2009 29th IEEE International Conference on Distributed Computing Systems Workshops

A MANET Based Emergency Communication and Information System for Catastrophic Natural Disasters

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ABSTRACT

When stricken by a catastrophic natural disaster, emergency rescue operation is very critical to many lives. Many people trapped in the disastrous areas under collapsed buildings or landslides may have a large chance to survive if they are rescued in "*Golden 72 Hours*". People evacuated from their home jammed in highways or dome shelters need to communicate to each other for various reasons. However, communication systems were usually down due to various reasons. The loss of communication systems made the rescue operation extremely difficult. Many people died before they got a chance to be rescued. This paper analyzes the causes that paralyzed the entire communication systems in Jiji Earthquake and proposes a MANET based emergency communication and information system that can support a large number of rescue volunteers under catastrophic natural disasters.

Keywords: Disaster Rescue, Mobile Computing, MANET.

I. INTRODUCTION

The solution presented in this paper belongs to Relevance Ring 1 because this paper proposes a special purpose MANET.

Almost every year, the world is stricken by numerous catastrophic natural disasters, such as earthquake, hurricane, typhoon, tsunami, etc. When stricken by a catastrophic natural disaster, such as Jiji/Taiwan Earthquake [4], SiChuan/China Earthquake [6], or Hurricane Katrina [5], emergency rescue operation is very critical to numerous lives. Many people trapped in the disastrous areas under collapsed buildings or landslides may have a large chance to survive if they are rescued in 72 hours, referred as "*Golden 72 Hours*". People evacuated from their home jammed in highways or dome shelters need to communicate to each other for various reasons such as allocation of rescue and relief resource as well as reunion of family members. However, communication systems, fixed or mobile, were usually down due to various reasons. Rescue teams in each stricken area consists of few trained professional squads, army, police, fire fighters, and hundreds of thousands of disorganized volunteers. The loss of communication systems made the rescue operation extremely difficult. In Jiji Earthquake, it took ChungHwa Telecom, the largest telecommunication operator in Taiwan, 15 days of 24/7 operation to restore its mobile communication systems. Many people died before they got a chance to be rescued.

Although establishing a temporary communication network to support emergency communications and networking is one of the most urgent tasks in a disastrous rescue mission, feasible technology options are very limited. We propose to use WiFi-ready notebook PCs owned by rescue volunteers themselves to construct a MANET to support such a need. Because the popularity of WiFi-ready notebook PC is very high nowadays, this solution would be highly feasible in many countries.

The platform is designed and implemented in two phases. In the first phase, a simple MANET is implemented to support emergency information system. In the future second phase, we will implement an "Autonomous P2P Ad-Hoc Group Communication Systems (P2Pnet)", which is a local wireless intranet based on P2P and MANET technologies. P2Pnet is used to support the communication need under temporary serverless infrastructure-less Internet-blocked environments such as nature disastrous area, battle-field and mobile learning environments.

Rescue people, voluntary or mission-specific professional, can use their own notebook PCs to construct a multi-hop ad-hoc network to form a basic wireless intranet first, then use our P2Pnet technology to form a higher level mission-specific network to support urgent communication needs such as VoIP, Push-to-Talk, and Instant Messaging, and mobile social network, etc.

1545-0678/09 $25.00 © 2009 IEEE
DOI 10.1109/ICDCSW.2009.72

Due to page limit, this paper will mainly focus on the system analysis and the design of the first phase platform.

II. CHALLENGES AND SYSTEM ANALYSIS

2.1 Impact of Communication System Crash

The impact of communication system crash to the Jiji Earthquake will be presented in this section. Many people trapped in the disastrous areas under collapsed buildings or landslides may have large chance to survive if they are rescued in 72 hours, called *Golden 72 Hour*. The loss of communication systems and information system created a big impact to the efficiency of rescue operation. Followings are a few painful lessons we learned from Jiji Earthquake first-handed. (One of the authors was right in a spot stricken by Jiji Earthquake to learn all the lessons first-handed.)

