Rescue Base Station

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ABSTRACT

Natural disasters are, unfortunately, a fundamental part of living on Planet Earth. Earthquakes, floods, tornadoes, hurricanes, and other events will continue to test the strength of the infrastructure modern society relies on, such as communication equipment like cellular networks. In this work, we propose The Rescue Base Station (RBS) a drop-in, solar power compatible, open-source GSM communication system for the scenarios where a large-scale calamity disrupts traditional modes of communication.

The system operates using asynchronously connected autonomous nodes and gathers useful information from users, eventually synchronizing this data across the network using distributed network protocols. It connects people through conventional GSM services allowing calls, SMS and smart phone features when available. The networks also provides a series of services for use during a disaster, such as intelligent call routing, attribute based search on different characteristics (name, occupation and blood group), voice-mail services, SMS broadcast alerts, and emergency short-codes, through which a victim can contact available doctors, fire fighters, police and rescue workers.

Categories and Subject Descriptors

C.2.1 [**Network Architecture and Design**]: [Wireless communication]

General Terms

Design, Experimentation, Performance, Human Factors

Keywords

ICTD; Dev; computing for development; openbts; disaster response; mobile phone; wireless communication

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1. INTRODUCTION

In emergency situations, access to reliable communication forms the basis of the rehabilitation efforts. The communication infrastructure needs to be restored within the *golden 72 hours* period [19], after which the survival chances of victims decrease drastically [10]. However, it may take weeks or even months to restore conventional communication. In the Wenchuan earth quake, about 50% of the deaths occurred within the first two hours [34]. Repair of cellular networks can take days or weeks, depending on the coping capacity of the disaster struck area [16]. The quicker the communication is restored; the greater will be the chances to save more lives [37]. Therefore, a quickly deployable communication network is a vital asset in disaster relief scenarios.

Global System for Mobile Communications (GSM) is the most widely used wireless technology. There are over 6 billion mobile phone subscribers globally [20]. We present a GSM based, quickly deployable base station, customized specifically for disaster relief. It uses the conventional 900 MHZ frequency band and works with almost all existing mobile phones.

Our software system for RBS is designed for such an environment by using two key design considerations:

(1) Provision of "islands" of disconnected RBS units which exchange user registration and call/sms record data with each other by piggybacking data packets on android phones, similar to SneakerNets [15], a technique which makes use of portable storage devices for the transfer of data between disconnected systems. The data, comprising of user profiles and call data records, is spread in a gossip-like fashion by a specially designed service for android smart phones.

(2) Definition and implementation of a communication model where user profiles and call data records transferred between RBS nodes are used for call routing at runtime, similar to Anycast [30]. In this scheme, RBS nodes keep information about which users are accessible within their range, as well as pointers to other users who are in the vicinity of other RBS nodes. When a caller wishes to connect with a callee, the call is placed directly if both caller and callee share the same RBS node, or is routed to another user who may have information about the callee. These *indirect* users may be chosen because they were in the vicinity of the callee in some other RBS zone in the past or because the Call Data Record (CDR) shows that the two users interacted with each other recently. The indirect user criterion is configurable via a rule-based calling system within RBS.

When (1) and (2) are combined, our system enables a communication model that doubles as a traditional cellular tower and a *person-finder* even when a user is not immediately accessible in an RBS zone. In our system, a caller who simply initiates a call may be automatically routed through a series of *indirections* (people who may know the recent whereabouts of the person), to help locate and connect with the callee. To synchronize the states of different rescue base stations (RBS), we propose a technique similar to Footloose [27]: an optimistic replication system based on physical eventual consistency.

The RBS system provides a search feature on the different attributes of a user such as name, occupation and blood group. We have modified OpenBTS [4] to allow storage of these attributes at the time of registration. The RBS system also includes a helpline which records user problems. This information can help rescue workers to minimize human fatalities during the *Golden 72 Hours*. Through the RBS emergency short-codes, a user can quickly connect with doctors, police, fire fighters and rescue workers. We have defined direct extensions for such professionals(service groups) in the RBS system.

We evaluated the RBS system in an in-lab experiment, in which packets were transfered between the disconnected RBSes until the data across them was consistent. To evaluate the system's performance on a larger scale, we designed a custom simulation framework which tests the rate of change of number of synchronizations with respect to people, RBS nodes and size of the data packets. The system is evaluated both with Line and Mesh network topologies.

Our contributions are summarized as follows:

1. Design and Implementation of RBS, a drop-in solar power compatible 2.5G GSM communication system for disaster scenarios. Our system offers:
   (a) Intelligent call routing;
   (b) Attribute based search similar to a yellow pages lookup;
   (c) Emergency voice-mail services;
   (d) Emergency short-codes to connect with rescue teams; and
   (e) Emergency Alerts
2. Eventual Consistency Model (ECM) to synchronize registration and transaction data supporting disconnected operation;
3. Evaluation of the RBS system through:
   (a) An experimental demonstration of the Eventual Consistency Model using USRPs; and
   (b) a large-scale simulation of a disaster scenario.

