Multi-Hop Relays for LTE Public Safety Network

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***Abstract* — Reliable and efficient communication is crucial to safety, as well as in situations involving disasters or emergencies. These situations make it particularly important that communication systems are fully operational. Given the shortcomings of public safety networks in cases of disaster, the 3GPP long term evolution (LTE) network has received a great deal of attention as a broadband access alternative for emergency situations. In this paper, we present the results of a performance evaluation using a multi-hop relay network (MRN) in the context of emergency and public safety communications. To overcome the current limitations of LTE networks and meet all public safety requirements, we propose an LTE-MRN interworking scheme that can achieve significantly better performance than the existing professional mobile radio systems, such as TETRA, APCO25, and DMR, in terms of throughput, packet loss rate, and delay.**

Keywords — LTE/LTE-A, Fixed and Mobile Relays, Multi-Hop Relays, Public Safety Network

I. INTRODUCTION

Long term evolution (LTE) is widely deployed as the global mobile broadband standard, while current public safety networks (PSN) suffer from slow data transfers. Given this, LTE technology is becoming a popular choice for broadband public safety communication systems [1]. The main advantage of using LTE for public safety is in performance, in terms of capacity and reliability, which fulfills the strict requirements of PSN users. In disaster events, communication is essential to recovery.

The current 3GPP LTE network is a network-based cell concentrator using a core network (CN) as its backbone, which provides connectivity to external services such as the Internet, email, and video streaming. There is no direct connection between any two user equipment (UEs), and even those under the coverage of a single base station or evolved NodeB (eNB) pass through the CN in uplink and downlink directions that require the double allocation of resources in air and backhauling networks, and thus cause extra delays. This architecture model is sufficient for commercial deployment when fixed infrastructures are available and no crises or emergency situations occur. However, it is clearly unsuitable if one or more entities of fixed infrastructures (eNodeBs or CNs) are not available. The main challenge when network infrastructures are not available is to enable mobile nodes to communicate directly or via other nodes that act as relays. Given this, it is interesting to investigate the impact of relay networks on enhancing the performance of LTE public safety networks. In fact, multi-hop communication via fixed and mobile relays has received research attention in existing literature [2], [3], [4] as part of LTE-advanced (LTE-A) network. This new approach could enable direct communication between UEs, using the cellular spectrum, which could allow large amounts of data (e.g. multimedia) to be transferred from one UE to another over relay nodes (RNs), as shown in Figure 1, below.

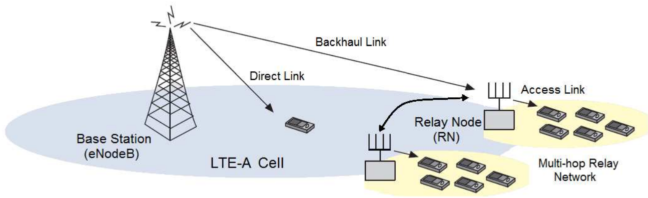

Fig. 1. LTE-MRN interworking systems

The objective of this paper is to propose an interworking strategy for LTE-MRN in order to overcome public safety challenges. The proposed solution, based on mobile and multi-hop relaying features, enables the system to operate in standalone mode without any central management or fixed infrastructures. The remainder of this paper is organized as follows. Section II describes the system model considered, while Section III describes the simulation model. Results and discussion are described in Section IV, with conclusion presented in Section V.

II. SYSTEM MODEL

The system model adopted in this work is depicted in Figure 2. The design consists of a number of PSN users, such as policemen or firemen, and relay nodes in the range of three LTE eNBs. The users and central command center can communicate with regard to content of common interest, such as files, maps, or live video from disaster areas (Cell B). In this paper, the benefits of multi-hop communication via fixed or mobile relays are presented, in terms of enhancing the uplink and downlink operation of public safety users, particularly in ensuring low levels of packet loss and delay and improving data throughput. Through the uplink, PSN users send real-time and non-real-time information to a central command center, which gathers all of the received information from the different users. The specialized personnel at the center process the data, and then send back the processed information through the downlink to the various public safety users in order to take appropriate action. For example, images and videos captured by a team in a certain zone of a disaster area can be shared with a team in another zone.

