The Functionality Discussion with LTE Simulator for Emergency Disaster-Resilient Network Systems

Chung-Hsien Tsai[1], Ang-Hsun Tsai[2], Wen-Pin Chen[3]
[1]*Department of Computer Science and Information Engineering,*
[2]*Department of Electrical and Electronic Engineering,*
[3]*School of Defense Science,*
Chung Cheng Institute of Technology, National Defense University, Taiwan
chtsai@ndu.edu.tw

Abstract*—The emergency communication system is a critical factor of any disaster rescue operation. Emergency communication based on an LTE system provides an evolution path toward broadband capabilities for existing and new public safety networks. The development of an LTE communication simulator is aimed at improving the performance of radio access. However, backhaul network such as base station and satellite-based relay would cause limited communication resources to hamper the rescue operation process. In this paper, we discuss the problems of disaster relief communication systems and investigate the requirements in the disaster scenario. Based on the previous LTE simulator comparison and the requirement of emergency communication, five functionalities are discussed that include disaster-oriented network management, mobility/user management, radio resource management, disaster-oriented flow management, and modeling framework. These five functionalities can help to evaluate overall resource management after disaster relief. The paper also conducted an offloading simulation to evaluate the radio resource usage for emergent disaster-resilient LTE network systems.

***Index Terms*—Disaster Relief; Emergency Communications; Rescue Operation; Simulator.**

I. INTRODUCTION

All terrestrial communication infrastructure is likely to be destroyed in a serious natural disaster. For example, in the East Japan Great Earthquake, only a few cellular base stations could still provide communication services. Since cellular phone services have greatly increased over the past decade, the damage combined with congestion caused communication problems for the rescue operation, resident safety confirmation, and medical treatment. The traffic flows increased to eight times larger than usual in about thirty minutes after the disaster [1]. The cellular communication system had serious traffic congestion problems that reduced the cellular system efficiency. Therefore, a robust communication method is urgently required to transport significant information even when severe disasters occur.

The emergency communication system plays a critical role just after a disaster [2, 3]. With victims and disaster relief teams trying to communicate with other people, the limited number of base stations becomes overwhelmed by traffic congestion problems. In addition, different disaster relief teams may not be able to cooperate with each other if they use different communication platforms. The lack of a common disaster communication protocol is often considered a principal shortcoming in relief activities. It is important that disaster relief teams should have a proper emergency network to communicate with each other.

The emergency communication based on LTE system has a great potential to improve the efficiency of rescue operations. The IP-based network architecture extends to integrate the Private Mobile Radio (PMR) of different relief teams. The disaster information from the first responders would be combined to generate the Common Operation Picture (COP). The efficiency of rescue operation would be promoted. In addition, the reduction of capital expenditure (CAPEX) and operational expenditure (OPEX) budgets are simultaneously considered. Therefore, LTE communication systems have become a common platform for emergency communications [4]. Jalihal et al. [5] designed a disaster communication system named DISANET, which consists of Wi-Fi, a satellite link, a GSM system and an LTE base station (BS). DISANET allowed voice, text and video communication between rescue workers and the operation center in order to improve rescue operation effectively. DISANET also supported safety confirmation for family members and friends. Gomez et al. [6] presented a resilient 4G-LTE communication system based on virtualization technology and distributed architecture. Utilizing a virtualized Evolved Packet Core (EPC) embedded in eNB and a device-to-device (D2D) communication scheme can reduce dependency between UE, eNBs and EPC. The dependency of communication system elements can improve disaster resilience. When a disaster destroys the backhaul link, the eNB which has virtualized EPC capability can still work. Even if the user is not in the service radius of eNB, device-to-device technology also provides end-to-end communication links and relay services. Taniguchi et al. [7] presented an application of Base Station Cooperation (BSC) for the disaster recovery. When BSs in some cells were attacked and destroyed by disaster, the survived BSs can be utilized to relay the desired signal. But user equipment would communicate with other BS in a far away distance, coordination of survived BSs could degrade transmission quality in disaster cells. Therefore, such an emergency communication system should reconsider cautiously the radio resource in the disaster area (DA).

