P2Pnet: A MANET Based Emergency Communication System for Catastrophic Natural Disasters

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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 an emergency communication system based on existing technologies may not be feasible since most technologies rely on a good transportation system, which is usually not available in a catastrophic natural disaster, to deliver essential equipments. Based on the first-hand experiences we learned from Chi-Chi Earthquake and 88 Flood that struck Taiwan in 1999 and 2009, respectively, this paper proposes to use volunteer's laptops to construct a large scale MANET based emergency communication system, P2Pnet, to support themselves in urgent crisis. We had implemented the first phase prototype as well as three application experiments on top of P2Pnet: a walkie-talkie-like emergency communication system, a mobile learning system that was taken as an alternative experimental environment as well as a rescue information system for earthquake disasters. This preliminary research demonstrates the feasibility of the proposed concept and points out future research directions. We wish this research may raise the awareness of the vulnerability of existing cellular networks and to stimulate more researches on emergency communication technologies for disaster response.

Keywords: Disaster Management, Mobile Computing, MANET, P2P, Emergency Communication

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 last 15 years include Chi-Chi (Jiji) Earthquake [8], 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. The victims trapped under the rubbles of collapsed buildings or landslides may have a higher chance of survival 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 operation. 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. Even worse, after many telecommunication deregulation movements occurred in the last two decades, most telecommunication operators in many countries has been investing their resources only on their own networks. Provisioning an emergency communication system for disaster response is mostly left behind everybody's agenda simply because private network operators have no legal obligation in disaster response. To fill this gape, we propose to use WiFi-ready laptops (and smart phones) owned by rescue volunteers themselves to construct a MANET to support thousands of disorganized disaster response volunteers. Because of the high popularity and interoperability of WiFi-ready laptops nowadays, this solution would be highly feasible and practical in many countries.

On top of MANET, we apply peer-to-peer technology to implement an "Autonomous P2P Ad-Hoc Group Communication Systems (P2Pnet)", which is used to support the communication need under temporary serverless infrastructure-less Internet-blocked environments such as nature disaster areas, battle-field, and mobile learning environments. Disaster response workers, voluntary or mission-specific professional, could use their own laptops to construct a multi-hop ad-hoc network to construct a basic wireless intranet first, then, use our P2Pnet technology to form a higher level mission-specific network to support urgent communication services such as Voice-Over-IP (VoIP), Push-to-Talk (PTT), Instant Messaging, and mobile social network, etc.

In Section 2, we will summarize the impact and the causes of the communication system crash observed in Chi-Chi Earthquake and 88 Flood as well as the technology options for a rapid deployment of an emergency communication system. The system requirements for P2Pnet will be presented in Section 3. In Section 4, the proposed MANET based P2Pnet will be presented. Section 5 will show some experiments. Final section is the conclusion and future research directions.

II. BACKGROUND

When a natural disaster strikes, the social network may be completely paralyzed as a consequence of vast damage to the government infrastructure, transportation systems, utility systems, etc. The impact of communication system failure 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. Based on the observation made in Chi-Chi Earthquake, the causes of cellular network failure and its impact to the disaster response operation as well as technology options for an emergency communication system were reported in [14]. It is summarized as follows.

2.1 Causes of Mobile Communication System Failure

Followings are parts of causes we witnessed first-handed in Chi-Chi Earthquake:

- Base station failure
- 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-handed observation, the communication systems were wiped out in 88-Flood 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.

2.2 Impact of Communication System Crash

. Followings are a few painful lessons we learned first-handed from Chi-Chi Earthquake.

- In such a catastrophic disaster, regular rescue teams including trained professional rescue squads, police, army, and fire fighters were far from sufficient for the disaster response operation. Furthermore, external assistance may be blocked by the paralysis of transportation systems in the beginning of a disaster as we can see from Haiti Earthquake [14]. Therefore, a large number of local volunteers must be mobilized in grassroots fashion to participate in the rescue and relief operations**.** However, without a good communication system, it was very difficult to organize and coordinate such a big grassroots disaster response corps.
- A large volume of disaster response resources for rescue and relief operations were misplaced because the assessment of disasters distribution was virtually blind and inaccurate in the early hours or even days after the quake. As a consequence, disaster response resources were distributed to the stricken zones hectically without any meaningful resource allocation. Unfortunately, reallocation of resources was very

difficult if not impossible because of paralyzed transportation systems. Misplacement of disaster response resources may cost many lives.

