Crowdsourcing Rural Network Maintenance and Repair via Network Messaging

Esther Jang
University of Washington
infrared@cs.washington.edu

Mary Claire Barela
University of the Philippines
mabarela@up.edu.ph

Matt Johnson
University of Washington
matt9j@cs.washington.edu

Philip Martinez
University of the Philippines
philip.martinez@up.edu.ph

Cedric Festin
University of the Philippines
cmfestin@up.edu.ph

Margaret Lynn
Unaffiliated*
maggietlynn@gmail.com

Josephine Dionisio
University of the Philippines
jcdionisio@up.edu.ph

Kurtis Heimerl
University of Washington
kheimerl@cs.washington.edu

ABSTRACT
Repair and maintenance requirements limit the successful operation of rural infrastructure. Current best practices are centralized management, which requires travel from urban areas and is prohibitively expensive, or intensively training community members, which limits scaling. We explore an alternative model: crowdsourcing repair from the community. Leveraging a Community Cellular Network in the remote Philippines, we sent SMS to all active network subscribers ($n = 63$) requesting technical support. From the pool of physical respondents, we explored their ability to repair through mock failures and conducted semi-structured interviews about their experiences with repair. We learned that community members would be eager to practice repair if allowed, would network to recruit more expertise, and seemingly have the collective capacity to resolve some common failures. They are most successful when repairs map directly to their lived experiences. We suggest infrastructure design considerations that could make repairs more tractable and argue for an inclusive approach.

ACM Classification Keywords
H.5.m. Information Interfaces and Presentation: Miscellaneous; K.6.4. Computing Milieux: System Management; C.2.3. Computer Systems Organization: Network Operations

Author Keywords
Rural Development; Internet Access; Technology for Development; ICTD; Crowdsourcing

*Currently at Google

CHI 2018, April 21–26, 2018, Montreal, QC, Canada

ISBN 978-1-4503-5620-6/18/04...$15.00

DOI: https://doi.org/10.1145/3173574.3173641

INTRODUCTION
Operating rural communications infrastructure is a difficult problem. Traditional centralized business models fail to scale to sparsely populated rural environments [12]. As a potential solution, researchers and practitioners are exploring transferring more network functions to the community through innovations like locally terminated web services [15], community edge caches [2], and community networks [3]. Network equipment owned and operated by people within the service area promotes sustainable operation by leveraging the capabilities of local actors to lower costs and increase responsiveness to local needs [12].

However, community-based support has its limitations. While often the equipment itself is poorly suited to the challenges of rural operation [23], the remote nature and limited availability of technical knowledge in many of these communities make maintenance the largest limitation on network growth [16]. For long term-sustainability, researchers and practitioners commonly train a small set of people (often a single person) with the skills to maintain and debug the specific technology installed. However, this training is time and resource-intensive, and in deployment settings may be rushed or inadequate. Even when successful, the skills learned are often marketable and may pull the best and brightest out of the community into better-paying jobs in urban areas [23].

In this work we investigate a different model of sustainable rural maintenance. We ask if it would be possible to "crowdsource" repair and maintenance of the infrastructure from the community with only their existing latent technical knowledge. Our research is driven by the observation that ordinary people may have the technical problem solving abilities to resolve most faults, but are typically forbidden from directly interacting with the infrastructure that is core to their daily lives. If they were empowered to directly maintain local infrastructure instead of just passively reporting problems to designated authorities, fault recovery could happen faster and more cheaply while building local technical capacity through experience.

To explore this new model, we leverage a deployed community cellular network in the remote, rural area of San Andres in the Philippines. This network has been in constant operation for over a year, with 758 distributed SIM cards and fifty to one hundred active users per day. Using this network's ability to send broadcast SMS to the community, we ask the following research questions: First, will community members engage in network maintenance based solely on network messages? Second, of those who do engage, how many can realistically fix common problems? Third, what limits their ability to conduct local repairs? Finally, how can the infrastructure be redesigned to better support community maintenance?

We sent each of the 63 active users on the San Andres network on the experiment day (in August 2017) an SMS message requesting that they come to the site of the cell tower to help fix a technical problem. With respondents we conducted a series of semi-structured interviews to understand the circumstances around their response to the message, their technical knowledge and prior repair experience, and whether they would be willing and able to participate in cell site repair. We conducted mock cell site debugging as part of the interviews to discover whether they were able to fix pre-defined issues involving solar power, antenna alignment, and equipment overheating.

In summary, we learned:

- Community members do come out in response to a request for repair assistance. The overall response rate was 37% and one variant of the message received over 50%.
- Nearly all of the respondents were able to resolve a simple issue with the solar power equipment.
- Most respondents were hesitant to attempt repairs themselves due to concerns of authority or damage liability.
- Respondents' capacity to resolve technical issues was high for components where they used the same or similar devices in their daily lives (e.g. solar sets), but low if the closest analogous devices they had required different treatment.

We believe our findings show that crowdsourcing strategies hold promise for motivating a variety of network repairs, provided the repairs are situated in the experiences of the community members and participant liability during repair is limited. Based on our results, we discuss design implications for alternative models of cell site maintenance that could be faster and more cost-effective than the status quo. Further work is needed to map expected repair problems onto common experiences, develop tools and techniques for finding specialized knowledge within the community, direct repair tasks to willing community members, and provide mechanisms and incentives for people to learn new repair skills.

RELATED WORK

Repair

Surana et al.'s seminal work on rural networking and repair in India [23] largely aligns with our experience in the Philippines. They identify power quality as the root cause of many failures and also describe issues such as antenna misalignment, unreliability of satellite backhaul, failed software updates, and misconfiguration as recurring challenges. We expect similarities in operating conditions will cause similar challenges.

Surana et al. see "self-fixing" (local repair attempts by non-experts) as a negative outcome because it can lead to unpredictable faults: "These attempts typically create new problems ... and in a few cases have even resulted in damage to equipment." In contrast, our goal of community-based maintenance means encouraging non-expert participation in repair to the extent of their abilities, while also taking care to prevent such damage. It is clear that opportunities are missed when local actors familiar with local technology and conditions are not allowed to engage with their infrastructure. Borrowing from the concept of ability-based design in assistive technology [24], we seek to include community members by mobilizing knowledge, skills, or social networks they already have, and using these as a basis for participation whether through further learning or recruitment of additional expertise.

Central to this challenge is a better understanding of the mechanisms and context of repair in community members' lives. Other work has argued that social mechanisms are particularly important in repair. As Houston observes [14], in their work focused on cellphone repairer networks in Uganda: "For independent technicians peer support becomes a significant part of their infrastructures of repair, as they cultivate a network of peers in the downtown area that can assist with difficult repairs or bridge gaps in their knowledge or practice." This work is the beginning of our attempt to discover, encourage, and leverage this repair capacity to create more resilient communities.

