Community Cellular Networks

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Cellular phones are a fundamental part of billions of peoples' lives, yet hundreds of millions remain without coverage. Concurrently, the cost of cellular equipment is dropping: for US$10,000, an individual can install an autonomous cellular network. These are defined as *community cellular networks*; effectively locally operated telecoms.

Our research focuses on enabling community cellular through the holistic design of effective socio-technical systems. This includes core network innovations, such as power management, as well as tools and designs supporting network operations. In this work we discuss our existing research results as well as potential future agendas.

Cellular networks are one of the largest human-created networks on Earth, encompassing over 6 billion subscribers [6], more than double that of the Internet. These networks empower people to connect with family and friends through voice, SMS and even data (e.g., Facebook) services throughout the world. These enormous networks are on the brink of a revolution. New open-source technologies, such as OpenBTS and OsmoBSC, are driving down the price and complexity of running cellular networks to the point where individuals can suddenly participate as operators [3]. Our research focuses on this shift and its implications: the socio-technical systems, structures, and policies required to support a future world of small-scale community-focused cellular networks and operators.

We have investigated this transition primarily in the context of rural connectivity in developing regions. Hundreds of millions of people in these regions remain without network connectivity, chiefly because it is too expensive for traditional cellular operators to install equipment in far-off regions with small populations and limited power and network infrastructure. As such, these regions are perfect targets for community cellular networks; few competitors, great need, and a deep understanding of network properties such as coverage [5].

This investigation requires a holistic use of tools and techniques from across computer science. The basic functioning of these networks asks deep questions about networking itself, focused on reducing power draw and operating in an environment where backwards compatibility is a fundamental requirement. The fact that this infrastructure, once the domain of only major nation-scale companies, is now becoming a consumer product, invites numerous HCI questions about the deployment, management, design, and understanding of community cellular infrastructure. Lastly, the marginalized communities likely to be the early adopters of community cellular bring forward development questions about the sustainability of these solutions.

We deployed one community cellular network in rural Papua, Indonesia, in an area far from any existing cellular service. In seventeen months of operation, the network has over 300 subscribers and has handled over 400,000 communications. Using this network as our test bed, our research focused on three key questions about the future of small scale community cellular networks:

Figure 1: Two examples of community cellular networks: Papua and Oaxaca. The Papua network (left) was installed in a tree, the Oaxaca network (right) in a shop.

- What technology is needed to enable community cellular networks?
- How can small scale community cellular networks be designed to suit their subscribers? and
- Are these networks capable of being financially sustainable for operators?

In this work, we describe our existing research addressing these concerns as well as our future research goals in the space of community cellular networks. We begin with a brief discussion of the concept of community cellular networks itself, as well as examples of their design and implementation, such as our network in Papua. We follow with a background on our existing work in the space. We finish with a discussion of future research agendas and conclude.

Community Cellular Networks

Community Cellular Networks [8] were first described in 2013. A community cellular network:

- Is owned and operated by a person or organization deeply embedded within the serviced community; and
- Is smaller-scale, with at most a dozen nodes; and
- Is trying to achieve goals that benefit the community.

To better demonstrate the reality of community cellular, we provide two real-world examples of running networks. Both are owned and operated by individuals within the community they serve.

The Papua Network

The first instantiation of community cellular was realized in rural Papua, Indonesia in February 2013 [3]. Though developed and deployed by the authors, this network is currently owned by a local wireless ISP that provides Internet service throughout the highlands of Papua. It is operated by the managers of a small missionary school situated within the community of Desa. It's a single network, servicing a single community, Desa, which is four hours drive from the nearest cellular coverage. One of the primary goals of the network is to provide basic connectivity to the community, specifically the teachers, so that individuals will have less incentive to travel to the big cities to communicate with their family and friends.

The Papua network has been running profitably for over 17 months as of June 2014, handling over 400,000 communications in that time. The network hosts numerous community-facing services, such as free local communications for emergencies, an SMS mailing list for teachers, and a community-wide singing competition.

The Oaxaca Network

As another example, the Oaxaca network has been operating in Oaxaca, Mexico since March of 2013. This network was built entirely separately from Papua, with neither team having knowledge of the other and without any influence from the authors.

