Research Statement

Kurtis Heimerl (kheimerl@cs.berkeley.edu)

Information and Communications Technologies, despite being criticized for detracting from our social lives and communities, can often create and reinforce offline relationships. Companies like Meetup allow people to gather for group activities. Facebook connects high school friends for decades. My research focuses on how to support and enable similar communities in other contexts, including developing regions, crowdsourcing, and education.

First, I explored the construction and operation of local, **Community Cellular Networks.** These networks, in contrast with traditional nation-scale carriers, are run by community members and support the community itself. We discovered the design space for these networks, showed they are sustainable by conducting a deployment in rural Papua, Indonesia, and developed novel power saving techniques by including user feedback in power scheduling. Second, I investigated how to empower communities with **CommunitySourcing**: crowdsourcing through physical kiosks, rather than from the Internet. Utilizing offline communities allowed for higher quality results and enabled tasks never before possible on crowdsourcing engines. Lastly, I developed **Metamouse**, a tool that allows groups (small communities) of students to share existing educational games. We showed that a majority voting scheme was best in terms of accuracy and minimizing social strife.

Community Cellular Networks

Cellular networks are the largest networks on Earth, encompassing over six billion subscribers, more than double that of the Internet. These networks empower people to connect with family and friends throughout the world. New open-source technologies are driving down the price and complexity of running cellular networks to the point where individuals and small organizations can suddenly participate as operators [10]. The Community Cellular project focuses on this shift and its implications: the technologies, structures, and policies required to support a future world of small-scale community-focused cellular networks. We deployed one community cellular network in rural Papua, Indonesia, in an area far from any existing cellular service. In eighteen months of operation, the network has over 400 subscribers, has handled over 600,000 communications, and has generated over 17000USD in revenue for the operator, a local primary school. There were three key research results from this work: experiences in the design of community cellular networks themselves, the sustainability of the Papua network, and *Virtual Coverage*, a novel mechanism for saving power by including users in power scheduling. I also cofounded a company, Endaga, to commercialize this research.

Design of Community Cellular Networks: Community cellular networks, by nature small scale and community managed, are likely to have different goals than traditional telecommunication firms. Similarly, the open-source technology utilized (e.g., OpenBTS, FreeSWITCH) enables flexible operation and customization for specific communities [7, 8]. In our recent work [4], we investigated the design choices available to operators of community cellular networks. These choices allow operators to customize the network for their specific communities. As examples, a healthcare NGO could install the system in an area where they are conducting immunizations and reduce prices for nurses or deploy an SMS service for immunization scheduling. We also discussed the design decisions made by two operating community cellular networks, ours in Papua and another in Oaxaca, Mexico.

One of the core design choices for community cellular operators is how they deal with spectrum licensing requirements [4]. Operators can work with the government or operate as pirate

networks. We also proposed an alternative mechanism for spectrum licensing for small scale rural community cellular networks: *GSM White Spaces* (GSMWS) [6]. GSMWS allows small scale operators (secondary license holders) to make use of underutilized spectrum in rural areas with spectrum-sensing base stations

Sustainability of Community Cellular Networks: A core goal of our work on community cellular networks is to bring telecommunications to people and areas without coverage. Though saving power and customizing the network for specific local communities are valuable contributions, the network must be able to run without financial loss for extended periods of time to survive in the real world.

We evaluated the sustainability of our community cellular network in Papua by calculating the revenue generated by the network and the profit for the operator [7, 8]. We found that if the operator purchases the entire cellular system on credit and shares the cost of power and satellite Internet access, the network is highly profitable for the local operator with over $370 per month in profit while paying off the entire capital expenditure in five years. Similarly, assuming the operator finances the entire installation, including solar power and a VSAT, they're able to make $72 per month. These results argue for the validity of the community cellular model of rural access.

