance in the event of breakdown beyond a node owner’s capacity to repair. This limitation in capacity is important. If the node owner described above had been able to repair his own node after the lightning strike, there is every indication that he would have been allowed to stay connected. The social protocol is rooted in reciprocity. Since breakdowns are inevitable, the end result is that those who refuse to engage lose their ability to connect (technically) to the CN. In this case, breakdown of hardware is used not as a learning opportunity, but rather to manage the social boundaries of the CN.

This could have an impact on CN members incapable of meeting accountability standards for reasons other than selfishness—for example, physical and mental disability, infirmity due to age or other ailment, lack of time due to parenting obligations, etc. Bidwell in her study of CNs in Indonesia found that “expectations for cooperation affect different parts of local society differently,” revealing that women and elders did not receive the help they required to be connected, despite assertions that those with access would “always help” those without [9]. Though our study did not reveal any similar cases, the possibility of future exclusion remains.

Another dimension of power in CN operations is knowledge, which is directly related to both the social and technological protocol for CN inclusion. The figure of the *leader* or the *geek* is viewed as problematic by many of CN members we spoke to. “Geeks” are people who have more technical knowledge and experience giving them a higher capacity for debugging and repairing network problems, but as a result they can take on too much responsibility. A CN can end up depending on geeks too much, and their efforts could dampen broad participation. The admins of the Cuban CN SNET, for instance, have a role as an obligatory passage point: other users are strictly dependent on their technical labor to remain connected [14]. Some members of AlterMundi, for instance, were concerned (based on experience with other technology projects) that a CN could become dependent on a single geek and then collapse if/when that person decides to move on. Marcos, a software developer with AlterMundi, explained that he tries not to help with too many technical issues in the network so that others with less expertise can expand their technical capacities by volunteering to repair.

Esther: So, for example, if you know, everyone is saying on the WhatsApp group that there’s a problem. Then do you go?

Marcos: No. I read it. I wait for the people to react, and for them to solve it. Many times the problem has nothing to do with the network itself. [Instead,] with the electricity, someone has unplugged the router. Or something like that.

Marcos's expertise is important when there is a bug in the LibreMesh software, but most issues do not reach that level of difficulty. This contrasts with the issue Bidwell identified in the Indonesian CN where those with more technical expertise said they would always help, but did not [9]. Instead, Marcos's decision to selectively not help others with maintenance is pedagogical, designed to foster broad participation. Stepping in to solve problems too often works against the kinds of collective learning and capacity building required for long term CN sustainability where expertise is more evenly distributed among community members.

In contrast to these problematized roles, members of the CNs have developed a formal, positive role for people to assume which they call the *referente*. A referente is a CN member who others can go to for help, usually with technical tasks, but their role extends beyond the technical to the social by working with community members as educators to help realize the political vision for the networks. Often, these are laypeople—technical novices who, through experience with the CN, have just enough knowledge to be useful to others. Florencia, a referente for Quintana Libre, sees growing the group of referentes as crucial for sustaining the network.

Through these and other experiences, we are convinced that the challenge is educate those leaders [referentes]... The people need to have this technical knowledge, need to have political vision, education, that can be available at the disposal of the communities and a bridge for the communities to hold [and] sustain the network.

While the “geek” image suggests highly-specialized technical expertise among a small set of enthusiasts, *referente* is a role more accessible to many community network members that includes some knowledge of the telecommunications technologies involved. “Geek” is a word of warning, a critique of knowledge hierarchy. *Referentes* are a strategy for resisting concentration of knowledge.

Martin, a software engineer and member of the Anisacate CN, has a slightly different view of the referente, one imbuing the role with a certain authority. Martin wanted to update the routers in their network. However, he hadn't (yet) made the change, explaining, “I don't want to challenge the referente.” In this instance, an expert prioritized the social value of referentes to the CN over a quick technical solution. Thus, despite an envisioned non-hierarchical relationship between referentes and other CN members, they, like “leaders” or “geeks,” shape how and when others contribute.

In summary, CN inclusion in these cases depends on three kinds of regulatory conditions: technical agreement between nodes, collective repair, and ongoing resistance to concentration of technical knowledge. The normal assistance CN members provide each other to reestablish connection in the event of failure depends on informal standards of reciprocity, and a perceived lack of reciprocity is as significant as technical failure in determining inclusion/exclusion. These informal standards of reciprocity on which this is based, as observed by Bidwell in Indonesia, can also obscure power imbalances within a community, which is an ongoing concern for the CNs.

5 DESIGNING FOR A REPAIR COMMUNITY OF PRACTICE

5.1 Design Decisions

The LibreRouter is a distillation of principles, values, techniques, and practices, as a whole, not only the device, but the whole proposal. Like, the way we offer the LibreRouter tries to put together... a set of tools that allow the communities to explore the community network territory by themselves, having the capacity to reach out if they need help. —Nicolás Pace

AlterMundi (re)designs their technologies to change *how* the networks need maintenance so that lay people can become more involved in the social relations of maintenance. This section documents technical choices intended to make the community of practice more accessible to novices, thus inscribing AlterMundi's political vision discussed in 4.2.2 into the networking hardware and software. AlterMundi designs for a repair community of practice by (1) helping novices learn

to maintain networking hardware, (2) promoting mutuality of engagement in the community of practice (section 5.2), and (3) flattening the learning curve for network maintenance (section 5.3).