The Oaxaca network is owned as the common property of the village and all its citizens. A town assembly meeting authorized the purchase of network equipment and the installation of attendant infrastructure, and tasked the town's government representatives with the operation and administration of the system. Equipment and infrastructure were purchased with the help of a loan from the local credit union of which 80% of the inhabitants are members and a small amount of local municipal government funds.

Current Research

We have been involved in the space of community cellular networks since our early work in 2010 [2] exploring the questions surrounding locally owned cellular infrastructure. Others have similarly explored the space [9]. In this section, we discuss our existing research agendas and results.

Enabling Community Cellular Networks

Telecommunication providers and industrial associations (e.g., GSMA, ITU) have made it clear that power is the primary limiter for rural cellular networks. 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. In existing networks, power is saved through periodic duty cycling. Networks are completely powered down for long periods of time, for instance at night if the network is solar powered. Our field research in Uganda [5] showed that this is a fundamentally unacceptable solution to many people; they demand cellular access for cases like emergency communications.

Our solution, Virtual Coverage [1], is a more sophisticated form of duty cycling. The base station (BTS) is put to sleep (into an idle mode) during periods of inactivity, as measured by the BTS 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 BTS. We deployed Virtual Coverage in our Papua network and saw a reduction in power draw of the BTS of 56.6% overnight [4] over a 6 month period while still handling hundreds of night-time communications.

Key Innovations: Availability in cellular networks is traditionally determined by cellular engineers. They often time outages with grid outages to reduce battery requirements. The key innovation of virtual coverage is bringing users into this process of provisioning power in their networks. Users are empowered to control when the network is available by signaling their desire to communicate with our autonomous radio.

Figure 2: Examples of the installation of a VBTS and a WUR.

Designing Community Cellular Networks

Community cellular networks, by nature small scale and community managed, are likely to have different goals than traditional nation-scale for-profit telecommunication firms. Similarly, the open-source technology utilized (e.g., OpenBTS, FreeSWITCH) also enables flexible operation and customization for specific communities [3]. In prior work [8], 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 a cellular tower in an area where they are conducting immunizations and set prices to be lower for nurses, provide network credits for participation, or deploy an SMS service for immunization scheduling.

Key Innovations: The most important factor in this work is recognizing the *flexibility* of this locally owned infrastructure. Cellular networks, once only available to major firms, are suddenly available to individual users and operators, and their design needs to change in order to fit the wider variety of goals and incentives. This research elucidates the design space of variables available to these users and operators, creating a better understanding of the possibilities.

Sustainability of Community Cellular Networks

A core goal of our work on community cellular networks is to provide systems that bring telecommunications to people and areas that currently do not have coverage. Though saving power and customizing the network for specific local communities are valuable contributions, at the end of the day the profitability of the network itself is a primary factor in the its continued operation. The network must be able to run without financial loss for extended periods of time to survive in the real world. Similarly, by keeping money within the local organization, our system encourages local entrepreneurship and provides employment opportunities for people within the community itself.

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 [3] over nine months of operation. We found that if the operator purchases the entire BTS on credit at 12.4% APR (the World Bank rate for Indonesia) and shares the cost of power and satellite Internet access, the network is highly profitable for the local operator with over $368 per month in profit while paying off the entire capital expenditure in five years, assuming no growth in network subscribers. Similarly, assuming the operator finances the entire installation, including solar power and a VSAT, they are able to make $66 per month in profit, while still paying off the entire investment in five years. Assuming a growth rate of 5 users a month, these numbers jump to $401 per month and $99 per month in profit. These results argue that community cellular is a commercially viable model for bringing cellular telephony to extremely rural areas such as Papua.

Key Innovations: The core contribution of this work is a demonstration of the feasibility of community cellular networks. While research is often on the cutting edge of technology adoption, when attempting to influence policy and society knowing the economic viability of the technology is extremely important. This demonstration involved a number of HCI toolsets, including quantiative analyses, qualitative field interviews, and economic modeling.

