A Multi-hop Walkie-Talkie-Like Emergency Communication System for Catastrophic Natural Disasters

Yao-Nan Lien, Li-Cheng Chi, and Chih-Chieh Huang

Dept. of Computer Science, National Chengchi University, Taipei, Taiwan, R.O.C.

{lien, g9613, g9823}@cs.nccu.edu.tw

***Abstract*—**When stricken by a catastrophic natural disaster, the efficiency of disaster response operation is very critical to life saving. However, communication systems, including cellular networks, were usually crashed due to various causes making the coordination among a large number of disorganized disaster response workers extremely difficult. Unfortunately, rapid deployment of many existing emergency communication systems relies on a good transportation system, which is usually not available in a catastrophic natural disaster. We designed a multi-hop walkie-talkie-like communication system based on P2Pnet platform, which is a MANET P2P network constructed using volunteers' laptops. This system can support a large number of voluntary workers in the early hours of a catastrophic natural disaster when external assistance is blocked by the paralyzed transportation system. The multi-hop version can help to bypass the obstacles that block face-to-face communication as well as direct WiFi communication links. We wish to stimulate the research on the emergency communication systems that is inexpensive and easy to deploy for future catastrophic natural disasters.

Keywords: *Disaster Response, Emergency Communication, Mobile Computing, MANET.*

I. INTRODUCTION

Almost every year, the world was stricken by numerous catastrophic natural disasters, such as earthquake, hurricane, typhoon, tsunami, etc. Large scale tragedies occurred in the past decade include Chi-Chi (Jiji) Earthquake [1], SiChuan Earthquake, Hurricane Katrina, South-Asia Tsunami, Haiti Earthquake, Chile Earthquake, QingHai Earthquake, etc. When stricken by a catastrophic natural disaster, the disaster response operation is very critical to life saving [2,3,4,5]. The victims trapped in disaster zones under collapsed buildings or landslides may have a higher chance to survive if they are rescued in 72 hours, the *Golden 72 Hours*. The people evacuated from their homes and jammed on streets or in shelters need to communicate with each other for reasons ranging from allocation of rescue and relief resources to the reunion of family members. However, communication systems, fixed or mobile, were usually crashed due to various causes severely crippling disaster response efficiency. Disaster response corps consists of trained professional squads, army, police, fire fighters, and hundreds of thousands of disorganized volunteers. Loss of communication systems made the coordination among disaster response workers extremely difficult, especially in the early hours or even days of a disaster while only disorganized local volunteers were available for disaster response. In Chi-Chi Earthquake that struck Taiwan in 1999, it took Chunghwa Telecom, the largest telecommunication operator in Taiwan, 15 days of 24/7 operation to restore its cellular networks. Therefore, there is a great need to deploy a large scale emergency communication system rapidly in a disaster to support a large number of disorganized voluntary workers. Although such a task is very critical to disaster response, practical technology options, however, are very limited because they may either rely on a good transportation system to deliver hardware equipments to disaster zones or be insufficient in capacity. We proposed to use WiFi-ready laptops owned by rescue volunteers themselves to construct a MANET based P2Pnet to support thousands of disorganized rescue volunteers [2,3]. Because the popularity of both WiFi-ready laptop and portable power generators is very high nowadays, this solution is highly feasible in many countries.

Rescue people, voluntary or mission-specific professional, could use their own laptops 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 Voice-over-IP (VoIP), Push-to-Talk (PTT), Instant Messaging, and mobile social networks, etc.

We also designed and implemented a single-hop walkie-talkie-like communication system to support emergency communications in the early hours of a disaster [2]. The system is extremely simple such that it can be easily set up by non-professionals in hectic environments. However, due to the natural limitations of WiFi network, the communication beyond 12 meters will face a severe packet loss and long delay time. The WiFi links may also be blocked by obstacles such as rubbles of collapsed buildings. Without a good communication, the rescue workers in the two sides of a collapsed building may interfere with each other [3,5] as shown in Figure 1, which is a real picture taken in Chi-Chi Earthquake. Therefore, the single-hop system has its limitations in a disaster response operation.

Fig.1 Street blocked by a fallen building

This paper presents the design of a multi-hop walkie-talkie-like emergency communication system that can extend the effective communication range as well as bypass obstacles as shown in Fig. 2.