2. POTENTIAL USE CASES

Rescue Base Station (RBS) is a drop-in cellular network specifically designed for disaster scenarios. The system is targeted to address emergency needs of the affected population, rather than just emergency workers. In this section, we describe a few recent disasters that have afflicted the world (and primarily developing regions) and contextualize our system through the experience gained from them.

2.1 The Kashmir Earthquake

On 8th, October, 2005, the valley of Kashmir and its surrounding regions were jolted by a severe earthquake. It claimed 86000 lives and injured over 80,000 people [24]. The losses suffered were extensive, affecting almost 3.5 million people. A sturzstrom (debris avalanche) comprising 80 million m^3 buried four villages [26].Destruction of electrical equipment resulted in wide spread power failures and damaged around 33,225 power lines [31]. The telecommunication infrastructure was also severely damaged and the services were down for weeks[2]. 86 telco exchanges, which is 36% of the total number of exchanges, malfunctioned [31]. Some of the worst hit areas were completely cut off from the relief authorities. An additional outcome was a total lack of coordination between the rescue workers and the victims. Concerned family members, relatives and friends had no way to confirm the fate of their loved ones. The law and order situation also suffered resulting in attacks on rescue workers and relief vehicles. There was an outbreak of pneumonia and diarrhea which could not be curtailed due to the damage to health care facilities and lack of awareness among the victims. Around 1000 health care facilities in the area were damaged, or were not operational[31].

2.2 Indian Ocean Earthquake and the Tsunami

On 26th December 2004, a tsunami hit the Indian Ocean affecting 1.7 million people across 14 countries [28]. The final death toll, 226,226 (including 49,648 missing people) exceeds that of any known tsunami in history [9]. It caused widespread power failures, disruption of telecommunication services, and destruction of other information infrastructure. Several communication towers collapsed due to the tsunami, which disrupted communication and cellular telephone networks [13]. The supply of fuel, food and medicine was affected due to the destruction of roads[29]. The situation was exacerbated when supply centers and rescue workers were attacked. Health care facilities were either completely destroyed or rendered unusable. Stagnant water caused diseases like malaria and dengue. Measles and respiratory infection were also rampant at the camp sites. In Aceh province, Indonesia, 85 % of the people reported diarrhea [35].

2.3 System Requirements:

The experience of both the Kashmir Earthquake and the Indian Ocean Tsunami provided us with a set of requirements for our RBS solution which are as follows:

1. The network should be self-powered and quickly deployable;
2. The equipment used should be man-portable;
3. The network should support dynamic addition and subtraction of GSM nodes;
4. The network should be adaptive and usable i.e. based on a technology which is already in routine use of a number of people;
5. A service to connect or update users about the status of family, relatives and loved ones;
6. A communication service to improve coordination between the rescue workers;
7. A mechanism to broadcast urgent announcements;

8. A service to contact available health-care, law-enforcement professionals and rescue workers;
9. A mechanism to identify profession and blood group of the registered users; and
10. The network should support a quick calling mechanism (direct dial codes)

3. DESIGN AND IMPLEMENTATION

With the above requirements in mind, we have designed the *Rescue Base Station* (RBS). RBS consists of numerous services, some in-network and some user-facing, supporting user needs in the disaster relief context. These include the registration of users on our network(as connectivity to existing cellular networks may be unavailable), eventual consistency (to provide consistent information to users and relief workers), dynamic network support(to cope with the changing network traffic), intelligent call routing and attribute-based search (to allow users to find and connect with each other based on our consistent data model), emergency voice-mail messages (to effectively and appropriately channelize the rescue teams), network short codes (to contact relief workers), and message alerts (supporting those workers).

3.1 User Registration

The disruption of conventional cellular services limit communications at a disaster site. To restore this communication, we propose a rapidly deployable cellular network. The first step of any network is getting users onto the network. In the GSM protocol, handsets immediately attach to *any* tower if traditional coverage is unavailable. In this case, they will attach to our tower and immediately receive an SMS with instructions on registering their phone and joining the network. The user then registers with our network by sending an SMS to the extension *111* (as detailed by the instruction SMS) and once registered they can make calls and send SMSes.

In registering with our network a user provides the following information:

1. Contact Number
2. Name
3. Occupation
4. Blood Group

The template of the registration SMS is as follows:

<mobilenumber> <name> <occupation> <bloodgroup>

If users register with their existing handsets and SIMs, they will be able to avail the 2G services i.e. they can make calls and send SMS to users connected with the same RBS. They will be able to avail our custom services as well. However, these users will not contribute to the eventual consistency of data. Users can unregister from the RBS system by sending an SMS to the extension *113*.