- Streets were blocked by collapsed buildings so that the rescue workers were divided into isolated groups (Fig. 1). While one group was doing sound-sensitive operation to detect survivals under the rubbles of a collapsed building, the group on the other side was using heavy machinery to dig the rubbles. Similar problems were reported in Haiti Earthquake that some sound sensitive operations were interfered by ambulance sirens.

Fig.1 Street blocked by a fell building in Chi-Chi Earthquake

A much longer list can be found in [7,11,14,24]. In summary, the impact of communication system crash to a disaster could be catastrophic.

2.3 Technology Options

Feasible technology options are constrained by two major limitations. First, available resources (i.e. funding) for the deployment of an emergency system for a large number of voluntary workers is limited. Secondly, the transportation system may have been paralyzed such that delivering needed equipments to the disaster zones in time (in Golden 72 Hours) is a big challenge. Followings are a few conventional technologies reviewed in [14].

- **Walkie-Talkie**

The most convenient and reliable communication system for emergency is walkie-talkie. It doesn't rely on any infrastructure to operate and is very easy to use. However, the popularity of walkie-talkie in many countries is far less than laptops, not to mention cell phones. Although regular rescue squads may already be equipped with similar equipments, most volunteers may not.

- **Amateur Radio**

Amateur Radio, also known as Ham Radio, is a long range wireless communication system used mostly for hobby and services [9]. It doesn't need a backhaul link to support its operation such that it is also a good choice for emergency communication. Unfortunately, due to its low popularity, the probability of having such equipments right in the stricken zones is even lower than Walkie-Talkie.

- **Mobile Base Stations for Cellular Networks**

Cellular operators usually have some mobile base stations that use satellite links as backhauls and can be deployed to a demanded zone in a few hours [19]. However, due to its high cost, cellular operators may not have sufficient number of such equipments for a large scale disaster. Furthermore, mobile base station is too heavy to drop from air and have to rely on a good transportation system to deliver to the stricken zones. The help is limited.

- **Specialized Emergency Mobile Communication Systems**

Various equipment vendors are offering special emergency mobile communication systems [1]. Specially designed systems are expensive and can offer only a limited number of handsets under limited funding. It is prohibitively expensive to deploy sufficient capacity for a large scale disaster. Thus, due to limited monetary resource, it is far from sufficient for a large number of volunteers. Similarly, it relies on a good transportation system to deliver to the stricken zones. Finally, the equipments made by different vendors may fail to interoperate, or even interfere, with each other [11].

- **MANET Based P2Pnet**

We propose to use WiFi-ready laptops (and smart phones if possible) to construct a MANET based group communication system to support emergency communication and information network, called *P2Pnet*. In recent years, WiFi-ready laptops that can last for several hours is becoming a very popular and universally compatible device. When stricken by a natural disaster, survivals and volunteers can use their own laptops to construct a P2Pnet rapidly. Using P2P communication technologies, a P2Pnet is able to support walkie-talkie-like communication, Push-to-Talk, VoIP, and network information systems for a disaster response operation. Compared to other options, no extra hardware cost is needed and can be set up by local ordinary PC users. Thanks to the popularity of laptops and WiFi based WLAN, their hardware and network interoperability is very high, which makes the configuration of MANET much easier than other options. The software can be delivered via Internet, airdrop, hand-carrying to the stricken zones, or even embedded into laptops.

Electricity will probably be knocked out by even a small disaster such as a snow storm. Power generator has long been a typical equipment in most contingency plans. A small 1000 watts portable power generator will be able to charge several dozen laptops. In some areas such as Taiwan, portable generators are very popular because of a large population of flea-market-style night markets. On the other hand, the battery life for laptops has been extended to 8 or more hours. As mini-laptop or tablet PC (such as iPAD) that consumes less power than regular laptops, gains its momentum, we can anticipate that the chance of having many long-life laptops is very high in many areas. Compared with other heavy machinery, the fuel required to power up several dozen laptops is nominal, even the fuel left in the tanks of the automobiles is sufficient to do so. Therefore, power supply for P2Pnet won’t be a big problem.

No single technology can fulfill the demands completely. A disaster response operation has to utilize whatever available once a disaster ever occurs provided that they do not interfere with each others. We can anticipate that constructing a P2Pnet for emergency communication is completely feasible in many areas of the world. It would be foolish to ignore such a technology as an option for disaster response. This paper will focus on the design of MANET based P2Pnet.

