2009 10th International Symposium on Pervasive Systems, Algorithms, and Networks

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

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Abstract—When a catastrophic natural disaster strikes, an organized and effective rescue operation is essential to rescue those victims trapped under collapsed buildings or landslides as well as to relief massive survivals who lose their life support. However, communication systems were usually paralyzed by many causes. The loss of communication systems made rescue and relief operations extremely difficult costing many lives unnecessarily. We had proposed a MANET based emergency communication and information system, P2Pnet, which can support a large number of voluntary workers under catastrophic natural disasters. This paper demonstrates the design of a subsystem of P2Pnet, a Walkie-Talkie-like communication system, which can be used in the early hours or days after a natural disaster strikes. 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 Rescue; Mobile Computing; MANET*.

I. INTRODUCTION

Almost every year, the world is stricken by numerous catastrophic natural disasters, such as earthquake, hurricane, typhoon, tsunami, etc. When a catastrophic natural disaster strikes, such as Jiji/Taiwan Earthquake [4], SiChuan/China Earthquake [6], Hurricane Katrina [5], 88-Flood/Taiwan, or L'AQUILA/Italy Earthquake, an emergency rescue operation is very critical to numerous lives. The victims who are trapped under collapsed buildings or landslides may have a large chance to survive if they are rescued in 72 hours, referred to as "*Golden 72 Hours*". A natural disaster might also paralyze live support systems, such as power, communications, running water, food supplies, and medical supplies, etc. Massive survivals who were struggling for their lives need an organized and effective relief operation to keep them alive. However, communication systems, fixed or mobile, were usually paralyzed by many causes. 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 regular communication systems made the rescue and relief operations extremely difficult costing many lives unnecessarily.

Although establishing a temporary communication network to support emergency communications and networking is one of the most urgent tasks in such a mission, feasible options, especially for voluntary workers, are usually very limited in many catastrophic disasters. Lien et. al. proposed to use WiFi-ready notebook PCs owned by rescue volunteers themselves to construct a MANET to support thousands of disorganized rescue volunteers [2,3]. Because the popularity of both WiFi-ready notebook PC and portable power generators is very high nowadays, this solution is highly feasible in many countries.

Autonomous P2P Ad-Hoc Group Communication Systems (P2Pnet) [3] 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 mentioned natural disasters, battle-field and mobile learning environments.

Rescue people, voluntary or mission-specific professional, could 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 Voice-over-IP (VoIP), Push-to-Talk (PTT), Instant Messaging, and mobile social networks, etc. The Walkie-Talkie-like communication system shown in this paper is a system designed on top of P2Pnet.

978-0-7695-3908-9/09 $26.00 © 2009 IEEE
DOI 10.1109/I-SPAN.2009.85

II. BACKGROUND

The impact of communication system crash to a disaster could be catastrophic. To many people's surprise, cellular mobile communication systems that were thought highly dependable in emergency were completely wiped out in many cases. The observation made in Jiji Earthquake is reported in [2,3]. The causes of communication system failure as well as the requirements for an emergency communication and network system were also reported in [2,3]. It is summarized as follows.

2.1 Causes of Failures and System Analysis

Followings are parts of causes we found in Jiji Earthquake:

- Base stations crashed
- Trunks broken
- 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 needs a miracle for a communication system 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 amount of trunks were broken because of broken roads and bridges.

Environmental Constraints

- Outgoing link (Internet) is either not available or very limited such that most Internet based services are not available.
- WiFi-ready notebook PCs of non-uniform capacity are assumed very popular.
- Portable power generators are assumed available.

Functional Requirements

- User interface must be simple, easy to learn, and fool-proof.
- Devices must be fault-tolerant.
- Devices 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 notebook PCs 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 notebook PCs. 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
- maintain minimum level of throughput
- give precedent to QoS over throughput
- provide class-based priority services so that scarce resources can be allocated based on the degree of emergency
- provide high member coverage for group communications

2.2 MANET Based P2Pnet

Lien at. al. [2,3] proposed to use WiFi-ready notebooks to construct a MANET based group communication system to support emergency communication and information network, called *P2Pnet*. Using P2P communication technologies, a P2Pnet is able to support temporary group communication and information networks. Compared to other options, no extra hardware cost is needed. Most functionality will be 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 to support higher level communication services such as Walkie-Talkie, Push-to-Talk, and VoIP communications. Logical architecture is shown in Fig. 1.

