Experimental Emergency Communication Systems Using USRP and GNU Radio Platform

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***Abstract*—One lesson learned from recent large-scale disasters is that the destroyed communication infrastructure severely burdens the relief operation and the recovery mission. How to establish a temporary emergency communication system (ECS) providing reliable communication channels upon deployment becomes a must. An Universal Software Radio Peripheral platform with GNU Radio is employed for experimential purpose with basic voice communications and short message services. With the aid of pre-installed APP in victims' smartphone, valuable information about the victim, such as the identity, location, or physical condition, can be automatically delivered to the developed BS, which significantly facilitates the rescue work. Furthermore, BS acting as a relay could provide direct voice connectivity between victims and relief workers, thereby avoiding considerable fatalities.**

***Index Terms*—Emergency communication system, disasters, GUN radio, GSM, OpenBTS, USPR**

I. Introduction

Since the beginning of the 20th century, the natural disasters such as tsunamis, floods, hurricanes and earthquakes are getting more and more frequent and violent. The resulting severe destructions incur the loss of power and damage of infrastructure, thereby introducing large-scale termination of communication services [1]. Such communication interruptions thwarted the critical first few hours and days for relief work and threaten the sustainment of survivors' life. The Great East Japan Earthquake lesson us that instead of building an indestructible system, we should create emergency communications systems (ECS) to provide information exchange among individuals impacted by the disaster (e.g., victims or evacuees) and those involved in disaster relief (i.e, relief workers) for relief work and post-disaster missions [2]. Obviously, such ECS should support sufficient bandwidth to meet most people's needs and leverage a basic communication tool most people possess.

The primary objective of ECS is to provide reliable communication services to the victims located in the coverage holes due to the damage of infrastructure. Rather than recover these infrastructures (might require from one week to four months), taking an emergency *device* into disaster area serving emergency communications is more appropriate. With the aid of the emergency device, the residents could communication with each other, the relief workers, or relatives by using the *handsets* they carried. When we design a ECS, the device at server side and the handsets at client side as well as the suitable communication technology for information conveyance need to be considered together.

Following the paradigm, we designed a practical implementation of ECS. In particular, we adopt the low-power radio base stations (BSs) as the emergency devices, which is originally designed to be deployed at disrupted telecommunication areas for the extension of coverage and the improvement of spatial reuse in heterogeneous network [3]. Instead of supporting advanced data services, a frugal design is more suitable for the disaster zone with limited resources, that is, basic voice communications and short message services (SMS) are enough. It implies that Global System for Mobile (GSM)-based emergency BSs (EBSs) is an appropriate implementation. Regarding the handset at client side, the cellular phone is the most widely used communication tool and is friendly for APP development. The pre-installed emergency APP could exchange the location and identity information of the owner via SMS to the EBS in an autonomous fashion, which obviously facilitates relief operation.

By exploiting recent development in Software Defined Radio (SDR) [4], which can substitute most of back end hardware with real-time software applications, the implementation of such GSM-based EBS becomes much more economical and efficient. In particular, the mature development of Universal Software Radio Peripheral (USRP) [5] and GNU radio [6] drives an effective SDR solution called Open Base Transceiver Station (OpenBTS) [7]. With an emulation of GSM architecture over USRP radio boards, OpenBTS has been successfully implemented to provide voice connectivity and SMS in rural regions at a very low costs [8]. Moreover, the feature of low power consumption prolongs the operation time, which is significant important in the disaster region. Obviously, the deployed EBSs can cooperate together and establish a emergency communication network (ECN) in order to support wider range of communications.

The aim of this article is to shed light on GSM-based BS

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deployment in disaster area and discuss their implications on issues of emergency communications and relief operations. Section II outlines the impacts of disaster on ECS. The necessity of a suitable ECS is identified from the perspectives of communications capabilities and networking features. The next section builds on this motivation to describe the system architecture of EBSs and the network architecture of ECS. The details of how proposed ECS operates are described in Section IV. Finally, Section V concludes this work.