III. SYSTEM ANALYSIS

In addition to the long list of common system requirements for a typical IT system, we learn mainly from Chi-Chi Earthquake the following constraints and requirements specific to an emergency communication system that can support a disorganized voluntary disaster response operation for a large scale disaster.

Environmental Constraints

- Outgoing link (Internet) is either not available or very limited.
- Server may not be available.
- Internet based services, such as Skype or Twitter, may not be available due to limited Internet access.
- There is a very stringent time constraint for volunteers to learn the usage of the system. In other words, the system must be very easy to deploy and its use model must be very straightforward.
- WiFi-ready laptops or hand-held devices of non-uniform capacity are assumed very popular and available.
- Portable power generators are assumed available.

Functional Requirements

- User interface must be simple, easy to learn, and fool-proof.
- Devices must be fault-tolerant such that misusage will not crash a device.
- Devices do not need a complicated setup procedure.

- The system must support broadcast based multimedia communications, while unicast 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 or smart phones of non-uniform capacity in a disorganized chaotic environment.

Without plenty of resources and time, it is not easy to develop a system that meets all the requirements listed above. Simplicity, user-friendliness, and robustness cost a fortune to achieve. Therefore, our design philosophy is to trade functionality for robustness, developing basic functions only and giving up advanced features. Considering the difficulty of system deployment in a disorganized chaotic environment, we do not recommend any system that needs to change PC's system software. In other words, any feasible solution had better be executed at the application lever. For this reason, many previously proposed solutions may not be applicable to our target 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
- Provide class-based priority services so that scarce resources can be allocated wisely based on the degree of emergency
- Provide high member coverage for group communications (i.e. high network connectivity)

It is required that system level functionalities will remain unchanged as much as possible. Moreover, the MANET that utilizes IEEE 802.11 network protocol won't be able to support high throughput. Therefore, the system doesn't have to support heavy load applications. As a consequence, we give precedence to QoS rather than throughput. With limited network resource, a good QoS scheme will provide a smarter resource utilization to support a more efficient disaster response operation. Finally, in a disaster response operation, there is a frequent demand to locate a particular equipment or person who has a special skill, such as a hydraulic steel cutter as well as its operator. Thus, it is important to provide high member coverage so that it can support such a demand better under the environments where the connectivity is an issue.

IV. MANET Based P2Pnet

Based on the system analysis shown in Section III, we designed a MANET based P2Pnet to support disaster response operations.

4.1 System Architecture

P2Pnet is a serverless peer-to-peer communication network based on MANET to support temporary group communication and information networks. As depicted in Fig. 2, some nodes may have satellite communication capability performing gateway functions so that all other nodes can access Internet through gateways if they are ever available.

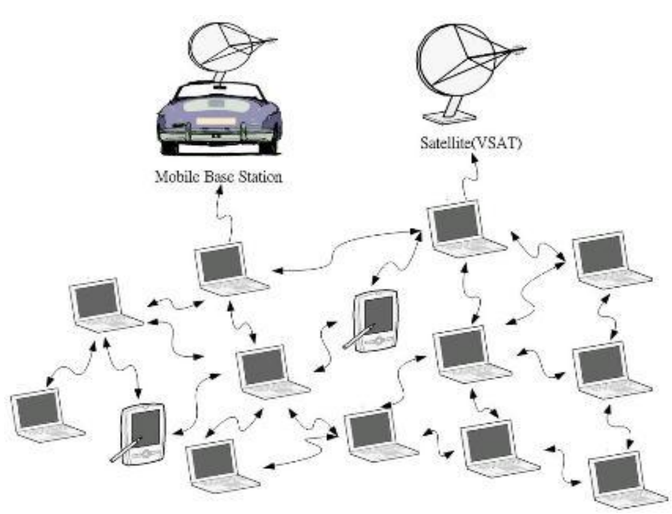

Fig. 2 Physical Architecture of P2Pnet

On top of MANET, there is a layer of peer-to-peer network service to support higher level communication services such as walkie-talkie, Push-to-Talk, and VoIP communications. Logical architecture is shown in Fig. 3.

The logical architecture of P2Pnet follows the traditional layered architecture with an intermediate layer between Network Layer and Transport Layer. To avoid reinventing wheel, this architecture reuses as much existing network technologies as possible.