The radio resource evaluation is directly related to the efficiency of search and rescue operations. When an unpredictable disaster happens, the emergency communication system should satisfy the needs of disaster relief workers at least (and even victims) in the DA. This type of evaluation of emergency communication system capacity is very difficult. The mobile operators or providers could build a testbed to simulate a complex LTE system, but researchers in academia could not. Therefore, a simulator is an appropriate tool with which we can evaluate and verify the performance of an LTE system.

Most LTE simulators are not specially designed and developed for disaster relief activities. The lack of functions, such as protocol stack, uplink channel and mobility would affect the simulation output required to meet the needs of a disaster scenario. The protocol stack in the transport layer affects the different transport types. Uplink data flows simulate the path of data transmission from disaster relief workers to the LTE communication system. The mobility simulate the devices moving around with relief workers. In addition, some schemes, such as bandwidth aggregation [8], handover [9] and resource block allocation [10], can improve the efficiency and fairness of radio resource in the disaster scenario. Traffic offloading technologies [11] such as Local IP Access (LIPA), Selected IP Traffic Offload (SIPTO) and D2D, focus on reducing traffic congestion to enhance communication capacity.

In this paper, we discuss not only the functionality of disaster relief communication systems, but we investigate the requirements in a disaster scenario. By analyzing and comparing the simulators in [12, 13, 14, 15], we provide a simulator framework that consists of five functionalities: (i) disaster-oriented network management, (ii) mobility/user management, (iii) radio resource management, (iv) disaster-oriented flow management, and (v) a modeling framework.

These functionalities are designed specifically for disaster rescue operations. The simulation of traffic offloading methods in LTE systems is the critical functionality to improve the radio resource usage of an LTE communication system. The simulator that is designed for rescue operations could be used to evaluate communication capacity just after a disaster, or for regular training.

II. Communication Architecture of Rescue Operations

When an unpredictable disaster occurs, the terrestrial communication infrastructure may well be destroyed in the affected area. The government organization would immediately set up a Central Emergency Operation Center (CEOC) to support the rescue operations. However, the communication services in the DA could be useless, or at best unstable. For example, Richter scale 6.4 earthquake occurred in southern Taiwan on February 6, 2016 [16] caused the numbers of about 116 deaths and 550 injuries. Most of casualties were due to serious collapse at the Weiguan Kinglong Building in Tainan. The CEOC was set up rapidly to conduct disaster relief teams into serious DA. Disaster relief teams mainly consisted of National Army, Fire (obligatory included), Aircrew, Coast Guarders, and Policemen (obligatory and civil included). The first day of earthquake occurred reached up to 2,822 responders to support rescue operations. Nevertheless, 143 base stations are damaged due to power failure and transmission interruption. The mobile communication operators had to provide six mobile base stations to cope with communication needs of rescue operations. Therefore, the disaster relief teams should have an emergency communication system that is capable of supporting the rescue operations.

In an emergency communication network, the backhaul portion of the network comprises the intermediate links between the CN, or backbone network and the mobile network for DA. The backhaul network for disaster-resilient communication system typically has two designed schemes [7]. One is the satellite-based communication [17, 18], the other is BSC [19]. However, the satellite communication needs a special device for the signal transformer to integrate into mobile emergency communication system. Based on the height of the satellite, the channel characteristics of the satellite communication have large path loss, coherent time and transmission delay. BSC should consider that the survived BSs could be located at a far away distance. The signal transmission has large path loss and strong interferences from surrounding adjacent cells. The link quality would be decreased. The mobile emergency communication would be certainly affected. Therefore, the radio resource of emergency communication would be limited. How to utilize the limited radio resource is key point for rescue operation.