3.2 Eventual Consistency Model

In the aftermath of a disaster, multiple rescue teams are deployed at different rehabilitation sites. Due to unavailability of conventional networks, these rescue teams are disconnected from each other. Such a scenario dictates the need for an eventual consistency model(EVM) to synchronize data across these disconnected rehabilitation sites. Volunteers and rescue workers acts as the data carriers between the disconnected RBSes as shown in Figure 1. Ensuring eventual consistency can greatly enhance accuracy of information distributed across RBS(es). Due to consistent states, a user can access data collected from all the RBS(es). Services like intelligent call routing, attribute based search, voice-mail and emergency short-code services benefit from this model. For example, users searching for a doctor will have access to data collected from all the disconnected RBS(es). Another advantage is the prevention of redundant registrations. If two RBS(es) are in a consistent state, users moving across them will not need to re-register.

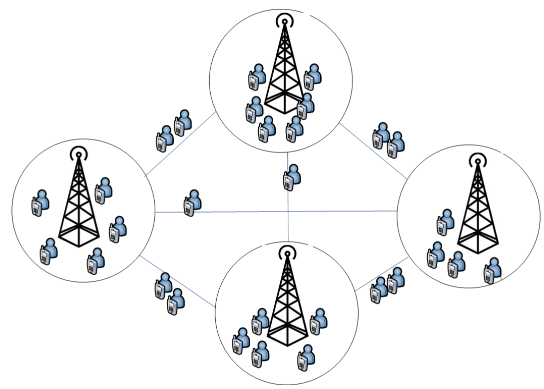

Figure 1: Disconnected RBSes

In Footloose [27], the candidate devices whose states need to be synchronized are part of a network. However, the RBS(es) do not share any network connection; therefore, we need an alternate medium to carry the required data from one RBS to another. By utilizing the distributed android devices as data carriers, chunks of data are transfered between different RBS(es). GPRS is used as the primary data sharing mechanism between the RBS(es) and the mobile devices.

The eventual consistency model involves the synchronization of two types of data. 1)User registration records. 2)Call transaction records. Each record is stored in a database on a RBS and also inserted in a file referred to as a chunk. In the system, chunks are atomic units of data, carried from one RBS to another to synchronize the user registration (subscriber registry) and call transaction databases.

3.2.1 *Eventual Consistency Client*

We have developed an android service which runs on each distributed mobile device. It is responsible for transferring chunks across RBS(es). As soon as a mobile device enters the range of an RBS, it downloads a chunk. After the download is complete, the user may carry that chunk to any adjacent RBS and upload that chunk to it. This process is triggered on the occurrence of the following events. 1) When the device registers with a RBS. 2) When the device enters the range of one RBS from another.

The android service(client side) is supported by php and python scripts running on each individual RBS (server side). Three php scripts are responsible for the following tasks.1) Round Robin serving of registration chunks 2) Round Robin serving of transaction record chunks 3) Storing the chunks uploaded by a mobile device. A python script reads data from an uploaded chunk and then inserts it in a RBS database. After addition of records in the database, the uploaded chunk is added to a shared pool of chunks that are available for download. Additionally, the script creates new chunks when necessary.

3.2.2 Network Characteristics

The RBS network is capable of providing 2.5G services. We have used open source software stack currently being developed by Fairwaves [1]. We have used the following modules to enable GPRS over the network:

1. Transceiver station (OpenBTS)
2. Gateway GPRS support node (GGSN)
3. Serving GPRS Support Node (SGSN)
4. Packet control unit (PCU)

Our maximum achievable speed is *76 kb/s*. We have dedicated 4 communication channels for packet data. Each RBS in our system is stand alone, without any back-haul. Therefore it does not provide Internet services; instead we use GPRS to establish a local area network to transfer data to/from the mobile and RBS, and eventually spread it across adjacent RBS(es).

3.2.3 Chunk Handling

There are 2 types of data chunks in our system: Transaction chunk and Registration chunk. Both types of chunks are created in a sharable folder hosted on Apache 2. These chunks are accessible to the android service running on the mobile devices. Each data packet in our system is compressed and uncompressed on our RBS(es) using deflate algorithm . As the maximum possible speed in the network is *76 kb/s*, we have set the size of a chunk to be *74 kb*, after compression; and each chuck contains up to 500 tuples. We have kept it so to ensure that the packets are effectively uploaded or downloaded even during brief RBS and Mobile encounters.