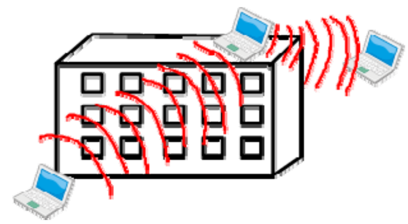

Fig.2 Bypassing an obstacle by multi-hop

II. BACKGROUND

The impact of communication system crash to a disaster could be catastrophic. To many people's surprise, cellular networks that were thought highly dependable in emergency were completely wiped out in many cases. The observation made in Chi-Chi Earthquake is reported in [3]. The causes of communication system failure as well as the requirements for an emergency communication and network system were also reported in [3]. It is summarized as follows.

2.1 Causes of Failures and System Analysis

Followings are parts of causes we found in Chi-Chi Earthquake:

- Base stations crashed
- Power lines or backhaul links broken by bridge and road breakage
- Backup power generators failed
- Cooling systems for critical equipments failed
- Cell phones ran out of battery and chargers not available
- Communication network traffic jams

Threatened by so many sources of potential failures, it calls for a miracle for a cellular network to survive. According to our first-hand observation, the communication systems were wiped out in 88-Flood/Taiwan mostly by a single cause – a large number of power lines and backhaul links were broken because of broken roads and bridges. Power is easy to restore, but backhaul links aren’t.

Environmental Constraints

- Outgoing link (Internet) is either not available or very limited such that most Internet based services are not available.

- Wireless links (such as WiFi) may be blocked by obstacles
- WiFi-ready laptops of non-uniform capacity and portable power generators are assumed very popular.

Functional Requirements

- User interface must be simple, easy to learn, and fool-proof.
- Devices must be fault-tolerant and do not need a complicated setup procedure.
- 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.
- The system must be very easy to deploy on many laptops of non-uniform capacity in a disorganized nearly-chaos environment.

With limited resources and time, our recommendation is to trade functionality for simplicity, developing basic functions only and giving up most advanced features. Considering the difficulty of deployment in a disorganized nearly-chaos environment, we do not recommend any system that needs to change system software. In other words, any feasible solution had better be executed at the application lever. For this reason, many solutions proposed by many research teams may not be applicable to our targeted environments – thousands of disorganized voluntary laptops. Furthermore, because the hardware and system software are out of our control, it is not possible to tune the performance at the system level. These constraints lead to the following performance requirements:

Performance Requirements

- provide tolerable QoS for multimedia communications
- give precedent to QoS over throughput
- must be able to bypass obstacles

2.2 MANET Based P2Pnet

To meet the requirements shown above, we proposed to use WiFi-ready laptops to construct a MANET based group communication system to support emergency communication and information network, called *P2Pnet* [3]. Using P2P communication technologies, a P2Pnet is able to support temporary group communication and information networks. Most functionalities are designed at the application level. System level functionalities will remain unchanged as much as possible.

System Architecture

On top of MANET, there is a layer of peer-to-peer network service, called *Network Service Layer,* to support higher level communication services such as Walkie-Talkie, Push-to-Talk, and VoIP communications. In this layer, three basic networking modes are as follows:

- **U1net (Uncontrolled Single-Hop Group Communication Network**) 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. Because it is the easiest to construct, it is to be deployed in the early hour of a disaster when all the organizational efforts are not in place yet.
- **UKnet (Uncontrolled K-Hop Group Communication Network)** 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 early hour of a disaster when all the organizational efforts are not in place yet.
- **CKnet (Controlled K-Hop Group Communication Network)** This is a more advanced mode and can support secure unicast services such as VoIP. It requires more organizational effort to construct such a network mode and may not be easy to construct in the early hours of a disaster.

2.3 System Developments and Deployment

When a disaster strikes suddenly, there is not much time allowed to deploy a full-functional P2Pnet. The simplest network function, U1net can be deployed first, followed by UKnet, to support walkie-talkie-like communications in the early hour of rescue operation. This paper reports the implementation of UKnet as well as one of its applications, multi-hop walkie-talkie-like emergency communication system.

III. DESIGN OF UKNet

The design of UKnet is an extension of U1net [2] such that the tow systems are very similar. UKnet is also implemented in Java programming language on JXTA platform [6]. It consists of 5 subsystems:

1. P2P Connection Management
2. Voice Capturing and Encoding
3. Packetization and Transmission
4. Packet Receiving
5. Mixer and Playback

3.1. P2P Connection Management

The *JXTA* platform is employed as our peer-to-peer network platform [6]. The physical network is encapsulated within the JXTA Platform, which is a set of open protocols that enable any connected device on the network to communicate and collaborate in a P2P manner.

To implement the broadcast communication function on JXTA platform, one peer acts as a message sender, and others act as listeners. However, since a unique IP address may not be available in the early hour of a disaster, we use Class D IP address to broadcast packets to others.