- In a catastrophic disaster, regular rescue teams including trained professional rescue squads, police, army, and fire fighters were far from sufficient for the emergency rescue mission. A large number of volunteers must be mobilized to participate in the rescue operation. However, without a good communication system, it is very difficult to organize and coordinate rescue volunteers.
- Transportation system was paralyzed not only by broken bridges and roads, but also by a large number of disorganized voluntary rescue vehicles.
- A large volume of rescue and relief resources were misplaced because the assessment of disasters distribution is virtually blind and inaccurate in the early hours even days after a big quake. As a consequence, the higher accessibility a stricken spot, the easier to receive external resources. Unfortunately, reallocation of resources may not be possible because of paralyzed transportation systems. In SiChuan Earthquake, some soldiers were even dropped to the disaster areas by parachutes. It is impossible to reallocate them if they were misplaced. Misplacement of rescue and relief resources may lead to catastrophic consequence. Each stricken spot may have many vulnerable survivals, such as injured people, babies and hospital patients, whose lives are highly dependent on relief resources. Misplacement of demanded medical equipments and supplies as well as life-support resources could cost numerous lives.
- Trained and skill-specific professional rescue squads were misplaced to wrong spots. For instances, a professional rescue squad specially trained and equipped for detecting survivals trapped under collapsed buildings was sent to a spot where was known having no trapped survival.
- Some injured people died after being rescued from under tons of building debris because of ambulant not available or being sent to over-saturated hospitals.
- Streets were blocked by the collapsed buildings so that the rescue people were divided into two isolated groups. While one group was doing sound-sensitive operation (e.g. using a high sensitive sound detector to detect any human sound under debris), the group on the other side was using heavy machinery to dig the debris.

The list is much longer than what we mentioned above. In summary, the impact of communication system crash to a disaster could be catastrophic.

2.2 Causes that Crashed Communication Systems

To many people's surprise, cellular mobile communication systems that were thought highly dependable in emergency were completely wiped out in many cases. Followings are parts of causes we found in Jiji Earthquake:

- Base stations were crashed.
- Trunks connecting base stations to MSCs were broken almost everywhere, especially broken roads and bridges. (Trunks were laid along roads and bridges).
- Backup power generators were out because of fuel exhausted.
- Critical hardware equipments were down because cooling tower fell down or cooling pipes were broken.
- Cell phone ran out of battery and had no way to recharge because of power line failure or simply chargers not available.
- Communication systems were overwhelmed by extremely huge traffic.

Threatened by so many sources of failure, it requires a miracle for a cellular mobile communication system to survive in such a catastrophic disaster, even for a robust system with 99.999% reliability. Even if there is a miracle, volunteers do not know each other and do not have time to remember large amount of phone numbers. Thus, a survived cellular communication system provides not too much help either.

2.3 Environmental Constraints and System Requirements

Following are the constraints and requirements for an emergency communication system that can support a voluntary rescue operation for a catastrophic disaster.

Environmental Constraints for a Disastrous Spot

- Outgoing link (Internet) is either not available or very limited.
- Server is probably not available.
- All Internet based services, such as Skype, are not available, because of no Internet access.
- There is a very stringent time constraint that volunteers are not able to use those devices that have a complicated user interface. In other words, user interface must be very simple.
- WiFi-ready notebook PCs are assumed very popular.
- Portable power generators are assumed available.

Functional Requirements

- User interface must be simple, easy to learn, and fool-proof.
- Devices do not need complicated setup procedure.
- Devices must be fault-tolerant such that misusage will not crash a device.
- The system must support broadcast based multimedia communications, while unicast communication mode is optional.
- Only basic functions are required, advanced features are optional.
- The system must not demand high power, must be able to recharge using a portable power generator.

Without plenty of resources and time, it is not easy to develop a system that meets all the requirements listed above, especially the first three. User-friendly and robustness cost a fortune to achieve. Therefore, our recommendation is to trade functionality for simplicity, developing basic functions only and giving up most advanced features.

Performance Requirements

- provide tolerable QoS for multimedia communications
- maintain minimum level of throughput
- give precedent to QoS over throughput
- provide class-based priority services
- provide high member coverage for group communications

2.4 Available Options of Emergency Communication Systems

There are few options for emergency communication systems.

- **Walkie-Talki**e

  Perhaps Walkie-Talkie is the most convenient and reliable communication system for emergency. However, the popularity of Walkie-Talkie in many countries is far less than notebook PCs. Although regular rescue squads may already equipped with similar equipments, most volunteers may not have such equipments. Even if Walkie-Talkie handsets are widely available, we still need a data network that can support information services such as resource allocations.

