On the Use of Nomadic Relaying for Emergency Telemedicine Services in Indoor Environments

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Abstract. The need for high-quality on-the-spot emergency care necessitates access to reliable broadband connectivity for emergency telemedicine services used by paramedics in the field. In a significant proportion of recorded cases, these medical emergencies would tend to occur in indoor locations. However,broadband wireless connectivity may be of low quality due to poor indoor coverage of macro-cellular public mobile networks, or may be unreliable and/or inaccessible in the case of private Wi-Fi networks. To that end, relaying is emerging as one of promising radio access network techniques that provide coverage gain with improved quality of service. This paper analyzes the use of nomadic relays that could be temporarily deployed close to a building as part of the medical emergency response. The objective is to provide improved indoor coverage for paramedics located within the building for enhanced downlink performance (throughput gain, lower outage probability). For that scenario, we propose a resource sharing algorithm based on static relay link with exclusive assigned subframes at the macro base station (MBS) coupled with access link prioritization for paramedic's terminals to achieve max-min fairness. Via comprehensive system-level simulations, incorporating standard urban propagation models, the results indicate that paramedics are always able to obtain improved performance when connected via the relay enhanced cell (REC) networks rather than the MBS only.

Keywords: Emergency Telemedicine, Relay Node, Relay Enhanced Cell, Indoor Coverage, Long-Term Evolution, Outage Probability.

1 Introduction

Emergency telemedicine is the usage of telecommunication technologies by Emergency Medical Services (EMS) providers (hospitals,paramedics,etc) so as to ensure a rapid and coordinated medical care to patients at emergency sites [1, 2]. This typically enables emergency use cases, such as, setting up a communications link to provide field paramedics with expert opinion from physicians at a hospital or trauma center, thus enabling better-informed diagnosis or medical interventions by the EMS responder. Or then, a high-speed link may enabling sharing of large amounts of patient measurements or images prior to transfer to relevant trauma center.

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Contemporary modern communication technologies, especially the wireless technologies (e.g modern wireless,Wireless Local Area Network or WLAN,satellite,etc) improves the intra- and inter-organization (hospitals,fire brigade,police station,etc) collaborations in emergency or disaster management [2, 3]. Furthermore, the continued developments in mobile broadband networks are now opening new possibilities in emergency telemedicine for exchange of diagnostic-quality digital medical images (e.g. ultrasound scans) and high-resolution interactive or streaming video from emergency sites [3]. Nevertheless, these broadband mobile network technologies also inherit some network limitations(resources scarcity,link throughput,etc), particularly in indoor environments, where the distant outdoor MBS yields poor radio links with low SINR levels (Signal-to-Interference-and-Noise-Ratio) due to in-building penetration loss and distant-dependent path losses [4, 5]. This will in-turn leads to less than optimum quality of service (e.g. reduced link throughput) which may prove to be unreliable for emergency telemedicine applications, particularly for indoor environments where most medical emergencies have been noted to frequently occur [6].

Relaying is emerging as one of the promising radio access techniques for providing coverage gain and improved quality of service in cell edge and/or indoor environments [4, 11–17]. This paper aims to show the relaying benefits (one being the improved throughput in indoor environment) in a REC network from the perspective of the indoor emergency telemedicine use case. To that end, we perform a comparative study of the REC network performance (in terms of throughput and outage probability) against that of the conventional macrocellular connectivity used in existing mobile networks. In the remaining part of the paper, Section 2 presents the comparative analysis of communication technologies and potential benefits in indoor emergency telemedicine use case scenarios, while Section 3 outlines the system model considered for this study. Simulation methodology and results with conclusive remarks are provided in Sections 4 & 5 respectively.

2 Nomadic Relaying for Emergency Telemedicine Services

A number of wireless networking technologies are considered for use to support indoor emergency telemedicine services [3]. Private WLANs are one of the most common means for subscribers to provide broadband wireless extensions to their residential fixed access lines. However, these WLANs may expose patient data on poorly secured open networks or may be inaccessible to EMS responders due to access controls settings by the WLAN access point (AP) owner. Moreover, lack of centralized management of private APs means that guarantee of services (through admission control, traffic flow prioritization etc.) cannot be provided for emergency telemedicine users [6].

