# Design of Agency Communication for Contingency Cellular Network


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***Abstract*—We proposed a Contingency Cellular Network (CCN) for Mission Critical Public-Safety Networking in natural disaster by connecting disconnected base stations together with wireless links and constructing a wireless multi-hop cellular network. CCN can support existing large number of mobile phone users with reduced capability. Because the receiver of a phone call in a disaster area is usually a resource owner (agent), not a particular person, we designed a special Agency Communication mode for CCN allowing its users to initiate a phone call to a nearby resource by dialing a designated agent number, instead of a real phone number. To verify our design, we implemented a small scale prototype using laptop PCs with IEEE 802.11 Wireless LAN to emulate the CCN network and Android smart phones with VoIP software to emulate user terminals.**

**Finally, we conducted a series of experiments to evaluate the performance of the prototype system. The experimental results show that the prototype system can respond promptly to the user registration and call set-up requests. Mouth-to-Ear Delay can be effectively controlled below 400 ms when there is no more than 30 calls originated. This system may be used as a reference for the future development of contingency communication networks.**



***Keywords—Disaster Management, Emergency Communication, Mobile Communication, Ad Hoc Network, Group Communication.***


## I. Introduction

Most base stations were crashed in a disaster due to the breakage of power source or backhaul links [5]. Based on this fact, we designed a Contingency Cellular Network (CCN)[1] for Mission Critical Public-Safety Networking (MCPN)in natural disaster, by connecting service disrupted but physically intact base stations using wireless links to form a multi-hop cellular network. The main design philosophy of CCN is to reuse existing disconnected base stations to save cost and deployment time as well as to support large number of existing users. The reasons are as follows: (a) wide coverage of mobile communication network; (b) widespread use of cell phones; (c) only a low-cost add-on module is needed to repair a disconnected base station; (d) low-barrier of use. One crucial non-technical reason is that a cell phone might be the first thing carried by most victims and people who escape from their homes or work space when a disaster strikes. Therefore, reconnecting disconnected base stations in the disaster area to provide a low-cost large-scale emergency communication service is a good option.

The system architecture of CCN is illustrated in Fig. 1. A survival base station is a base station that has the external link connected to the core network. An isolated base station is a functional base station that losses its connection to the core network. One or more survival base station together with a set of isolated base station connected to each other via long range wireless links to form a tree topology CCN network. Messages and phone calls are initiated by mobile devices and then forwarded hop-by-hop to other nodes or to the core network via a survival base station. All required equipment to rescue a base station are packaged into a *Contingency Recovery Package* (CRP) and are delivered to the site.

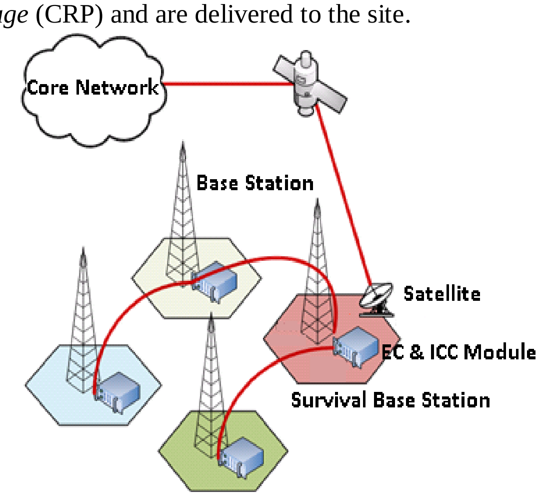


Fig. 1. System Architecture of CCN.

*Contingency Recover Package* (*CRP*) consists of a power module, two or more Inter-Cell Communication Modules (*ICC Module*), and an add-on processing module, which is referred to as Emulated Controller Module (*EC Module*). CRPs can be stored in national disaster response centers and/or cellular operators and delivered to the selected base stations via airdrops or helicopters. The EC Module is connected to a base station in the first step. Then, ICC


[1] This project is funded by Ministry of Science and Technology, Taiwan, R.O.C., MOST 107-2221-E-468-005

Modules are used to connect the base station to its neighbors in the second step via long range wireless links. If there is no way to connect to the core network, some CRP may equip with a satellite modem to establish a connection to the core network. The overlapped network provides the connectivity between base stations and core network. Anyone who has a cell phone can access service through these base stations. The software system architecture of CCN are shown in Fig. 2.

