Chapter 20

Mobile Broadband Scaling and Enhancement for Fast Moving Trains

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Additional information is available at the end of the chapter

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Abstract

Internet is an important part of our life, whether traveling or at home. The broadband services available at home are reliable and are usually at constant speed. The people traveling especially in fast moving trains are at higher mobility and may be moving in areas of less connectivity, and providing a reliable service to them is a challenging task. One possible solution to this is to provide communication through an on-board Wi-Fi, which takes services from a central Wi-Fi situated in the middle of the train, which is connected to cellular radio service long-term evolution for railways. The network consists of LTE-R which is dedicated for railway communication only, a public mobile network, which supports LTE-R in the areas of no coverage and high traffic conditions and a public safety network in emergency conditions. The work is verified with the help of simulations on MATLAB, considering different traffic scenarios. The BSs placed at a distance of 2.5 Km and antenna height used is 45 m are equipped with 3G and 4G interfaces, a universal mobile telecommunications services (UMTS) and radio access network (RAN). The UMTS interface is used for voice services and handover when spectrum available in the next cell is less.

Keywords: RAN, LTE-R, GSM-R, UMTS, access schemes, high-speed trains

1. Introduction

The internet is an inseparable technology from our day to day life. Certain countries are working on deploying LTE-R specially dedicated for railway communications. The Republic of Korea has brought into place the national disaster safety network since 2015, which costs over $1.6 billion and is established in 700 MHz frequency band [1]. The LTE-R network also works in the same frequency band. However, the global system for mobile-railway (GSM-R) is the most widely used communication standard, especially in Europe. The GSM-R is employed for more than 10 years as a stable integrated wireless communication technique. With the emerging technology, the rate requirement of the calls arrive in the network also increased, GSM-R is not able to meet the service requirements both in terms of capacity and speed. The LTE-R emerged as a solution to meet the demand generated, it provides benefit related to connectivity and also increases performance [2]. The public safety network mainly used by fire-fighters, police, rescue team, medical emergency, etc., and sometimes railway network also uses it for communications related to controlling of the train and its crew. For the reliable and secure functionality of railway communication, a dedicated and fast communication network is required and LTE-R provides a dedicated and reliable frequency band. The on-board passengers also require high rate data services, which is also a challenging task. For the efficient utilization of this available frequency band, research needs to be done to lay down assignment schemes which can use it optimally.

2. Related work

The work in the literature on the LTE-R communication technology is related to modeling of channels with a layout of LTE-R network [3–5]. In [6], coexistence of railway and public safety network is considered; it poses challenges like co-channel interference and priority of services. In the literature, techniques have been proposed to reduce the co-channel interference together with interference alignment and channel diagonalization. One proposed in [7] uses coordinated multipoint (CoMP) by utilizing a two-step precoder in presence of a multi-user CoMP. The paper in [8, 9] proposes schemes related to power control and interference management in 3rd Generation partnership project (3GPP). For all the schemes proposed [6–9], in order to achieve benefits in form of better quality of service (QoS), fairness in assignment and load balancing a complex feedback mechanism is required to provide channel state information (CSI) additionally. The work in [6] employed enhanced inter-cell interference cancelation (eICIC) and further eICIC (FeICIC) in presence of coordinated scheduling (CS) CoMP under the RAN sharing case for offloading more public safety users to the railway network. However, CS CoMP is utilized for the LTE-R eNodeBs. In [10], a dynamic ICIC along with CS CoMP is employed in order to perform interference management for both public safety and railway networks existing together. The paper considers a CS CoMP between public safety (PS) LTE and LTE-R eNodeBs, public safety LTE eNodeBs, and LTE-R eNodeBs. The radio resource assignment management is investigated like a resource sharing scheme which is ware of interference in [11], a joint scheduling mechanism in [12], and a game-based resource allocation in [13]. These schemes optimized system efficiency and throughput by using resource assignment independently. The assignment schemes algorithm did not provide priority to any type of calls and no consideration for mission-critical services (MCS) of a user.

The literature also contains research papers which work on LTE-MIMO performance improvement when using antenna arrays; the work is very limited for their employment for railway communication in [14]. The high-speed railway's unique property [15] is the presence of the line of sight (LOS) component. Due to the unique characteristics of high-speed railways [16], for instance, the existence of the LOS component and the deficiency of scattering in a series of bridges seriously influence the MIMO performance [17]. The work needs to be done on enhancing characteristics of antenna arrays in order to enhance the LTE-R efficiency [15–17]. The LTE-R in [18], which are LTE specifications for railway communications, they are proposed in order to meet the high-speed train requirements of broadband communication. The handover of calls is a critical issue, which becomes more critical for real-time calls as the probability of handover failure are more in high-speed railway due to high speed. The problem of handover is enhanced due to the existence of only hard handover supports in LTE. The hard handover needs to be taken properly and in time for non-disruption and drop of calls during handover.

