

# Design of Contingency Cellular Network

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*Abstract*—When a catastrophic natural disaster occurs, the efficiency of disaster response operation is crucial to life saving. However, communication systems, such as cellular networks, were usually crashed due to various causes that made coordination difficult for many disorganized disaster response workers extremely. 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 propose an emergency communication system, Contingency Cellular Network (CCN), by connecting disconnected base stations together with wireless links and portable power generators. CCN can support existing mobile phone users with limited capability. Such a system can support a large number of voluntary workers in the early hours of a catastrophic natural disaster, thus saving many lives. Design philosophy and high level system architecture of our framework are presented in this paper.

*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. We synthesize the impact of large-scale natural disasters, such as 921 Chi-Chi Earthquake (Taiwan) [2], 88 Flood (Taiwan), SiChuan (China) [5] and Haiti earthquakes as follows:

- (1) the collapse of buildings,
- (2) paralyzed traffic in the disaster areas,
- (3) paralysis of entire communications network,
- (4) lack of professional disaster response workers,
- (5) dysfunctional administrative command system.

Bottlenecks of disaster response caused by these impacts are:

- (1) the hindrance of the terrain and the paralyzed traffic system,
- (2) difficult allocation of resources and misplacement of resources,
- (3) difficult coordination and communication troubles among the disaster response workers.

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. [3,4].

### B. Communication Systems Crash

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:

**Service disconnection in the base station:** Common reasons include (1) the destruction of the strong earthquakes; (2) power outage (the backup batteries can last only 1 to 2 hours, and 70% of the 3300 disconnected base stations during 88 Flood were out of power); (3) the backhaul of the base station was destroyed.

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

### C. Research Motivation

Survival rate can greatly increase by breaking the bottleneck of disaster response and improving the efficiency of the relief to rescue the trapped victims when the disasters break out. As a consequence, more precious lives can be saved.

Building on the disaster research over the years, we know that the majority of disconnected mobile base stations stop operation due to power outage and disconnected backhaul, not because the structure of base station is destroyed.

The purpose of the study was to investigate how to connect the disconnected base stations and to build an emergency contingency communications system in the most convenient and fastest way so that cell phones in a disaster zone can function partially.

## II. CHALLENGES AND COMPARISON OF CONTINGENCY COMMUNICATION SYSTEMS

### A. Grant Challenges of Contingency Communication

TABLE I. 7-ABILITY OF CONTINGENCY COMMUNICATION NETWORK

7-ability	<b>Practicability</b>	<ul style="list-style-type: none"> <li>• low development cost</li> <li>• easily access to the equipment</li> <li>• construct rapidly and easily</li> </ul>
	<b>Popularity</b>	<ul style="list-style-type: none"> <li>• large amount</li> <li>• user friendly</li> </ul>
	<b>Usability</b>	<ul style="list-style-type: none"> <li>• key services to response works</li> <li>• support mobility</li> <li>• high quality of service</li> <li>• long standing time of terminals</li> </ul>
	<b>Capacity</b>	<ul style="list-style-type: none"> <li>• sufficient number of concurrency users</li> <li>• resist the burst of call request</li> </ul>
	<b>Sustainability</b>	<ul style="list-style-type: none"> <li>• long sustained time</li> <li>• quick recover</li> </ul>
	<b>Operability</b>	<ul style="list-style-type: none"> <li>• have operation and maintain functions</li> <li>• can adjust network topology, bandwidth allocation and etc. accord to the requirement of response workers</li> </ul>
	<b>Adaptability</b>	<ul style="list-style-type: none"> <li>• disaster awareness</li> <li>• self-adjustment</li> </ul>

An emergency contingency communication system should be constructed rapidly and provides communication services in disaster areas. Due to the highly time demand and extreme environment conditions, there are seven issues which are called 7-ability (see TABLE I. ) have to be addressed when constructing and operating a contingency communication system. Especially, practicability, popularity, usability and capacity are the key issues and will be discussed about in our research.

### B. Comparison of Common Contingency Communication Systems

TABLE II. COMPARISON OF CONTINGENCY COMMUNICATION SYSTEMS

	Practicability			Popularity		Usability		Capacity
	Cost	Construction	Access 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 communication	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
CCN	Low	Middle	Middle (Air/Land transport)	Many	Easy	High	High	Number of BS

Common communications systems, such as walkie talkie, amateur radio, satellite communication, trunking radio, cell on wheels, MANET, have their own advantages and limitations (see TABLE II. ). Apart from the mobile base stations applicable to the general users, the rest can be used by specific target groups, rendering the disaster response communication almost impossible in the disaster areas. However, the mobile base stations 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. To accelerate the progress of

disaster response work, new disaster contingency communications systems need to be researched and developed to satisfy the basic needs of the communication in the disaster areas so that disaster response communication can be widely used in the disaster areas [1,3,4,6].