A new chunk is created if no record exists in the system (inception point), if the maximum number of records that can be stored in a chunk has been exceeded, or after an interval of 30 minutes. Each chunk is assigned a unique name which is a combination of a RBS-ID and Chunk-ID. A chunk retains that name as it hops across RBS(es) in our system. Whenever a new user registers with a RBS, its information is first inserted into the subscriber registry and then into a chunk. The maximum number of users that can be stored in the registration chunk is a configurable option which depends on the bandwidth provided by a RBS. A chunk when synchronized across all BTS(es) is redundant, and therefore, it should be deleted. Any deletion implementation will only work if we fix the total number of nodes in our system. For such scenarios we propose the following deletion policy. Each data chunk has 2 local variables, hop count and node count. Each successful transfer of chunk to the neighboring RBS increments the Hop count. The process is repeated until the hop count is equal to the node count(total number of RBS(es) in the system). When both these values are equal, it means that this chunk has been synchronized across all RBS(es), therefore, it is deleted from the system. However, one of the main features of our RBS system is dynamic addition and subtraction of nodes to cope with the call/SMS traffic spikes. The deletion technique can only be utilized if the number of RBS(es) is fixed.

Each low-end USRP development kit comes with a built-in 5GB (40Gb) storage space. A 500 tuples packet takes 74Kb of memory. So, a USRP device can possibly store about 57 million user registrations in 1 GB memory. Therefore, it is safe to assume that if chunks are kept in storage for the entire duration of the disaster response activities, the RBS(es) will not run out of memory.

We can have incomplete data chunk on the mobile or RBS i.e. if a user walks out of the range of the RBS before the completion or during the download. In case the chunk is not completely downloaded on a mobile device, it is automatically deleted by our service.

All call(s) or SMS(es) are logged by a RBS, it is first inserted into the transaction database and then into a chunk. Each transaction chunk is uniquely identified in our system.

At any point in time, multiple chunks may be stored in each RBS that are available for download. The chunks are served to users in a round robin fashion.

3.2.4 Chunk Locking

A chunk is locked i.e. not available for download until the following conditions hold true:

1. the maximum number of records to be packed in a chunk is reached; or
2. a timeout occurs after 30 minutes.

The concept of chunk locking has been introduced to avoid redundant data transfers. Imagine a scenario where chunk locking is not used. A user U_1 downloads chunk X to his phone from RBS B_1. The user then uploads this chunk to another RBS B_2. In the meantime additional users have been added to chunk X on B_1. Now when another user U_2 carrying the chunk X enters the range of B_2, the older records from X already stored in B_2 will be uploaded again. As we are operating under bandwidth constraints, this unnecessary upload of data will have a negative effect on the performance of the system. A user simply cannot carry the difference of data between a source and a destination RBS because the destination is unknown until the user actually enters its range. Thus, locking the chunk is an effective optimization to reduce bandwidth usage.

Chunk locking can increase the time needed by the RBS(es) to reach a consistent state. To counter this we have introduced the concept of timeout. If a chunk is not shared for a specific amount of time, it is locked and made available for download regardless of the number of users stored in it.

3.2.5 Optimizations to Chunk Uploads

When a mobile device is about to upload a chunk to an RBS, multiple checks are enforced on the mobile device and the base station which try to minimize redundant uploads.

A map is maintained on the mobile devices that stores information about the chunks that have been uploaded, and the RBS(es) it has been uploaded to. This map is updated only when a successful confirmation of an upload is received. Before any upload, this map is queried to find if the device has uploaded this chunk to this RBS before. In case of a positive match, the device does not proceed with the upload. In case of a negative response, the device asks the RBS if it already contains a copy of the chunk. This may happen if another mobile device has already uploaded a chunk with the same name to this RBS. If the RBS contains such a chunk then the upload is abandoned.

As the base stations are disconnected, a user might register on more than one RBS. Chunk transfer between such RBS(es) may lead to duplication of records in each RBS's subscriber registry. During the storage of chunk data, we avoid record duplication by skipping the insertion of a record if it already exists in the subscriber registry.

4. CONNECTIVITY IN DISCONNECTED ENVIRONMENT

Our system consists of a number of disconnected RBS(es). Each RBS in our system offers GSM services to a set of people who are registered with it, and are in its coverage range. The call/SMS record data is stored locally on each RBS. People traveling between the disconnected RBS(es) act as data carriers. Data is spread across the RBS system in a SneakerNet[15] like fashion, and it eventually synchronizes/updates data on each node. To maximize the possibilities of connectivity our system offers following services.