AlterMundi has tried to make the networks they support easier for laypeople to understand. By representing information about the network in accessible ways, users can develop better mental models of how the network functions.

Traditionally, network administration is done via a command-line console or desktop user interface. Experience with the command-line is a sign of software expertise, and these consoles are almost always accessed on a laptop or desktop computer, which many cannot afford. AlterMundi has built a mobile application, LiMe App, that makes many tasks normally done on a command-line possible from a smartphone via a graphical interface. AlterMundi developer Gio notes that they made one task, the traceroute, more legible in the LiMe App by replacing Internet Protocol addresses (IPs) with Spanish names for network nodes.

When I do, for example, a traceroute, for me was very comfortable to just see the IPs. But [for] the community it's not... So the feature request was "please, in the traceroute, show the names, the actual names of the nodes, so we don't have to go in the map and look for the IP address."

This user-driven feature demonstrates an advantage of broad participation in CN development: an engaged group of lay repairers can help improve interfaces for networking technology. Bidwell describes the co-design of the LiMe App in more detail, and argues that it is part of a commoning practice [7]. Concisely and accessibly representing network state directly supports repair. By sharing screenshots of the LiMe App in WhatsApp groups, laypeople communicate network state and recruit debugging help via a smartphones.

To support repairs to the LibreRouter hardware, one of two internal boards is designed with a simple circuit layout so that repairers can comprehend it visually; the other replaceable board concentrates the most complicated components. Similarly, the hardware is made easier to inspect with an abundance of General-Purpose Input/Output (GPIO) pins.

For users who want to get more deeply involved in tinkering with the network, the LibreRouter firmware and LibreMesh software are open source and written in Lua,⁶ selected because it is an easy language to learn even if it is not the favorite tool of AlterMundi's software developers. The software and hardware are both documented thoroughly online (albeit for a somewhat technical audience), with some of AlterMundi's non-expert members on the documentation team. We have not collected data on whether these attempts to make the technology more hackable are being appreciated by users.

Experimenting and tinkering are important for developing practical technical experience. Whether it's a new phone experimentally thrown in the river [27] or an old computer gleefully destroyed [17, p.9], hardware designated for experimentation is made educationally useful since learners can use it without fear of destroying something valuable. Spare parts are useful for more than just successfully completing repairs, the primary use identified in earlier work [22, 29]. Nicolás Pace described the importance of having extra devices to work with.

Because we don't have the resources available, like the equipment, or the money to purchase the equipment, ... our capacity to learn, to experiment, to tinker, to break [is reduced]... if you can break something, it's like you feel much more confident that you can try things out. And if it breaks, you put another one.

To make the LibreRouter and its parts readily available, thought has gone into the supply chains for various components. Part of the motivation for concentrating the most complicated parts of

⁶<https://lua.org>

the router on a single small board is that it is small enough to ship inexpensively (compared to shipping costs for the whole router). Since the design is all open source, even that circuit board could be manufactured by any organization with an electronics laboratory. Likewise, AlterMundi's parabolic antenna design is carefully configured for manufacturability by a common blacksmith. Molding metal into a true parabola is challenging, but their approximation of a parabola is easy to manufacture while retaining functionality.

5.2 Designing to Shape Social Relations

In two of the CNs we visited, participants discussed using a captive portal (a web page to which a WiFi router redirects users when they connect) to set expectations for how people should participate in the network. They envision captive portals as one way to teach newcomers that a CN is not a commercial service, but a community project. Natalia explicitly connected teaching with setting the expectation that users contribute to the network.

For someone that is not part of the network, they need to learn. They can use the network, but they should learn. So if the billboard—the page—should appear not only when they connect... they should be disconnected every 30 minutes maybe, and they need to connect again and to see a video again... It's like reinforcement learning. You as a teacher, you say something, and you do it again, and you do it again, and you do it again. And that way, if you're like this, then you will [get] fed up and you will go.

Natalia wants a captive portal not only to educate people about the CN's social mission, but to ensure that most network resources go to those who become CN members. In making this proposal for a captive portal, Natalia is engaging in design. As imagined, the captive portal would contextualize and interrupt access to the Internet, thus serving as both a rhetorical tool and technical form of gatekeeping. Through interacting with this portal, new users would have to negotiate what the CN means to them—in the theory of communities of practice, such *negotiation of meaning* is a foundation for *mutual engagement* between network users [50, p.73]. Since maintenance is a core part of being a member of the CN, encouraging people to join is also about expanding the repair community of practice.

Another example of social design is the remote support platform in development by AlterMundi to facilitate collaborative problem solving among CNs globally, and between CNs and distant technical experts. Nicolás Pace articulated part of AlterMundi's learning philosophy for us, arguing for the importance of peer-to-peer education.

When networks teach each other, they are the same level. They are not like the hacker over there and we the common people. And that creates a lot of bridges that make the learning process much easier. It can happen with materials and it can happen with training too.