## III. CONTINGENCY CELLULAR NETWORK (CCN)

### A. Design Philosophy of CCN

Design philosophy of CCN is to employ existing disconnected base stations in the disaster area. The reasons are as follows: (a) wide coverage of mobile communication network; (b) widespread use of cell phones; (c) add-on modules that repair disconnected base stations could be created with low cost; (d) low-barrier of use, which are mostly needed in current disaster response communication. One crucial non-technical reason is that cell phone might be the first thing carried by most victims and people who escape from their homes when a disaster comes. Therefore, reconnecting disconnected base stations in the disaster area to provide a large-scale emergency communication service is a good option.

*Contingency Recover Package (CRP)* includes power module, inter-cell communication module (*ICC Module*), and an add-on processing module, which is referred to as Emulated Controller Module (*EC Module*). First, EC Modules are connected to base stations. Second, we use ICC Modules to construct a multi-hop wireless network and rebuild connections between base stations and core network. And then, these base stations can provide some limited service. Anyone who has a cell phone can access service from these base stations. If there is no way to connect to the core network, some CRP may include satellite communication modules (*SC Module*) to support the connection to the core network. Depending on the available fund, some number of CRPs can be previously stored in the national disaster response center and transported via helicopters to the selected stations to construct CCN rapidly.

### B. System Architecture of CCN – Level 0

Contingency Cellular Network (CCN) is constructed by reusing the disconnected base stations in the disaster area. The Level 0 system architecture of CCN is illustrated in Fig. 1. Components of CRP are described as follows.

**Power module:** It includes a portable power generator and fuel that is sufficient to provide required electricity by a base station for a few days. Note that although most base stations have backup power, they can only last a few hours in general.

**Inter-Cell Communications Module (ICC Module):** Its main function is to establish connections between base stations. It should be noted that there is no wired connection between base stations in general. Major components of ICC Module are a wireless transceiver and an antenna. Base stations are usually built as high “cell towers” and a few miles away from each other. Therefore, there is seldom a line-of-sight problem between two adjacent cell towers. A long range WiFi or WiMAX may be able to connect two adjacent stations

together. The topology of a cell phone network is almost fixed over time so that the direction of each antenna of each ICC module can be measured or calculated in advance.

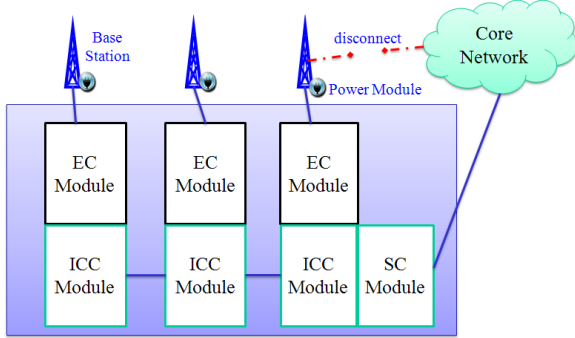


Figure 1. System Architecture of CCN – Level 0

**Emulated Controller Module (EC Module):** EC Module is the core controlling component of CCN. Its main functionalities are establishing connections between base stations and transferring telecommunication signaling and data into VoIP package. Then, it acts as the IP backhaul allowing base stations to provide communication service. Because the wireless bandwidth of CCN is rare, EC Module provides communication without using wireless resources to increase concurrent users.

Low-cost solutions to implementing EC Module are many, one of which is a laptop equipped with interface to the ICC module and the target base station.

**Satellite Communications Module (SC Module):** It provides the connection between CCN and core network. Thus, people in a disaster area can communicate with outside. Satellite communications equipment, which is not confined to the geographical boundaries, can connect to the core network directly. However, only a few base stations can be installed due to the high cost of satellite communications equipment. Others connected to core network through survival base stations by multi-hop. Thus, the external bandwidth can be shared by all the recovered BS of a CCN.

To satisfy the communication requirements of a disaster response mission, CCN supports three types of communication modes: ordinary, walkie talkie like and agency modes.

**Ordinary Mode:** the original 1-1 communication mode.

**Walkie Talkie Like Mode:** CCN supports walkie talkie like communication mode. Response workers can dial a special number and join a walkie talkie group. Because multi-casting data between different base stations may exhaust too much inter-BS wireless bandwidth, members in the same group is constrained to connect to the same base station in a CCN.

**Agency Mode:** 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 mode enables victims and disaster response workers to contact the one who is nearby and has ability to help them.