3.2. Voice Capturing and Encoding

An input voice stream is first digitalized into an 8000 samples/sec and 16 bits/sample PCM stream, and then chopped into a stream of 30 ms frames. Each frame of size 480 bytes is then encoded into a smaller frame of 50 bytes using iLBC codec, which is specially designed for VoIP and has been using by many successful VoIP services such as Skype. The entire encoding latency is then at least 30 ms. Related parameters are summarized in Table 1.

Table 1 Parameters of Voice Capturing and Encoding

Sampling Frequency	8000Hz
Sample Size	16bits
PCM Stream Bandwidth	128kbps
PCM Frame Size	30ms, 480Bytes
iLBC frame Size	50Bytes
Output Stream Bandwidth	13.33kbps
Compression Ratio	10.42%

3.3. Packetization, Transmission and Receiving

Each iLBC frame is packetized into an IP frame with UDP and IP headers and then sent to the network under the control of UDP. A transmission thread is standing-by to take the frames output from iLBC codec and to convert them into packets. A receiving thread is standing-by to filter incoming packets. (Those packets that are transmitted by this peer itself are filtered out.)

3.4. Mixer and Playback

It is rare, but not impossible, that two or more users talk at the same time. Therefore, a mixer is needed to combine all PCM streams together. The resulting PCM stream is then stored in a dejitter buffer. The PCM stream is then played back in a regular pace to reduce jitter.

IV. EXPERIMENTS

Because P2Pnet will be deployed hectically using volunteers' laptops, our system was implemented at the application level. As a consequence, performance is a major issue. Therefore, the performance of both single-hop and 2-hop systems were evaluated in our laboratories. In 2-hop system, the conversation was made between two far apart laptops and the third laptop was placed in the middle performing as a relay node (Fig. 2).

The laptops used in the experiment are in mixed brands with P4 (or up) CPU and at least 256 Mbytes main memory running Microsoft Windows XP or Windows 7 operating system. Each one has an 802-11g WLAN on board. To set up ad-hoc WLAN mode, all laptops must use the same SSID and the same radio channel.

4.1 Performance Evaluation

MOS, delay time, jitter, and packet loss rate were the evaluation metrics. In both systems, MOS value was between 3 and 4 if the distance is below 12 meters. However, MOS fell between 2 and 3 if distance is beyond 15 meters in single hop system and beyond 21 meters in 2-hop system. It is obvious that the single hop system can only support voice communication within 12 meters while a relay node between two communicating nodes can extend the voice communication range to 20 meters. This phenomenon can be explained by examining delay time and packet loss rate shown in Table 2 and 3. Delay time and packet loss rate were too high in single hop system if the distance is beyond 12 meters while they were reduced by relay node in 2-hop system.

Table 2 Evaluation results (single hop)

Distance (m)	6	9	12	15	18	21
MOS	4	4	3	3	3	2
Avg. delay (ms)	441	455	507	651	498	641
Max. delay (ms)	586	629	705	931	639	1066
Jitter	22.9	28.3	32	44.2	31.2	41.6
Avg. Loss Rate (%)	13.5	18.4	28.4	28.9	33.3	35.5

Table 3 Evaluation results (2-hop)

Distance (m)	6	9	12	15	18	21
MOS	4	4	4	3	3	3
Avg. delay (ms)	412	414	496	490	519	518
Max. delay (ms)	564	539	629	594	715	752
Jitter	30.5	31.7	47.7	41.7	62.1	67.6
Avg. Loss Rate (%)	5.2	9.9	14.7	17.7	20	21.3

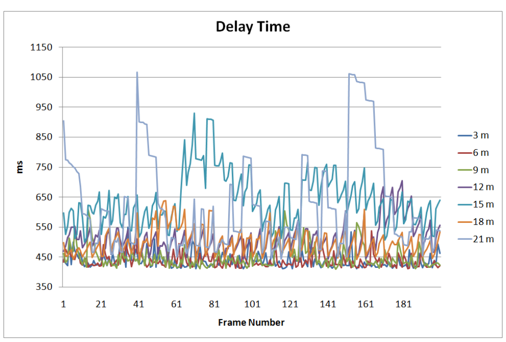

Fig. 3 Delay Time at Diff. Distances (single hop)

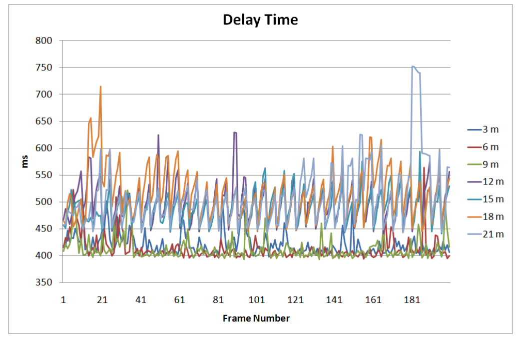

Fig. 4 Delay Time at Diff. Distances (2-hop)