**Power module:** consists of a portable power generator and required fuel that is enough to provide electricity to a base station for a few days.

**Inter-Cell Communications Module (ICC Module):** is used to establish connections between base stations. (There is usually no wired connection between base stations.) Major components are wireless transceivers and antennas.

**Emulated Controller Module (EC Module):** is the main controlling component of CCN. Its main functionalities are establishing connections between base stations and transferring telecommunication signaling as well as acting as a PBX to provide intra-CCN communication services.

There are many low-cost solutions to implement EC Module. A powerful laptop equipped with interfaces to the ICC module and the target base station (most likely an Ethernet interface) running Linux operating system will be enough.

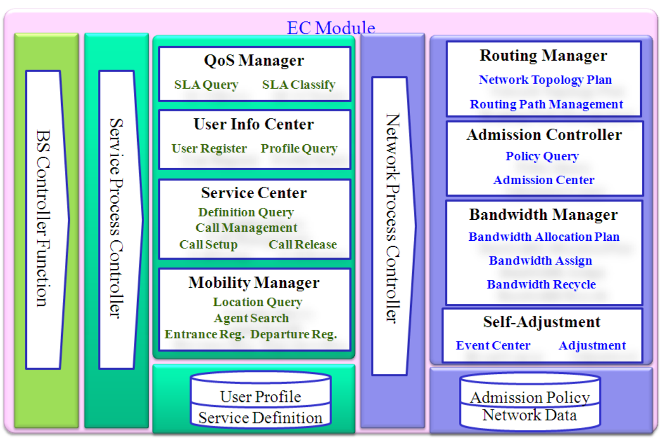


Fig. 2. Software functional architecture of EC module.

The backhaul network of cellular network is the network to connect base stations and MSC. Current wire based backhaul network technologies are T1/E1 copper, optical fiber etc. In the CCN, ICC Modules are employed to construct a multi-hop wireless backhaul network to recovery the connections between base stations and MSC. The design details such as topology design, bandwidth allocations, OA&M, etc. can be found in our previous published articles [5,6,7].

Because the receiver of a phone call in a disaster area is usually a resource (agent), not a dedicated person, we designed a special Agency Communication mode for CCN allowing CCN users to initiate a phone call to a nearby resource by dialing a designated agency number. To verify our design, we implemented an emulated CCN system using an IEEE 802.11 WLAN, laptop PCs, and Android smart phones.

## II. Related Works

Cellular backhaul network are often constructed by using landline broadband technology. Wireless broadband solutions such as microwave, long range Wi-Fi, satellite, etc. are often used in the rural area to reduce the construction cost [1, 6]. Hence, when base stations are crashed in a disaster due to the breakage of their landline backhaul links, using wireless backhaul technologies to recover the function of base stations is a feasible option. Moreover, there are several other approaches, such as Arial Base Stations, being proposed to provide contingency communications to the first responders [2,3,4]. Among them, 3GPP's LTE-Direct, which allows mobile devices to communicate to each other without the support from base stations and core networks [2], will become increasingly important. However, there are some major issues yet to be solved. First, the channel allocation is a big issue when the base station and core network cannot provide this functionality. Certain distributed channel assignment mechanism must be established to avoid potential co-channel interference problem. Secondly, agent-based communication is yet to be designed on LTE-Direct environment. The integration of CCN and LTE-Direct technologies will offer a better solution for MCPN.

## III. Agency Communication mode

### A. Assumptions

The majority of phone calls in a disaster area shares some common characteristics: First, the intended callee is most likely the owner of a resource, such as power cutter or medical supply, not a specific person. Secondly, the caller and the callee may not know each other such that the caller may not know the phone number of the callee. Third, their urgent level are variant. Based on this characteristics, we deisgn an agency communicaiton mode to support CCN users. Finally, we assume that CCN has a mobility management database to support user mobility.