Infrastructure

Susan Leigh-Star [22] notes that in urban areas technical infrastructure achieves a degree of invisibility. This is not the case in rural areas. As Graham and Thrift [9] point out, the social aspect of infrastructure is made visible by crashes and failures, when people must be mobilized to restore service. In rural areas failure is more common, largely due to less reliable power. This work highlights the technosocial nature of communications infrastructure, embodied in not only technical machinery but the labor required to keep it functioning.

In the Philippines, the social layers of infrastructure become even more important for system functioning as infrastructural failure due to sabotage or theft is also prevalent [19]. The Philippines' largest telecoms provider, PLDT, asserts that up to eighty percent of service interruptions are caused by third-party action [7]. The country's second leading provider, Globe Telecom, works with local police in mounting countermeasures against cable thieves which include arrests and litigation [1]. While enlisting the services of private and public institutions to install more sophisticated surveillance and security systems may be one way to address such failures, an alternative is to mobilize the users of the infrastructure by engaging them as co-owners who are equally authorized and accountable for its maintenance. This is a key advantage of community models and motivates our effort to mobilize a closely situated user base with extensive experience in rural repair.

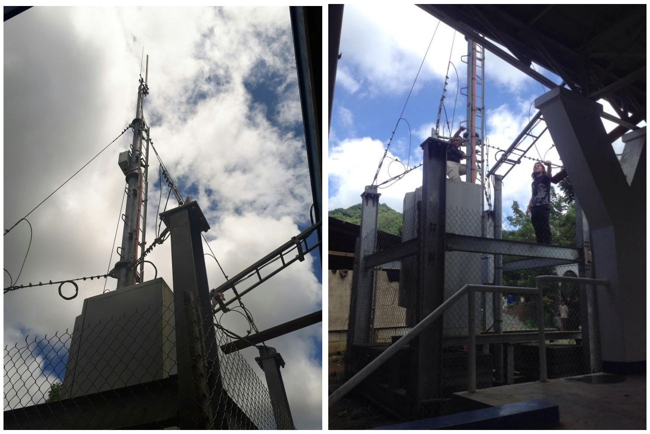

Figure 1. The cell tower site in San Andres, where the experiment was conducted. The VSAT and power equipment are housed in the large metal box at bottom, the BTS is mounted midway, and the antenna is visible at the top of the tower.

Community Networking

Community networking has been explored as a means for providing connectivity in remote areas not economically viable for traditional telecommunications operators to serve [6]. Researchers have explored these decentralized, community-owned models of network operation for a wide variety of technologies including WiFi [4] and cellular [25]. These interventions have largely been successful [11] from a sustainability perspective, with the networks being able to pay for their own operation and often make a small profit. However, scaling these networks in rural areas has been challenging. The largest Community Cellular Network, Rhizomatica [20] is only fifteen nodes, largely due to the repair and maintenance issues described in this paper. Working in areas with better power and backhaul capabilities, Gufi.net [3] (an 802.11 community mesh network) has been able to scale aggressively to thousands of nodes, showing that easing the infrastructure difficulties may be the key to scaling the networks.

Crowdsourcing

This work touches on a number of fields within crowdsourcing. The first is situated crowdsourcing [13], the use of crowdsourcing techniques that leverage knowledge available within a physical community. Researchers have varied their interventions across interaction technologies (e.g., Public Kiosks [8]), rewards (e.g., Candy [10]), and goals (e.g., Disaster Mapping [18]). In this work, we conducted situated crowdsourcing within a rural community to solve infrastructure repair questions using SMS, which is a novel contribution to the space.

CONTEXT

Overview

San Andres is a rural barangay (the smallest unit of political management throughout the Philippines, analogous to a town or neighborhood) within Tanay, a first class municipality of Rizal province in the central area of the island of Luzon in the Philippines. It is approximately 60km away from Quezon City, which is a highly urbanized city and part of Metro Manila. Barangay San Andres is largely rural and many locals travel to Manila for work while their families remain in San Andres. According to the census, the population of San Andres is 2,145, with 481 households as of December 2016, comprised of 1,122 men and 1,023 women. Most community members have not pursued education beyond high school. The demographics and economics of San Andres have been described in detail in other work [21], and we invite readers to review that work for a deeper understanding of the area.

Infrastructure

San Andres has no access to centralized grid power, network, or water, and instead uses localized solutions. The community operates a generator that was installed over a decade ago, with payment for power being collected by a local government agent canvassing for users with active light sources during the night. As of the present study, the generator had been inactive for two months due to an unknown technical issue. The community had reached out to the regional government for assistance in repair, but no repair had been initiated.

A community cellular network [11] using the CommunityCellularManager software [5] was installed in San Andres in February 2016 and continues to operate to this day. The network provides 2G cellular service to the community with local SIMs and prepaid credit (referred to as "load") sold by agents within the community. The cellular site is located at the Barangay Hall in the center of the community. The site is powered by a solar array installed on the Barangay Hall roof and backhauled through a satellite terminal.

Repair

Repairs for infrastructure installed and maintained by the barangay government follow a centralized structure where only specifically designated staff are authorized to troubleshoot and perform repairs. Locals who have observed issues and are affected by the problem are told to report it to the designated staff, usually a Tanod (analogous to a sheriff). If the staff are not able to perform repairs by themselves, they escalate the issue and request external help, especially if the equipment in question is of proprietary technology or not familiar to local repairmen. The reporting and sourcing of external experts takes time, decreasing the likelihood that the issue will be resolved quickly. This is the repair model applied to the community generator, which currently remains unfixed while the Barangay waits for the municipal government to act.

The management of the community cellular network is similar, with issues related to the installation first being directed to the assigned Tanod and then the Barangay Captain (the community head), who escalates it if unresolved by simple techniques such as power cycling. Neither the Tanod nor the Captain have had any specific technology training, so most issues are escalated.

Centralized repair models assume the majority of infrastructure knowledge exists outside the community. But the community does have technical knowledge, especially regarding consumer electronic equipment. Small solar panels (< 50W) are common on many roofs, as are dishes and receivers for satellite television. Those who can't afford satellite TV service often have portable DVD players, and cellular phones are ubiquitous with over one thousand devices detected by the network. The installation and use of this equipment is done primarily by locals leveraging their own technical capacity. For instance, people have learned that the satellite television antennas must be pointed south to receive service, and they know that the nearest cellular coverage is fifteen minutes away by powered tricycle. This local knowledge is either acquired through one's immediate social network e.g. between neighbors sharing solar panels, or through an external contact, like a satellite TV installer recommending quick antenna fixes for when signal is lost. Once present, applicable practical knowledge is disseminated through local social connections.

Since it takes time and money to visit or acquire expertise from the municipality center or "town proper" (around a 45 min drive away), the common preference is to perform these tasks locally as much as possible. Tasks such as dismantling electric fans and cleaning them or connecting broken wires for lights are typically done locally. If something cannot be fixed within the household, there is a local repairman who can handle basic appliance repairs. Residents will only consider seeking services from the town proper if they cannot resolve the problem locally.

