Transforming Community-based Healthcare with CommScape

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Community Health Workers (CHWs) perform home visits for rural populations, provide basic healthcare, educate the population on disease prevention, refer patients to in-facility treatment, and have the potential to capture vital data for predicting and preventing disease. These programs capture important information for research and monitoring, but face challenges in using the information to improve service delivery. We propose an information system for CHWs that not only captures but operationalizes data with a careful composition of technologies, including data visualization and delay tolerant networking. CommScape, an application for mobile phones, allows CHWs to capture, visualize and share key information like personal medical histories and trends and alerts. We posit that CommScape can improve CHWs' quality of care, ability to predict and prevent diseases, and allow for better allocation of health resources.

1 Introduction

1.1 Community Health Workers

Healthcare is a fundamental challenge for rural populations in low-income countries. Patients living in extreme poverty rarely seek care until it is too late. For many, home visits from Community Health Workers (CHWs) are their primary mode of contact with the health system. CHWs are often tasked with carrying out home-based disease prevention education, detecting and referring those at risk for, or in the early stages of, common and dangerous diseases such as tuberculosis and malaria, and providing hands-on services such as pre- and post-natal care. CHWs serve an even more significant role than facility-based services in terms of encouraging preventive actions such as using mosquito nets, adopting safe water practices, and ensuring that children receive immunizations and proper nutrition. CHWs not only provide direct patient care, but can facilitate public health on a large scale. They can collect information that is needed at the regional and national levels for predicting and preventing disease and allocating resources.

CHWs lack the ability to capture, share and analyze information about their patients. Typically, CHWs fill out paper surveys for research and monitoring purposes. Paper forms are stored and then entered by a separate team of data clerks, often racing against a perpetual backlog. Recently, well-resourced CHW programs have begun to use electronic data collection tools [3, 5, 13]. Even with these tools, there lacks the back-end infrastructure that would allow CHWs to see the results of their work. Enabling collaborative information access and sharing between CHWs, their supervisors and the relevant health authorities would be an important step forward in improving healthcare.

CHWs work in isolated areas where travel is difficult and basic services like electricity and telephone connections are sparse or non-existent. In these regions, penetration of cellphones and wireless network coverage far outstrip that of desktop computing. Earlier studies have found mobile devices effective for data collection and service delivery in a variety of settings, including micro-finance and community healthcare [6, 10, 14]. Recent advances in mobile technology, delay tolerant networking, and collaborative data visualization have made it practical to support a larger set of CHW activities in areas with minimal infrastructure. Towards this end, we have built CommScape, a prototype system that enables information capture, visualization, and sharing, and provides a model for asynchronous conversation and collaboration.

1.2 Monitoring and Evaluation Challenges

Many improvements in healthcare, infrastructure, and quality of life in developing regions are being driven by a combination of grant-making, local and research orga-

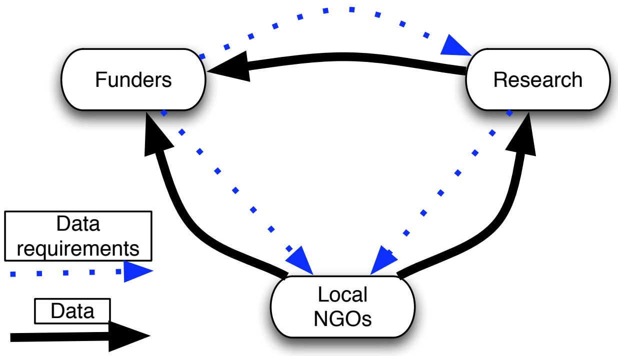

Figure 1. Data collection and reporting relationships between funders, researchers and practitioners.

nizations. Monitoring and evaluation (M&E) is a major challenge facing grant-makers and researchers. According to the World Bank,"prioritizing for M&E has become a mantra that is widely accepted by governments and donors alike." [12]. As shown in Figure 1, funders and researchers require practitioners to to fill surveys and report on indicators of progress. In the ideal case, top-down data collection requirements would be met by data collected for day-to-day operations. However, in low-resource organizations, monitoring systems are designed principally to meet donor data requirements [9]. Often, each report requires a separate paper form and a separate database. M&E indicators implemented as paper forms and corresponding data silos often decrease the ability of these organizations to operationalize data for improving service delivery.