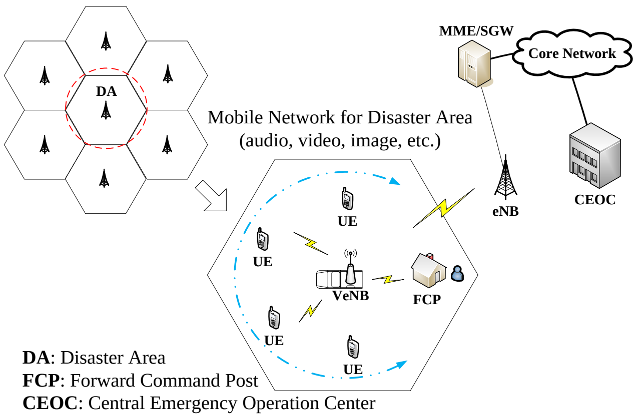

Figure 1: A communication scenario of the rescue operation

In the disaster rescue operation scenario as shown in Figure 1, we assume that the survived eNB can relay transmission signals as the backhaul. After the nature disaster damaged the center area, the terrestrial cellular communication systems are destroyed and the CEOC will be established. When the effect of nature disaster tends to be moderated, the relief workers are assigned to the DA. Then, the relief workers arrive in the DA, accompanied by a mobile emergency communication system such as vehicular eNB (VeNB). A Forward Command Post (FCP) is set up with VeNB. The mobile emergency communication network is established in close contact with the FCP. The VeNB communication services are provided through the wireless backhaul link. The relief workers wear UE to search for victims and report situations to FCP. All situations reported by relief workers are integrated into the COP later. The FCP commander can see clearly from COP which relief workers require more support. The situations of the DA also are reported back to CEOC in order to request disaster relief supplies such as large construction machinery, tools, medical appliances, additional relief workers, and so on.

The rescue operations consist of relief workers with smart phones, mobile base stations, and commanders in the FCP and CEOC. The relief workers continue to search for and to rescue victims. During this time, a large numbers of rescue information are transmitted through the LTE-based emergency communication. Hence, the communication system architecture is composed of an eNB Module and EPC Module, as shown in Figure 2. The eNB Module includes UEs, the eNBs and VeNBs in the DA. The EPC Module has

SGW/PGW elements to provide data networking between the VeNB and SGW/PGW. However, the COP needs a large amount of feedback information reported by relief workers. All transmission information would be propagated form UE to core network (CN). It could cause traffic congestion problems, especially in the limited backhaul.

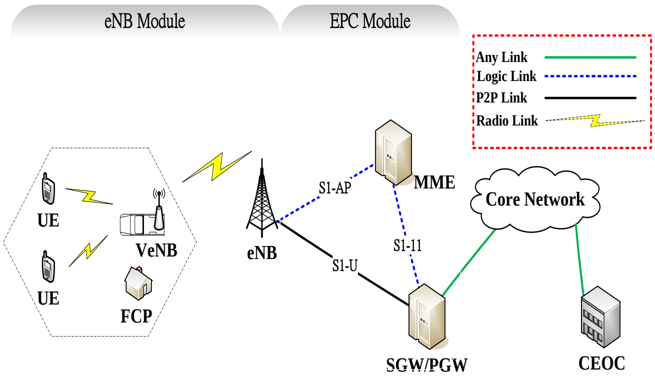

Figure 2: The LTE system architecture of the emergency communication

The communication capacity should also be considered in order to satisfy the requirements of relief workers and victims. Therefore, the traffic offloading mechanism is one of the good solution for traffic congestion. The VeNB based on traffic offloading mechanism should have smart evaluation and a decision mechanism to redirect the traffic flow under the same VeNB service. A large amount of traffic flows between the relief workers and FCP commander would be redirected. The limited backhaul loading and transmission delay would be significantly reduced. More backhaul transmission resource would be supported to communicate between the FCP and CEOC. The overall performance of rescue operation would be effectively improved.

III. Comparison of Emerging LTE Simulators

The performance evaluation of LTE systems is usually implemented via simulation. Most LTE simulators are designed for research into resource allocation management, scheduling strategies, inter-cell interference coordination, etc. LTE simulations are usually divided into link-level and system-level stages [20]. Link-level simulations focus on the performance of the physical layer. They involve some performance analysis, such as channel estimation, Multiple-Input Multiple-Output (MIMO), Adaptive Modulation and Coding (AMC), synchronization algorithms, feedback techniques, etc. Physical-layer modeling is critical for system-level simulations, which focus on the performance of network-related issues such as resource allocation, mobility handling, interference management, and network planning optimization. System-level simulations involve network layout and some performance measurement, such as the link quality reported by Channel State Information (CSI) feedback, the scheduling algorithm, and MIMO mode selection. The link-level and system-level simulations are used to evaluate the performance of LTE systems under various scenarios.