II. Impact of Disaster to Emergency Communication System

In this section, we investigate the necessary functionalities that an ECS should provide in the context of three phases of relief operations.

Preparation Phase. Without the information from the disaster region, the extent of the damage is hard to be predicted, which highly affects the preparation of the initial relief efforts. As a result, the relief workers need to rely on their own judgment on the scene and might not bring appropriate emergency equipments for relief operations. To prevent the above situation, the maintenance of mutual communication channels between disaster area and relief authority is necessary.

Action Phase. When the relief workers perform rescue action, following three functionalities are suggested:

- *Determine the identity, location and physical condition of the survivors.* With sufficient information about surrounding trapped survivors, the relief worker could determine an efficient and effective rescue sequence. Typically, the rescue team brings equipments like solar to detect the condition and location of trapped survivors. However, an quite environment is necessary for solar detection, which is difficult in disaster area, especially when others are digging using some heavy equipments. Moreover, the identities of victims are typically confirmed by self-declaration, which is infeasible for unconscious or trapped survivors. An alternative approach by querying the neighboring surviving residents is not precise and doubtful.
- *Help the survivors and evacuees get emergency support.* Since ECS is aimed at assisting rescue operations to first avoid fatalities, the desired quality of service (QoS) must be provided to headquarters, relief worker, responders for dispatching and commanding during rescue operations. If the direct communication between the conscious survivors and the relief workers is further established, the rescue process becomes more efficiently and effective. Moreover, the realtime communication channel between workers and emergency center could gain some extra few minutes to prepare what victims required, which can be lifesaving. It is also essential to maintain communication channels for those victims in different shelters [1].
- *Clarify the concerns from outside world.* The confirmation of whereabouts and safety of residents will be complied into a sensitive victim database including evacuees and missing lists [2]. Such victim database should be updated in realtime fashion from emergency center to relief authority in order to inform concerned relatives and friends. Moreover, the analysis result of database could reply the inquires from the government, the media, and the public.

Recovery Phase. The ECS should keep updating large volume of disaster situation information to relief authority, so that the authority, utility agents and industry representatives could cooperate to extract information, assess the damage, and make decision for reconstruction. As a result, maintaining the communication continuity is needed in both action and recovery phases. In particular, all the communications provided by ECS during disaster period should be seamlessly migrated to be supported by the repaired communication facilities.

A. Taxonomy of ECS

According to the above observations, we develop a novel taxonomy to classify the ECS, which identifies the major dimensions of communication: the peers participated, the technologies adopted, and the network established.

The scale of participants involving in communication. To support the mentioned functionalities, various communication capabilities involving different scale of participants should be supported by ECS, which are listed as follows:

- communications between ECS in disaster area and relief Authority (*EA*).
- communications between Victims and deployed Device (*VD*).
- communications between Victims and Relief workers (*VR*).
- communications among Relief workers (*RR*).
- communications among Victims (*VV*).
- communications between Victims and their Friends or relatives (*VF*).
- communications between ECS and reconstructed communication Infrastructure (*EI*).

The technologies of communication. This category concerns the technologies for communications among devices, between device and outside, as well as between handsets and device.

The features of networks build. Via the above various kinds of communication channels, an ECN for information conveyance is established. To meet the goal of avoiding fatalities, special features are needed for ECN to achieve the proper and effective rescue task force.

- *Topology*. The topology of ECN, including tree, mesh and ad hoc structures.
- *Rapid deployment*. Deployment processes must be simple and fault-tolerant without complex procedures [9].