Different funding organizations have different indicators, and many operations must gather multiple sets of overlapping data. This lack of donor harmonization has imposed a heavy burden on these organizations [12]. Data collection is a painstaking and time consuming process. Staff, from CHW to data entry clerks often become frustrated, complacent and disengaged because they do not see the fruits of their labor. The data flows one way, which health practitioners lament as "the one way street of public health."

What underpins this environment is an inefficiency of data movement and sharing. This is the motivation behind CommScape, to harmonize the data requirements of M&E and that for service delivery. Our vision enables CHW programs to efficiently collect high quality data, put it to use through visualizations, and enable discussion and insight with collaboration.

1.3 Related Work

Our work is inspired by the CommCare project, which is active in Tanzania and Uganda, and aims at automating the routine tasks of CHWs. CommCare assists CHWs by providing data collection and task planning automation [3]. Whereas CommCare focuses on iterative design to fine-tune the key use cases supporting current CHW activities, CommScape looks further down the technology road to architect an idealized model for information capture, sharing and analysis.

There are many other efforts in this space; in particular, there have been several successful pilots using handheld technologies for CHWs and other healthcare workers in resource-limited settings. In Tanzania, the handheld e-IMCI system can diagnose and treat the most common causes of child mortality [6]. Others include supporting clinical decision-making, distance learning for health professionals, and telemedicine in a variety of developing world settings [10, 11, 15].

1.4 The CommScape Vision

The CommScape vision is grounded through discussions with the CommCare team, the first author's participation in a contextual inquiry in a rural CHW program, and his observations working with a large HIV/AIDS treatment program in urban East Africa. CommScape's design is based on the use case of a CHW program of a non-governmental organization (NGO) that builds multifaceted community programs in the areas of micro-finance, agriculture- and livestock-extension, and community health promotion. When the program reaches full scale, two thousand CHWs will care for some three hundred thousand households. Each CHW is responsible for signing up and visiting 150 households around her own home. Each day, the CHW walks to a cluster of ten houses and performs a household visit. The basic visit management functionality is part of the CommCare system [3]. CommScape adds a flexible data architecture supporting visualization, annotation and asynchronous conversation.

At each household visit, CommScape supports CHW review of patients' medical histories through a timeline visualization and ability to drill-in to a particular visit. CHWs may review relevant messages or alerts. Data propagates asynchronously to a CommScape mobile phone. A data entry interface aids the CHW in recording basic health conditions: recent sicknesses, births, deaths, immunizations, mosquito nets, presence of latrines, etc. The CHW may capture general comments about the visit, or make specific annotations on data values from the interview. For example, the CHW may annotate that a child is lacking proper immunizations or note the household's plan to relocate before the next visit.

2 System

CommScape combines data entry, message-board style annotations, a visualization engine, delay-tolerant-networking, and data caching. This enables CHWs to gather, share, and collaborate around healthcare data, empowering them to improve the quality of care for patients, and to help predict and prevent disease. Since this is a first-itteration design, we have built a flexible data model upon which CommScape operates. The overall system architecture can be seen in Figure 2.

Each portion of the CommScape system fulfills a portion of our design goals:

Collaboration: CommScape enables a model for collaboration and conversation among CHWs, their supervisors and other health authorities, that can help them analyze, augment and assimilate quantitative information.

Information Gathering: CHWs can use CommScape to easily and effectively capture structured information such as form data from home-visit questionnaires, as well as unstructured information such as text, picture and voice annotations. CommScape uses statistical analysis and novel data entry mechanisms to improve data capture quality.

Visualization: CHWs can visualize key information such as personal medical histories and area healthcare trends and alerts. These visualizations can be annotated by CHWs and health authorities. These features encourage quicker and more nuanced insight and allow for smooth transitions of patient cases between CHWs.