Ikuno et al. [12] present an LTE system-level simulator based on MATLAB. The simulator consists of two main parts. One is the link measurement model used for link adaptation and resource allocation, the other is the link performance model used for determining the link Block Error Ratio (BLER). This structure can pre-generate the fading parameters offline in order to reduce computational complexity at run-time. The simulator is offered for free, and has the capability to evaluate the performance of the down-link shared channel of LTE Single-Input Single-Output (SISO) and MIMO networks. However, the lack of uplink channel structure would limit one-way data transmission. The complete LTE protocol stack is required in order to meet the LTE standard for transmission of various data types.

Piro et al. [13] provide an LTE-Sim simulator based on object-oriented C++. The simulator consists of four main components. The first component is the simulator. This is used for managing events that start, execute or end the simulation. The second is the frame manager, used for defining the LTE frame structure and for scheduling frames and sub-frames. The third is the flow manager, used for handling applications such as traffic generators of trace-based, VoIP, CBR and infinite-buffer models. The final component is the network manager, used for creating devices, handling UE position, managing the handover and implementing frequency reuse techniques. LTE-Sim is an open-source framework, and has the capability to simulate uplink and downlink scheduling strategies in multi-cell/multi-user environments, user mobility, handover procedures, Quality of Service (QoS) management, frequency reuse techniques, the AMC module, scheduling strategies, etc. However, the simulator only supplies the UDP protocol, without the TCP protocol. The HARO process is not supported in the current version.

Baldo et al. [14] present an LTE network simulator based on ns-3. The simulator was designed from a product-oriented perspective. It focuses on evaluating the performance of an LTE Self Organized Network (SON), and on testing RRM and SON algorithms. The SON capabilities, such as self configuring, self-optimizing, and self-healing, are important for LTE equipment vendors and operators in reducing CAPEX and OPEX. Furthermore, the simulator has the capability to evaluate radio resource management, QoS-aware packet scheduling, inter-cell interference coordination and dynamic spectrum access. The simulator based on ns-3 is also designed for LTE-EPC data plane [21] and handover procedure [22]. However, the simulation of traffic offloading methods should be designed specifically to meet the requirements of a disaster scenario.

Virdis et al. [15] provide a SimuLTE simulator based on the OMNeT++ modular simulation framework. The simulator consists of three main nodes. The first node comprises UEs used for implementing the UDP module, TCP module, IP module and Network Interface Card (NIC) module. The second comprises eNBs used for implementing the Point-to-Point Protocol (PPP) module, IP module and NIC module. The final node is the binder module used for storing information from UEs and eNBs, including other nodes (e.g., routers, applications). The simulator is an open-source system-level simulator that supports the data plane of the RAN and EPC, a complete LTE protocol stack, physical layer modeling, and scheduling capabilities. The simulator based on OMNeT++ also has a stable and mature framework, a large amount of simulation models, modular development, and a smooth learning curve. Some additional features such as D2D communication and Coordinated Multi-Point (CoMP) transmission will be added in future. However, simulation of the traffic offloading method is not supported in the current version.

Most of these LTE simulators are designed for evaluating the performance of communication system in normal situations. However, an emergency communication system must provide steady and reliable services. Limited communication resources and traffic congestion are the critical issues. To satisfy the demands of a rescue operation, the design and development of the simulator should incorporate these issues. Moreover, the relief workers will keep moving in order to search for and to rescue victims in the DA. Simulation of user mobility is therefore a key function to incorporate into relief worker activity. The uplink and downlink transmission are the basic data transmission types to evaluate delay and probable congestion problem. Based on these considerations, the suitable simulator for an emergency communication system should be one that is designed to be specifically disaster-oriented.