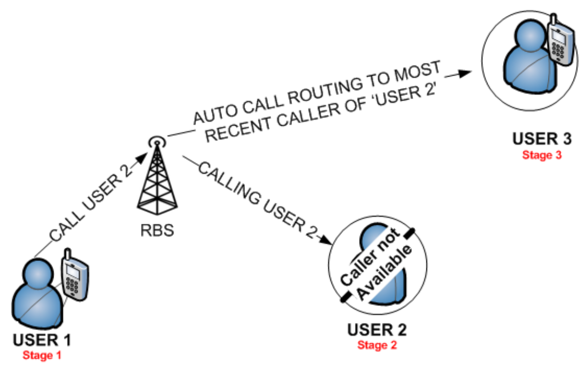

Figure 2: Intelligent Call Routing

4.1 Intelligent Call Routing

Intelligent call routing allows a caller to connect to a callee with respect to a connectivity rule(CR). Our system allows addition and removal of any number of CR(s) e.g 'most recent caller','same vicinity' or 'same profession type' so on and so forth. Each CR can have a number of levels for example. in the 'most recent caller' rule, our system behaves in the following manner 1)our system calls the callee 2) Failing to connect, it plays a call routing notification, checks the call records of the callee and connects the caller to the *most recent caller* who successfully called the callee; this is the first level for the 'most recent caller' rule. 3)Failing to connect to the most recent caller it connects the caller to the second most recent caller i.e. a person who called someone, who had successfully called the callee. This is second level for the 'most recent caller' rule. Our system allows any number of levels for a connectivity rule. Intelligent call routing scheme ensures that every call yields some information directly, or indirectly after a series of indirections. The purpose of this scheme is to help people connect with their loved ones, even if indirectly. Callee can be unavailable because of the following reasons:

1. The callee may be out of the range of the base station
2. The callee's phone is switched off
3. The callee might be busy with another call

In such cases, the RBS attempts to conventionally connect to a user, if the user doesn't respond, the caller is connected to someone who might have some information about the callee. Our system stores all call and SMS transactions along with their associated time stamp. Figure 2 provides a visual representation of the entire process.

4.2 Attribute Based Search

Timely access to information and individuals with certain attributes can be incredibly valuable in disaster scenarios. As an example, natural disasters often cause up to three times more injured than deaths [33]. Timely availability of blood to the injured can greatly reduce the number of fatalities [18]. Similarly, one needs to urgently connect to any of the available doctors, whether it be from among the victims or from among the rescue teams. Some may seek help from firefighters, law enforcement agencies, or he/she might want to search for a friend, family or a relative.

In view of the discussed user-scenarios, useful information like the name, occupation and blood group of a user is collected and stored in the subscriber registry at the time of registration. The system further provides *attribute based search* on the collected information. A user can send a text to the extension *7000* to search for relevant information. A python script parses the received message and extracts the search attributes mentioned. The subscriber registry database is then queried against these attributes and the results are returned to the user. The template of a search SMS is

$$'Search \quad < Attribute > \quad < value >' \tag{1}$$

A concerned user can search our system for a friend or a relative by sending an SMS 'Search name John' In reply the sender will receive a list of all the registered users with the searched name along with their contact numbers. A user can also search for people with a specific occupation. For example, in case of a medical query, a user can find the contact information of all the registered doctors by sending an SMS 'Search occupation doctor'. Similarly, a user can search for a specific blood group by sending an SMS: 'Search bloodgroup O+'. For the implementation of attribute based search, existing registration implementation of VBTS support libraries [3] was very helpful.

4.3 Emergency Voice-mail Services

Our system provides a helpline to record emergency information from any location. We have defined an extension *1122* in the FreeSWITCH dial plan, which the users can call to record their specific problems followed by their location. These recordings can be used to prioritize relief efforts by efficient channelization of resources. Each recorded file is labelled with the caller's name and his SIM's IMSI number. Through such labeling, the rescue workers can find additional information relevant to the caller.

Consider a scenario where a user calls our helpline to register an injury which has caused severe blood loss. Our system will find the blood type of the caller from his registration information, pass it along to a rescue worker, who may then accompany a blood donor to the caller's location.

4.4 Emergency Short-codes

While our voice-mail services provide an indirect way for users to record their problems, we have also defined four extensions in the FreeSWITCH dialplan to provide direct access to the following types of professionals (service groups):

1. Doctors (*7777*)
2. Police (*7700*)
3. Fire brigade (*7722*)
4. Rescue Workers (*911*)

We propose that survivors belonging to these service groups should register with the RBS system as soon as they are in range of an RBS. Furthermore, each RBS should be populated with the contact details of all officially known rescue workers.

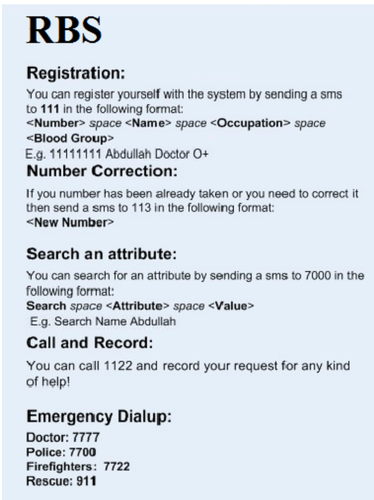

Figure 3: Sample Sticker

In case a user does not remember the exact extensions, we have also defined an ancillary extension: *8000*. A user can send a text message to this extension mentioning a service group. On receiving the SMS, the system retrieves a list of professionals belonging to that service group and calls each member sequentially until one of them responds or the list is exhausted.

We have designed a sticker to guide our users as shown in Figure 3. This sticker will be pasted on the back of each android phone which will be distributed by the rescue workers.