- *Automation*. The deployed devices for serving communication media can automatically connect the handsets carried by the victims and thus can collect, analysis, and notify information, which significantly reduces response time and increases the survival ratio.
- *Adaptability*. The network can change its behaviors in response to the dynamic changes in the severe environment. During the different periods of disaster, the architecture of the network might change in response to the demands of relief work.
- *Portability*. The emergency vehicles are difficult to reach the disaster scene since traffic arteries are always destroyed after a severe natural disaster. Hence, a light-weight ECS devices are very important for the recuse team who has already carried lots of heavy emergency equipments.
- *Sustainability*. Typically, the ECN is expected to be prolonged for at least 72 hours. To achieve that, the energy consumption of the operations should be optimized. Meanwhile, battery powered fashion is suggested since the battery replacement is more feasible than introducing a heavy power generator.
- *Security*. The sensitive information collected (such as victim database) or exchanged in the network should be carefully protected since different task forces such as rescue authority, local agencies, and military forces are involved in the relief operation [9]. In particular, victim's privacy should be context-aware or conditional to prevent the authorized access from rescue team [10].
- *Convenience*. To enlarge the popularity who use ECS, the ECS handset should be very common, often within the owners' easy reach to, and easy to operation without complicated interface.

B. The Existing Solutions

This subsecton surveys the existing ECSs and we focus on the ECSs for providing communications among individuals while those only for information collection (such as sensor networks) are not considered. Okada et al. [11], Google Loon and Softbank Balloon adopt the aerial devices to provide connectivity for general purpose. Regarding the communication for rural areas, VillageCell [12] and Kwiizya [13] enabled local users to achieve mutual communication by voice or SMS based on OpenBTS.

Lien et al. [14] designed a walkie-talkie-like ECS on top of a multi-hop network constructed via volunteers laptops. This approach allows two rescuers to communicate with each other via the ad hoc mode of IEEE 802.11. Mase et al. [1] developed an ECS for shelters consisting of a shelter server connected to the Internet and a set of shelter personal computers (PCs). A shelter PC can provide a communication to another adjacent shelter PC via message communication service. [15] further proposes multihop device-to-device (D2D) communications underlaid with existing cellular network for

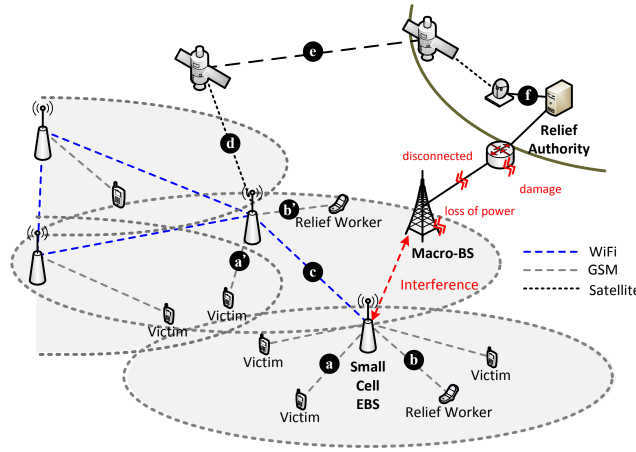

Fig. 1. The network architecture of ECS.

emergency communication. However, the power consumption due to relaying shall be carefully considered in the resource-constrained disaster area. EmergeNet [16] applies OpenBTS and FreeSWITCH to enable end-to-end communication with the aid of session initiation protocol (SIP). In our proposed framework, we further support the direct communications between victims and relief workers, which is significantly important for initial relief process.

III. Small Cell Emergency Communications System

As shown in Fig. 1, we apply the concept of low-power and low-cost EBSs as the devices to provide communication channels. We accordingly apply smartphones as the handsets for communication at the client side. By enabling satellite communication capability on the EBS, *communications between disaster area and relief authority* can be achieved (see Fig. 1 (d), (e), and (f)). Under the environment that original macro-BSs are damaged, the smartphone carried by the victims will automatically attach and register to the EBS arranged by the rescue team. As a result, the *mutual communication channel between victims and EBS* is established (see Fig. 1 (a) and (a')). With the aid of developed APP on phone, EBS could automatically collect information from the attached mobile phones and control them by using SMS.