### C. System Architecture of CCN – Level 1

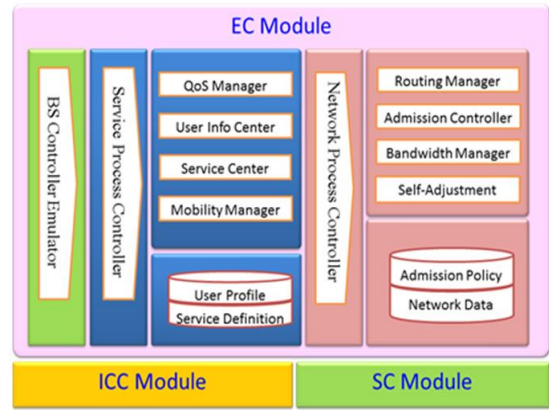


Figure 2. Architecture of EC/ICC Module

Level 1 system architecture is illustrated in Fig. 2. Some important components are introduced as follows. Service Process Controller is responsible for service procedure and cooperates with the function components to fulfill the service to the users. BS Controller Function deals with the communications protocol with base stations and transfers signal and data into VoIP package. Service Center supplies the necessary function to provide communication service. User Info-Center is responsible for user identity. Network Process Controller is responsible for network service procedure and cooperates with the function components to fulfill network service. Admission Controller prioritizes emergent phone calls to access the telephone service. The capacity of a CCN is usually smaller than usual public network, making it difficult to handle massive phone calls. Also, the degree of urgency varies, ranging from regular care phone calls to emergent calls for rescue in the disaster areas. Since not all phone calls can be answered, every possible means should be made to prioritize emergent phone calls to access the telephone service in the communications system.

### D. Service Process of CCN

Inter-BS call setup service process of an ordinary call is described as follow (see Fig. 3):

**Step 1~3 user access:** Caller sends a telephone call. BS Controller Function forwards the request to service process layer with callers' and callees' phone numbers.

**Step 4~5 service process:** User info-center is used to query the user information from user profile. Second, service center is used to identify the service procedure of the call request by querying service definition. Three, mobility manager is used to find out the location of callee. Four, QoS manager is used to decide the QoS according to caller's and receiver's identity. Finally, the call is forwarded to network service layer with callers' and callees' identities, QoS degree and callees' location.

**Step 6~8 network service:** Routing Manger is used to find out the routing path by referring the network topology recorded in network data. Bandwidth Manager is used to

provide bandwidth utility rate to admission controller. Admission controller is used to decide if the call is admitted or not according to bandwidth utility rate and emergency degree of the call. And then, the call request is sent to destined base station hop by hop through wireless links.

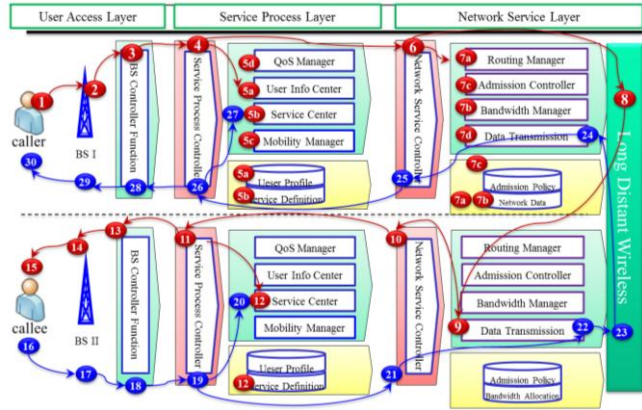


Figure 3. Inter-BS call setup service process

**Step 9-10 network service:** Network service controller forwards the call request to service process layer.

**Step 11-12 service process:** Service process controller used service center to query out the service definition and follows the service procedure.

**Step 13-15 user access:** Service process controller sends a signal to callee through BS Controller Function and the phone of callee is ringing.

**Step 16-30 call setup:** When callee answers the phone, the acknowledgement is sent back to caller and a virtual tunnel between caller and callee is built.

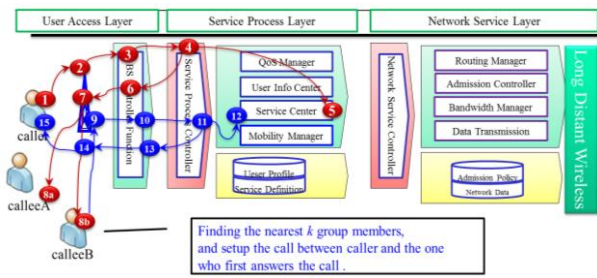


Figure 4. Agency mode call setup service process

Agency mode call setup service process is showed in Fig. 4. In step 4 and 5, service process controller uses service center to identity the call and find  $k$  nearby members of called agency group. If the  $k$  members are in the same base station, the call is multicast to them. Then the call is setup between caller and the member who first answers the phone. If some of the  $k$  members are in other base stations, procedure of sending the call to these members is similar to the procedure which is showed in Fig. 3.

#### IV. CONCLUDING REMARKS

When stricken by a catastrophic natural disaster, many communication systems, including cellular networks, usual crashed. 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 commonest problems that crushed base stations. It is difficult to enhance the availability of power lines and backhuls since they are highly dependent on the robustness of roads and bridges. Unfortunately, due to the paralysis of transportation systems, a disaster response operation in the Golden 72 Hours may have to rely on many disorganized local voluntary workers. Rapid deployment of many existing 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 communications system. The efficiencies of their disaster response operations are severely crippled. Therefore, we designed an emergency contingency communication network, CCN, by connecting disconnected base stations in the disaster zone with wireless links and portable power generators. CCN can support existing cellular users with limited capability. Such a system will be able to support many voluntary workers in the early hours of catastrophic natural disasters, and thus saving many lives.

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