The handover decision taken too early and too late both will lead to disruption in calls. In this chapter, the handover is done with the help of a device mounted on the train boggy, and passengers on-board get seamless handover. Also, the paper uses three types of LTE network: the public mobile LTE network, public safety LTE network, and LTE-R network. The LTE-R is used for railway communication services and passengers' on-board services, the public mobile LTE network is used for providing carrier aggregation (CA) [19] and access in areas with no LTE-R services. The public safety LTE-R is used in case of emergency services in areas with no LTE-R coverage.

The rest of the chapter is organized as follows. Section 3 discusses the problem statement and the network parameters used. In Section 4, the proposed work is explained. Simulation and results are given in Section 5. The chapter is concluded in Section 6.

3. Problem statement and network parameters

The LTE-R is a solution of railway communication which is employed to handle voice and data traffic for high-speed trains. Most of the research work in the literature is focused on providing compatibility of LTE-R with previous GSM-R, using public safety LTE networks which can be used for MCSs. The main problem in LTE-R communication is handover and availability. In this chapter, the LTE-R network is used for railway communication which uses public mobile LTE network for providing better services of railway and public safety LTE network in emergency conditions. The LTE system for any type LTE-R, LTE public mobile network, and LTE public safety all contains remote radio heads (RRH) which are connected to eNodeBs which are connected to each other by X.2 line and in the backbone connected to the wireless core network as shown in **Figure 1**. The RRH is used in all the three types of cellular systems. The railway communication system which uses RRH deploy fiber network to send information along the track. The LTE-R, LTE public mobile network, and LTE public safety deployed are equipped with the *eNodeB of two interfaces* UMTS *and* LTE. *The eNodeB provides access to user equipment's (UE) with different traffic requirements and different mobility. The 4G* LTE network structure and its 3G network are explained in this section. The *LTE* network with its 3G interface is illustrated in **Figure 2**.

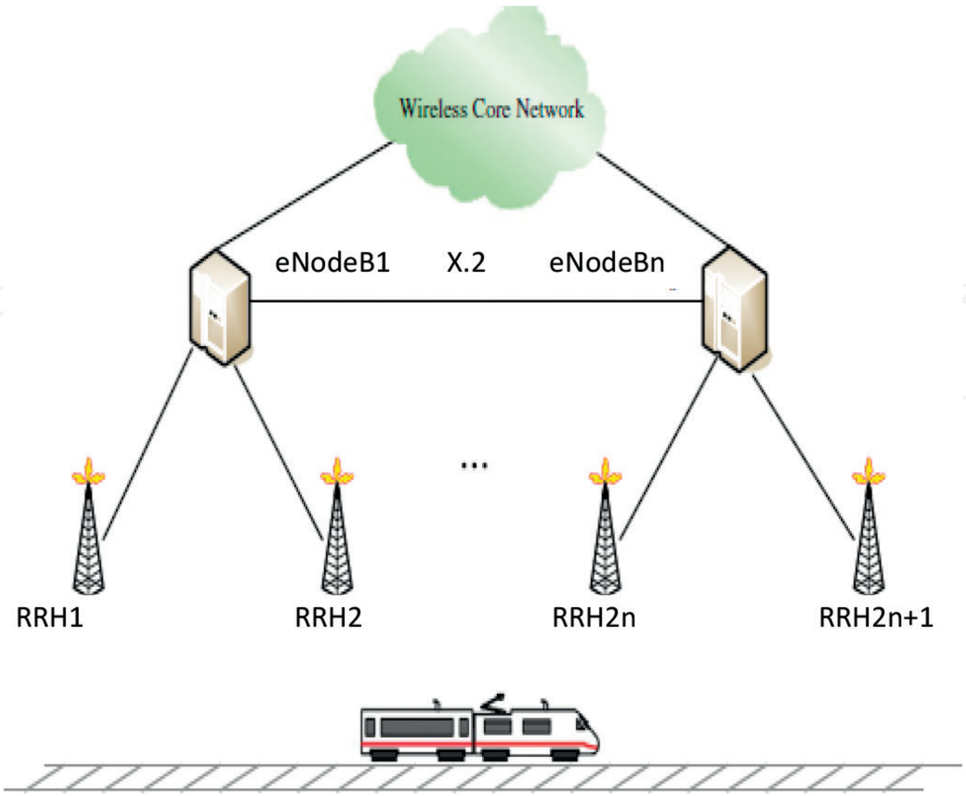

Figure 1. LTE-R system based on RRH.

