Challenges of Emergency Communication Network for Disaster Response

Jyh-Shyan Huang
Department of Computer Science
National Chengchi University
Taipei, Taiwan, R.O.C.
frank210@cht.com.tw

Yao-Nan Lien
Department of Computer Science
National Chengchi University
Taipei, Taiwan, R.O.C.
lien@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. Survival rate can be greatly increased by breaking the communication bottleneck. Based on our firsthand experience in 921 Chi-Chi Earthquake and extensive research, we synthesize a set of requirements for deploying an emergency communication network for disaster response (ECN-DR), which can be deployed and operated under extreme environment and unusually communication behaviors in disaster areas. There are seven challenges, called 7-ability, that have to be addressed when designing an ECN-DR. 7-ability includes popularity, usability, practicability, capacity, reliability, operability and adaptability. Popularity and usability are used to fulfill end-user requirements. Practicability, capacity, reliability, operability and adaptability are used to fulfill operator requirements. Finally, we propose high level system architecture of ECN-DR. Several research issues about how 7-ability can be achieved will be presented.**

Keywords- Disaster Management, Emergency Communications, Mobile Communication, Ad Hoc Network

I. INTRODUCTION AND MOTIVATION

A. The Impact of Large-Scale Natural Disaster

Frequently occurring large-scale natural disasters have been reported to cause great damage in recent years, claiming many people's lives, rendering millions people homeless, and causing huge financial loss. The earthquake that occurred in Haiti in 2010 alone claimed 230,000 people's lives.

When the disasters come, the destroyed areas are in chaos. Take the earthquake that happened on March 11, 2011 in North-eastern Japan for example. After the 9.0 magnitude earthquake, followed by a 23-meter high tsunami and the combined major natural disasters (i.e. nuclear crisis, earthquakes and tsunami), the world and the already experienced disaster response workers were stunned. From our firsthand experience and extensive research on several large-scale natural disasters, such as 921 Chi-Chi Earthquake (Taiwan) [2], 88 Flood (Taiwan), SiChuan (China) [6] and Haiti Earthquakes, we summarize a few factors that caused unnecessary hindrance to the previous disaster response operations as follows:

(1) paralysis of transportation systems,
(2) paralysis of communications networks,
(3) lack of professional disaster response workers, and
(4) dysfunctional administrative command system.

Due to such factors as poor communication/coordination of disaster response workers and insufficient information, disaster response work tends to procrastinate and its resource is severely limited. It is a pity that many precious lives could have been saved.

B. Analysis of Communication Systems Crash Reasons

Communications system is crucial to disaster response, but when the disasters come, these seemingly stable public communications networks were paralyzed. Surprisingly, we found that during 88 Flood and 921 Chi-Chi Earthquake, the cell phones were vulnerable due to mostly the following two reasons:

Service disruption of base stations: Common reasons include (1) the destruction of the strong earthquakes or flood; (2) power outage (the backup batteries can last only 1 to 2 hours, and 70% of the 3300 disconnected base stations during 88 Food were out of power); (3) backhaul links destroyed.

Critical hardware equipment was knocked down: Due to (1) power outage and (2) broken cooling system and overheated switch.

C. The urgency of emergency communication network for disaster response (ECN-DR)

Taking 921 Chi-Chi Earthquake for example, it took Chunghwa Telecom 15 days to repair its telecommunications network. During 88 Flood, disconnected base stations totaled 3,300, 1,800 of which belong to Chunghwa Telecom. 550 of Chunghwa Telecom base stations could not function properly after two days of urgent recovery operation. In other words, mobile communication networks were usually paralyzed and they could not be immediately repaired in the Golden 72 Hours.

Survival rate can be greatly increased by providing an emergency communication network to the disaster response as

Sponsored by National Science Council NSC 101-2420-H-004-006-MY3

soon as possible when the disasters break out. As a consequence, more precious lives can be saved.

D. Research Motivation

Over the years, many researchers devoted to research on designing of new ECN-DR [1,3,4,5,7]. Most of these studies only discuss about their network architecture of ECN-DR, but rarely discuss how the emergency communication requirements are fulfilled by their systems. According to Capability Maturity Model Integration (CMMI), system requirements analysis must be done before designing the system. Without system requirements analysis, the ECN-DR may not fulfill the requirements and have limited help. Hence, we are glad to propose our analysis of system requirements of ECN-DR and condense the requirements into several criteria. Researchers may use these criteria to judging the quality of their ECN-DRs.