### B. Agency Communication Mode

Disaster responders are organized into agent groups based on the resource type or specialty they posses. Each group has a dialable Agent Group Identification (AGID). Each group member can dial a special number to register into Agent Group Membership database (AG Member database, in short). When a user dials an AGID to initiates an agency call, the system retrives the list of group members and pages the K nearest members (K is a fixed number determined by the system operator). When the phone call is answered by a paged callee, the system set up the call between the caller and that callee. Finally, the systerm stops paging other group members. In addition to the mobility management database, an AG Member database is needed to support Agency

Communication Mode. The ER-model of AG Member database is shown in Fig. 3.

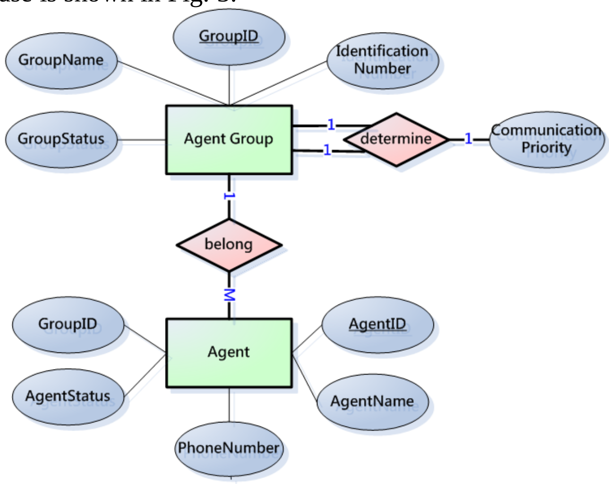


Fig. 3. ER-Model of AG Member database

## C. Registration Procedure

The registration procedue is as follows:

1. A group member dials a special number and submits its IMSI and IMEI to the CCN to initiate a registration request.
2. The originating node (base station) that receives the request submits a registration request to the AG Member database.
3. The AG Member database replies to the originating node.
4. The originating node replies to the caller.

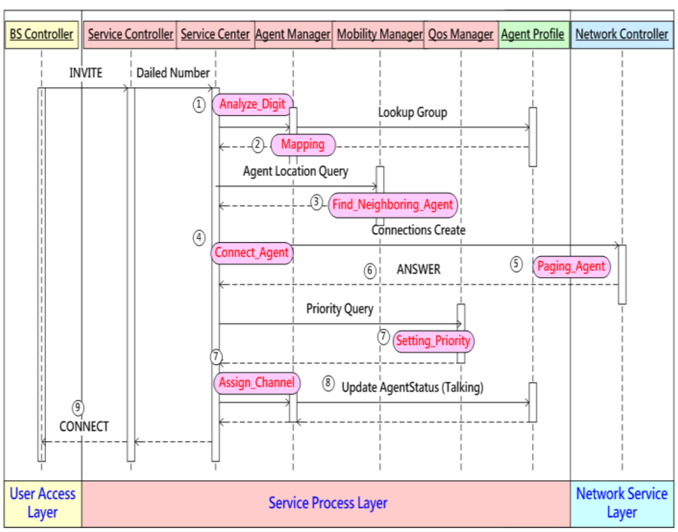


Fig. 4. Call Flow of call setup procedure

## D. Member Query and Call Setup Procedure

When a user initiates an agency call by dialing an AGID, the originating node proceeds with a member query, followed by a call setup procedure to establish the connection for the phone call. The details are as follows (see Fig. 4). Other procedures such as call release are skipped for space saving.

1. The originating node submits a member query to the AG Member database
2. When the list of group members is available, the originating node submits a location query to the mobility database to obtain the location information, which is all necessary information to setup the connection, of all group members.
3. CCN sends ringing signals (paging) to the K nearest members, gives priority to intra-cell neighbors.
4. When any callee answers the call, the system set up the connection between the caller and that callee.
5. CCN stops paging all other callees.