STUDY DESIGN

In this exploration we leveraged the network's ability to send SMS to query random members of a community (i.e. crowdsource) and gauge their interest and ability in maintaining their local network. We also interviewed participants for specific repair skills in regards to three common failure modes of rural cellular networks: power failure, antenna misalignment, and overheating equipment. Participants were paid 100 Philippine Pesos (approximately 2 USD) of network credit, but this incentive was not indicated in the SMS messages.

We note that the simulated scenarios, which include two of the most common fault categories as described in Related Work, could all be automatically detected by the system using basic sensors before affecting the functionality of local SMS. For example, a decrease in battery voltage below a threshold could trigger an alert including an estimate of remaining battery life. We also note that maintenance alerts would be most useful before service was affected, to prevent unexpected outages. Network issues for which local SMS could fail instantly, e.g. buggy software updates, would be rarer, require a different alert mechanism or feedback interface, and perhaps merit a more automated solution such as restoration to a checkpoint.

SMS Invitation

We began investigating our research question, "Will community members engage in network maintenance based solely on network messages?," by sending a series of SMS to *all active network users* and observing the response rate.

This involved first sending an "introduction" SMS explaining that a new repair system was being deployed in the community (see Table 1) to active users on the network to introduce them to the idea of community maintenance and repair of the cell site. This was written in the local language, Tagalog, and sent from the network number '0000' to prevent it (and the follow-up invitation) from being viewed as spam, which is common in the Philippines.

Six days later, on a Sunday during a three-day weekend, we conducted our interview-based study in the community. We sent invitations to participate via SMS from the same network number to all active users on the network that afternoon during the study duration. Approximately a third (21/64) of these users had not been active during the "introduction" phase and thus had not received the introductory SMS.

The invitation SMS, also written in Tagalog, asked the participant to come to the Barangay Hall of San Andres to help with a technical problem at the cell site. Each active user was randomly sent one of three variants of the invitation SMS, to provide insight into some of the factors that might affect response rate to infrastructure-generated repair requests. One message addressed the individual recipient alone, another message used phrasing that implied the message had been sent to more than one person, and the third identified a specific technology in need of repair, in this case the solar power system. Table 1 gives English translations of the SMS messages sent.

Repair Tasks

Following the SMS broadcast, we explored our research question, "Of those who do come out, how many can realistically fix common issues?" by asking each of the participants to resolve a set of three different mock network failure scenarios.

This involved in-depth interviews of participants who arrived to explore their ability to repair the types of common problems they would be recruited to solve. The interviews were conducted by native Tagalog speakers and consisted of a presentation of three different repair scenarios embedded within a semi-structured interview. For the scenarios, we were unable to create actual failures as the installation was actively servicing subscribers. Instead, we simulated tasks that were realistic in the context of the installation, of varying difficulty, and also feasible for the network to monitor and self-report. Participants were asked to try to debug the mock failures using a simulated SMS message (read aloud) that described the problem as though the network had detected an issue. They were first asked to assess the problem given only the message, and afterward were presented with photos of the installation as it would look in the failure case. The pictures were shown to the participant only when they asked for more information, or at a later time when they had explored all of their thoughts and were stuck. We provide three failure scenarios, in order of difficulty from easiest to hardest: Power Failure, Antenna Misalignment, and Equipment Overheating.

Power Failure

Power failure is an extremely common issue in the rural Philippines. In addition to the aforementioned generator failure, the San Andres cellular site was originally installed with insufficient solar power generation and would fail during periods of heavy cloud cover. A more common issue is simply debris on solar equipment: a buildup of dust, ferns or leaves on the panels that dramatically decreases the generation capacity of the site. It's also possible for the network to monitor the solar generation as most charge controllers have an available monitoring API. To simulate this fault we told participants that they received the following SMS from the network: "The Konekt cell site solar panels are not generating enough power." They

Table 1. SMS Messages sent during the course of the experiment.

Type	Text (English translation)
Introduction	"Hello from the network! We will be deploying a new system soon that asks subscribers to assist in the maintenance of the system. Please be on the look out for messages and come help if you have time."
Individual	"The cell tower is having a problem! Can you come to the Barangay center and help?"
Specific Tech	"The solar panels for the cell tower are having problems! Can you come to the Barangay center and help?"
Group	"The cell tower is having a problem! Can one of you come to the Barangay center and help?"

were allowed to ask the interviewers any simple questions about the state of the network to see if they could identify a potential solution. Once we established that they intended to inspect the panels or were stuck, we showed them a picture of solar panels with debris on them (see Figure 2). The task was considered complete if they described a solution similar to *clean the debris off of the solar panels*.

Antenna Misalignment

The Philippines is beset by a number of typhoons every year which can cause damage to towers, buildings, and any devices mounted up high. The tallest structures in rural areas often support cellular antennas to enable wide-area coverage. A common failure is a misalignment of the antenna, often pointed in the wrong direction or even flipped upside down. This can cause degraded coverage as the antenna may still be connected but no longer radiating in a way that maximizes coverage. As such, users may still get service near the tower, but the signal will degrade more rapidly over distance. Monitoring this failure is feasible and would require just the installation of a gyroscope into the antenna.

To simulate this fault the user was informed that they received the following SMS: "The position of the Konekt cell site antenna has changed." As with the power failure, they were allowed to ask questions until they either succeeded or failed to conclude that *the antenna is tilted and must be straightened*. For more information, they were shown a picture of the network with a misaligned antenna (Figure 2).

Overheating

Overheating equipment is a recurring problem given the tropical temperatures common throughout the inland Philippines. Many non-industrial devices assume cooling infrastructure that is too power-hungry to operate off of solar power setups. In another Community Cellular installation in Talisay, the access point's computer was incorrectly placed in an airtight container for rain protection; it would operate well during the night but fail intermittently due to overheating during the day. The base station would cycle periodically as it would heat up, fail and shut down, then restart and continue the cycle. Monitoring this failure is trivial as nearly all modern CPUs have temperature sensors to protect themselves against damage from overheating.

To simulate this fault, the participant was informed that they received the following SMS: "The CPU inside the Konekt cell site rack is overheating." We considered the issue solved if the participant proposed *increasing cooling or ventilation to the installation in any way*. For more information, we showed them a set of pictures of the inside of the San Andres cell site installation (Figure 2) even though the temperature issue does not have any externally visible features. We considered the unhelpfulness of visual inspection alone to be realistic to the scenario, and were interested in participants' reaction to the internal appearance of the cell site.