- **Emergency Mobile Communication Systems**

  Various equipment vendors are offering emergency mobile communication systems [7,8]. Specially designed systems are expensive and offer only limited number of handsets. It is prohibitively expensive to deploy sufficient capacity for a catastrophic disaster as big as mentioned cases. In summary, the capacity of current specially-designed emergency communication systems may be able to support regular rescue squads, but are far from sufficient for large amount of volunteers.

  Most cellular operators have emergency cellular systems that use satellite links as backhauls and can be deployed to a demanded area in a few hours. However, there are two problems. First, cellular operators may not have sufficient number of such systems for catastrophic disaster. Secondly, as mentioned in Section 2.2, volunteers do not know each other and have no time to memorize (or keep in handset) many phone numbers and may not have handset chargers in hand.

- **MANET based P2Pnet**

  We propose to use WiFi-ready notebooks to construct a MANET based group communication system to support emergency communication and information network, called *P2Pnet*. In recent years, WiFi-ready notebook PC that can last for several hours is becoming a very popular and universally compatible device in many areas. When stricken by a natural disaster, survivals and volunteers can use their own notebook PCs to construct a P2Pnet. Using P2P communication technologies, a P2Pnet is able to support Walkie-Talkie-like communication, Push-to-Talk, VoIP, and network information systems for emergency usage. Compared with other options, no extra hardware cost is needed.

III. MANET Based P2Pnet

3.1 System Architecture

P2Pnet is a serverless peer-to-peer communication network based on MANET to support temporary group communication and information network. As depicted in Fig. 1, some nodes may have satellite communication capability performing gateway functions so that all other nodes can access Internet through gateways if they are available. On top of MANET, there is a layer of peer-to-peer communication service to support higher level services such as Walkie-Talkie, Push-to-Talk, and VoIP communications. Three basic communication modes are supported as followings:

- **Uncontrolled Single-Hop Group Communication Network (U1Net)** Each node can broadcast data to neighboring nodes in one-hop distance. No authorization will be enforced. This mode can support short range Walkie-Talkie-like communications and is the easiest network to construct. This is designed for the usage in the early hour of disasters when all the organizational effort is not in place yet.
- **Uncontrolled K-Hop Group Communication Network (UKNet)** Each node can broadcast data to neighboring nodes in K-hop distance. No authorization will be enforced. This mode can support long range Walkie-Talkie-like communications. This is also designed for the usage in the early hour of disaster when all the organizational effort is not in place yet. However, it is a little more complicated than U1net so that it requires more effort to construct.
- **Controlled K-Hop Group Communication Network (CKNet)** This is a more advanced mode and can support unicast type services such as VoIP. It requires more organizational effort, such as assigning unique IP addresses, to construct such a network mode and may not be easy to construct in the early hours of a disaster.

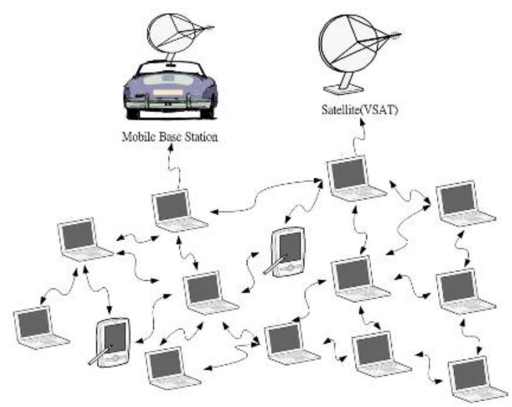

Fig. 1 Architecture of P2Pnet

3.2 Feasibility Assessment

The availability of compatible notebook PCs and power supplies are the two most critical feasibility factors.

Availability of Notebook PCs

In many countries, highly compatible notebook PCs equipped with 802.11 WLAN capability running TCP/IP network protocol is getting more and more popular. Starting from 2008, inexpensive mini-notebook PC has been very successful and has no sign to stop its momentum yet. Proliferation of computer literacy to the low income world in the near future has been in our vision. We can imagine that constructing a P2Pnet for emergency communication is completely feasible in many areas of the world. It would be foolish to ignore such a convenient communication tool.