## E. Call Processing

The call processing procedure is modeled as a pair of Finite State Machines (FSM), one for the originating site and the other for the terminating site. The simplified FSM diagrams are shown in Figure 5 and 6. The data flow is show in Fig. 7. The FSM mechanism is a very popular technology to implement a call processing procedure in telecom industry since it can greatly reduce processing overhead such that a small-scale hardware system can support large number of phone calls.

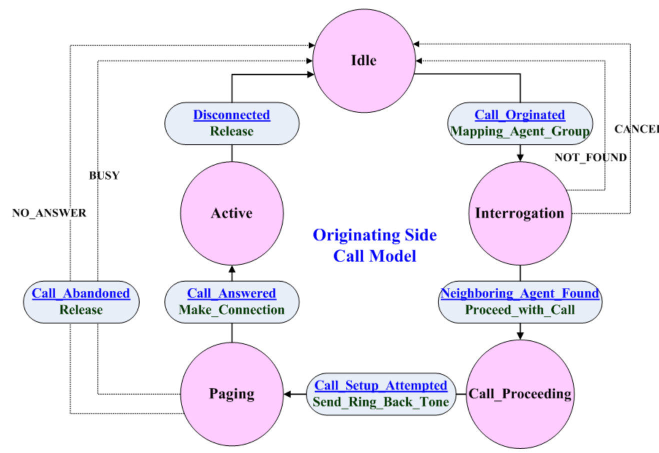


Fig. 5. Originating site Finite State Machine

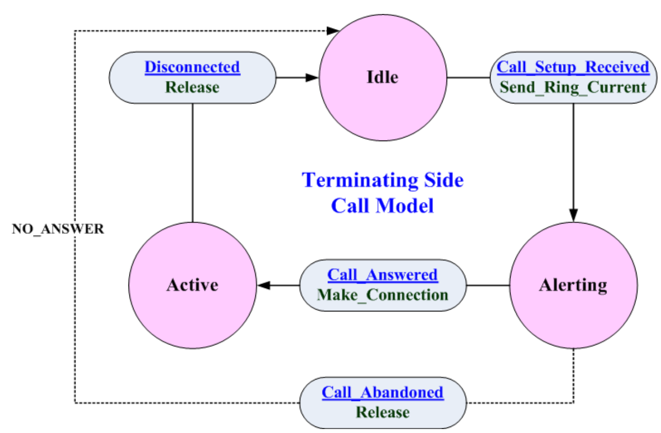


Fig. 6. Terminating site Finite State Machine

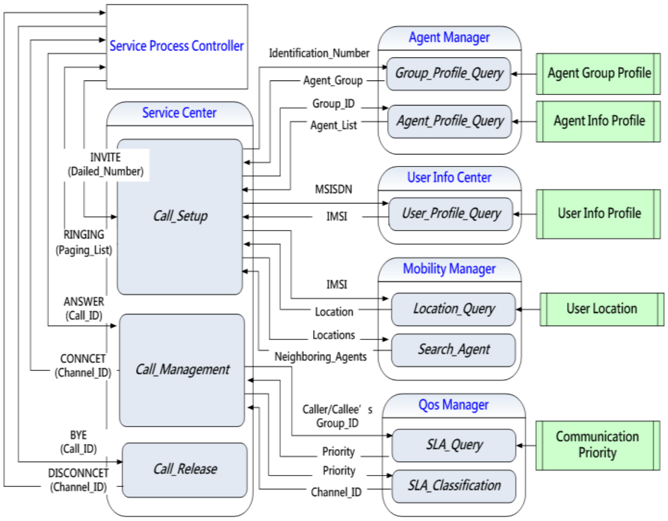


Fig. 7. Data flow of call processing

## IV. PROTOTYPE AND EVALUATION

To verify our design, we implemented a small-scale prototype using laptop PCs with IEEE 802.11 Wireless LAN to emulate the CCN network and Android smart phones with VoIP software to emulate user terminals. We also conducted a series of experiments to evaluate our prototype.