Semi-structured Interviews

Lastly, we investigated our final two research questions: "What issues limit the ability of local actors to repair" and "How can the infrastructure be redesigned to better support community maintenance?" though open-ended questions integrated with our prior repair scenarios. These questions gathered demographic information, inquired about familiarity with the technologies we discussed, and asked about personal repair experiences. We also focused on factors that might affect or predict respondents' willingness to participate in future community-crowdsourced repair, such as their self-reported confidence and willingness to repair, technical knowledge, and motivation for responding to our invitation SMS.

FINDINGS

Community Response

24 of the 63 active network subscribers who were sent an SMS responded in-person (38%). Of the 3 respondents 20 or younger (12% of respondents), all were male engineering students or recent graduates. Of the 7 between 21 and 30 (29%), 6 were women who identified as housewives, farmers, or product sellers around town, and one was a male farmer. Of the 5 respondents over 30 (21%), 3 were women (a housewife, a real estate agent, and a local "recycler/trader") and 2 were men over 50 with leadership positions in the local government, including one of the two assigned cell site caretakers. 18 of 24 respondents (75%) were women.

One female respondent participated in the repair tasks and interview but was removed from statistical analysis due to having accidentally received two of the three SMS invitations (our fault), and one male respondent did not participate in interviews due to arriving intoxicated.

Table 2. Community Response Rates and Times

Message Type	Response Percent	Count	95% CI	Avg. Time (min)	95% CI
Individual	**33%**	7/21	21%	**48.83**	54.05
Specific Tech	**24%**	5/21	19%	**57.51**	50.87
Group	**52%**	11/21	22%	**70.63**	41.50
Total	**37%**	23/63	12%	**61.14**	27.12

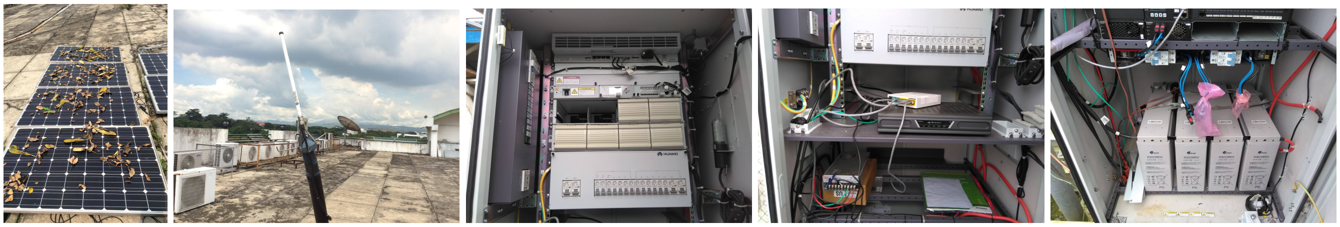

Figure 2. The photos presented to participants. From left is "Power Failure," then "Antenna Misalignment" and then remainders are "Overheating."

The Group message received the best response rate, with 11 of 21 participants physically responding to the SMS, compared to 7 of 21 participants for the Individual message and 5 of 21 participants for the Specific Technology message, X^2 (2, N = 63) = 3.835, p = 0.147. Though we lack enough respondents for sufficient statistical power in the present study, this difference between message conditions is contrary to our expectations and is supported by qualitative data reported below. Detailed response rates and times per condition can be found in Table 2.

Network effects

We observed that many participants who arrived at the site had either been prompted by others to go, or were sent on behalf of others based on personal relationships or perceived expertise. 11 of 23 (noting that the person in multiple experimental conditions was included in the qualitative analysis) respondents reported discussing the message, with 5 of the 11 reporting that they had asked someone else about it before coming, and 8 having been prompted by someone else, often a family member, to check their own phone for the SMS and come to the cell site. The participants seemed to understand that only those who had received the message on their own phones should go, perhaps because the messages included a request for personal action.

For example, one agricultural engineering student had been sent on behalf of his mother (with her phone in hand) on account of his technical training: "My mother might be too shy to come here. (...) She said I should come quickly (...) that I might be of help." Later, after her son told her that the questions were not hard, his mother also participated.

One woman had discussed the message with a group of neighbors before coming: "We read that there was a problem in the [signal]. (...) I also showed it to them." At least one other neighbor had also received the message and sent the respondent on their behalf with the SIM card that had received it: "The other SIM is with me. Their cellphone battery was empty. (...) They ask me to insert their SIMs [when their batteries are empty]. (...) Here, I brought two." The woman answered the repair scenario questions confidently and also had a solar set at home, which is likely why her phone was charged more often than her neighbors'. As such, we speculate that she may have been seen as the most experienced in the group with relevant technology. Another female respondent had chatted with several others after receiving the message, and came to the cell site with a group: "I said 'Oh, there's a message from zero zero (the network number)' then after we finished chatting I went to my sister by the store. There my friend [name removed] came out saying to go there. (...) So we all just came here."

Two respondents reported that they would have ignored or missed the message unless they had been prompted by someone else to check their phone and respond. One woman recounted: "I was sleeping when I received the text message. I wondered why because I do not know the meaning of it so I disregarded it. Then my husband's uncle (...) told me." Another said: "I was doing laundry and then my mother shouted at me. My cousins told me to look at my cellphone. I was busy outside and my phone was in silent mode." From these stories we draw that the mechanism of notification spreading through rumor may be important for both legitimization of the messages and timely recruitment. The sending of many messages to a socially connected group rather than single individuals could be more effective for timely finding of the availability, willingness, and sufficient expertise to solve simple problems.

Furthermore, several respondents discussed the importance of cell signal to their community and their livelihoods during the course of the interview, suggesting that the social accountability and reward for responding to a group SMS may provide positive incentives for problem-solving. When asked if she would be willing to volunteer her help in the future, one woman working in recycling and trading said: "If we can we would surely do it since it would be our way of helping the whole Barangay community, Barangay San Andres specifically. It is very hard if there's nothing like this." One housewife in her late 30s explained that she responded because: "I am interested in contributing to improvements of the signal to the likes of the people." A woman who had left home in the middle of doing laundry said: "Of course I had to come. There could've been a signal interruption." Some expressed self-interest as well; one female real estate agent said, "I felt that it would be very difficult if there is no signal here in our place. Since I am an agent, I would have to get gas to go to the next bayan (next town), whereas in our Barangay there is already a signal."

Successes and failures in repair

Solar panel obstruction

We found that most participants were successful in addressing the power failure task, with 22 of 23 participants successfully identifying the solution to clear the debris on the solar panels, and 20 of the 23 also giving correct explanations of why the debris should be removed.

The one participant who did not correctly identify the solution did not have a solar set at home, and stated that she was unfamiliar with solar panels. However, in general the other respondents indicated understanding of basic solar panel function regardless of whether they had them at home, suggesting that this knowledge is common throughout the community.

15 of 23 respondents had solar sets at home, and two others had neighbors or relatives with solar panels. One housewife who did not have solar at home explained correctly that she would "wipe it. (...) Because the sun, some of the sun's rays are blocked by the leaves so they do not directly enter the solar panel." In contrast, of the three who did not give an explanation along the lines of "block[ing] the light from the sun," two were owners of solar sets. One explained that she knew to clean the panels "Because that is also what we use" and the other said that debris could weaken the panel structure.