In this study, the requirements for an emergency communication network are summarized into seven criteria which are called 7-ability and discussed in section II. In section III, we introduce two typical ECN-DRs and demonstrate how to use 7-abiliy as criteria to find the advantages and limitations of the ECN-DRs. Then, we propose our suggestion of the system architecture of ECN-DR. In section IV, we present the relations between 7-ability and network functions and discuss how 7-ability is achieved. Finally, we propose our conclude remark in section V.

II. 7-ABILITY OF ECN-DR

According to our firsthand experience and observations, emergency communication system should be constructed rapidly and provides communication services in disaster areas. Due to the stringent time constraint and extreme environment conditions, there are seven challenges which are called 7-ability as shown in TABLE I and have to be addressed when constructing and operating an emergency communication system. Popularity and Usability are used to fulfill the end-user requirements. Practicability, Capacity, Reliability, Operability and Adaptability are used to fulfill the operator facing requirements.

A. Abilities for end-user requirements

Popularity: Due to the rareness of terminals, most common emergency communication systems, such as satellite communication, trunking radio and amateur radio only can be used by specific groups. Most victims and volunteer disaster response works cannot access to these communication systems. Besides, users need training before using terminals of trunking radio and amateur radio, hence both systems can only be used by military or professional disaster response groups.

***User Friendly*:** ECN-DR should choose terminals which are user friendly and easy to use. Thus, most people can use it.

***Sufficient Amount of terminals*:** For example, satellite communication may be the most seen communication system in the disaster area. Due to insufficient amount of satellite phones, most people cannot access to satellite communication service. Cell phones might be the first thing carried by most victims or volunteer disaster response workers. It is easy to use and ready to use without deployment as long as cell phone network is functional, which means cost and time. Hence, using cell phone as the terminals (handsets) is a good option. Considering the popularity of notebook and tablet PC, they are good options too.

TABLE I. 7-ABILITIY OF ECN-DR

7-ability	*Practicability*	• low development cost • easily access to the equipment • construct rapidly and easily
	Popularity	• large amount • user friendly
	Usability	• task oriented communication services • mobility • adequate quality of service • long standing time of terminals
	Capacity	• sufficient number of concurrency users • resist the burst of call request
	Sustainability	• long sustained time • rapid recovery
	Operability	• have operation and maintain functions • can adjust network topology, bandwidth allocation and etc. accord to the requirement of response workers
	Adaptability	• disaster awareness • self-adjustment

Usability: Because the extreme conditions of disaster areas, ECN-DR has to properly deal with all kind of user's unusual communication requirements. And thus, ECN-DR will be helpful to life relief work. To possess usability, ECN-DR should provide task oriented communication services, support mobility, and have adequate QoS. Besides, the handsets of ECN-DR should have long standing time.

***Task Oriented Communication Services*:** includes ordinary (POTS), walkie-talkie-like and agency communication services. Because disaster response workers need to cooperate with each other, only providing ordinary communication service is not sufficient. ECN-DR should support walkie-talkie-like communication service which is wildly used in team work. Besides, people in a disaster area may not know each other. When a victim needs a doctor, he doesn't know how to contact the nearby doctor and receives medical treatment immediately. Agency communication service allows him/her to dial the number of a specific agent, not personnel, that enables him to contact a nearby doctor.

***Adequate Quality of Service*:** It's life matter. Good communication quality can lead to good understand with caller and callee and may save life. On the contrary, misunderstand may cause unpredictable damage.

***Long Standing Time of Terminals*:** Power outage is a common consequence of a natural disaster. Even though portable power generators may be available to support disaster response operation, they may not be able to support large scale recharge services for terminals. Therefore, the longer a terminal can stand the better.

***Mobility*:** Because disaster response workers need to walk around, ECN-DR should support mobility.

B. Abilities for operator requirements

Practicability: Practicability is the basic requirement and first consideration of the operator of ECN-DR**.** The primary consideration of operator is how to make the ECN-DR become immediately possible. There are several requirements need to be discussed, such as low deployment cost, easily acquisition of equipments, easy and rapid deployment.