Layer	Functional Modules					
Application Systems	Disaster Rescue Info Sys	Mobile Learning Sys.	Battle Field Manage. Sys.			
Application Functional Modules	FTP/HTTP/Telnet/etc.	PTT	VoIP	P2P Streaming	Location-Aware Applications	
Transport	TCP	UDP	Partial-Reliable TCP	Partial-Reliable UDP	Hop-by-hop TCP	P2P Multicasting
Network Service	Uncontrolled Single-Hop Group Communication Network (U1net)	Uncontrolled K-Hop Group Communication Network (UKnet)	Controlled K-Hop Group Communication Network (CKnet)			
Network Routing	Ad Hoc Network	Mesh Network	VANET			
Physical	RF Positioning System	WiFi	WiMAX			

Fig. 3 Logical Architecture of P2Pnet

Physical and Network Layers

The most popular wireless network technologies these days are IEEE 802.11 (WiFi) and IEEE 802.16 (WiMAX). WiFi is a proven technology with very high degree of business success. Most people agree that WiFi will continue to be the dominant wireless LAN technology, especially in ad hoc mode, while WiMAX is a newer but has not been a business success yet.

Furthermore, most commercial WiMAX networks are built like a cellular network that relies on vulnerable landline-based backhauls, and thus, may not be able to survive a major disaster. Therefore, P2Pnet is mainly designed on top of WiFi-Based MANET. However, WiMAX will not be excluded if it is ever available.

RF based positioning technology nowadays are very mature and popular. We could employee such a technology to support positioning service in a disaster zone. For instance, knowing the positions of all rescue equipments or trapped victims (if they can transmit any RF signal using their own hand-held devices) will make the rescue mission faster and more efficient. The most popular positioning technology is the Radiomap approach, in which, a wireless device compares the measured radio signals to a map of prerecorded radio signals to determine its own location. Although this approach can reach a high accuracy, it is not applicable to a disaster response operation because it demands a lot of human efforts to build a radio map in advance. Therefore, a triangulation based positioning system, in which, a wireless device calculates its location based on the signal attenuations from at least 3 location-known transmitters, is more appropriate. To adopt this approach, some number of inexpensive WiFi access points (APs) will have to be installed using portable powers to support the positioning services. Also, to combat the instability of received RSSI (Received Signal Strength Index) to further enhance the accuracy, Violettas proposed a collaborative localization to leverage the variance in location accuracy [20]. It utilizes the estimated locations of collaborative neighbor nodes to help adjust error correction. Furthermore, in some cases, if the installation of APs is not feasible, a peer-based positioning technique can be adopted. Banerjee and Chan developed such non-infrastructure-based real time location system (RTLS) [3,4]. Each pair of the wireless devices that are in communication range uses measured RSSI to estimate the distance between them. A spatial 2-D plane can therefore be constructed. If GPS or any other infrastructure-based positioning system is opportunistically available for at least three nodes, the relative locations in the spatial 2-D plane can be translated into absolute locations. In the worst case when absolute locations are not availabe, knowing relative locations is still helpful.

At the Network Layer, many successful MANET algorithms are available ready for use. For instance, the popular AODV (Ad hoc On Demand Distance Vector) routing algorithm [21] can be used in P2Pnet since the locations of P2Pnet nodes may change frequently in a disaster response environment. Moreover, due to the randomness nature of MANET in a disaster environment, network connections are usually unstable such that the constructed network may be broken into a few isolated networks frequently. A new technique, called "Opportunistic Network", or "Delay Tolerant Network" can be applied to extend the packet delivery probability and thus to improve the stability of the constructed P2Pnet. Routes are built dynamically, while messages are en route between the sender and the destination(s), and any possible node can opportunistically be used as next hop, provided it is likely to bring the message closer to the final destination. Pelusi surveys the interesting case studies and organizes forwarding approaches in this challenging environment [18].

Wireless mesh networks (WMNs) is another emerging WLAN technology [22,23] that has a potential to be adopted by P2Pnet. With little more management efforts than MANET or opportunistic networks, a WMN can be fast deployed autonomously if some powerful laptops are pre-installed with the software and carried into the appropriate positions. This WMN will serve as a communication backbone. Tsai proposed a cross-layer routing design to efficiently achieve throughput and delay [22]. Moreover, an overlay P2P multicast tree can be constructed at little extra cost [23]. Thus, streaming service can probably be supported too. These mesh laptops might be prepared by the fire department or a disaster response cops as a "first-aid" package. P2Pnet will adopt WMN technology if a reliable product is ever available.