Availability of Power Supplies

Electricity will be most likely knocked out even in a small disaster such as a snow storm. Power generator has long been a typical equipment in most contingency plans. In some areas such as Taiwan, portable generators are very popular because of a large population of flea-market-style evening markets.

On the other hand, the battery life has been extended from 2 hours to 8 hours. As mini-notebook PC, that consumes less power than regular notebook PCs, gets its momentum recently, we can anticipate that the chance of having many long-life notebook PCs in many areas is very high. Compared with other heavy machinery, the fuel consumed by P2Pnet is only a small fraction of total fuel consumption.

3.3 System Developments

P2Pnet has been developed in two phases. The first phase is to develop a simple MANET. Only simplified information service is supported. In the second phase, a more advanced system will be constructed. It will be able to support broadcast-based and unicast-based multimedia communications such as Walkie-Talkie and VoIP conference.

IV. EXPERIMENTS

On top of the first phase platform, a simple MANET, we designed a Rescue Information System for Earthquake Disaster (RISED) [2, 3] and a mobile learning platform over P2Pnet, *NCCU-MLP*. We also conducted a research based on NCCU-MLP to study the effectiveness and the behavior of a group of English learning students and to test our P2Pnet concept [1]. (It is unrealistic to test our design in a real catastrophic earthquake.)

4.1 Rescue Information System for Earthquake Disaster

RISED is designed to support resource and information management for the rescue mission in a catastrophic earthquake. The ER model is shown in Fig. 2

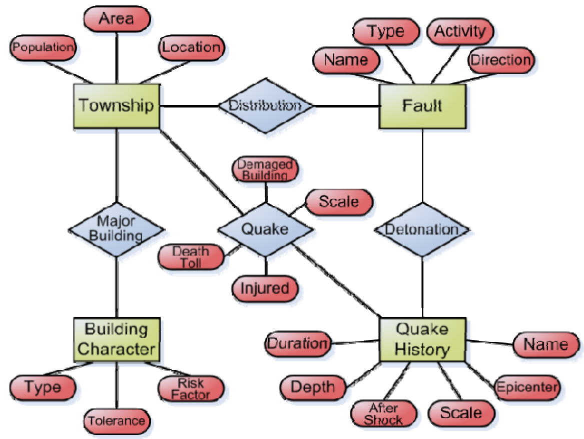

Fig. 2 ER Diagram of RISED

RISED provides seismic related information to assist disaster assessment. Useful information includes seismic fault locations, population distributions, building characteristics, and quake history. Together with collected real-time disaster statistics, the information system can support a more accurate disaster assessment for a better distribution of rescue and relief resources. The details of the system can be found in [2].

4.2 A Study of Mobile Learning

This research studies the effectiveness and the behavior of a group of English learning students over a mobile learning platform (NCCU-MLP) developed in National Chengchi University (NCCU). The goal of NCCU-MLP is to improve students' English ability as well as to update teachers' teaching using the latest technology. It offers a multimedia based English learning environment as well as Push-to-Talk (PTT) and whiteboard capability for group communications. The technology aspects of the experiment results are summarized in this section.

- The transmission quality of wireless radio signals is highly dependent on the weather conditions, especially on rainy days. As a consequence, the stability of mobile network connection is lower than fixed networks..
- The software system in a mobile computing environment is much more complicated than its counter part on fixed networks. Thus, it needs more effort to make the software

system robust. Our recommendation is to trade functionality for simplicity.

- Compared with voice communication tool, such as PTT, whiteboard is even less ideal for group communication. First, people are used to talk than to write. Secondly, voice communication is more convenient than hand-writing.
- Users prefer full-duplex conversation mode (such as VoIP) to half-duplex mode (such as PTT). However, it remains a great technical challenge to offer group voice communication in full-duplex conversational mode under limited bandwidth.

V. CONCLUDING REMARKS

The most important lessons we learned from numerous disasters are that mobile communication system is vulnerable and the loss of communication system may have a catastrophic consequence. This paper analyzes the causes that paralyzed the entire communication systems in Jiji Earthquake and proposes a P2Pnet that uses notebook PCs to construct a MANET based emergency communication and information system. Brief system requirements and system design are presented. A prototype of Disastrous Earthquake Rescue Information System is presented. Finally, a P2Pnet prototype was tested in an English mobile learning class. The technical aspects of experiment results are presented.

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