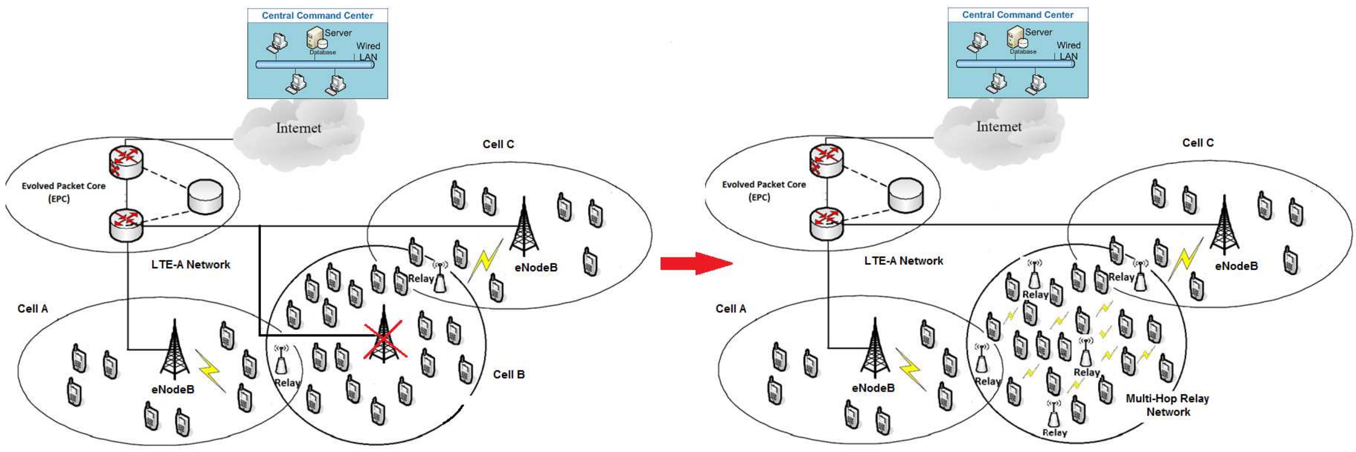

Fig. 2. System model in emergency situation

A. *Fixed and Mobile Relay*

Relaying is considered to be one of the key functionalities for 3GPP LTE-A networks, improving cell-edge user throughput, reducing network deployment time, and extending coverage to new areas [5]. Through relaying, the UE communicates with the network via a relay node that is wirelessly connected to a macro cell, by using LTE radio interface technology [2]. The eNB may serve one or several relays, in addition to directly serving UEs [2]. In a 3GPP relaying solution [3], the relay node will appear to UEs as an ordinary cell, whereas to the eNB, it will appear as a UE with special capabilities. The terms "backhaul" and "access link" are often used to refer to eNB-RN connections and RN-UE (user equipment) connections, respectively, while "direct link" corresponds to traditional eNB-UE connections.

The donor-relay link may operate on the same frequency as the relay-terminal link (inband relaying) or on a different frequency (outband relaying) [2]. Relay stations can be classified into fixed and mobile relay stations, according to their mobility [2]. Fixed relay stations are usually used to cover hot spots and increase cell edge throughput. Fixed RNs can be easily mounted on towers, poles, tops of buildings, or lampposts. A relay system can be made mobile to allow temporary RN deployment, or in order to provide additional coverage and capacity in areas where the macro base station (eNB) or fixed RN provides bad coverage or experiences network congestion. The best example may be in the case of emergency/disaster recovery, where rescue authorities experience network congestion problems due to excessive number of calls made by affected individuals in an emergency area. Mobile RNs are normally equipped with batteries on which to operate. Energy consumption is of the utmost importance, especially if PSN users need to operate in an emergency area for a long time and continuously communicate information during a disaster recovery period. These RNs may also have physical structure limitations involving weight, size, and power usage, unlike fixed RNs [6, 7]. In the remainder of this article, we use RNs to mean both fixed and mobile stations.

B. *Multi-Hop Relay*

Multi-hop wireless networking has traditionally been considered in the context of ad-hoc and peer-to-peer networks. However, extensive research on multi-hop cellular networks has been carried out over the last few years under the guise of relay networks. Multi-hop relaying is a relaying technology considered appealing in relay networks, in which RNs communicate with each other either directly or via a relay [8]. This relaying functionality can be realized either via a fixed relay or mobile relay, depending on the application scenario. In the public safety scenario, a multi-hop relay can be used to serve a disaster area together with fixed and mobile relays, in order to form a mesh network [8].