Another important technology is VANET. According to what we observed in Chi-Chi Earthquake, most roads near stricken zones were either broken or jammed by disorganized vehicles that carry rescue and relief resources. In many hurricanes such as Katrina, highways near anticipated stricken cities were all jammed by the evacuation vehicles. If these vehicles were able to communicate to each other, they will be much more organized resulting in a more efficient rescue and relief operation. Thus, VANET technology is very helpful.

Network Service Layer

Due to the loss of Internet connection, many network services such as VoIP and instant messaging may stop functioning and have to be reimplemented for the loss of connection to critical servers. To reduce redundancy, we designed an intermediate layer on top of the Network Layer, called Network Service Layer, to facilitate networking services to the Application Layer. In this layer, three basic networking modes are defined as follows:

- **U1net (Uncontrolled Single-Hop Group Communication Network**)

  In this mode, 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 first in the early hours of a disaster when a disaster response infrastructure is not in place yet.

- **UKnet (Uncontrolled K-Hop Group Communication Network)**

  In this mode, 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 hours of a disaster when a disaster response infrastructure is not in place yet. However, it is little more complicated than U1net so that it requires more effort to deploy.

- **CKnet (Controlled K-Hop Group Communication Network)**

  This is a more advanced mode and can support unicast services such as VoIP. Many technical challenges, such as unique IP addresses, routing, yellow-page (i.e. the mapping from a personal to an IP address), neighbor discovery, authentication, etc. are yet to be overcome. Furthermore, it requires more technical support and organizational effort to deploy such a network mode such that it may not be easy to deploy in the early hours of a disaster.

4.2 Autonomous P2P Vehicular Ad-Hoc Group Communication Systems

As mentioned in the previous section, VANET can play an important role in supporting emergency group communications. Having a self-supplied stable power source, each available automobile can support a reliable and powerful laptops. Thus, a VANET can serve as the backbone of a P2Pnet in a disaster response operation. However, under disastrous circumstances, the infrastructure to support a full functional VANET may not be available. Therefore, only the inter-vehicle communication (IVC) technology (or peer-to-peer communication) will be considered. The network environment of VANET is quite different from those of traditional wired networks and IEEE802.11 based wireless networks due to its high mobility and critical requirements of packet forwarding and routing.

Many applications have been developed so far due to the increasing research on the VANET related technologies. However, most researches only focus on resolving a single problem and lack of comprehensive solution to the problem. Furthermore, the environmental constraints of P2Pnet are quite different from that of a regular VANET. We thus propose an integrated solution specially designed for P2Pnet. The issues under consideration are the mobility model in a disaster area, bandwidth resource management, disaster-specific routing and multicasting algorithms. Protocols for Network Service Layer (U1net, UKnet, and CKnet) will be tailored for VANET. Communication-specific applications such as VoIP, Push-to-Talk, and P2P Streaming will also be adapted to VANET. Other disaster-specific applications such as routing for ambulance on jammed highways will also be developed. Through these applications, we can support a more efficient disaster response operation.

4.3 System Developments and Deployment

P2Pnet is designed with an intention that it can be easily implemented by a small group of network software engineers. Because of its simplicity, interoperability, and adaptation of existing technologies, implementing a prototype of P2Pnet presents no technical challenge at all. A prototype of P2Pnet has being developed by us in two phases. In the first phase, a simple P2Pnet with U1net capability was implemented for the experiments that will be reported in Section VI. In the future second phase, a more advanced system which will be able to support both broadcast-based and unicast-based multimedia communications will be constructed. The purpose of this paper is to stimulate related research and point out future research directions.

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 to support walkie-talkie-like communications in the early hours of a disaster. If time is allowed, UKnet and CKnet can be deployed in turn to establish a more advanced network as well as full functional VoIP services. U1net and UKnet can be quickly deployed using the 255.255.255.255 broadcast address when unique IP addresses are not available. To support CKnet, many critical issues mentioned in Section 4.1 must be resolved. To deploy such a system requires organizational human intervention. Thus, CKnet can only be deployed when there is some form of organization established in a disaster response operation, which may not be possible within the Golden 72 Hours of a disaster.