The smartphones carried by the relief workers could also connect to the EBS. In this case, the *direct voice communications between victims and relief workers* is build via the relay of EBS (see Fig. 1 (a) and (b)), which introduces an effective rescue operation. When multiple EBSs are established as an ECN, a wider range of communication services are provided. The *voice communication among relief workers and headquarters* in ECN helps the controlling and commanding of rescue tasks, thereby facilitating the relief operation (see Fig. 1 (b), (c), and (b')).

Meanwhile, ECN supports *communications among survivors and evacuees* in different shelters (see Fig. 1 (a), (c), and (a')). Via the EBS with satellite communication capability, the ECS further support *communications between victims and*

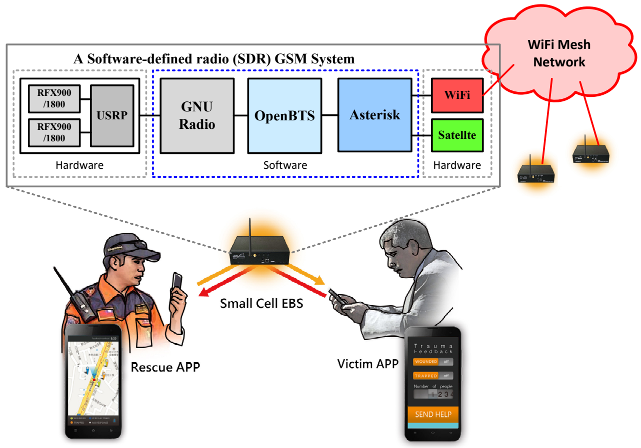

Fig. 2. The schematic architecture of OpenBTS-based GSM network

their relatives or friends in the outside world (see Fig. 1 (a), (c), (d), (e), and (f)). During the post-disaster period, the infrastructure is reconstructed and the telecommunication services are resumed. The EBS might incur interference and thus burden the signaling from the recovered macro-BS. We can apply recent innovation such as cognitive radio (CR) [17] to mitigate the mutual interference and further to *migrate communications from EBS to repaired macro-BS*.

A. OpenBTS System Architecture on EBS

As shown in Fig. 2, the EBS is a software-defined radio (SDR) [4] GSM system. It utilizes the hardware platform of Universal Software Radio Peripheral (USRP) [5] to convert the analog signal received from the radio frequency (RF) daughter board (RFX900/1800) to digital signal and fed the digital signal into an embedded system. The digital signal is then processed by OpenBTS. OpenBTS is an open source software implements the GSM air interface functionality. Instead of forwarding calls through to an operator' core network, OpenBTS delivers calls to a private branch exchange (PBX) (such as Asterisk [18]) via SIP. The EBS is equipped with a WiFi interface to connect to a Wifi-mesh-based wireless backhaul network. Several EBSs are interconnected by the wireless backhaul network. Optionally, the EBS can also equipped with a global position system (GPS) receiver to assist the positioning of survivors.

Several issues exists if we want to implement the EBS using OpenBTS. First, the numbering plan of OpenBTS is defined in a configuration file. The network should know a users identity (i.e., IMSI) and associate each IMSI with a phone number. A user needs to know another users number before making a phone call. However, it is impossible to configure numbers to survivors in prior because survivors IMSIs are unknown. To deal with this issue, we proposed an automatic registration system using SMS. The proposed system keeps a list of IMSIs for all relief workers in each EBS. In GSM, each user will register to a nearby EBS by sending it IMSI. The EBS will send an assigned phone number to a newly registered relief worker using SMS. The EBS will also periodically update the phonebook of all relief workers through SMS such that the relief workers can easily communicate with each other. Upon receiving registration request from a victim, the EBS simply assign an ID to the victim and announce the number specially reserved for emergency call (e.g., 911). The emergency call will be automatically transferred to a nearby relief worker.