### A. *Experimental Setup*

The system architecture of the prototype is shown in Fig. 8, where ACS is the central database containing mobility database and AG Membership database. Hardware and software specification are listed in Table 1 and 2. The correspondence between CCN and prototype system components are listed in Table 3. A laptop PC with an Intel 2.5GHz Core-i5-2520M CPU is used to emulate a base station. Microsoft Access is used for database. Each cell phone is an Android smart phone running VoIP App.

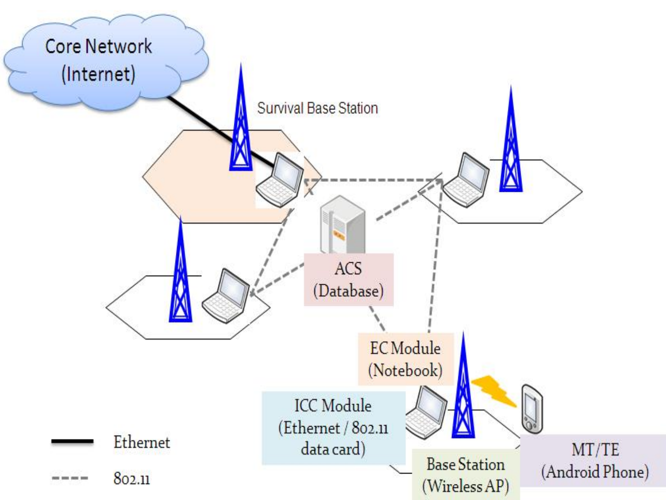


Fig. 8. System architecture of prototype system

Table 1. Hardware specification of prototype system

| **Hardware Specifications** | |
|---|---|
| **Laptop PC** | |
| OS | Windows 7 |
| CPU | Intel Corei5-2520M CPU @2.5GHz |
| Memory | 2GB |
| Wireless Card | Intel Centrino Advanced-N 6230 |

Table 2. Software specification of prototype system

| **Software Specifications** | |
|---|---|
| Development Tools | Eclipse IDE for Java Developers |
| | ADT Plugin for Eclipse |
| Java Development Kit | Java jdk1.6.0_33 |
| **ACS Server** | |
| Data Base System | Microsoft Office Access 2007 |
| **UA Implementation API** | |
| Java Development Kit | Java jdk1.6.0_33 |
| Software Development Kit | Android SDK 2.2+NDK Revision 8b |
| Speech Codec | iLBC (internet Low Bitrate Codec), sampling freq. 8000Hz, 16 bits /sample |

Table 3. Correspondence between CCN and prototype system components

| CCN | Prototype |
|---|---|
| Cell Phone | Android phone (ACS APP + VoIP) |
| Base Station | Wireless AP |
| EC Module | Laptop PC |
| ICC Module | IEEE 802.11 data card + Ethernet data card |
| Database Server | ACS (AD Member Database) |
| Core Network | Internet |

The performance metrics includes registration latency, call setup and release latency, and voice quality. To obtain the performance measurement, a network monitoring software, Wireshark, is used to capture and analyze network traffic. The number of users is set in the range between 10 and 100. The size of registration message and control message is 62 bytes, K (the number of paged group members) is set at 5, 10, 15, and 20 respectively. Session holding time is set at 60 sec. Each experiment is repeated for 100 times.

### *B. Experimental Results*

The average registration time for 10 and 100 concurrent users is 267 ms and 2198 ms, respectively, which shows that the performance of registration procedure is acceptable under heavy use. The average paging time for 10 and 100 concurrent users when K is set to 5 is 744 ms and 4939 ms, respectively. The detailed breakdown is shown in Fig. 9.