4.5 Message Alerts

Emergency broadcasts are a simple and effective way to get important information out to as many people as possible. Our system broadcasts emergency SMS alerts to locally registered users within the range of a particular RBS. For example, notifying people of an expected storm, necessary precautions to take and a list of secure sites nearby. This is a bandwidth expensive operation and should only be used when absolutely necessary. Hence, this feature is only available to the heads of rescue and support groups.

4.6 Dynamic Addition and Removal of RBSs

Network congestion [14] is a very serious problem in disaster scenarios. The RBS deployed in a densely populated region may overload due to the abundance of traffic. To efficiently handle variable load, we can remove base stations from regions experiencing sparse traffic and place them in regions with heavy traffic. As all RBS are disconnected, there will not be any negative impact of such a dynamic node configuration. RBS is man-portable and can be transported easily. As an alternative solution, addition of a larger (50W) amplifier boosts the capacity of our system by supporting 35 concurrent calls per RBS.

5. EVALUATION AND RESULTS

Disaster relief systems are extremely difficult to evaluate in a real-world context. Disasters are unpredictable with varying impacts on communities. For these reasons, we evaluated our eventual consistency model through both a lab-based experiment and a disaster simulation.

5.1 Lab Test

We tested the RBS eventual consistency model in our lab utilizing a pair of Ettus B100 universal software defined radio peripherals (Figure 4) to demonstrate the transfer of packets between the disconnected RBS(es).

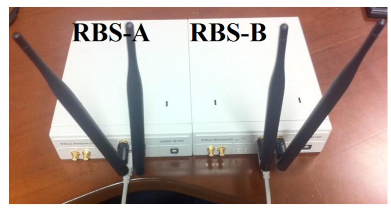

Figure 4: B100 USRPs

The mobile devices when moved between the RBSs (RBS $_A$ and RBS$_B$) successfully downloaded and uploaded the data. The scripts read the chunks and transferred data to the local registration and transaction databases respectively.

The RBS A and RBS B both have 0.89 MBs of data i.e. 50000 registrations on each RBS. The data on each base station was unique.

The service on each RBS divided the data into 100 uniquely identifiable chunks. Four new users were registered with both RBSes. The mobile phone service was installed on all participating android phones(data carriers). When the mobiles were in range of RBS $_A$, each one of them downloaded a unique chunk. Then, the devices were moved to RBS $_B$. Each device uploaded the chunk, deleted it and then downloaded a new one from RBS $_B$. The process of uploading and downloading was repeated, as the devices were moved between the disconnected RBS(es). With a bandwidth of 76 kb/s, 74 kb chunk was downloaded in approximately 1 second. The participating subjects were moved 105 times between the disconnected RBSs after which both the databases were synchronized to 100000 records each. There were 5 incomplete transfers; our android service automatically deletes the incomplete downloads from the mobile phone(s). We observed some interesting stats i.e. as we increased the number of participants(mobiles) in the experiment, number of rounds to reach eventual consistency decreased. Figure 5 shows a plot of number of people against the number of rounds it takes them to synchronize data across RBS(es). A round is defined as a single to and fro movement between two RBSes.

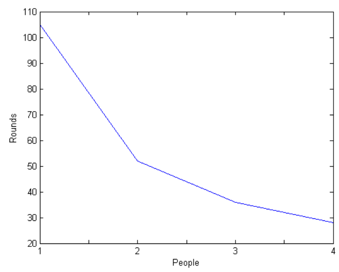

Figure 5: People VS Rounds

5.2 Disaster Simulation

We have designed a custom simulation framework to evaluate our eventual consistency model. To accurately measure the performance of our system, it is tested on following two network topologies.

1) In Mesh topology, each node is connected to all other nodes directly. Therefore, a user at any RBS can move towards any other RBS without hopping through any other node. 2) Aschenbruck et al.[5] present a realistic topology recognizing the importance of mobility in disaster areas. This study advocates separation of the room, and an organized movement of civil protection forces and disaster victims between incident site, causality treatment area, transport zone and hospital, in a linear fashion.

In-between the RBSs the movement of users was modeled with the Random way point [7] and disaster area [5] mobility models. Each simulation started with random distribution of data chunks and people (data carriers) across RBS(es), followed by the arbitrary movement of people between the disconnected RBSes. A successful transfer of data chunk from one RBS to another is one synchronization. The simulation consisted of a number of synchronizations until the data on all disconnected RBSes reach a consistent state.

5.2.1 *Simulator*

The RBS system consists of a client side Android service and server side php and python scripts. The system is tested in-lab and initial results are presented in section 5.1.

To measure the performance of our system on a larger-scale, a customized simulator has been designed in python, it helped in the study of the affects of change of different independent variables on the number of overall synchronizations to reach eventual consistency. Each simulation scenario runs until the data is synchronized across all other RBS(es). The simulations are designed to study the affect of the following independent variables on the number of synchronization:

1. Number of RBS Nodes
2. Data Packet Size
3. Number of People

To track the precise number of synchronizations, each experiment was repeated 4 times. Each data point on the graph is an average of four runs.