III. SIMULATION

A. *Model Description*

The performance of the proposed LTE-MRN scheme has been evaluated with a scenario involving three eNBs (failure occurs in eNB_B during simulation) and 20 RNs. The simulated environment was outdoors, with UE and RN in the mobility model displaced randomly at a fixed speed of 0.5 and 2 meters per second, respectively. Figure 3 shows the LTE-A network with multi-hop RNs.

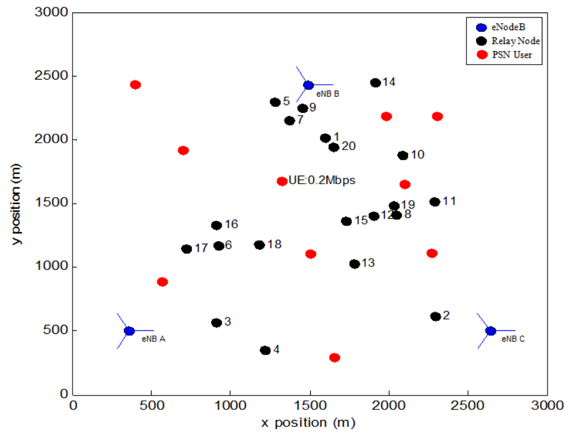

Fig. 3. Network simulation model

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B. *Propagation Model*

The propagation model used is for an outdoor zone with path loss model:

$$\text{Path loss} = 32.4 + 20 \log (F) + 20\log (D) \quad (1)$$

With F denoting the frequency (Mhz), and D the distance between the terminal and eNB/RN (Km).

The LTE and MRN network simulation parameters are presented in Table 1.

Table 1. LTE and MRN network parameters

Parameters	LTE eNodeB	LTE Relay Node
Transmission power	43dBm	30 dBm
Transmission gain	20 dB	2 dB
Reception gain	2 dB	2 dB
Frequency	2.2Ghz	2.4Ghz
Supplementary attenuation	20dB	20 dB
Sensibility	-100 dBm	-100 dBm
Bandwidth	10 MHz	5 MHz

C. *Traffic Model*

The traffic model used was either of the non-real time or real time type, as characterized by parameters in Table 2.

Table 2. Video application parameters

Parameters	Values
Video flow	1 Mbps
Maximum delay tolerated	150 ms
Video packets per second	25Pps
Acceptable maximum packet lost	10%

IV. Results and Discussion

The performance of LTE-MRN has been compared to LTE and LTE single-hop relay networks (LTE-SRNs) in a public safety scenario. In the simulations involved, throughput, packet loss, and delays were the metrics calculated to help verify the studied scheme's performance.

A. *Throughput for Non-Real-Time Traffic*

Figure 4 shows the UE throughput cumulative distribution function (CDF) for LTE, LTE-SRN, and LTE-MRN.

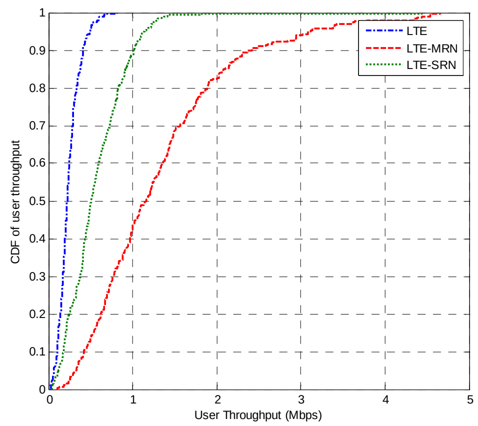

Fig. 4. UE throughput distribution

In the previous graphs, the LTE-MRN performance is clearly shown to be better than that of LTE and LTE-SRN. Hence, under the same network conditions, the LTE-MRN can reach higher throughputs than both LTE and LTE-SRN.

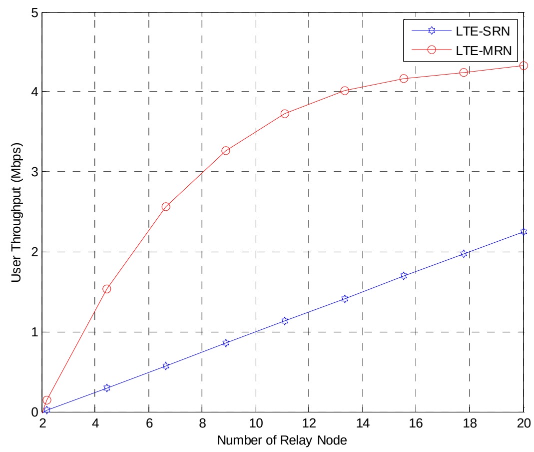

Fig. 5. Total throughput per RN concentration

Figure 5 shows how the received throughput is affected by the number of RNs for both LTE-MRN and LTE-SRN.