Despite this knowledge, 6 of the 23 felt uncomfortable cleaning the panels without further training or assistance. One woman, a banana farmer, answered without hesitation, "Yes, I will clean it on my own will. It is not heavy work and this signal helps us a lot." Two others said they would only inform the authorized personnel, as "They will be the ones to fix it because they are the maintenance staff." Most respondents indicated that they could take action after obtaining permission from the authorities, explaining that "usually we are not allowed to go inside or mess with it" and "we are really the kind of people that do not tamper with things if we are not allowed." The authority-based barriers to repair are discussed in depth in § 5.3 *Barriers to successful repair*.

Another 6 of the 23 mentioned the difficulty of climbing up to reach the solar panels: "If it is on lower ground, I possibly can. If it is too high, it will be difficult for me." However, three indicated that they would be willing if there was a ladder or known safe way to climb. These concerns highlight that safety procedures would have to be established for any physically risky or strenuous tasks.

Antenna misalignment

The antenna misalignment task presented more of a challenge, with only 13 of 23 participants offering any solution, and only 11 of the 13 mentioning that the antenna needed to be "straightened" or "aligned." 3 of the 13 also mentioned moving the antenna to "find the signal," perhaps indicating a misconception that the antenna was for backhaul reception.

19 of the 23 participants (including 9 who had stated the solution) expressed a preference for "someone knowledgeable," "authorized personnel," "technicians," the "operator" or even a participant's husband to do the adjustment instead, even if they themselves knew what was wrong and had been shown how to do it. By this point in the interview 4 of 23 participants had explicitly expressed a fear of liability. For example, one woman had said during the solar panel task that "others are also afraid to touch it, they might step on something, break something. They might be held responsible for it and they can't pay for it." An agricultural engineering student mentioned during the antenna task that "If someone unskilled were to interfere then the problem might worsen."

Only 3 respondents expressed confidence in being able to successfully adjust the antenna on their own: a student in his late teens used to tinkering on his own with electronics, one housewife in her mid 20s who said tentatively "If it is not dangerous, maybe I can do it," and a woman who said she could do it with the help of her husband. One housewife in her late 30s was confident when she thought it would be possible to adjust the antenna from the ground using a bamboo pole like her satellite television antenna at home, but after seeing the picture was no longer willing. A tricycle driver in his early 50s who had been one of the maintenance personnel assigned by the operator expressed a fear of danger in handling the equipment: "Ma'am, that's dangerous because we might get electrocuted there. We're not going to touch it." We draw from these comments that in addition to authority-based barriers, knowledge and confidence barriers exist that cause people to try to minimize liability even when they suspect they know the solution, deferring the task to others. The perceived cost and difficulty of repairing or replacing the equipment may also factor into the townspeople's relinquishing of responsibility.

CPU overheating

The CPU overheating task was the most challenging, with 1 of the 23 participants proposing a solution that would address the root cause of the problem, inadequate ventilation. The one participant, a lay minister in his early 50s, immediately suggested upon hearing the problem statement that "There is an electric fan inside, it provides cooling. (...) That means the electric fan is not working." The respondent seemed to be drawing on prior knowledge or experience with cooling electronics, as he had apparently never interacted with the cell site before. While we would have accepted a simpler solution such as leaving the enclosure open, his strategy of installing a commonly available electric fan in the unit would likely have worked as well.

Of the 18 participants who offered any solution, 15 proposed solely the mitigation strategy of turning the system off and/or disconnecting it from the battery and "letting it rest" for times varying from 20 minutes to a day. Many expressed confidence that this action needed to be taken even if they did not know the root cause of the problem: "I just know that if it overheats, it must be turned off." We did not find this a sufficient answer as the machine automatically duty cycles to limit heat damage.

When we asked participants to recount another experience with overheating technology, 4 described a TV overheating while charging or running off a generator, 2 described cellphone overheating while using or charging, and 3 described overcharging of a battery. 5 mentioned "overuse" or "running continuously" as a cause of overheating. We identified commonly held beliefs that overheating could be an expected result of using a device intensively, running it for too long, or overcharging its battery, where the only appropriate recourse was to shut off or disconnect the equipment and wait. As one sari-sari (convenience store) operator commented, "Whenever we watch TV for a long period of time, it usually heats up. Sometimes, other stuff blows up when they overheat. (...) I just turn it off when it heats up. Then, I wait for a long time before I open it (turn it on) again." Another woman said, "Because usually, that's the problem with electronic things. (...) sometimes, it might explode because of the heat, it needs to be killed." Two respondents recounted personal experiences with wires burning or a television exploding after overheating, and 6 of 23 explained the danger of fire or explosion to justify their recommendation: "I will turn off the CPU to prevent the risk of fire." One respondent linked the cause of the overheating to the cell tower accidentally being left on at night though the maintenance personnel had been instructed to turn it off to avoid draining the battery: "[The cause is] overuse, because there is a time for our signal here, maybe it got too long because sometimes it's on at 11, before it was just at 10, when we close (turn off) our lights it's already gone."

In 13 of the 17 cases where participants offered any solution to the CPU problem, the solution was the same as the one described in the recounted experience, suggesting the experiences as a source of their beliefs about what should be done. (Respondents were asked for solutions before their prior experiences, so that their solutions would not be affected by their stories.) We identify a potential barrier to maintenance in that some technical problems with the basestation may map poorly onto their personal experience with systems they have access to every day. For this problem, the cell site needed to be treated not as a single device with an off switch such as a TV or phone, but as a system with many supporting components and an accessible internal environment which is designed for continuous operation. The error message participants were given, while perhaps helpfully specific to an expert technician, caused them to treat the error symptom incorrectly by prompting references to non-analogous common experiences.

Barriers to successful repair

The barriers to success on repair tasks that we observed in the above sections can be summarized as follows:

- Lack of authorization and ownership
- Fear of further damage to the equipment and liability
- Fear for personal safety while handling equipment or performing strenuous tasks such as climbing to the roof
- Lack of knowledge and skills to solve some problems

We recommend that successful preparation of a community for management of technical infrastructure (whether crowd-based or on a smaller collective scale) must address these concerns for the maintainers whether via traditional training or other methods, some of which we propose below. We note that the issue of authorization is mainly a socially constructed barrier, while the latter three could be mitigated by implementing both social and technical solutions to increase knowledge and proficiency, so we treat the two groups of barriers separately in the following discussion.