V. EXPERIMENTS

To verify the concept of P2Pnet, we implemented a prototype with U1net and UKnet capability and a mobile learning environment, *NCCU-MLP*, on top of this platform [5]. A mobile learning experiment using NCCU-MLP is conducted to study the effectiveness and the behavior of a group of English learning students. As a secondary objective, this experiment was also used to evaluate our P2Pnet since it is impossible to create a real catastrophic earthquake to test our design. We also designed a Rescue Information System for Earthquake Disaster (RISED) [12] that can help to improve the effectiveness of a disaster response operation.

The prototype was implemented based on 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 [13]. On top of this platform, a Push-to-Talk (PTT) and white-board functionality along with other mobile learning functionality was implemented to support the NCCU-MLP.

5.1 Walkie-Talkie-Like Emergency Communication System

A walkie-talkie-like communication system based on U1net and UKnet was implemented for the performance evaluation in terms of engineering quality. Up to 4 laptops were used in the experiments. These laptops were in mixed brands with Intel P4 or better CPU and at least 256 Mbytes main memory running Microsoft Windows XP, Vista, or Windows 7 operating system.

Each one has an 802-11g WLAN on board. The input voice is first digitalized into an 8000 samples/sec and 16 bit/sample PCM stream and then chopped into 30 ms frames. Each frame of size 480 bytes is then encoded into a smaller frame of 50 bytes using iLBC codec [10], 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. The experiment showed that U1net is easy to implement, but its full-duplex mode of VoIP has a large room to improve. When the distance between two nodes was longer than 10 meters, the packet loss rate may be higher than 10%, which is not tolerable for telephony applications. On the other hand, UKnet based multi-hop walkie-talkie system can extend the effective communication range up to 20 meters.

The performance of P2Pnet is difficult to improve since it must be implemented at the application level on non-uniform voluntary laptops. It is unrealistic to tune the system at the system level. Nevertheless, a short range full-duplex VoIP is still useful in a disaster such as an earthquake since face-to-face communications may be blocked by a lot of obstacles. For instance, as shown in Fig. 1, a street was blocked by a fallen building making the rescue operations in the different sides of the building interfere with each other. In that case, the face-to-face communication was blocked even though their line-of-sight distance was very short. Therefore, a short range full-duplex mode VoIP may still be helpful in such situations. If WiFi links are blocked by obstacles, our UKnet based multi-hop walkie-talkie system can easily bypass obstacles as shown in Fig. 4.

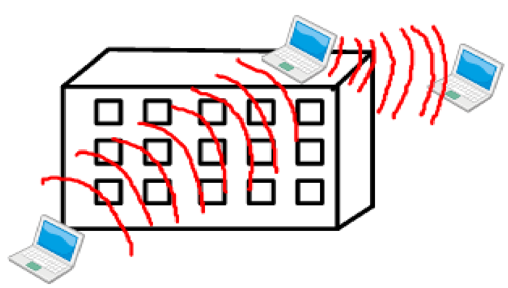

Fig. 4 Bypassing an obstacle by multi-hop

Another interesting problem, called "*Proximity Problem*", specific to a disaster response operation is that two VoIP clients might be too close to cause a severe echo or even echo avalanche. Proximity problem is unlikely to occur in regular VoIP usages since VoIP users tend to be far apart. However, in a disaster response operation, the distances between users are usually not under any control and are essentially randomly distributed such that the Proximity problem may be inevitable. Unfortunately, our experiment found that conventional echo cancellation mechanism failed to deal with this extreme problem. We developed a VAD (Voice-Activity-Detection) based echo cancellation technology to solve this problem. The details can be found in [14,15].

5.2 A Study of Mobile Learning on P2Pnet

This cross discipline research studied the effectiveness and the behavior of a group of English learning students over the mobile learning platform, NCCU-MLP, which was developed by us in National Chengchi University (NCCU) [5]. The goal of NCCU-MLP is to support students' English learning as well as to update teachers' teaching using the latest mobile computing technology. It offers a multimedia based English learning environment as well as Push-to-Talk (PTT) and whiteboard capabilities for group communications. At the time of this experiment, the walkie-talkie-like functionality wasn’t available yet. The prototype was tested in this experiment because we were unable to create an earthquake to test our system. The technology aspects of the experiment results are summarized in this section.