The shortcomings when sharing the commercial networks has prompted the deployment of dedicated *Professional Mobile Radio* (PMR) systems launched, in order to enable a reliable network coverage for the emergency responders (e.g, Terrestrial Trunked Radio (TETRA), Association of Public Safety Communications Officials International Project(APCO-25)) [7]. However, these PMR networks are typically narrowband systems which lack capabilities to support the advanced multimedia emergency telemedicine applications. Broadband satellite communications provides

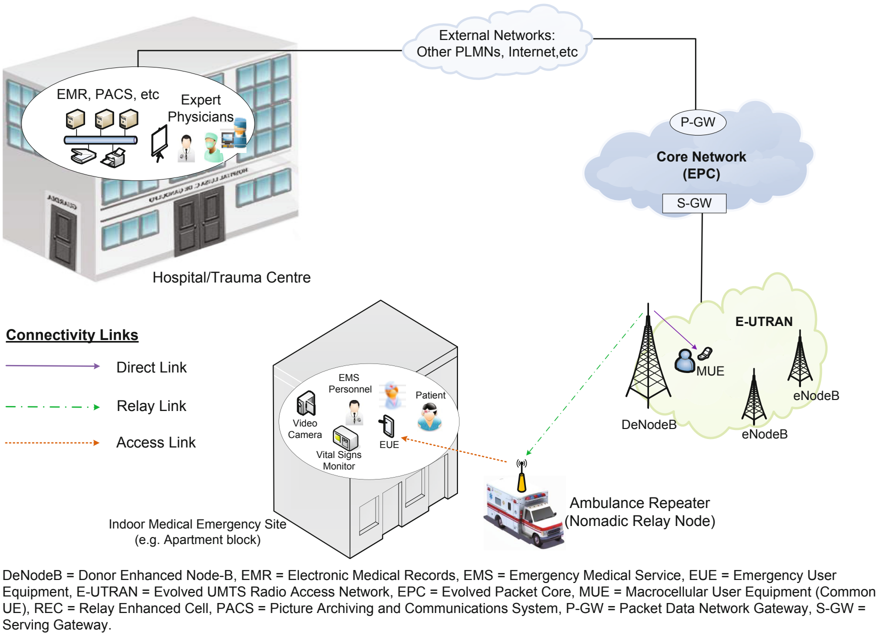

Fig. 1. Usage of a nomadic relay node to provide improved coverage in indoor emergency areas

another alternative. However, the satellite terminals cannot be used for high data rate indoor service provision due to bulky terminals, stringent line-of-sight requirements and high latency [3, 6, 8]. As a result mobile broadband networks (and evolutions beyond 3G) provide arguably the most attractive option for emergency telemedicine use cases [3, 8]. This is also previously noted in various experimental telemedicine studies or practical implementations in third generation (3G) mobile networking environments [9, 10]. However, these networks employ conventional macrocell deployment for providing coverage in a wide-area. Yet, in many cases they also admit some difficulties for enabling improved services with guaranteed QoS in indoor environments [4].

To that end, multi-hop relaying emerges as a promising deployment scenario, provides an improved network performance gains in the existing macro-overlaid networks. Relay node (RN) being a low-power base station, can be considered as an intermediate access point between User Equipment (UE) and 3GPP Long Term Evolution Advanced (LTE) compliant macro base station, known as Donor Evolved Node B (DeNB) [11]. Likewise, nomadic relaying being semi-static in nature, allows temporary RN deployment in emergency areas, even providing additional indoor coverage [12].

Figure 1 presents a schematic end-to-end overview of relay enhanced cellular (REC) network for emergency telemedicine scenario, comprises a two-hop nomadic RN (N-RN) deployed within the macro-overlaid network. From the network operator perspective, all the emergency telemedicine devices (tablet PC,Smartphone,etc.) would be consider as a UE providing broadband access to the mobile network. The mobile core network can be accessed by EMS responders, either via the DeNB direct link or alternatively, via the two-hop relaying where the UE-RN transmissions are facilitated by the Access link while the RN-DeNB transmission is done via a wireless Relay link.

Yet the relaying benefits being explored from the mobile operator-subscriber aspect,however, their feasibility for public safety need to be examine. Below are few two-hop relaying benefits justifying the relay usage in emergency telemedicine scenarios.

- Enabling high spectral efficiency with improved network coverage and throughput at dead spot (due to shadowing) or at cell edge (poor eNB coverage) [13, 14].
- With low capital/operational cost (CAPEX/OPEX) and low power constraints, the benefits might probably be the elimination of the cost barrier in making RNs available in large volumes and ease of operation (e.g. in terms of powering requirements) [15].
- Wireless relay link with no line of sight (LOS) requirements, enabling flexible RN deployment options to provide improved coverage for EMS responders from relay-deployed-ambulance near to patients located within indoor environments [15].
- Decode-and-forward (DF) relaying though increases the system complexity, intended to provide a noiseless signal transmission via a two-hop link in urban environments (where the signals certainly experience multipath fadings) [16].
- A multimode relaying directly route the user data to mobile operator core network via internet via wired and/or wireless link. Thus, incorporates a diversity to emergency telemedicine, in case of macrocellular network being unavailable or destroyed [17].