Authority structure as a barrier to engagement

As discussed above, the first barrier most people encountered to engagement with repair of the site was a lack of authorization combined with a strong sense of exclusiveness around cell site management. 17 of 22 (77%) of participants (excluding one of the 23 because he was one of the assigned personnel) said they had to request permission of the people in charge of the site before beginning to investigate any problem. Only after being encouraged to consider the situation as if they had been authorized would they continue to think through the scenarios with us. One woman who teaches day care explained, "there's a maintenance person assigned and we can give suggestions like what he needs to check for example the battery, we can suggest that. That's all Ma'am." The people in charge of the cell site were identified variously as "the barangay officials," "the Tanod," "the Barangay Captain," "the maintenance person/personnel or staff," "Kuya [Martin]," or in one case, "Sir [Michael] from [Operator]" (names changed) for whom one respondent had a phone number. This distinction between one's ability and one's agency to solve a repair scenario is represented in Table 3. To better estimate population success rates and adjust for variable sample sizes, percentage of successful task completion is given as adjusted Wald point estimates [17].

One of the respondents with the strongest authority-based reservations, the lay minister, was also the only one who solved the CPU overheating problem correctly, a success that might have been lost without his engagement. When first asked if he would help fix the solar panel issue, he said "I cannot intervene, I have no experience." While discussing the antenna issue, he commented that he did not usually even look at the cell site "Because I think that it is not allowed to go there. That area is exclusive." While he acknowledged that "No one said that we are not allowed to go there," he said that if cell service stopped working he would "just wait (...) Because someone is taking care of it, we cannot just mess with it. (...) if it becomes worse, we are the ones who get punished by our [Barangay] Captain." He suggested that in order to improve cell site maintenance, the townspeople would need more training: "they need to call [Operator] again for- so that someone will help and learn how to open and close (turn on and off) [the cell site]."

Others expressed more confidence in their ability to repair once allowed. An agricultural engineering student explained that he had never looked at the solar panel because "There's a sign that says "No ID, No Entry" [1]. Only authorized personnel are allowed. (...) It's hard to interfere just on my own but if I was ordered to... I can manage."

One woman mentioned that she could learn from observing, and would be confident after instruction: "If we were allowed, we could do it ourselves. (...) Sometimes, I tinker with our [solar] setup, at least [we own it] if it breaks down. But for this, we really don't try. (...) We just usyoso (watch as a bystander from a distance) when they (the maintenance personnel) check it out. (...) We just look closer when they're about to fix it. (...) If they will teach us, it can be done, Sir, for us to help. But it is forbidden. We were forbidden by the captain."

This attitude suggests a few potential low-hanging fruit towards building repair capability over time: to encourage close observation and opportunistic learning by available community members (perhaps recruited by broadcast SMS) whenever experts are at the site debugging issues, and to encourage low-risk visual inspection of the site by the broader community to learn its default appearance, even if they are not willing or able to handle the equipment. We also propose that a community ownership model for the cell site would more readily facilitate a sense of shared responsibility than the telecom-owned model used here in Tanay, and make it easier to establish shared accountability for interactions with the site instead of a blanket "keep out" policy.

[1] There was no such sign at the site.

Table 3. **Summary of the number of people who, for each problem (Solar, Antenna, and Heat) and message type, proposed any solution (Proposed), expressed a willingness to act on their proposal without calling the official personnel (Agency), and whose proposed solution was correct (Solved). Note that proposing a solution was required to be able inquire about agency and the quality of the solution. In bold are adjusted Wald point estimates.**

		Individual	Specific Tech	Group	Total
Solar	Proposed Solution	6/7 (86%/**78%**)	4/4 (100%/**83%**)	11/11 (100%/**92%**)	21/22 (95%/**92%**)
	Felt Agency to Solve	6/6 (100%/**88%**)	3/4 (75%/**67%**)	7/11 (64%/**62%**)	16/21 (76%/**74%**)
	Solved Correctly	6/6 (100%/**88%**)	4/4 (100%/**83%**)	11/11 (100%/**92%**)	21/21 (100%/**96%**)
Antenna	Proposed Solution	3/7 (43%/**44%**)	3/4 (75%/**67%**)	7/11 (64%/**62%**)	13/22 (59%/**58%**)
	Felt Agency to Solve	0/3 (0%/**20%**)	0/3 (0%/**20%**)	3/7 (43%/**44%**)	3/13 (23%/**27%**)
	Solved Correctly	2/3 (66%/**60%**)	3/3 (100%/**80%**)	6/7 (86%/**78%**)	11/13 (85%/**80%**)
Heat	Proposed Solution	5/7 (71%/**67%**)	4/4 (100%/**83%**)	8/11 (73%/**69%**)	17/22 (77%/**75%**)
	Felt Agency to Solve	1/5 (20%/**29%**)	0/4 (0%/**17%**)	6/8 (75%/**70%**)	7/17 (41%/**42%**)
	Solved Correctly	1/5 (20%/**29%**)	0/4 (0%/**17%**)	0/8 (0%/**10%**)	1/17 (6%/**11%**)

Making technical problem solving easier

One theme that emerges from the interviews above is that the activities of repair are situated in an ecosystem of analogous technologies and common knowledge currently available to the community. Suggested repairs for our staged problems were usually grounded in personal stories of repairing or mitigating issues with commonly available household systems. Furthermore, suggested repairs and technical knowledge were often ubiquitous among those who gave solutions, with 21 of 22 solutions given to the power problem being solar panel cleaning, 11 of 13 solutions to the antenna problem being "straightening," and 15 of 18 solutions to the overheating problem being to turn off or unplug the cell site and "let it rest" for some time before turning it back on. This commonality of experience shows that there is a body of local knowledge and understanding about how to deal with errors that needs to be taken into account when designing for repair.

We further observe that this body of knowledge arises partly from the availability of other consumer devices locally available, the affordances present for maintaining these devices, and popular theories of how they work and behave based on common experience. The repair suggestions are largely correct if the device to be repaired is the same as the one they have used or seen personally, as in the case of the solar problem. On the antenna issue, we found that 9 of the 13 respondents who were willing to give any solution had a GSAT receiver or TV with an antenna at home, out of 11 total respondents who owned one of these devices. This suggests that previous experience with antenna adjustment helped participants understand the problem. However, 8 of the 11 correct respondents still did not feel "knowledgeable" enough to perform the repair themselves, indicating that their experience did not give them enough familiarity to overcome the barriers of fearing damage to the equipment or themselves and potential liability.

Therefore, one avenue we see towards making repair problems easier is to design the appearance of our infrastructure's components to look like other devices in the ecosystem based on how they should be treated. A potential research direction in this vein could be to try to source as many maintenance-related affordances of the infrastructure as possible from the community of installation itself, even recruiting community members to help procure these as part of a DIY-style installation process. For example, a commonly available electric fan could be placed inside the enclosure for cooling, as suggested by one respondent. External components and housing, if not the core equipment itself, could be locally sourced when practical for ease of care and replacement. Disconnect switches for the batteries could also look like commonly available breakers found locally. During the CPU overheating task, several participants expected to know how to disconnect power, mentioning a plug or a "main switch": "I think [the main switch is] this one, it looks like a breaker right?" However, another successful direction could simply be to improve signage of the components; one woman mentioned that the labels on the switches in the pictures shown for the CPU problem were too small to read, but "Maybe when I'm there I will just read it and find the switch off." On the antenna, a large "This Way Vertical" sign with an arrow pointing up could have dispelled many hesitations about its intended direction.