- The transmission quality of wireless radio signal 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 design of P2Pnet must take this into consideration.
- The software system in a mobile computing environment is much more complicated than its fixed network counterparts. Thus, it needs much more effort to make the software system robust.
- Users prefer full-duplex conversation mode to half-duplex mode. However, it remains a great technical challenge to offer group voice communication in full-duplex conversational mode under limited bandwidth.

- The PTT was implemented by sending speaker's voice packets to a central server then distributing to all listeners. A long delay time, approximately 1 sec., was sensible by listeners.
- Compared with voice communication tool, like VoIP or PTT, whiteboard is even less ideal for mobile group communication. First, people are used to talk than to write. Secondly, voice communication is much more convenient than hand-writing in a mobile environment.

In summary, the use model is very critical to mobile computing in general. It requires more extensive researches to learn a better use model specifically for the devices used in disaster response operations.

5.3 Rescue Information System for Earthquake Disasters

RISED is a database system with some decision support features and is designed to support a more efficient disaster response operation for catastrophic earthquake disasters [12]. RISED is able to provide the most up-to-date disaster response related information such as disaster locations, possible damages to both lives and constructions, available rescue and relief resources, the shortest way to the disaster zones, etc. RISED can be deployed in a two-tier architecture: a central RISED in the central disaster response center and some local RISEDs in local disaster response centers. The central RISED is responsible for nationwide disaster assessment and resource management. A local RISED collects local seismic and DR-related data and then uploads it to the central RISED periodically at ordinary days. When an earthquake ever strikes, a P2Pnet can be deployed immediately and the local RISED will be activated on the P2Pnet. If the P2Pnet can access to the Internet, the central and local RISEDs can exchange information for a more accurate disaster assessment as well as a better management on a disaster response operation. If, unfortunately, the P2Pnet has no access to the Internet, local RISEDs will have to operate independently. The design details are documented in [12].

RISED is composed of four decision support subsystems: Disaster Assessment, Fastest Rescue Route Generation, Health Care and Relief Resources Management, and Wounded Victim

Arrangement. Based on the analysis of disaster response efficiency in Chi-Chi Earthquake, we highly recommend giving the priority to these four decision support features in order to improve the disaster response efficiency for an earthquake disaster. As mentioned in Section 2.2, the assessment of the disaster distribution was usually blind and highly inaccurate such that disaster response resources might be allocated inadequately costing many lives unnecessarily. Based on the seismic database, the population distribution, and quake-resistance index of buildings, the Disaster Assessment Subsystem can help to make a more accurate disaster assessment to support a better resource allocation. Due to the limit of research resource, only a very primitive assessment model is adopted in RISED. A more sophisticate assessment model, which is beyond our current research capability, is needed to enhance its accuracy. Fastest Rescue Route Generation Subsystem collects real-time road status and performs path-planning to facilitate disaster response transportation. Due to the potential of a large scale damage of roads and bridges, the popular GPS navigation devices or path-planning services will all fail. It is obvious that a path-planning system that can collect and use the most up-to-date road status to perform path-planning is very critical to a disaster response operation. The Health Care and Relief Resources Management Subsystem provides an efficient disaster response resource management for a better resource allocation. From Chi-Chi Earthquake, we learned first-handed that DR resources were poorly allocated leading an inefficient disaster response operation. A similar phenomena occurred in the Haiti Earthquake was revealed by TV news. Therefore, such a resource management will be very helpful. Finally, Wounded Victim Arrangement Subsystem is a special resource management system dedicated to the mediation among victims, ambulances, and hospitals in an earthquake disaster. This subsystem can help rescue teams to send earthquake victims to the right hospitals or first-aid stations eliminating unnecessary transfers as happened in Chi-Chi Earthquake.

VI. CONCLUDING REMARKS

The most important lessons we learned from numerous disasters are that cellular networks were vulnerable and the loss of communication system may have a catastrophic consequence. This paper analyzes the causes that paralyzed the entire communication systems in Chi-Chi Earthquake and proposes a P2Pnet that uses laptops and hand-held devices to construct a MANET based emergency communication and information system. Brief system requirements and system design are presented. A P2Pnet prototype was tested in an English mobile learning class. The technical aspects of experiment results are presented. Finally, a prototype of Disastrous Earthquake Rescue Information System is also presented. This preliminary research is far from complete. We hope this research can stimulate more researches to tackle the grant challenges we have or have not found.

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