Remote Information Exchange: CommScape enables asynchronous information exchange and conversation among CHWs, their supervisors and health authorities. The system caches a relevant subset of data, visualizations and annotations on a CHW's mobile device for offline use. The system updates the caches with new information for synchronization when online.

Our vision for the CommScape system is akin to the data warehousing and business intelligence operations at a large enterprise. With mobile phones, CommScape harmonizes many data sources, summarizes data into analytical representations (visualizations), shares aggregate information, and enables *everyone* to participate in analysis. As such, CommScape takes an incremental step towards distributed grassroots business intelligence supporting the activities of community health workers.

2.1 Gathering and Annotating Data

Primary data gathering is done through electronic forms, which mimic the paper forms that CHWs currently use in the field. We expect the type of data gathered by CHWs to change over time, so the forms are based on a flexible data model. In addition to raw data, we capture annotations and calculate statistics in the data model with the ultimate goal of improving data quality. In a parallel project, some of the authors have been working to improve data quality using dynamic forms [2]. This work, once field-validated, will be merged into the next version of CommScape.

In CommScape, collaboration between CHWs is enabled through annotations, which can be made on any data form, data visualization, or data record. Annotations are accumulated in a message-board style, and associated with the application view and user. This flexibility enables discussion of data and debate over interpretations, as well as easy referencing of relevant evidence. This conversation style is a common method for collaborative visualization [4]. This model may also be leveraged as an asynchronous and iterative process for data entry form design. Users may share comments about many types of data and metadata — including forms, specific annotations, form elements, or even particular data values.

2.2 Visualizing Data

Visualizing data is an important technique for understanding and explaining information. Furthermore, visualizations can allow users to share ideas with each other. Recent websites including Swivel[1] and ManyEyes[2] have brought many of these capabilities to the general public, enabling easy upload and visualization of data, as well as discussion about these visualizations. Our goal of enabling data visualization for rural health is motivated by the success of these systems in provoking conversations about data, leading to increased understanding. Moreover, with smart phones, it is possible to continue these collaborations asynchronously in the field.

CommScape includes visualizations of a visit map, timelines, and patient history. The visit map assists with planning patient visits, while timelines enable an overview of patient health. Data charts are the most widely applicable visualization, providing patient history, general trends, and many other visualizations that may be appropriate to the patient visit. Examples of these visualizations can be seen in Figure 3. The data visualization graphics are created with the Flare visualization package[3]. We use this library to provide interactive graphics, such as partial selection on a graph.

The visualization engine is built upon on the flexible data model that forms the backbone of CommScape. Visualization definitions (VizDefs) define the data query and parameters of a visualization. Each visualization is defined by a set of visualization columns, which can be measures, dimensions, or categories (as opposed to a static type, like "bar"