Low Deployment Cost**:** Although, ECN-DR is important to disaster response operation, many lives may be saved as ECN-DR works. But, ECN-DR do not engage in making profit and the opportunity of using ECN-DR is occasional. Unlike military or commercial communication network which have abundant research and development fund, governments and carriers do not willing and cannot invest the same fund to develop and deploy ECN-DR. Deploying a ECN-DR which can cover most area and survive in any large scale disaster may cost too much. To concern with practicability, deployment budget of ECN-DR should be limited.

Easy Acquisition of Equipments**:** Due to the hindrance of the terrain and the paralyzed transportation, external aid is usually difficult to transport to the disaster areas. In the beginning of a disaster, helicopters may be the only vehicle can be used to transport needed equipments. Hence, the size and weight of ECN-DR equipments should fit to air transport. In addition to external aid, it has better to build an ECN-DR by reusing network equipments and techniques on hand to lower the deployment cost and make ECN-DR deployment rapidly and easily.

Easy and Rapid Deployment**:** Survival rate is highly dependent on the rescue speed. The earlier the victims are rescued, the higher the survival rate is. The survival rate is 90% within 24 hour; 50% between 25 to 48 hour; 20% between 49 to 72 hour and less than 5% after exceeding 72 hour. To save more lives, ECN-DR should be deployed as quickly as possible. Moreover, there are not sufficient professionals, ECN-DR may need to be deployed by non-professionals and thus ECN-DR should be deployed easily.

Capacity: Number of telephone calls in the disaster areas exceeds that in usual time. Take SiChuan Earthquake [6] for example. The disaster areas have ten-time phone calls than usual in internal areas; 5-to-6-time phone calls than usual in external areas; and 80-time phone calls than usual from Beijing to the disaster areas. With limited capacity, ECN-DR won't be able to support massive phone calls that flow into the stricken area. However, it must support large amount of victims and voluntary disaster response works within stricken areas as well as limited incoming and outgoing calls. Furthermore, ECN-DR should have ability to resist the burst of call request, to prevent itself been crashed by the massive phone calls. Besides, ECN-DR should prevent some coverage area from being starvation which is caused by resisting the massive incoming call.

Sustainability: ECN-DR should be deployed as quickly as possible and operating until the public communication network is recovered. Since recovery of public communication network may take several days even weeks. For example, in 921 Chi-Chi Earthquake, it took Chunghwa Telecom 15 days to repair its telecommunications network.

Long sustained time: Before the full recovery of public communication networks, ECN-DR should operate continually for several days. Long sustained time is required.

Rapid recovery**:** Because ECN-DR is the primary communication network to people in the disaster before the recovery of public communication networks, ECN-DR should continually provide service. Even if an ECN-DR is broken down, it should recover quickly.

Adaptability: Like a battle field, the situation in a disaster area may constantly change due to aftershocks, fires, and progress of disaster response, etc.. Therefore, an ECN-DR must be able to adapt to the changing environment.

Disaster awareness**:** ECN-DR should have good awareness to disaster effect and arranges network resource to coverage area according their damage situations.

Self-adjustment**:** Moreover, an ECN-DR has to sense the variation of disaster area and adjust itself automatically to fit the change and thus ECN-DR can function well with low maintenance cost and satisfy the requirement of users.

Operability: An ECN-DR may need to continually operate for a couple of weeks. Operation, administration and maintenance functions which are called OAM functions are needed to keep an ECN-DR running.

OAM Functions**:** When an ECN-DR was broken down by unexplained reasons. OAM functions should help operator to identify the problem and recovery the broken ECN-DR quickly.

III. COMPARISIONS OF ECN-DRS

A. Typical ECN-DRs

Conventional ECN-DRs include walkie-talkie, amateur radio, trunking radio, mobile satellite phone, and cell-on-wheel (mobile base station). Two typical new ECN-DR technologies are WiFi based Ad Hoc network (***MANET***) and Base Station based Ad Hoc network (***BSNET***) [7]. A MANET based system uses notebooks and tablet PCs to construct a ECN-DR. Hybrid Mobile Ad-Hoc network [1] was a two-level hierarchical MANET. It takes WiFi mesh network as the user access layer and WiMax and Satellite mesh network as network layer to support multimedia traffic such as VoIP and multimedia streaming. Users can use a notebook or smart phone with VoIP applications to access the communication service. A BSNET reuse disconnected cellular base stations and long distant wireless links to form an Ad Hoc network. In such a system, disconnected BSs connect to cell phone core network through the BSNET. And thus, users can use their cell phones connect to the base stations and make phone calls.