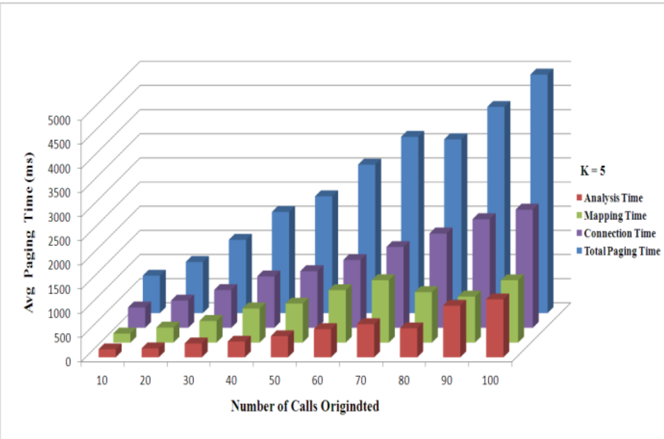


Fig. 9. Average paging time at K=5

The average call setup time (including paging time) for 10 and 100 concurrent users is 1455 ms and less than 10 sec., respectively as shown in Fig. 10. While call release time is between 240 ms and 6000 ms.

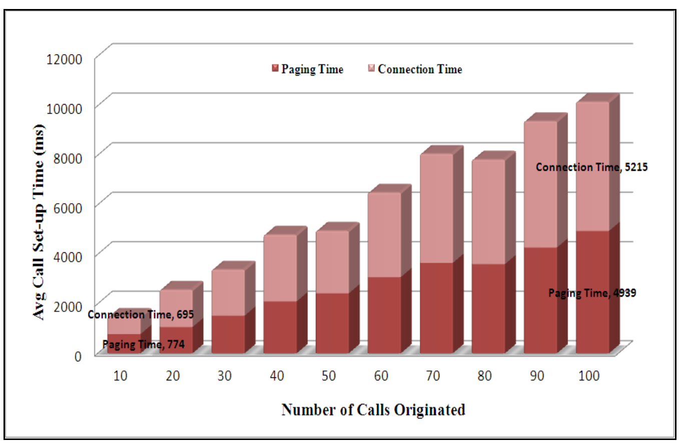


Fig. 10. Average call setup time

As shown in Fig. 11, the average Mouse-to-Ear Delay (MED) for under 30 concurrent users is between 339 and 357 ms. When the number of concurrent users is more than 30, the MED is increasing gradually until 80 users.

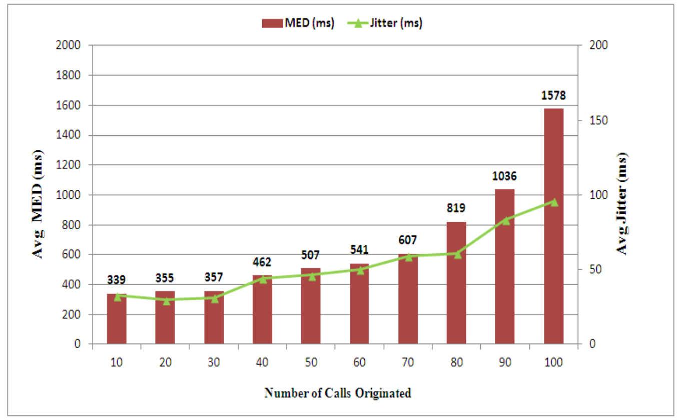


Fig. 11. Average MED and Jitter.

## V. CONCLUDIND REMARKS

An efficient disaster response operation relies on a good communication system and is crucial to life saving. However, communication systems, such as cellular networks, usually crashed due to various causes that make coordination extremely difficult for many disorganized disaster responders. Unfortunately, rapid deployment of many existing MCPN proposals relies on a good transportation system, which is usually not available in a catastrophic natural disaster.

CCN, which can be deployed easily and quickly, is designed to support large number of existing mobile phone users in a large-scale natural disaster. Since disaster responders may not know each other, an agent-based group communication mode becomes the most useful communication service. This paper proposes an Agency Communication mode to support CCN users. There are still many other issues yet to be solved to create a realistic MCPN. More resources are in demand to devote to this type of research.

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