[1] http://swivel.com
[2] http://many-eyes.com
[3] http://flare.prefuse.org

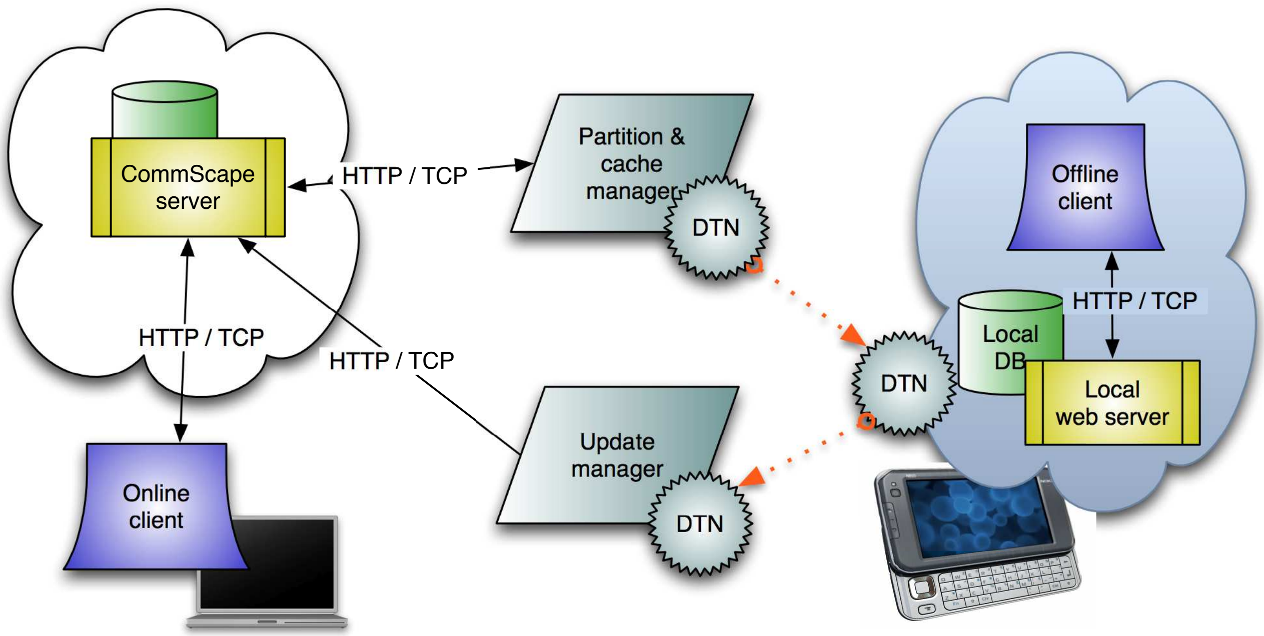

Figure 2. Architecture of the CommScape System. The main components are (1) a collaborative data visualization engine, (2) a mobile front-end for information capture, visualization and annotation, and (3) a delay-tolerant information synchronization layer.

or "chart"). This is similar to the VizQL approach taken by Tableau [8]. The VizDef and the data query statement provide an interface to accessing domain specific data. We maintain this narrow interface within the VizDef abstraction to keep our system flexible. The data model features a "catalog" of data sources and visualizable elements, similar to a traditional relational database catalog, which defines the objects in the databases. CommScape's catalog maintains metadata about data sets from many sources, including access information, tables, columns, data types, constraints and statistics. We based this catalog on the *information_schema* table in MySQL [4].

2.3 Disconnected Operation

CommScape is used in situations where there is little to no network connectivity, so disconnected operation is necessary. The state of the art in networking in areas of intermittent connectivity is Delay Tolerant Networking (DTN) [7], which allows packet-based communication across many types of networks, including challenged ones. DTN uses store-and-forward routing at each hop, and gracefully handles intermittent connectivity, even when an end-to-end route through the network is never achievable. This is used in CommScape for both client and server updates.

[4]http://mysql.com

When the CommScape client generates an update, the data is captured locally. This allows the client to see their annotations and visualize the data they inserted. Next, the data is sent over DTN to the CommScape server: DTN will attempt to route the packet to the destination. Upon its arrival, the data is in the same state as if that update had happened over a direct network connection. When the server sends a database update over DTN, the update reaches the phone and is momentarily cached before a process discovers and applies the update to the local database.

With limited storage on a mobile phone, the question of what data to make available offline to the CHWs is important and an open area for research. In our initial implementation, we replicate a subset of the database statically based on pre-determined heuristics. We choose geographic heuristics so that a CHW working in a region will have data for that region and its surroundings. After evaluating the performance of the device in a disconnected setting, we will consider other strategies.

2.4 Implementation

CommScape runs on any Adobe Flash enabled browser, whether in a mobile device or a PC. The current CommScape implementation runs on Nokia N810 mobile tablets, which support and have sufficient resources to run Adobe

Form entry on a household visit

Selecting a part of a visualization and annotating

Figure 3. The CommScape system, showing the visualizations that support community health workers during household visits, and when planning to see patients.