Jitter is calculated using (1), where J(i) is the jitter of i-th packet and D(i,j) is the difference between the delay time of i-th and j-th packets.

$$J(i) = J(i-1) + (|D(i-1,i)| - J(i-1))/16 \qquad (1)$$

To prevent the dejitter buffer from inducing too much delay time, the dejitter buffer is set to only one frame, 30 ms. Therefore, the frames that are overdue by more than 30 ms are useless. The jitter of 2-hop system is higher than its single hop counter parts since the forwarding mechanism in the relay node increases the jitter as we anticipated. However, the quality of voice seems not affected by jitter due to the use of dejitter buffer.

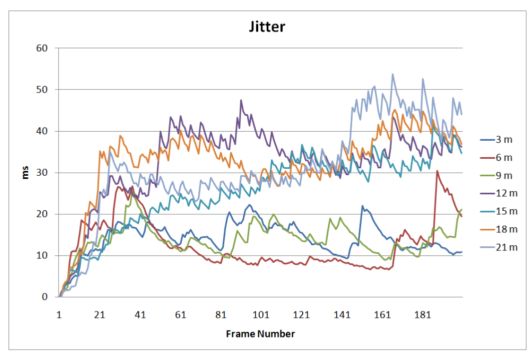

Fig. 5 Jitter at Diff Distances (2-hop)

Packet loss seems to be the most harmful to the quality of voice communication. As loss rate goes beyond 10%, the voice quality deteriorates rapidly. Therefore, under current implementation, the maximum allowable hop distance is about 10-12 meters, which is determined by loss rate, and the number of hops for a full-duplex mode conversation is two, which is determined by the delay time. In the future, we will add error correcting mechanism into the encoding scheme to reduce packet loss rate. It is much more difficult to reduce delay time to extend the number of hops as well as the voice communication range, since such a voluntary system has to be implemented at the application level as indicated by the analysis shown in Section 2.

4.2 Usability Assessment

Although the effective range for full-duplex voice communication is too short to compete with face-to-face communication, it is still very useful to the rescue operation of a disaster such as an earthquake. We learned from Chi-Chi Earthquake that short range face-to-face communications might be blocked by obstacles such as collapsed buildings as shown in Fig. 1. Our multi-hop system can bypass the obstacles easily in such a situation. Furthermore, half-duplex mode communication can tolerate much longer delay time. Therefore, our system can provide long range walkie-talkie communication even though the delay time may be very high. .

V. CONCLUDING REMARKS

The most important lessons we learned from numerous disasters are that cellular networks are very vulnerable and the loss of communication system may have a catastrophic consequence. This paper demonstrates the design of a multi-hop walkie-talkie-like communication system over a MANET based P2Pnet. The system is designed to support emergency communications in the early hours or days of a natural disaster. It is very useful in the situation when face-to-face communication or wireless links is blocked by the obstacles since our multi-hop system can bypass obstacles easily. We wish to stimulate the research on the emergency communication systems that is inexpensive and easy to deploy for catastrophic natural disasters.

REFERENCES

1. Weimin Dong, et al., *Chi-Chi, Taiwan Earthquake Event Report*, Risk Management Solutions, Inc., *https://www.rms.com/Publications/Taiwan_Event.pdf,* retrieved Mar. 2010.
2. Yao-Nan Lien, Li-Cheng Chi and Yuh-Sheng Shaw, "A Walkie-Talkie-Like Emergency Communication System for Catastrophic Natural Disasters", *Proc. of 10th Inter'l Sym. on Pervasive Systems, Algorithms and Networks (ISPAN09)*, Dec. 14-16, 2009.
3. Yao-Nan Lien, Hung-Chin Jang and Tzu-Chieh Tsai, "A MANET Based Emergency Communication and Information System for Catastrophic Natural Disasters", *Proc. of IEEE Second Int'l Workshop on Specialized Ad Hoc Networks and Systems*, June 26, 2009.
4. Sarah Underwood, "Improving Disaster Management," *Comm. of ACM,* vol. 53, no. 2, Feb. 2010, pp. 18-20.
5. ITR-RESCUE, Robust Networking and Info. Collection Project, *http://www.itr-rescue.org/research/networking.php*, retrieved Feb. 2010.
6. JXTA, https://jxta.dev.java.net/, retrieved June 15, 2010