3 System Model

A LTE-Advanced compliant RN has been proposed to use for the considered emergency communication scenario. The adopted relay operates with the type 1 inband configuration, where the relay and access link transmissions are time-division multiplexed and operate at the same carrier frequency. Moreover, the relay link can coexist with direct link, sharing the same frequency spectrum with DeNB users, enabling a full frequency reuse [11]. Consequently, the REC network performance depends on a resource partitioning strategy between the relay and direct links, along with an effective scheduling technique to allocate relay resources on the access link. Orthogonal Frequency Division Multiple Access (OFDMA) is employed as a radio interface for LTE-Advanced DL transmission, splitting the system bandwidth into narrow orthogonal subcarriers each with 15 kHz spectrum bandwidth. Furthermore, in 3GPP LTE-Advanced, a physical layer radio frame composed of 10 subframes, has a total duration of 10 msec. Each subframe comprises two consecutive 0.5 msec time slot. Hence, twelve consecutive orthogonal subcarriers are aggregated into physical resource block (PRB), which comprises a total bandwidth of 180 kHz and 0.5 msec duration. The PRB is used as a basic resource element for assigning the network resources to UE by a 3GPP eNB scheduler.

In the downlink, an inband RN quits transmission towards UEs on access link, while during the reception from DeNB via relay link, however, an RN needs to enable a backward compatibility towards Rel-8 UEs by sending cell-specific reference and control signals in all DL subframes. Hence, it facilitates the configuration of Multi-Media Broadcast over Single Frequency Network (MBSFN) subframes in DL, allowing the RN to inform the Rel-8 UEs, not to expect transmission from RN, by sending control signals in the first OFDM symbols of a blank subframe [18]. In this study, three subframes has been reserved as the MBSFN subframes for DL relay link transmissions at the DeNB side. In remaining seven subframes, a simultaneous transmission of eNB and RN enabled on direct and access link respectively, creates an interference to neighbouring cells. Moreover, all the eNB interference towards RN, are avoided, as all the cells use the same frame format. To that end, a Max-Min Fairness (MMF) scheduling technique is used to distribute the network resources at eNB on direct link as well as at RN with relay link constraint. From cellular system perspective, this algorithm aims to maximize the minimum user throughput by allocating more network resources to UEs with low Signal-to-Interference-and-Noise-Ratio (SINR), with a condition that all UEs obtain same throughput level. The UE throughput is calculated for given SINR level as follows [19];

$$TP_{user} = BW_{PRB}.BW_{eff}.\log_2\left(1+\left(\frac{SINR}{SINR_{eff}}\right)\right) \tag{1}$$

where (1) represents a modified version of Shannon's capacity formula with parameters known as the bandwidth efficiency (BW_{eff}) and SINR efficiency $(SINR_{eff})$ with values of 0.88 and 1.25 respectively. They presents the performance loss to the network implementation and signal processing losses, while (BW_{PRB}) is bandwidth of one PRB (valued 180 kHz). The COST231-Walfisch-Ikegami (WI), path loss model is adopted in the simulations, which models both indoor and outdoor radio propagations [5]. The selected channel model accounts for distance-dependent path loss, shadowing as well as indoor penetration loss. To estimate the indoor losses, external and internal walls penetration losses has been explicitly modelled in line with COST 231 report [5].

4 Methodology and Results

The simulated network consists of seven hexagonal cellular eNB sites each possess three sectorized RF antennas to provide coverage to three sectors. Furthermore, it is assumed that there are 10 UEs randomly located in each sector. A $5 * 5$ grid layout residential building is assumed in central sector at two locations,i.e. cell center and cell edge. The building includes eight EMS responders (each with one emergency UE or EUE) scattered in random locations within the building. A vehicular nomadic RN is located 50 meter away from the building and provides indoor coverage. In simulations, we assumed downlink scenario with 3GPP use case 1 (Urban)and Inter-Site Distance (ISD) of 500m. It represents the typical case, where indoor emergency incident could occur. The baseline scenario with eNB only deployment is used as a reference.