5.2.2 *Simulation Results*

The Experiments show the affects of these variables on number of synchronization. Before starting the simulator, data chunks and data carriers (people) were randomly distributed across the RBS(es) using mersenne twister pseudo random number generation algorithm [23]. The simulation starts with random selection of a number of RBS(es). On each selected RBS a random number of people may choose to leave to other adjacent RBS(es). Each movement is recorded in a 2d square matrix. If a person moves from RBS 1 to RBS 2 the value in the second column of the first row is incremented. Each person selects a random destination RBS [23]. This process is repeated until the data chunks are synchronized across all RBS(es). The simulation stops as soon as the data is completely synchronized across all RBS(es).

The effects of changing the independent variables on the number of synchronization to reach eventual consistency are described below:

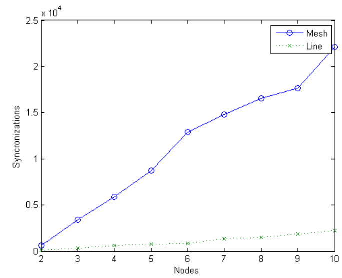

Figure 6: Nodes VS Synchronizations

Node Count:
The number of synchronizations required to reach eventual consistency against the number of nodes is shown in Fig. 6. The Number of synchronizations in Mesh topology rose steadily as we increased the number of nodes, except between 5-6 and 9-10, where there was a steep rise in the number of synchronizations. Line topology outperformed mesh network topology. Initially, for mesh, the difference between the number of synchronizations to reach eventual consistency for mesh and line was equal to 175; towards the end of the experiment Mesh required 5 times more synchronizations compared to Line topology.

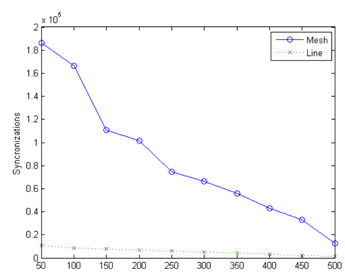

Figure 7: Packet Size VS Synchronizations

Data Packet Size:
To reduce the number of synchronizations to reach eventual consistency, the size of each data packet can be increased thus reducing the total number of data packets to be synchronized across RBS(es). In order to observe the effects of packet size on synchronization count, another experiment was conducted whose results are shown in Figure 7. Number of nodes in this experiment was equal to 6. Number of synchronizations decreased with an increase

in the packet size. Between 250 tuples/packet(t/p) to 300 t/p and 150 t/p to 100 t/p there was a steep decrease in the number of synchronizations. Line topology required less number of synchronizations compared to Mesh. In the start for 50 t/p Mesh required 18 times more number of synchronizations than line. Towards the end of the experiment Mesh required 9 times more synchronizations as compared to Line.

People:
An experiment was conducted to investigate the effect of the number of people participating in eventual consistency against the number of synchronizations. Figure 8 shows that increasing the number of people results in a gradual increase in number of synchronizations for line topology, whereas for Mesh it increased rapidly.

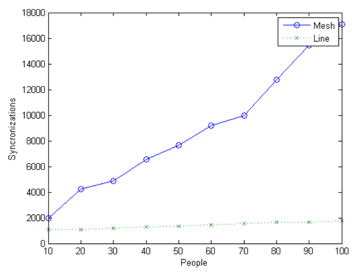

Figure 8: People VS Synchronizations

Line topology required less number of synchronizations as compared to Mesh topology. For line topology, rate of change of number of synchronization with respect to the number of people was less than that of the Mesh topology. For 100 people, the number of synchronizations to reach a state of eventual consistency for Mesh was 10 times greater than that of line topology. Unlike the experiment (section 5.1), the movement of data carriers in the simulation is not uniformly distributed across all the disconnected RBS(es). For example, data carriers may randomly choose to visit a destination RBS whose data state is already consistent with the source RBS. Such movements are redundant, and do not contribute to eventual consistency. Therefore, results of the simulation are different from the experimental demonstration.

6. DISCUSSION

6.1 Privacy

Any system that involves the collection of personal user data may raise privacy concerns. We address such issues by allowing anonymous registrations. During registration, users who do not wish to disclose their identities can skip input of all personal information except their contact number. The system still allows such users to avail the 2G emergency services.

Moreover, the storage of data is only temporary as all records will be deleted as soon as relief efforts are completed. Such steps ensures that personal information and call history of user is not used for any commercial purpose. Similarly, our service(android phone) automatically deletes a data packet as soon as the packet is synchronized with any neighboring RBS node.