As Houston describes in "Caring for the next billion," [14] "Designers might treat the inner workings of devices as truly user-accessible areas, and mark out more and less attainable tasks based on the complexity of these techniques." We argue that to effectively make the inner workings of rural technology discoverable and accessible, we must have empathy for the common repair experiences and practices of the rural communities where it will be situated. We should consider what the behavior of the technology in both working and error conditions implies about how it works, what other devices in the ecosystem people might consider similar, and what device state could be made transparent to encourage solution discovery during maintenance and repair.

DISCUSSION

Study biases

In any situated field study biases will impact the distribution of participants and final results. We speculate that the novelty effect of this temporally limited trial may have attracted participants who would not have remained engaged for repeated sessions. Furthermore, while details of payment were not included in the invitation, one participant mentioned rumors of an "operator promo" at the Barangay Hall which may have incentivized responders. In the opposing direction, the short and unprompted nature of the study invitation could have led to it being interpreted as spam by suspicious users and we may have seen more response in a longitudinal study as participants learned to trust the messages.

We identify a possible confound in that 1/3 of the SMS sent explicitly mentioned solar panels (the "Specific Technology" condition), so respondents to this message might have been skewed towards those who knew more about solar panels. Only 6 of the 23 respondents were in the Specific Technology group, and we did not find a statistically significant difference in how well they did on the repair tasks.

Limitations of Crowdsourcing

One potential limitation of this repair model is that the response times seen in our study were often over an hour. Failures have different time sensitivities from months (e.g., antenna misalignment) to minutes (e.g, fire) and crowdsourcing may be better suited to less time-sensitive issues. While response times in the current repair model would almost surely be slower, one can imagine a spectrum of solutions from assigning a full-time guard (fairly resource-intensive) to designing an automated response. For our mock repair scenarios we selected faults for which we could easily build monitoring infrastructure, that did not need immediate responses, and that would not affect the system's ability to send an alert SMS.

Similarly, continued investigation of repair practices will likely reveal both knowledge and skills that already exist in the community and those that are largely lacking. For example, we do not expect the community to have the capacity to debug software issues (though we would be excited to be wrong). In practice some training may still be needed for conveying important functional knowledge that is missing, but would be more focused and less intensive as a result of our work.

Future Work

Gender and Reach: Houston mentions that: "caring for technological things in repair is still largely a male occupation (as it is in much of the repair literature)." [14] In contrast, a majority of our respondents were women. We learned that many participants' husbands were away in Manila for work during the day or intermittently throughout the week. Given the location of the infrastructure at home in the community and the threefold larger responsiveness of women to these SMS messages, it is clear that there are opportunities to move away from the status quo of enlisting only a few males in leadership positions for maintenance work. This may involve training the women in technical work or enlisting younger engineering students eager to gain recognition in their community.

Our study finds other arguments for having a broader or crowdsourced base of repairers. The SMS-based system we have proposed takes advantage of existing rumor-based sharing mechanisms and social relationships to find local expertise quickly. Individuals' phones are frequently low on battery due to local power issues, and are often left unminded as a result of relatively infrequent use compared to the constant checking of urban users in a connectivity-rich setting. Locally broadcast messages rely on the collective checking of a larger number of people, resulting in an overall faster response.

Power Dynamics: Future work will investigate the effect of our strategy on the power dynamics of cell tower management. We believe it would help shift the power of cell network stewardship and ownership to rural communities, but we do not mean for the system to circumvent local power structures. We hope to support a wide range of options for error reporting and engagement. Crowdsourcing elements could be configured to support an authority hierarchy of the community's own design, while still promoting wide engagement. For example, the system could only send SMS alerts to a set of designated recipients (even a single person), or only instruct untrained recipients to find the designated community members as quickly as possible and report the problem.

Rewards: Even if the response rate was dependent on rumors of a network load or promotion, it would be reasonable for a telecom to offer such compensation to community members "on commission" for fixing problems as they arise. Such a system could be designed to reward informants or referrals as well as the fixers themselves to encourage recruitment of expertise. The system could also provide social rewards, such as publicly shared "Thank Yous," for important repairs.

Infrastructure Interfaces: This work only briefly touched on the large question of how to present network status to users. The information must be in a form that is easily interpreted by the user and which stands alone with minimal context or expertise. For example, instead of giving an exact temperature measurement, the readings can be bracketed into qualitative descriptions (e.g. above normal, very hot – will cause basestation to shut down). Suggestions for corrective action could also be also bundled with the error alert. The affordances available in the networking technology itself will constrain the design of such interfaces.

CONCLUSION

In this work we explored the idea of "crowdsourcing" repair knowledge and ability for cell network repair from the local community using SMS messages. Working with a rural community in San Andres, Rizal, Philippines, we sent all active network subscribers ($N = 63$) an SMS asking them to come to the cell site to help fix a technical issue. 24 of these community members responded, of whom 18 were women. We then asked those who came to try to resolve three mock equipment failures. We found that nearly all were able to solve a simple solar panel issue, many had some capability to solve an antenna alignment issue, and only a few were able to correctly address an overheating CPU. Exploring further, we found that the biggest barriers to local repair were concerns about authority or liability. We believe that these results demonstrate a large latent capacity for local repair in rural areas, especially for equipment similar to consumer electronics used at home.

ACKNOWLEDGEMENTS

We would like to thank Mae Sincere (Cere) Blanco, Camille Corcega, the other members of the Wireless Communications and Engineering Lab at U.P. Diliman, and the student translators at U.P. for their help. We'd also like to thank Paul Xavier Villa, Charlotte Mallari, and Odie Fresco, and the people of Tanay for sharing their community and our funders Facebook and Toshi Matsushima for their gracious assistance. Lastly we would also like to acknowledge the time and effort spent by the reviewers to make this into a better work. Thanks everyone!