This potential online community of local CN maintainers could help repairers learn in a manner similar to the webfora that Ahmed *et al.* found in Dhaka, Bangladesh [3]—perhaps with more collaboration.

On a local level, this online community has been created. WhatsApp groups for each CN were formed early on to promote collaboration, and they are used for debugging (described above). As town-wide chat groups, these have strengthened social bonds. In Quintana, creation of the CN group led to organization of unrelated activities and creation of additional local groups. Though creating WhatsApp groups is not design in the usual sense, we include it here since it was a technical reconfiguration intended to mediate the networking technology's need for maintenance, similar to the remote support platform.

5.3 Designing for Repair

Fixing or replacing components on circuit boards is an advanced, yet relatively common, repair practice. Jackson et al. describe repairers in Dhaka fixing broken connections on motherboards, a task complicated by the density of components on the board [25]. To simplify repair for novices, as described above, AlterMundi divided the LibreRouter circuit board into two boards. A smaller, denser, replaceable board holds the CPU and the most complicated components, while the larger one is designed for easier access and analysis. The modular design principle is further used to make components that are likely to fail replaceable. Gio described components inside the LibreRouter.

In the middle there is this gas arrestor that protects from electricity discharge, ... and eventually those gas arrestors may burn. ... [Y]ou can see here they are mounted in a way that it is very easy to replace them.

With replaceable gas arrestors, fixing a fault caused by electrical discharge is no longer a lengthy procedure that demands significant expertise, but rather a simpler task that a novice (with the right spare parts) could be coached through. Modular hardware design (à la the Fairphone) has been recognized as supporting repair. In Wyche et al.'s study of rural Kenyan mobile phone repair, participants lament the non-modular design of the circuits in cheap phones compared to the multiple separate circuits of brand-name phones [52].

In addition to modularity, the pins on the LibreRouter's larger board are physically arranged for easy soldering. The board's solder points are exposed on one side, with pins spaced for easy access.

These design decisions shape the LibreRouter, like those described above that shape the LiMe App, the antennas, the potential captive portal, eRepo.io, and the remote CN support platform. Across all of them, we see technologists making decisions intended to not to minimize repair but to change the maintenance of the networking hardware, whether to make it easier (as with replaceable gas arrestors), more accessible (changing the names on the traceroute), or to encourage those who use the network to participate in running the CN (as with the captive portal).

6 CONCLUSION

ANT suggests that social realities emerge from within networks of actors and objects [30]. Uniquely, ANT views non-human creatures and non-living objects as potential actors in the formation of social reality. CN operability and sustainability in this case create particular kinds of demands and relations—for example, demands on “geeks” to incorporate design decisions that facilitate collaborative problem solving and that walk the delicate line between revealing overwhelming detail and obscuring necessary information.

The repair community of practice is maintained intentionally through workshops, assemblies, barbecues, and more that sustain relationships between CN members. This community of practice simultaneously maintains the networking hardware and is reproduced through the hardware's need for maintenance, which is its *raison d'être*. Norms around collaborative repair allow the group to function like other communities of practice: relations of mutual accountability structure cooperation on a joint enterprise [50]. When AlterMundi redesigns the networking technology to make repair more accessible, the vision of broad participation in collective work is inscribed into the hardware and software. And as AlterMundi's technical work reshapes the manner in which the technology needs repair, the networking technology in turn lends durability to the repair community of practice.

Protocol of inclusion and exclusion rooted in technical and social frameworks present opportunities for power relations extant in communities to influence network functionality in differentiated ways. In this case, the only evidence of exclusion found suggested the dual significance of both

technical and social protocol in regulating network access. A failure to meet standards of reciprocity in this case resulted in an unwillingness on anyone's part to repair a node. And yet, had only one member offered to repair, exclusion would not have happened. Such informal standards could present opportunities for abuse as has been found in other studies, and it suggests future longitudinal research on community network sustainability.

This study highlights the complexity of the relationships involved in repair, with a particular interest in the role of the networking technology as an actor. Due to this complexity, supporting repair requires a deep understanding of the social relations at play. In that direction, our analytic approach may be valuable for technology designers. Building on this study, one could ask (thinking with ANT) "what role does this technology currently play in the social context of its maintenance?" and (thinking with Wenger) "what sort of repair community of practice should this technology be designed to support?"

Jang et al. outlined a map for fostering a robust repair ecosystem, depending on availability of tools and parts, experts to learn from, opportunities and funding for practice, and accessible formal education and institutional certification [29]. In this case, we find a robust repair ecosystem without formal education or certification; instead, CN assemblies and expectations of personal responsibility help establish the protocol of reciprocity required to maintain network functionality.

We identify some specific ways in which technical artifacts can support a novice community of practice of repair and maintenance, including: (1) making technologies more understandable by novices, (2) fostering social relationships that support learning, (3) reducing the need for "geek-only" repairs, (4) making advanced repairs more accessible, and (5) making devices, parts, and repair tools abundant and affordable. Design decisions that addressed each of these points were significant in this case and can serve as guide and inspiration, but they must be understood as part of AlterMundi's broader engagement in the repair community of practice.

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