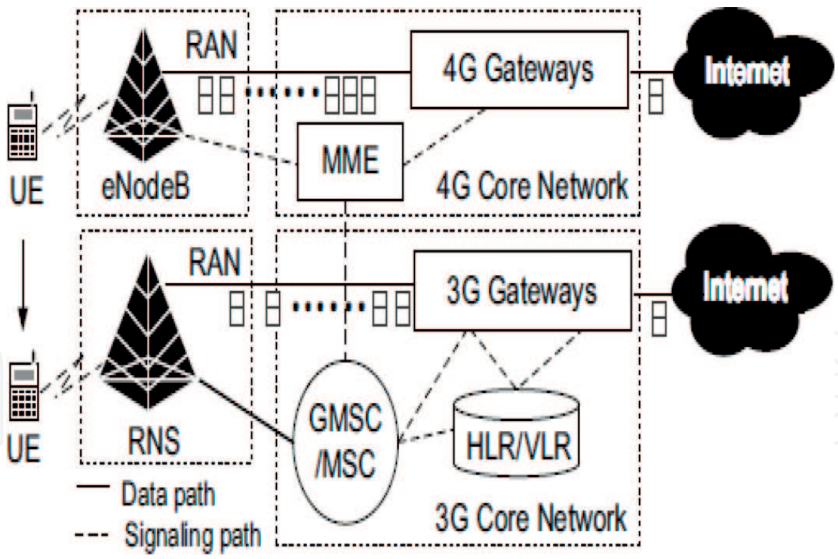

Figure 2. 4G-3G core network architecture.

The data (packet) service is offered by *LTE* network. It consists of a core network radio access network (*RAN*) and mobile stations (MSs). Its *RAN* uses eNodeB, i.e., *LTE* base station (BS) which allows access to MSs. The network core is IP-based and uses mobile management entity (MME) in order to locate MSs movement, e.g., location update and paging information. The 4G gateways are used to route packets between the 4G RAN and the Internet.

In contrast, the 3G network provides support to both data and voice calls or in other words packet switched and circuit switched calls. Its *RAN* uses radio network system (RNS) to allow access to radio resources. Its network consists of (a) Gateway mobile switching center (GMSC/VLR) which stores/updates user location. (b) 3G gateway provides data (packet) service and the route between the RAN and the internet.

The UMTS [20] interface adopts VSF-OFCDM in order allocate OVSF codes of a code tree spread in two dimensions: time and frequency. The LTE/LTE-A uses orthogonal frequency division multiplexing access (OFDMA) which uses a fixed frame for downlink transmission. The size of a radio frame in OFDMA is 10 ms which is divided into 1 ms, 10 sub frames. Each sub frame is further divided into two slots of 0.5 ms. Each slot has seven or six consecutive OFDM symbols. A basic scheduling unit in LTE is resource block (RB) which is composed of a time slot in the time domain and in frequency domain 12 consecutive sub carriers. The RB(s) are allocated to a call(s) when a call arrives or may vary at each transmission time interval (TTI).

3.1. LTE-R services

The LTE-R communication architecture for railways is given in **Figure 3** [21]. The main components of it are *Base station controller (BSC), home subscriber server (HSS), policy and charging rules function (PCRF), mobility management entity (MME), serving general packet radio service (GPRS) support node (SGSN), and packet data network (PDN).*

The LTE-R communications are used to provide services with minimum latency and least failure. The suggestion given in E-Train project [6], LTE-R must provide the services given below with higher level of security, the higher efficiency with better QoS.

1. *Control Systems Information Transmission:* The control information must be transmitted wirelessly in real time with a time delay less than 50 ms. The information related to the

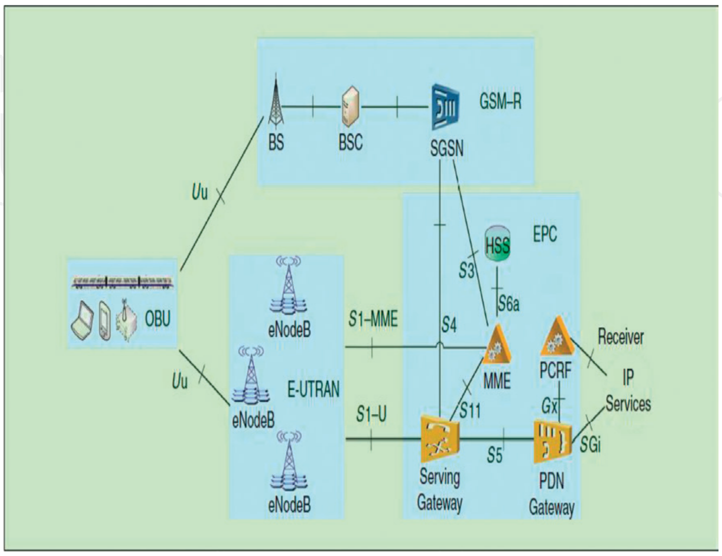

Figure 3. The LTE -R architecture for HSR communication.

location of the train is detected by radio block center (RBC) and radio equipments on the train. This will enhance the accuracy of tracking and dispatch of the trains. LTE-R may also be used in future for transmission of information for automatic driving conditions.