The second issue is to route the SIP calls among several EBSs. The routing of the SIP calls in Asterisk is based on a fixed IP address. However, the location of each EBS in the wireless backhaul network is not known in prior. Therefore, it is impossible to configure a routing table in advance. To deal this issue, we create a self-organized network based on the concept of Bluetooth. The first EBS which completes the initialization procedure should act as a master node while the remaining EBSs act as slave nodes. The master node should continuous broadcast its IP address to slave nodes through the WiFi mesh network. The slave nodes should report their IP addresses to the master node to maintain a routing table.

IV. The Operations

This section describes how to apply the proposed ECS to disaster area. The advantage of lightweight makes OpenBTS be easily equipped in a robust case for transportation. The EBS can be air dropped by the helicopter or carried by the rescue team to the disaster area. Once landed, the relief workers need to clear all the cables and unfasten the black restrict belt. Then the relief worker simply pushes the button to inflate the balloon, which carries the antenna up to take advantage of good line of sight, low interference, and long transmission range. The additional WiFi interface embedded on the EBS establishes an ECN in the mesh fashion for serving more participants.

Basically, APPs and EBS are hooked together, that is, APPs can recognize the paired EBS by pre-installed cellular ID (CID) of EBS. Once a resident downloads the victim APP on his/her smartphone, the owner needs to fill some personal information to facilitate future relief task force. The information specifically includes the name, home address, emergency contact name and relationship, emergency contact phone, as well as blood type. The information is installed in the victim APP locally and will not be exposed, and thus the privacy is protected. Except the personal information, victim APP will start periodically recording the GPS value and corresponding time value as the reference of current position.

When a disaster happens, the early warning system will notify the residents. Once the victim APP receives the alarm, it will immediately record the current GPS and timing values. Moreover, the victim APP will start recording GPS and corresponding time values in a much higher frequency to ensure that the location information is precise. If unfortunately the disaster makes the building collapsed and traps residents, the victim APP containing the latest location information can be exploited to position the trapped victims.

When the EBS is deployed by the rescue team, the smartphone carried by the trapped victim will detect the existence of EBS by comparing the received CID. Then the smartphone can attach and register on the EBS and thus EBS basically identifies that the smartphone is located nearby. The EBS can allocate a communication channel to each registered smartphone using some designed scheduling algorithm.

Once the victim APP senses the existence of communication channel, the first part of the program "automatic reply" is performed, where a short message containing the personal and location information is sent to the EBS. By analyzing the GPS information, the precise position of the victim is identified by the EBS and is stored. EBS then replies a short message to the victim APP to trigger the second part of program "intentional reply", where an apparent button appears on the screen. The victim can push the button, fill in the current physical status (such as trapped or the level of wounded), and the APP will send results to the EBS via short message. To assist in the survivors who cannot operate the smartphone due to injury, a voice notification is enabled like "there is a rescue team nearby, please say Mayday". After receiving the voice distress signal, the APP will encoded it as a short message and notify the EBS.

Depending on the different kinds of responses from the victim APPs (automatic, intentional, or voice signal), different physical conditions can be distinguished at ECS. The ECS further forwards the analyzed data to the rescue APP at relief worker. Then the location, identity, and emergency contacts of surrounding victims are marked on the offline maps where different colors represent different physical conditions of the victims. With such information, the relief workers can determine an efficient rescue process. Meanwhile, the EBS will periodically notify the trapped survivors that the progress of rescue process in order to make them clam. The relief worker could even directly establish voice channel to communication with the conscious survivors in order to speed up the relief process.

V. Conclusions

The proposed ECS adopts mesh topology, integrates technologies of GSM, WiFi, and satellite communications, and provides various kinds of communication capabilities among participants. With autonomous SMS exchanging functionality, precious information about potential survivors are gathered, which make relief process more effective and efficient. The direct voice channel between victims and relief workers further reduces the number of fatalities. Participants could just operate the APP on their own smartphones to achieve the above functionalities, which facilitates the spread of APP and thus is beneficial for life saving. Yielding a limited cost, providing various kinds of communication capabilities, imposing no interference on existing infrastructure, the ECS with CR capability has great potential as an efficient solution to serve urgent needs from victims and relief workers.

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