Flash in its browser. In 2009, these mobile phones retail for $200 USD. We chose this type of device because we expect the price to drop; expecting a convergence of the right cost and benefit at the time of large scale CommScape deployments. Of course, we must look at the total cost of a system in terms of capital and maintenance cost. For CommScape, this includes network infrastructure, servers and operational fees, local support contracts, training costs, facilities costs and other deployment costs – including handheld devices.

The application is written using the Adobe Flex [5] platform. In offline mode, the flash executable communicates with a lightweight proxy web server on the phone. Architecturally, we run a client-side proxy web server that caches server-side code, captures client communications, and forwards updates to the main server opportunistically. The client-side web server uses a lightweight client-side database with a replicated subset of relevant data in the same schema as that of the central database. For the client server, we chose Lighttpd[6]. It is an extremely lightweight web server that can be run on limited hardware. We use the reference implementation of DTN (DTN2)[7] for the connection between the client and the server. For the client database, we chose SQLite3[8], a lightweight relational database. SQLite3 is used in many cellular phones and other embedded systems. We use all open-source technologies to implement CommScape, and the application itself is open-source.

[5]http://www.adobe.com/devnet/flex
[6]http://www.lighttpd.net
[7]http://www.dtnrg.org/wiki/Code
[8]http://sqlite.org

3 Next Steps

3.1 Deployment

An important lesson from developing regions IT projects is that it is difficult to understand in advance all real-world constraints of the deployment location, and that this understanding is only obtained with significant on-the-ground experience [1]. As such, we plan to iterate on the CommScape vision in quick cycles with our partners in the field. Our field work will continue in 2009 in Uganda with the Millennium Villages Project. There, we will pilot and perform user study on the data collection component, and at the same time, refine the design and implementation of visualizations and the collaboration model. We plan to launch a pilot of the larger system with a partner in East Africa in 2010.

3.2 Applications

CommScape as a platform is designed to handle a variety of applications. One such is scheduling and way-finding. During a visit, CommScape may capture GPS readings to supplement "map cues" that tell a CHW how to find a patient's home. The latitude and longitude readings form the basis for a patient-tracking knowledge base. Mapped onto map cues, CommScape can support algorithms for more sophisticated scheduling and way-finding. More generally, the data model accommodates whatever sensors are outfitted on the mobile phone: photo, video, audio, air quality, and of course, medical diagnostics such as temperature, blood pressure and on-site assays.

CommScape can be used to help CHWs share information with in-facility supervisors and off-site consulting doctors. We can enable health workers to monitor patient data, CHW comments and sensor readings from the field. Based on visualizations of this information, cases are triaged, commented on or forwarded to a consulting doctor. The doctor then reviews the case and can make a recommendation, ask for more information, like a photo or audio recording; or recommend an in-facility visit. The CHW receives the doctor's message, and provides appropriate guidance to the patient.

4 Summary

We have developed a general framework for empowering CHWs. In the short-term, we will conduct the necessary field work to customize the system for the specific usage scenarios that we have outlined, which will be tested through pilot deployments. Each scenario outlined above represents a milestone against which we will recalibrate the CommScape vision. First, we will collect data through forms and measure how data quality can be improved through novel data entry techniques, including the use of summarized knowledge from previous encounters. In ensuing scenarios, we will determine which visualizations or reports would most benefit CHWs, and validate the collaboration and conversation model.

Looking to the long-term, we must support deeper collaborative information analysis to help identify important trends that can better direct and support community health worker tasks. This means expanding beyond the CHW, and fostering a virtual information analysis community between CHWs, supervisors, doctors and other health authorities, across different organizations.

There is a dramatic gap in healthcare between the poorest billion people in the world, who live on less then a dollar a day, and the rest of the world. CommScape is a vision that helps bridge the stark health-equity gap. By applying data management, networking and human computer interaction, we can improve the level of healthcare in developing regions. CommScape can enable CHW-led data collection, operationalize that data, and encourage sharing and collaboration between CHW's, supervisors, doctors, and other health authorities.

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