Table 1 enlists the system parameters used in simulation. Via comprehensive system level simulations, a comparative study of eNB only and REC networks performance is carried out, in terms of cumulative distribution function (CDF) of indoor EUE data rates. Moreover, we also examine the impact of RN transmission on the performance

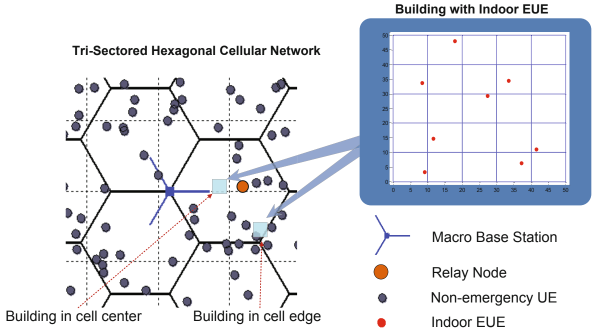

Fig. 2. Relay enhanced cellular (REC) network

Table 1. Simulation parameters

Parameters	**Value**
DeNB Parameters	
Carrier Frequency	800 MHz
Transmission Bandwidth	10 MHz,48 PRBs for data & 2 PRB for signalling
eNB Transmit Power	46 dBm
eNB Elevation Gain	14 dBi
eNB Antenna Pattern	$A(\theta)$ = - min $\left[12\left(\frac{\theta}{\theta_{3dB}}\right)^2, A_m\right]$ $\theta_{3dB} = 70^\circ$ and A_m = 25 dB
RN Parameters	
RN Transmit Power	30 dBm
RN Antenna Pattern	Omni-directional
RN-eNB Elevation Gain	7 dBi
UE Parameters	
UE Transmit Power (Maximum)	23 dBm
UE Received Diversity Gain	3 dBi

of non-emergency UEs of only those eNBs, which are serving the indoor EUE. Figure 3 indicates the simulations carried out for cell center and cell edge with UE performance constraint of 2 Mbps. Figure 3 (left) shows that the REC network outperforms the eNB only deployment, with almost 70% indoor EUEs in cell center case and 77% indoor EUEs in cell edge case, achieve a data rate of higher then 6 Mbps (i.e. from mid to high data rate levels). This gain is due to the fact that indoor EUE receive good enhanced signal quality from RN as well as experience less competition for radio resources. However, in addition to performance constraint of 2 Mbps, the high power eNB creates interference towards the indoor EUEs, resulting a 2% outage in the cell center scenario, which is negligible for the cell edge scenario where the eNB interference decays over the long distance. Similarly, figure 3 (right) shows the CDF plots for outdoor non-emergency UE data rates. The results demonstrate the deterioration impact of RN deployment on the performance of outdoor non-emergency UEs, due to the RN

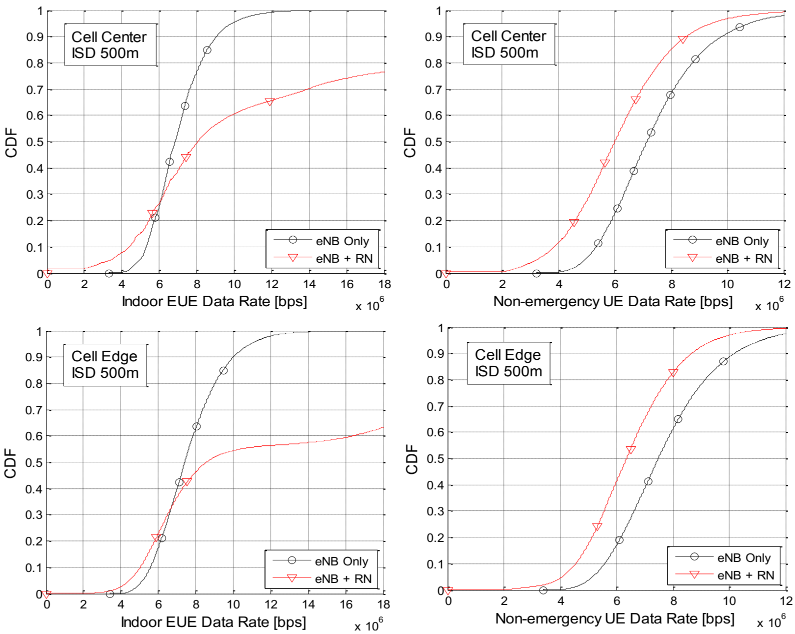

Fig. 3. CDFs of indoor EUE (left) and non-emergency UE (right) data rates

interference power. However, this degradation is insignificant as compared to the indoor coverage provided in emergency events.

5 Conclusion and Future Work

This paper investigated the benefits of improved indoor coverages enabled by REC network deployments in emergency telemedicine scenarios. Moreover, this paper outlined the architectural implementation of REC network as well as yields a comparative analysis of RN deployment to legacy eNB only networks in 3GPP downlink urban scenario. Simulation results show that indoor coverage has been significantly improved in relay-based system , with only insignificant performance degradation for outdoor non-emergency UEs.

In future work, we will investigate the performance of multiple un-coordinated REC used by various PMR organizations. These RNs coexist and operate in the same frequency band , compete for the available radio resources at eNB. Hence, a scheduling mechanism with pre-defined requirement will be needed for optimal RN operations.

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