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

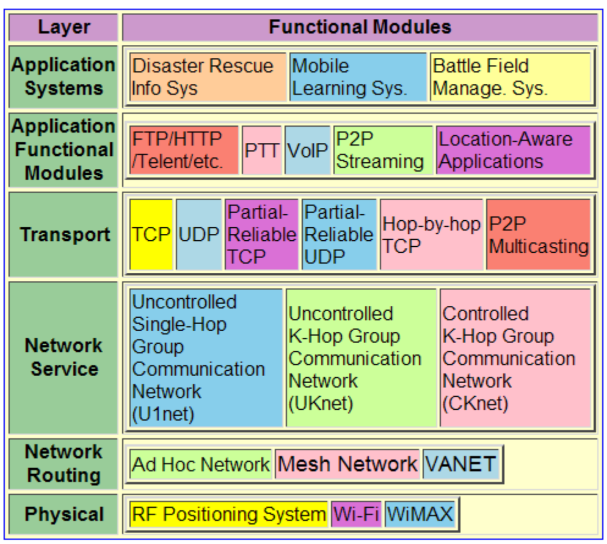

Fig. 1 Logical Architecture of P2Pnet

Physical and Network Layers

In order to use all available resources in a disastrous situation, P2Pnet will try to incorporate most available network technologies, including WiMAX, Mesh Network, and VANET. 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 is used in P2Pnet due to a high mobility environment.

Network Service Layer

Due to the loss of Internet connection, many network services may stop functioning. For instance, most VoIP or instant messaging services require users to access centralized registration servers. Therefore, many important networking services must be reimplemented. To reduce redundancy, we designed an intermediate layer on top of the Network Layer, called *Network Service Layer*, to facilitate networking services at the Application Layer.

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 to support Walkie-Talkie-like communications in the early hour of rescue operation. 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.

III. DESIGN OF U1Net

Considering the cross platform portability, the system is implemented in Java programming language. 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

In U1net system, the *JXTA* platform is employed as our peer-to-peer network platform [7]. The physical network is encapsulated within the JXTA Platform. JXTA technology is a set of open protocols that enable any connected device on the network to communicate and collaborate in a P2P manner. JXTA peers create a virtual network where any peer can interact with other peers and resources directly, even when some of the peers and resources are behind firewalls or network address translations (NATs), or even on different network transports. "Peer" is the smallest component in JXTA platform. Each peer has several EndPoints acting as communicating ports. Each EndPoint uses a "Pipe" as its communication channel to another peer. Peers are partitioned into different peer groups by their services. Each peer group has the same group name, group ID and group advertisement message. Each U1net user client program has its own JXTA Manager to manage all its own EndPoints. The actions a JXTA Manager can perform are sending *Advertisement* Message, joining a peer group, and obtaining a dedicated socket. This architecture is shown in Fig. 2.

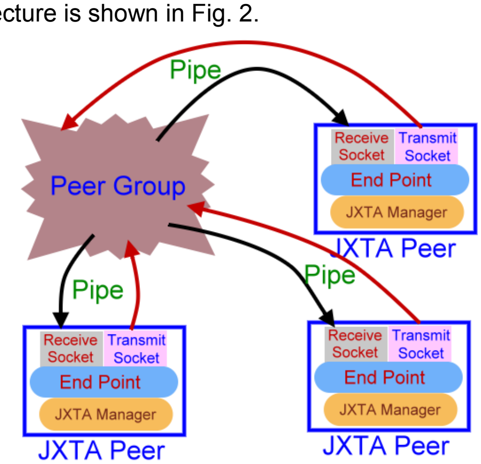

Fig. 2 U1Net over JXTA Platform

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. Therefore, messages on U1net couldn't go across NAT or Firewall. Nevertheless, it is unlikely that there is any firewall or any NAT existing in our targeted environments.

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. This procedure is shown in Fig. 3 and the related parameters are summarized in Table 1.

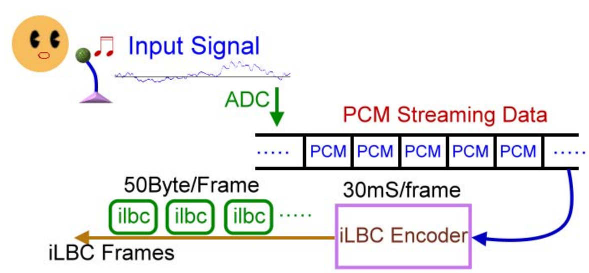

Fig. 3 Voice Capture and Encoding Procedure

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. The above procedure is shown in Fig. 4.

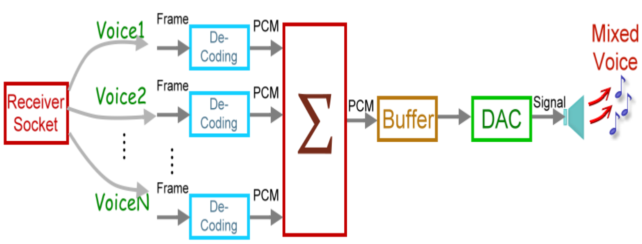

Fig. 4 Mixing and Playback Procedure

IV. EXPERIMENTS

Although we can't anticipate the performance of a real system that is deployed hectically using volunteers' notebooks, it still makes sense to evaluate the system we developed in our laboratories. As technology moves forward, more and more capable notebooks, PDA and smart phones will be more widely available. The results obtained in our experiments can serve as a baseline performance.