Including Users in Power Scheduling: Telecommunication providers and industrial associations (e.g., GSMA, ITU) have made it clear that power is the primary limiting factor for rural cellular networks. Most towers are powered by diesel generators, and driving fuel to these on a regular basis is expensive and potentially dangerous. Reducing the power draw of cellular stations is the most direct way to further reduce the cost of rural cellular installations and empower local communities to take control of their infrastructure.

Our solution, *Virtual Coverage* [5], reduces the power draw of the equipment by including users in the power scheduling. The base station goes "sleep" (into an idle mode) during periods of inactivity, as measured by the system itself. This typically happens during overnight hours, when little communication takes place. When the network is idle, users can "wake" it using a novel wake-up radio device or through a modified handset. Once the network is awake, users are able to communicate normally until the network is again inactive and returns to "sleep". Incoming communications similarly wake the base station. We deployed Virtual Coverage in our Papua network and saw a reduction in power draw of 56.6% overnight [2] over 6 months.

Endaga: One of my primary motivations in conducting academic research is real-world impact. In early February 2014, I cofounded Endaga to commercialize our work on community cellular networks and bring cellular access to the billion people internationally without it. In Late 2014 we closed $1.2M in financing from angel investors such as Mitch Kapor, Jeff Hammerbacher, Sanjit Biswas, and the Knight foundation. We have also formed carrier partnerships for future deployments with firms such as Roshan of Afghanistan. With the company in good shape financially and with a solid leadership team in place, I plan to return to my core interest of academic research in 2015.

CommunitySourcing

Crowdsourcing, the use of armies of people from the Internet to do small tasks for pay, has received a lot of research interest. However, many individuals with highly desired skills do not participate in these marketplaces. This means that it is difficult to conduct many high-level, complicated crowdsourcing tasks requiring specialized skills.

CommunitySourcing attempts to resolve this by utilizing a physical kiosk to do crowd work [3]. The physical kiosk enforces locality of the participants; it's not just anonymous people from the Internet but real people from the local community. This local property allows us to bring higher quality crowdsourcing tasks to these specific communities of people throughout the world, raising crowd work to the next level. We evaluated CommunitySourcing by building Umati, the CommunitySourcing vending machine. It allows us to target specific communities with specific tasks and rewards. We targeted the undergraduate computer science population at Berkeley with grading tasks and candy rewards. We showed that Umati allowed us to grade exams more accurately at lower cost than the traditional expert grading, while Amazon's Mechanical Turk, representing traditional crowdsourcing, failed to accurately grade the exams.

Metamouse

Many children in resource-limited areas never use a computer by themselves. Instead, all interactions are through sharing equipment. The goal of the Metamouse project [1, 9] was to develop techniques for sharing educational computer games among groups of users without requiring modification of the games (or even access to source code).

The technique developed was voting through mouse clicks. Users are all forced to click on the same part of the screen to make progress; when enough users had agreed by clicking in that general area the click was sent along to the application for processing. We compared a system requiring complete consensus among users against a simple majority model and a traditional single click system as a control. We found that the majority model was superior, as it had similar educational outcomes to the consensus model but created significantly less intra-community strife among users.

Future Research

My graduate research has focused on the use of technology to build, support, and empower communities and groups. This is done through deep technical knowledge, extensive field work, and real world deployments. As I transition into my faculty career, I will continue to interact directly with communities and explore how technology can support them, both online and off.

Community Cellular Services: Community cellular networks provide a powerful platform for service delivery. Services such as Awaaz De[1] and Polly[2] have been shown to have enormous impact in communities. We can deploy these and similar services on the base station itself, setting prices to be free or even subsidizing use. We plan to explore the space of voice and SMS services to support community development and involvement in rural areas.

[1] https://awaaz.de/
[2] http://www.cs.cmu.edu/~./Polly/

Cooperative CommunitySourcing: In our initial deployment of Umati: The CommunitySourcing Vending machine, we noticed that groups of users would use the machine at the same time. They worked together to select the grade and chose snacks that were easily divided up (e.g., Skittles over Snickers). We are keen to support this behavior; we expect that groups of people will produce better grades than individuals and reduce fraud. We've begun modifying Umati to support multiple graders on smartphones, still collocated with the machine. We will use Metamouse-like voting schemes and investigate the best way, in terms of accuracy and cost, to crowdsource from physical groups of workers.