B. *Packet Loss for Real-Time Traffic*

Figure 6 depicts comparative packet loss performances for LTE, LTE-SRN, and LTE-MRN.

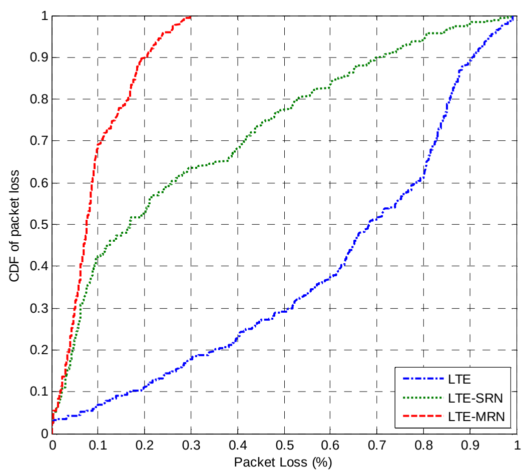

Fig. 6. UE Packet loss distribution

It can be seen from this figure that the packet loss rates of LTE and LTE-SRN tend to be similar, and that packet loss is high compared to LTE-MRN, which clearly minimizes loss by generating high throughput, with respect to the required throughput.

Figure 7 shows how packet loss can be reduced by increasing RNs in the LTE-MRN and LTE-SRN.

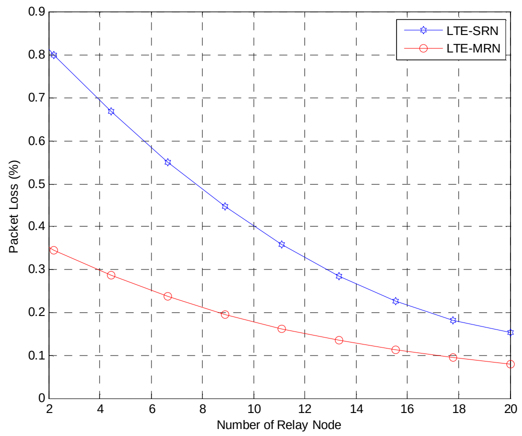

Fig. 7. UE Packet loss per RN concentration

C. *Delays in Real-Time Traffic*

Figure 8 shows the delays that occur when users move around a network with different levels of RN concentration. It can be seen that the increment in RNs introduces delay, since it creates more hops between source and destination nodes.

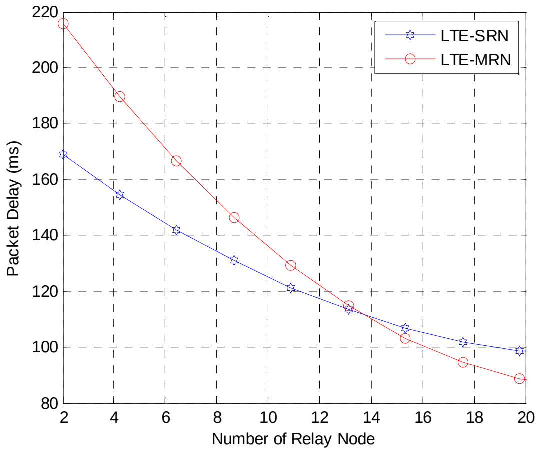

Fig. 8. Delay per RN concentration

From these overall results, it is clear that the LTE-MRN offers better performance than both LTE and LTE-SRN in public safety situations. This is because it takes into consideration the cooperation between RNs, along with a mechanism for operating in standalone mode, without a need for fixed infrastructures.

V. CONCLUSION

Relaying provides an attractive means of coverage extension and throughput enhancement. 3GPP has already started supporting single-hop relay nodes in LTE-A networks (Rel. 10 & 11). In this paper, we present a multi-hop relay scheme for an LTE public safety network. Its performance is evaluated in terms of throughput, packet loss and delay. We show that better performance can be achieved by supporting multi-hop RN functionality. We also find that LTE-MRN performs well in different RN concentrations and mobility scenarios. A recommended further study could involve the development of an adapted scheduler, as a radio resource management solution that would tackle the issue of delay in a concentrated RN scenario.

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