Up to 4 notebooks were used in the experiments. The notebooks 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 Vista operating system. Each one has an 802-11g WLAN on board. To set up ad-hoc WLAN mode, all notebooks must use the same SSID and the same radio channel.

4.1 Delay time, Jitter, and Loss Rate

In such a short range, the propagation delay time is nominal. Thus, the PCM-to-PCM delay time was small if two notebooks are within 12 meters, 386 ms in average, which is acceptable for full-duplex voice communication. However, when the distance reaches 18 meters, the delay time will be too long to support full-duplex communication mode. Therefore, half-duplex mode, such as Push-to-Talk, is more adequate. The measured delay time and jitter are shown in Table 2, Fig. 5 and 6, respectively.

Table 2 Delay Time at Diff Distances

Distance (m)	6	12	18	24
Avg. delay time (ms)	279	386	923	1018
Max. delay time (ms)	454	704	1069	1262

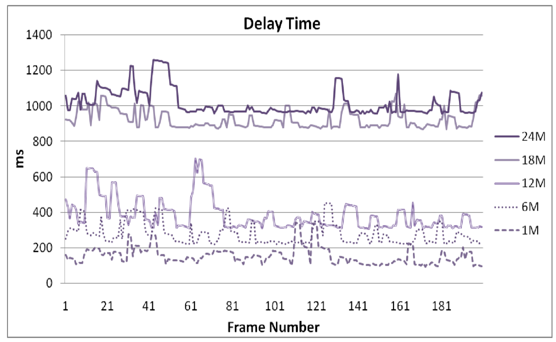

Fig. 5 Delay Time at Diff. Distances

The 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.

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

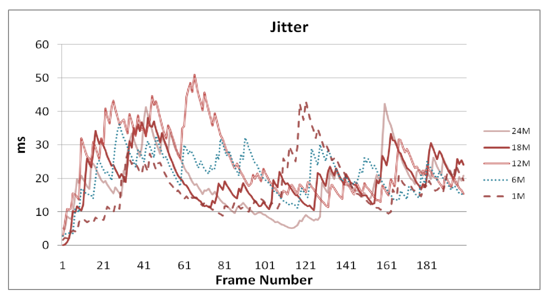

Fig. 6 Jitter at Diff Distances

What more harmful is packet loss. The average loss rate is approximately 11%, which is way above 3%, the common acceptable standard. In the future, we will add error correcting mechanism into the encoding scheme to reduce packet loss rate. To prevent the dejitter buffer from inducing too much delay time, we restrict the buffer to be one frame, 30 ms, only. Therefore, the frames that overdue by more than 30 ms are useless.

4.2 Connection Stability and Voice Quality

In our experiments, the connections were mostly good in short distance. However, the stability of the WiFi connection is highly depending on the WiFi hardware. In the worst case, the voice quality (MOS) deteriorated quickly when the distance reaches 6-8 meters and LOS (Line of Sight) was blocked. The MOS can be as low as 2-3. Beyond 10 meters, the connection was hard to make. An external WiFi hardware performs much better than on-board one. It is beyond the control of system software. Nevertheless, we anticipate that the stability of WiFi hardware in the future notebooks will be gradually improved. Judging from the short range connectivity of some notebook PCs, UKnet is in need to extend the range of our Walkie-Talkie-like communication system for them to be useful in real disaster rescue missions. Although delay-tolerant-network technology is not helpful for VoIP application, it is helpful for other applications. Another thing that needs to improve is the power consumption of WiFi hardware operated under ad hoc mode.

4.3 Echo and Proximity Problems

Every notebook has a microphone and a speaker on-board. We anticipate that most of the notebooks in the future will have both microphone and speaker built-in. (Many old-style notebooks may not built-in with a microphone.) An echo cancellation mechanism must be in place to eliminate echo.

When two notebooks are too close without any block in acoustic paths, severe echo or even echo avalanche may occur due to complicated acoustic coupling and feedback. This is called the "*Proximity Problem*" in this paper. When two notebooks are too close, the voices of two users as well as the sounds of two notebooks may be picked up by the microphones of both notebooks. A complicated acoustic coupling may occur resulting a severe echo avalanche. Proximity problem will not likely occur in regular VoIP usage since users are usually far apart. However, in our targeted environments, massive-voluntary disaster rescue operation, the distance of users are usually not under any control and are essentially randomly distributed. Regular echo cancellation mechanism fails to deal with this special problem. We developed a VAD (Voice-Activity-Detection) based echo cancellation technology to solve this problem. The detail is beyond the scope of this paper and will be reported in the future.

V. CONCLUDING REMARKS

The most important lessons we learned from numerous disasters are that mobile communication systems are very vulnerable and the loss of communication system may have a catastrophic consequence. This paper demonstrates the design of a Walkie-Talkie-like communication system over a MANET based P2Pnet. The system is designed to support emergency communications in the early hours or days after a natural disaster strikes. We wish to stimulate the research on the emergency communication systems that is inexpensive and easy to deploy for catastrophic natural disasters.

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