Exploring Offline Interactions: Though my work has often focused on bringing the benefits of connectivity to the world, offline services are just as important. In the most remote places on Earth, connectivity remains too expensive. Even in dense urban situations, wireless signals sometimes disappear. I plan to explore user interface improvements for intermittent and disconnected networks, including leveraging these challenges to support peer-to-peer and other social and community building services.

Dissent Networking: Throughout the world, despotic governments are shutting down telecommunications infrastructure in order to inhibit political discourse and suppress popular political movements. Community cellular networks, being inherently decentralized, could provide an alternative mechanism for bringing communications to subjugated peoples. Our goal is to eventually build small-scale cellular networks that can be utilized by actors within these environments to connect their peers in troubled situations. This will require a deep thinking about user perspectives and behavior, as iterative design isn't possible during actual events.

[1] **Kurtis Heimerl**, Janani Vasudev, Kelly G. Buchanan, Tapan Parikh, Eric Brewer. A Case Study on Designing Interfaces for Multiple Users in Developing Regions. 1st Annual Symposium on Computing for Development (DEV), December 17-18, 2010, London, United Kingdom
[2] **Kurtis Heimerl**, Shaddi Hasan, Kashif Ali, Eric Brewer, Tapan Parikh. An Experiment in Reducing Cellular Base Station Power Draw with Virtual Coverage. 4th Annual Symposium on Computing for Development (DEV), December 6-7, 2013, Cape Town, South Africa
[3] **Kurtis Heimerl**, Brian Gawalt, Kuang Chen, Tapan Parikh, Björn Hartmann. Communitysourcing: Engaging Local Crowds to Perform Expert Work via Physical Kiosks. ACM SIGCHI Conference on Human Factors in Computing Systems (CHI) '12, May 5-10, 2012, Austin, Texas.
[4] **Kurtis Heimerl**, Shaddi Hasan, Kashif Ali, Peter Bloom, Joshua Blumenstock, Eric Brewer, Tapan Parikh. Designing Community Cellular Networks. In Submission
[5] **Kurtis Heimerl**, Kashif Ali, Joshua Blumenstock, Brian Gawalt, Eric Brewer. Expanding Rural Cellular Networks with Virtual Coverage. 10th USENIX Symposium on Networked Systems Design and Implementation (NSDI) April 2-5 2013, Lombard, Illinois.
[6] Shaddi Hasan, **Kurtis Heimerl**, Kate Harrison Kashif Ali, Sean Roberts, Anant Sahai, Eric Brewer. GSM Whitespaces: An Opportunity for Rural Cellular Service. In Submission
[7] **Kurtis Heimerl**, Shaddi Hasan, Kashif Ali, Eric Brewer, Tapan Parikh. Local, Sustainable, Small-Scale Cellular Networks. International Conference on Information and Communication Technologies and Development (ICTD) '13, December 7-10, 2013, Cape Town, South Africa
[8] **Kurtis Heimerl**, Shaddi Hasan, Kashif Ali, Eric Brewer, Tapan Parikh. A Longitudinal Study of Local, Sustainable, Small-Scale Cellular Networks. Information Technologies & International Development (ITID), 2015 (to appear)
[9] **Kurtis Heimerl**, Janani Vasudev, Kelly G. Buchanan, Tapan Parikh, Eric Brewer. Metamouse: Improving Multi-user Sharing of Existing Educational Applications. International Conference on Information and Communication Technologies and Development (ICTD) '10, December 13-16, 2010, London, UK
[10] **Kurtis Heimerl**, Eric Brewer. The Village Base Station. ACM Workshop on Networked Systems for Developing Regions (NSDR), June 15th, 2010, San Francisco, CA