REFERENCES

1. 2014. 10 Globe Cable Theft Suspects Arrested. https://www.globe.com.ph/press-room/10-globe-cable-theft-suspects-arrested. (May 2014).
2. Anirudh Badam, KyoungSoo Park, Vivek S Pai, and Larry L Peterson. 2009. HashCache: Cache Storage for the Next Billion.. In *NSDI*, Vol. 9. 123–136.
3. Roger Baig, Ramon Roca, Felix Freitag, and Leandro Navarro. 2015. Guifi.Net, a Crowdsourced Network Infrastructure Held in Common. *Comput. Netw.* 90, C (Oct. 2015), 150–165. DOI: http://dx.doi.org/10.1016/j.comnet.2015.07.009
4. German Castignani, Lucien Loiseau, and Nicolas Montavont. 2011. An evaluation of IEEE 802.11 community networks deployments. In *Information Networking (ICOIN), 2011 International Conference on*. IEEE, 498–503.
5. Facebook. 2017. CommunityCellularManager. https://github.com/facebookincubator/CommunityCellularManager. (2017). Accessed: 2017-05-7.
6. Hernan Galperin and François Bar. 2006. The microtelco opportunity: evidence from Latin America. *Information Technologies & International Development* 3, 2 (2006), pp–73. http://itidjournal.org/itid/article/view/225
7. James Galvez. 2016. PLDT Calls for Uniformity in Telco Policies. *The Manila Times Online* (Nov. 2016).
8. Jorge Goncalves, Denzil Ferreira, Simo Hosio, Yong Liu, Jakob Rogstadius, Hannu Kukka, and Vassilis Kostakos. 2013. Crowdsourcing on the Spot: Altruistic Use of Public Displays, Feasibility, Performance, and Behaviours. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing (UbiComp '13)*. ACM, New York, NY, USA, 753–762. DOI: http://dx.doi.org/10.1145/2493432.2493481
9. Stephen Graham and Nigel Thrift. 2007. Out of order: understanding repair and maintenance. *Theory, Culture & Society* 24, 3 (2007), 1–25.
10. Kurtis Heimerl, Brian Gawalt, Kuang Chen, Tapan Parikh, and Björn Hartmann. 2012. CommunitySourcing: Engaging Local Crowds to Perform Expert Work via Physical Kiosks. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '12)*. ACM, New York, NY, USA, 1539–1548. DOI: http://dx.doi.org/10.1145/2207676.2208619
11. Kurtis Heimerl, Shaddi Hasan, Kashif Ali, Eric Brewer, and Tapan Parikh. 2013. Local, Sustainable, Small-scale Cellular Networks. In *Proceedings of the Sixth International Conference on Information and Communication Technologies and Development: Full Papers - Volume 1 (ICTD '13)*. ACM, New York, NY, USA, 2–12. DOI: http://dx.doi.org/10.1145/2516604.2516616
12. Kurtis Heimerl, Anuvind Menon, Shaddi Hasan, Kashif Ali, Eric Brewer, and Tapan Parikh. 2015. Analysis of Smartphone Adoption and Usage in a Rural Community Cellular Network. In *Proceedings of the Seventh International Conference on Information and Communication Technologies and Development (ICTD '15)*. ACM, New York, NY, USA, Article 40, 4 pages. DOI: http://dx.doi.org/10.1145/2737856.2737880
13. Simo Hosio, Jorge Goncalves, Vili Lehdonvirta, Denzil Ferreira, and Vassilis Kostakos. 2014. Situated Crowdsourcing Using a Market Model. In *Proceedings of the 27th Annual ACM Symposium on User Interface Software and Technology (UIST '14)*. ACM, New York, NY, USA, 55–64. DOI: http://dx.doi.org/10.1145/2642918.2647362
14. Lara Houston and Steven J. Jackson. 2016. Caring for the "Next Billion" Mobile Handsets: Opening Proprietary Closures Through the Work of Repair *(ICTD '16)*. ACM, New York, NY, USA, Article 10, 11 pages. DOI: http://dx.doi.org/10.1145/2909609.2909658
15. D. L. Johnson, Elizabeth M. Belding, and Gertjan van Stam. 2012. Network Traffic Locality in a Rural African Village. In *Proceedings of the Fifth International Conference on Information and Communication Technologies and Development (ICTD '12)*. ACM, New York, NY, USA, 268–277. DOI: http://dx.doi.org/10.1145/2160673.2160707
16. Zahir Koradia, C. Balachandran, Kapil Dadheech, Mayank Shivam, and Aaditeshwar Seth. 2012. Experiences of Deploying and Commercializing a Community Radio Automation System in India. In *Proceedings of the 2Nd ACM Symposium on Computing for Development (ACM DEV '12)*. ACM, New York, NY, USA, Article 8, 10 pages. DOI: http://dx.doi.org/10.1145/2160601.2160612
17. James R Lewis and Jeff Sauro. 2006. When 100% really isn't 100%: improving the accuracy of small-sample estimates of completion rates. *Journal of Usability studies* 1, 3 (2006), 136–150.
18. Sarvapali D. Ramchurn, Trung Dong Huynh, Matteo Venanzi, and Bing Shi. 2013. Collabmap: Crowdsourcing Maps for Emergency Planning. In *Proceedings of the 5th Annual ACM Web Science Conference (WebSci '13)*. ACM, New York, NY, USA, 326–335. DOI: http://dx.doi.org/10.1145/2464464.2464508
19. Syril Repe and Mary Judaline F. Partlow. Globe Cell Site in Guihulngan Bombed. http://www.philstar.com/region/767131/globe-cell-site-guihulngan-bombed. (????).
20. Rhizomatica. 2017. Rhizomatica. https://www.rhizomatica.org/. (2017). Accessed: 2017-05-7.

21. Kushal Shah, Philip Martinez, Emre Tepedelenlioglu, Shaddi Hasan, Cedric Festin, Joshua Blumenstock, Josephine Dionisio, and Kurtis Heimerl. 2017. An Investigation of Phone Upgrades in Remote Community Cellular Networks. In *Proceedings of the International Conference on Information and Communication Technologies and Development (ICTD '17)*. ACM, New York, NY, USA.
22. Susan Leigh Star. 1999. The ethnography of infrastructure. *American behavioral scientist* 43, 3 (1999), 377–391.
23. Sonesh Surana, Rabin Patra, Sergiu Nedevschi, Manuel Ramos, Lakshminarayanan Subramanian, Yahel Ben-David, and Eric Brewer. 2008. Beyond Pilots: Keeping Rural Wireless Networks Alive. In *Proceedings of the 5th USENIX Symposium on Networked Systems Design and Implementation (NSDI'08)*. USENIX Association, Berkeley, CA, USA, 119–132. http://dl.acm.org/citation.cfm?id=1387589.1387598
24. Jacob O. Wobbrock, Shaun K. Kane, Krzysztof Z. Gajos, Susumu Harada, and Jon Froehlich. 2011. Ability-Based Design: Concept, Principles and Examples. *ACM Trans. Access. Comput.* 3, 3, Article 9 (April 2011), 27 pages. DOI:http://dx.doi.org/10.1145/1952383.1952384
25. Mariya Zheleva, Arghyadip Paul, David L. Johnson, and Elizabeth Belding. 2013. Kwiizya: Local Cellular Network Services in Remote Areas. In *Proceeding of the 11th Annual International Conference on Mobile Systems, Applications, and Services (MobiSys '13)*. ACM, New York, NY, USA, 417–430. DOI: http://dx.doi.org/10.1145/2462456.2464458