6.2 User Movement Trends

Our eventual consistency model works best if there is rapid movement of users across RBS(es). Lack of movement, however, results in failure to synchronize data across disconnected RBS(es). We propose to address this issue through strategic positioning of RBS(es) at frequently visited sites. For example, relief camps near drinkable water sources and hospitals make ideal candidates to deploy a RBS. This enhances the probability of movement between RBS(es) which in turn enhances consistency between them. More generally, it is our expectation that certain populations (e.g., relief workers) will generally travel widely and be good vehicles for eventual consistency.

6.3 Power / Energy

Transfer of data packet to and from the base station can be a power expensive operation. Keeping such constraints in mind we limit the chunk size to an optimal value of 74 kb, to ensure that upload or download operation must not take more than a second. Thus, minimal cellphone power is consumed while participating in our eventual consistency model. We also plan to integrate compact-charging units with our base stations to support charging of some common mobile phone batteries via Solar/Wind energy.

7. RELATED WORK

Large-scale natural disasters occur with little warning. As a result, massive engineering efforts are expended with the goal of minimizing the impact of these events, both in terms of human lives and infrastructure. In this context, wireless communication is one the most sought after technologies for disaster management systems. As such, there have been several disaster response systems proposed using a variety of network protocols, including VSAT, Wi-Fi (802.11), HAP, LAP and GSM.

7.1 Satellite link

Besides a few exceptions [11], Satellite technology can be deployed at any favorable site globally. There are numerous systems proposed which advocate the use of satellite communication in a disaster site [6] Similar systems are being designed to fulfill data needs of tele-medicine applications, which are specifically targeted for serving rural populations and disaster response [12]

Satellite, by nature of its expensive and high-power ground stations, is best suited for empowering a few important actors in a disaster. RBS, using existing low-power handsets, instead provides valuable services to the wider community of affected people in an area. Satellite connections can be used for network backhaul, however, and so we believe these two technologies are complementary.

7.2 WIFI

Wifi is a widely adopted and supported technology throughout the world, with ubiquitous, inexpensive receivers. The primary limitation of Wi-Fi is its limited range; only up to 200m. This limitation has been resolved for point-to-point links, providing long range (>50km) and high speeds [25]. Point-to-point links generally require line-of-sight, a key limitation when trying to cover a large population in an urban environment. Similarly, Wi-Fi is extremely common and operates in unrelated bands, causing issues with spectrum management in dense urban situations. Solutions have been developed, such as a Lein's MANET based emergency information and communication system [22]. The system supports a large number of rescue workers/volunteers via Wi-Fi ready notebook PCs. However, the basic limitations of the protocol and frequency band are hard to overcome, while GSM provides wide-area communication in a licensed band.

7.3 HAP and LAP

High altitude platform operates from 17 to 22 km. As the Platform operates at lower altitude compared to the satellite link, one can claim it to be more reliable and faster [21]. It usually requires a ground gateway for direct ground communications. To address this limitation, there is another proposed system which is a combination of low altitude platform and Wi-Fi (802.11) technology. The idea is to provide Wi-Fi connectivity with the help of tethered balloons, specifically to address medical emergency needs [32]. These solutions have the same issues as existing Satellite and Wi-Fi systems, which is another reason we focused on GSM systems.

7.4 GSM Systems

Lastly, other researchers have explored the space of cellular solutions in disaster scenarios. Crane et el. [8] present a rapidly deployable GSM network which makes use of the cellular communication as the primary platform. They have proposed a number portability technique to disallow malicious registrations. Their proposed solution requires cooperation from the existing telecommunication companies and they require PSTN and VOIP gateway, to allow off-network calls. Heimerl et el [17] enabled 2G communication services in two villages of Indonesia. The BTS is operated with a micro hydro power generator, and supports international SMS and local calls. Wypych at el [36] presents a GSM system with aerial deployment capabilities. The system can be deployed at high altitudes and promises a uniform GSM coverage over an area of 3.4 km. Such flight control system provides a viable upgrade to the conventional deployment techniques of disaster response systems. These systems provide the inspiration for RBS, showing us the potential value of autonomous GSM solutions in disaster scenarios.

8. CONCLUSION

Disruption of communication is an inevitable consequence of a natural calamity. Timely (within golden 72 hours) restoration of communication services can improve coordination, boost up rehabilitation activities, and considerably reduce the number of fatalities. In this paper, we have presented a solar power compatible, quickly deployable disaster response system; the RBS network. The system consists of disconnected base stations (RBS) which create islands of connectivity. Data chunks are transferred between the disconnected RBS(es) using mobile phones; resulting in an eventual consistent state of the data across RBS(es).

A set of custom services have been developed on top of an open source GSM cellular network which aids in disaster response activities. Our system enables a user/rescue worker to search for a doctor, blood donor, a law enforcer or a missing relative through an SMS service, or can connect with a pool of rescue teams (doctors, firefighters etc.) via emergency short-codes. Users can get information about their relatives via intelligent call routing. Usage of these services can be instrumental to minimize the loss of human life and property.

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