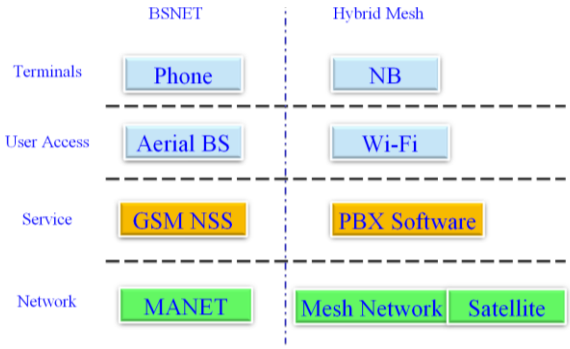

Figure 1. System architectue of BSNET and Hybrid Mesh

System architecture of BSNET and Hybrid Mesh Network are showed in Fig. 1. .

B. Comparison of ECN-DRs

TABLE II. COMPARSIONS OF ECN-DRS

	Practicability			Popularity		Usability		Capacity
	Cost	Construction	Acquisition of Equipment	Number of Terminals	User Friendly	Mobility	Quality	Concurrency users limited
Walkie-Talkie	Low	No need	Easy	Regards the area	Easy	High	Middle	Number of handsets
Amateur Radio	Middle	Need professionals	Easy	Few	Profession-als only	Low	Middle	Number of handsets
Satellite communi-cation	Extreme High	Existing system	Easy	Few	Easy	High	Middle	Number of handsets
Trunking Radio	High (devices are few)	Easy	Hard (Land transport)	Few	Learning is needed	High	High	Number of handsets
Cell on wheels	High (devices are few)	Easy	Hard (Land transport)	Many	Easy	High	High	Number of cell on wheels
MANET	Low	Need professionals	Easy (devices on hand)	Middle	Easy	Middle	Low	Bandwidth of MANET
BSNET	High	Need professionals	Middle (Air/Land transport)	Many	Easy	High	High	Bandwidth of External Link
Hybrid Mesh	High	Need professionals	Middle	Middle	Easy	High	High	Bandwidth of External Link

Using the 7-ability to examine current often used ECN-DRs, MANET, BSNET [7] and Hybrid Mesh [1], we will find that they have their own advantages and limitations as shown in TABLE II. 7-ability can be used as a guideline when designing an ECN-DR.

Walkie-talkie, amateur radio, satellite communication and trucking radio are often used systems. All of them need dedicated terminals and only can be used by specific target groups. They have high usability and practicability, but low popularity.

Cell-on-wheels and BSNET are applicable to the general phone users and have high popularity. However, cell-on-wheels make transportation to the afflicted areas difficult and its number is limited. As a result, it can only be used in certain areas, making it difficult to meet the communication needs in the afflicted areas. BSNET uses disconnected cellular BSs to construct an aerial Ad-Hoc Network which is difficult and need professionals. BSNET should simplify construction difficulty to become more practicable.

MANET and Hybrid Mesh are applicable to notebook users. BSNET which is applicable to mobile phone users has higher popularity than MANET and Hybrid Mesh. On the contrary, Construction difficulties of MANET and Hybrid Mesh are easier than BSNET. MANET and Hybrid Mesh are more practicable in terms of construction. However, their quality are skeptical for one critical reason: a GEO satellite link and VoIP over MANET may cause a long delay time which may severely hurt the quality of a phone conversation. Finally, both MANET and BSNET require non-commercial financial support for research and development due to their lack of commercial incentive.