IV. FUNCTION DISCUSSION FOR DISASTER RELIEF

Most of LTE simulators have been developed to provide performance analysis, resource block allocation, frequency reuse techniques, scheduling strategies, etc. However, the suitable simulator for an emergency communication system should have a disaster-oriented design that considers relief worker mobility, demand for services, bandwidth aggregation, handover and suitable scheduler. Especially, the backhaul networks with large propagation delay should be taken into account of disaster-oriented design. Moreover, the simulator is designed to meet the LTE standard where possible. To satisfy disaster relief operations, our study discusses the following critical functionalities. Under the applicability of aforementioned simulators in the disaster scenario, some comparisons of LTE simulators is shown in Tab. 1. Some basic function follows the LTE standard, but few functions are suitable for rescue operation. For example, the traffic offloading mechanisms almost are not taken into account because the backhaul network problem for emergency communication is ignored. Without these critical functions, emergency communication would be lack of reliability. Therefore, disaster-oriented functionalities should be discussed by emergency disaster-resilient network condition including the RAN, backhaul network and CN.

A. Disaster-oriented Network Management

This functionality is mainly intended to create the network topology. The emergency network should consider the RAN, backhaul and CN composition. For example, a set of cells and network nodes, such as UEs, eNBs and MMEs/SGWs, would be deployed in the scenario of a disaster. A single cell is identified as the unique identifier (ID) in order to determine radius and position. The MMEs/SGWs manage eNBs and UEs. The UEs act as relief workers, FCP commander, victims, etc. Moreover, the LTE protocol stacks, especially in the IP, TCP and UDP protocols, should be developed to simulate the transmission of various data types (i.e. text, image, video, voice, etc.) between RAN and EPC. The network topology and transmission of various data would cause additional delay time. This is an important factor for emergency communication capacity.

B. Mobility/User Management

This functionality has the capability to simulate the mobility of relief workers, and the handover procedure. The mobility of relief workers means that they wear UEs and move anywhere to search for and to rescue victims. The designed functionality is intended to simulate the movement of relief workers. The design of mobility models could support random walks and random directions in order to simulate real rescue operations. The application of random walks is to model the fact that relief workers can search in any place to rescue victims waiting for help. The application of random directions reflects the way that relief workers are affected by the limitations of topography to change their direction in order to search for victims. The requirement for a handover procedure comes from the fact that, if the DA is too large for the VeNB to provide communication services effectively, more than two VeNBs are required to support rescue operations. Hence a handover procedure becomes necessary for efficient resource scheduling.

C. Radio Resource Management

This functionality is mainly to simulate radio access between UEs and eNBs. The radio access should consider channel conditions, bandwidth management, eNB scheduling, Radio Access Technologies (RAT), etc. In a disaster environment, wireless transmission faces serious issues such as large-scale, small-scale fading and environment noise. The channel structure should be designed with those effects in mind. In addition, the uplink and downlink channel structures are necessary to simulate data transmission. Bandwidth management is used for UEs to determine the operative bandwidth and the available sub-channel. The eNBs should schedule the radio resources according to the Channel Quality Indicator (CQI) values reported the channel condition by UEs. There are generally some downlink scheduling algorithms such as generally Proportional Fair (PF), Modified Largest Weighted Delay First (M-LWDF), and Exponential Proportional Fair (EXP).

Table 1
Comparison of Simulator Functionalities

Simulators / Functionalities	MATLAB-based [12]	LTE-sim [13]	ns3-LTE [14]	SimuLTE [15]
Mobility/ User Management	NO	YES	YES	YES
Radio Resource Management	The lack of uplink channel structure	YES	YES	YES
Disaster-oriented Network Management	The lack of complete LTE protocol stack	The lack of TCP protocol	YES	YES
Disaster-oriented Flow Management	NO	The lack of traffic offloading mechanisms	The lack of traffic offloading mechanisms	The lack of traffic offloading mechanisms
Modeling Framework	MATLAB	Static C++	ns-3	OMNeT++

However, not all of scheduling strategies are suited for the disaster scenario. The fairness of radio resource need careful consideration. Radio access should be based on Orthogonal Frequency Division Multiplexing Access (OFDMA). The access technologies can provide both Frequency Division Duplex (FDD) and Time-division Duplex (TDD) methods. Such radio access, when combined with the HARO process, is sufficient to meet LTE standards.