Future Research Agenda

Our existing research has focused on solving hard technical challenges that can have immediate impact on the world. This is done through deep technical knowledge, extensive field work with affected users, and real world deployments of the technology. We will continue to interact directly with users in their environment and investigate potential solutions to their problems at the all levels of the stack: infrastructure, interfaces, and organizational structures. In this work we focus on three particular systems ripe for HCI research: data access, network services, and infrastructure design.

Data Access

The value of Internet access is hard to overstate. It has toppled regimes, brought educational content to the farthest researches of the world, and shared critical information about the society that surrounds us.

Despite this, the Papua network has had only voice and SMS service since it's inception in early 2013. Only these basic services were requested by the operators at the time, and the network has flourished in spite of the lack of data access. As of a few months ago, OpenBTS supports data access through 2.5G GPRS. Introducing broader generic Internet access to the community has the potential to yield dramatic changes, as well as enable new technologies and systems within the network itself. We hope to enable generic data access some time in 2014, bringing Internet to a community where it has never been widely available before.

Potential HCI Research Questions:

- What Internet services are most valuable to rural communities?
- How can Internet services be designed to encourage local interaction? and;
- How do network primitives (e.g., naming, pricing, or billing) affect Internet usage?

Network Services

As first discussed an earlier white paper [2], owning the infrastructure provides an economical platform for developing community-facing network services. These services can be priced relatively cheaply as the communication is often completely constrained within the system, requiring little interaction (or payment to) outside entities. As such, we hope to continue to explore the space of network applications and their use within our communities.

There are numerous examples of such applications. In building out our system in Papua [3] we implemented a simple credit transfer service. The point of this system was to allow for peer-to-peer distribution of network credits, reducing the amount of work for the operator by allowing users to sell credits to each other. While this has been the dominant use of the system, we noticed that users have begun transferring credit between themselves, rather than just from credit resellers to subscribers. Essentially, a local currency has developed.

Similarly, we built a system called "Desa Idol", a village singing competition similar to prior work [7], in Papua. Following on the demonstration of the value of Facebook in rural communities, we also built an SMS to Facebook gateway, allowing anyone in the community to communicate inexpensively with Facebook friends all over the world.

Potential HCI Research Questions:

- How can we design network services (e.g., naming) that support and encourage local communications?
- What communication primitives (e.g., voice, SMS or data) are most easily adopted by rural users and why?
- How and why are people using network credits as a local currency, and what interfaces can we build to further encourage that behavior? and;
- How can we encourage users themselves to build network services and generate their own content?

User Interface Implications of Infrastructure Design

One of the key concepts underlying this work is that what used to be core network infrastructure, designed by and only available to highly trained engineers and scientists, is suddenly available to individuals and small organizations. This is not a new concept: it can be argued that the Internet was built in the same way. In fact, only the invention of the World Wide Web brought the Internet to the layperson. Similar (but less wide reaching) advances have happened for 802.11 wireless, FM radio, and a variety of other technologies.

This pattern argues that these core infrastructure pieces should be *designed* with individual users in mind. If the Internet were designed for users to interact directly with it, would IP addresses exist? Would DNS be the international mess it is now? Potentially. As cellular, in particular, is in a state of flux, transitioning from the globally ubiquitous 2G GSM technology to modern 4G LTE systems, it is worth analyzing what changes could be made to these systems to support smaller user-centered networks.

- What would core infrastructure (e.g., cellular or 802.11) look like if designed in a user-centered manner?
- What changes can we make to existing protocols and systems to encourage local ownership and reduce technical complexity? and;
- How can the standardization process incorporate user-centered design principles?

Conclusion

Cellular phones are one of the most impactful technologies of the last century, with over 6 billion subscribers in just twenty-five years of operation. In this work we discussed our research on Community Cellular Networks: cellular infrastructure that can be owned and operated by individuals rather than more traditional nation-scale telecommunication firms. We described the Papua network, our manifestation of community cellular in Papua, Indonesia that was deployed in February of 2013 and has handled over 400000 communications in seventeen months of operation.

We discussed the research results from this deployment, including the benefits of involving users in power scheduling, how these networks are designed, and the sustainability of our installation. Lastly, we discussed future research agendas, including adding data support, investigating the use of the credit transfer service, other network services worth implementing, and the user-centered design of core infrastructure.

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