IV. IMPLEMENTATION ISSUES TO SUPPORT 7-ABILITY

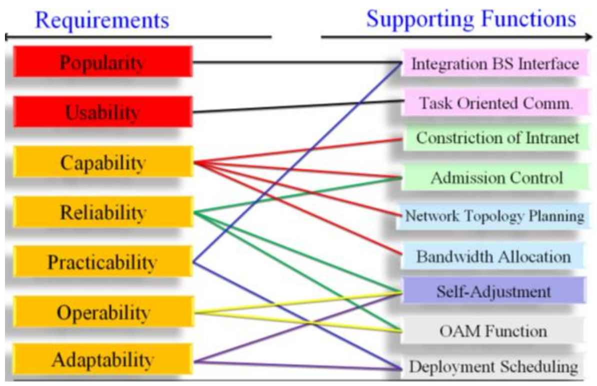

Figure 2. How 7-ability achieved

7-ability and how these abilitiese can be achieved are showed in Fig. 3. Integration BS Interface is the possible way to achieve Popularity and Practicability. Popularity may be the most important ability of ECN-DR, but most common emergency communication system do not have sufficent popularity. It is because their terminals are dedicated and not easy to acquire. If the ECN-DR has an integration BS interface and can connect to cellular base stations, the ECN-DR can service cell phone users to achieve high popularity. Moreover, the size of cellular BSs is small and easy to transport. And, there may have a number of cellular BSs which are intact but out of service in the disaster area. Reusing these cellular BSs to construct ECN-DR can raise the success rate and thus the ECN-DR may have higher praticability.

Task oriened communications includes ordinary, walkie-talkie -like, and agency communication. Walke talkie is the often-seen communication apparatus for disater response operations. Agency communication response to redirect the call to the one who has required resources or skill and nearby. A injured victim can use agency communication to call a nearby doctor and gets help. Task oriened communications make the ECN-DR more usable.

Capacity may be achieved by construction of Intranet, admission control, network topology planning and bandwidth allocation. ECN-DR is an tempoary system and impossible to accept all incoming calls. Admission control can protect the system from be crashed by the burst of calls. Network topology planning and bandwidth allocation maximize system capacity by using bandwidth efficiency.

Integration BS interface and deployment schedule make the ECN-DR more practicable. Due to the limited transportation capacity of air drop or helicopters. Network devices of ECN-DR should be transported serveral times. Deployment scheduling determines the best deployment sequence to maxmize the benefits of disaster response operations.

V. CONCLUDING REMARKS

When stricken by a catastrophic natural disaster, many communication systems crashed, including cellular networks. The loss of communication system may have a catastrophic consequence. From Chi-Chi Earthquake and 88 Flood, we learn that power outage and backhaul link breakage were the two common problems that crushed base stations. It is difficult to enhance the availability of power lines and backhauls since they are highly dependent on the robustness of roads and bridges. Unfortunately, due to the paralysis of transportation system, the disaster response operation in the Golden 72 Hours may have to rely on many disorganized local voluntary workers. The deployment of many conventional emergency communication systems relies on a good transportation system, which is usually not available in a catastrophic natural disaster. Coordination among these disorganized disaster response workers has become extremely difficult without the support of the communications system. The efficiencies of their disaster response operations are severely crippled.

Through our research of emergency communication network over the year, we had learned that an ECN-DR should have the 7-ability. And thus, the ECN-DR may be constructed quickly in the first time and provide communication service to victims and disaster response workers to sustain and help more victims to survive. We propose a suggestion of high level architecture of ECN-DR in the paper. And then, we discuss important research issues about how the 7-ability may be achieved. We hope that this paper may help those who are willing to devote themselves to the research of emergency communication network. And thus, more lives will be saved.

REFERENCES

[1] Y. Bai, W. Du, Z. Ma, C. Shen, Y. Zhou, and B. Chen, "Emergency communication system by heterogeneous wireless networking," in Proc. of IEEE Wireless Communications, Networking and Information Security (WCNIS), June 2010.

[2] 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.

[3] H.C. Jang, YN. Lien, and T.c. Tsai, "Rescue Information System for Earthquake Disasters based on MANET Emergency Communication Platform," Proc. of the IWCMC 2009, pp. 623-627, June 2009.

[4] 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 Workshop on Specialized Ad Hoc Networks and Systems, Montreal, Canada, June 26, 2009.

[5] Yao-Nan Lien, Li-Cheng Chi and Yuh-Sheng Shaw, "A Walkie-Talkie-Like Emergency Communication System for Catastrophic Natural Disasters," Proc. of ISPAN09, Dec., 2009.

[6] Yang Ran, "Considerations and Suggestions on Improvement of Communication Network Disaster Countermeasures after the Wenchuan Earthquake", IEEE Communications Magazine Jan. 2011.

[7] Zhenhong Shao; Yongxiang Liu; Yi Wu; Lianfeng Shen, "A Rapid and Reliable Disaster Emergency Mobile Communication System via Aerial Ad Hoc BS Networks," in Proc of IEEE Wireless Communications, Networking and Mobile Computing (WiCOM), Sept., 2011.