D. Disaster-oriented Flow Management

This functionality is mainly to simulate LTE bearers, network traffic generators, and traffic offloading mechanisms. LTE bearers are generally of two different kinds in the simulation. One is the Evolved Packet System (EPS) bearer used between UE and EPC, and the other is the radio bearer used between UE and eNB. Depending on different QoS requirements, the EPS and radio bearers can be classified as either Guaranteed Bit Rate (GBR) or Non-Guaranteed Bit Rate (non-GBR). Moreover, a network traffic generator is used to produce data packets. Certain application models, such as trace-based, VoIP, CBR, and infinite buffer would be supported. However, the regular data transmission path would go through every network node and LTE element. As such, all the communication resources would be consumed, especially in constructing COP. The problems of limited communication resources and traffic congestion could be improved by use of a traffic offloading mechanism. Traffic offloading technologies, such as LIPA, SIPTO and D2D, have been identified by 3GPP as the key solution to cope with this challenge. The simulation of traffic offloading methods is the critical functionality needed to improve radio resource usage in LTE communication systems.

E. Modeling Framework

The purpose of the modeling framework is to ensure easy operation of the simulator. An LTE system has complex features and functions, and needs to be modular in order to reduce the complexity of implementation. The modeling framework is related to the platform, software, tools and programming language that are used. It requires the use of stable, easy to use, and special maintenance tools to develop the simulator.

V. Evaluation Result

After function discussion on the requirement of disaster relief, traffic offloading mechanisms is a critical function for emergency communication simulator. In this paper, we have an initial evaluation of offloading scheme-LIPA in simulation. The simulation parameters setting are given in Tab. 2.

Table 2
Simulation Parameters

Parameter	Value
Number of VeNBs	1
Number of Survived BSs	6
Number of UEs	10
Cell Radius	500 m
System Bandwidth	10M Hz
Scheduling Algorithm	Round Robin
eNB/UE Power Gain	46/23 dBm
eNB/UE Antenna Gain	14/0 dB
Standard Deviation of Shadow	8 dB
Channel Fading	Rayleigh Fading

The performance of traffic offloading technologies is shown in Figure 3. The temporal data transmission results are compared between conventional network and LIPA in different backhaul capacity. When the disaster happened, the network condition became worse and could not keep stable. Even if 15 hours later, the network condition could still be worse because high demands of disaster information were accessed on the web. The network condition would decrease the backhaul capacity visibly. Then, we assume different backhaul capacity in our simulation. The scheme-LIPA transmissions present better performance of delay time than conventional transmissions. It is because that conventional transmissions must travel through the worse condition network such as backhaul and CN. Traffic offloading technologies such as LIPA can redirect the traffic flow without traveling through unnecessary network elements. The performance of LIPA shows that the delay time is not significantly increased during the traffic congestion. Therefore, how to avoid the backhaul and CN congestion in the disaster scenario is an important factor.

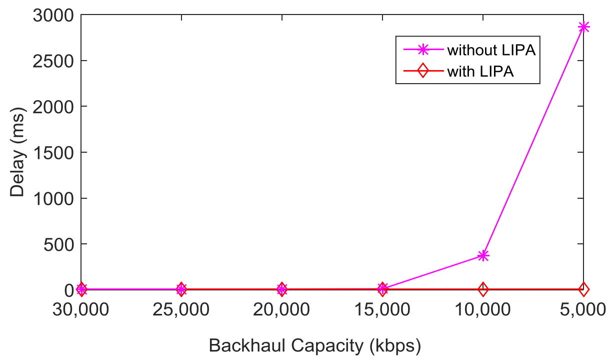

Figure 3: The performance of traffic offloading technology

VI. Conclusion and Future Work

An unpredictable disaster may well cause large and equally unpredictable loss of life and property. Time is the valuable resource in such situations. The purpose of an LTE simulator for emergency communication is to allow disaster relief teams to evaluate whether or not their communication resources are fit for rescue operations. The simulation results could verify the stability and reliability of emergency communication so that disaster relief teams can search and rescue efficiently. The most important thing is to rescue more lives. However, most functions of simulator are lack of traffic offloading mechanisms. In the future, we will follow these critical functionality discussions of disaster-orient demands to develop the suitable simulator for emergency communication. The simulator combining traffic offloading technology can avoid traffic congestion problems and improve the use of radio resources, especially in unpredictable environments. Moreover, the simulator could be used for future emergency-response exercises.

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