2. *Monitoring in Real-Time:* The LTE-R can provide video monitoring of all the parts involved in railway transport like rail tracks, rail bogies, connector, etc., in real time. The video monitoring of infrastructures where railway tracks are running, e.g., tunnels in order to provide safety in case of natural or man-made disasters. This monitored information needs to be shared at two places at the same time the control center and the train in real time with a delay not greater than 300 ms.

3. *Multimedia Dispatching:* The LTE-R provides information of drivers and yards to the dispatcher and improves dispatching efficiency [22].

4. *Railway Emergencies Information:* In case of emergency information, like two trains running on the same track, failure of engines, track broken, and accidents, the information needs to be sent not only to the railway authorities, but also to the public safety departments like ambulance, fire-fighters, police, etc., for faster rescue operation. The communication needs to be fast, accurate, and may contain images or videos with a delay not greater than 100 ms when containing videos or images.

5. *Internet of Things (IoT) of Railway Communications:* The railway IoT services like trains tracking, real-time queries, mail services, etc.

In addition to these services, LTE-R must have provisions to provide services like e-ticketing in mobility, upgrading of passenger information, seat reservations dynamically.

4. Proposed work

The LTE system consists of train access units (TAU) which are the on-board unit for access. The number of TAUs used on the train depends on the number of train bogies. In this chapter, two TAUs are placed, one in front and another in back, to reduce their mutual interference. A third TAU is placed which helps to communicate in borrowing capacity from LTE public mobile network and LTE public safety network. The TAUs are connected to inboard access points through an optical fiber. The passengers in the train experience a seamless wireless access. The call with their types and priority are defined below:

A. Emergency calls: Highest Priority needs urgent attention and is denoted as EC.

B. Railway control, track monitoring, railway dispatch information's: Medium Priority and are denoted by MP.

C. Data traffic generated by Passengers: Least Priority denoted by LP.

The algorithm works as follow when a call arrives:

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i. Generate a call.

ii. Check the call type (A,B,C)?

iii. For HP (Check whether a voice or data call?)

Data call

Assign LTE interface of LTE-R network. If no RBs available in LTE-R network, shift MP and LP calls using LTE-R network to public safety LTE network which is supporting the LTE-R network to handle HP calls.

Voice call

Assign UMTS interface.

iv. For MP (Check whether a voice call or data call)

Data call

Assign LTE interface of LTE-R network. If no RBs available in LTE-R network, shift LP calls using LTE-R network to mobile LTE network which is supporting the LTE-R network to handle MP calls.

Voice call

Assign UMTS interface.

v. For LP (Check whether a voice call or data call)

Data call

Assign LTE interface of LTE-R network. If no RBs available in LTE-R network, use mobile LTE network which is supporting the LTE-R network to handle LP calls.

Voice call

Assign UMTS interface.

vi. End the call and release the resources.

The calls are served by on-board wireless units, which request for capacity from TAUs. The TAUs request for capacity from RRHs which are connected to eNodeB. The algorithm works fine for any type of call, any location when a number of users are limited and it's in connectivity area of LTE-R.

Let the number of users which LTE-R can serve are U_{LTE-R} and the number of call request are C_r, where $C_r > U_{LTE-R}$. The LTE-R network needs to borrow capacity for remaining calls $C_r - U_{LTE-R}$. The TAU situated in center will facilitate it, all the calls request which will arrive when the LTE-R capacity is fully utilized will be served by central TAU. The TAU will send the request to LTE public mobile network eNodeB, which may be placed at a larger distance as compared to LTE-R eNodeB placed closely. These calls handled will be at higher latency. When the capacity of LTE-R becomes available, some of the calls are shifted to the LTE-R network again. The LTE public mobile network is used for rural areas also, as LTE-R is not deployed in remote areas.

The handover request is also done through these TAUs; the handover request is not between user equipments and eNodeB. The TAU request for handover to RRH (eNodeB) is done well in advance by estimating the speed of the train and time to connect. The total handover is done using TAU which is seamless for user perspective. The algorithm uses the distance by which two eNodeBs are separated and the power TAU receiving from them (which basically depends upon speed). The problem in handover is complex and it becomes more complex when the next serving eNodeB does not have enough capacity to support, the algorithm in this chapter searches for nearby LTE public mobile network RRH and request for connectivity and if LTE public mobile network does not have enough capacity to handle the request. The capacity load of the three TAUs is shared among three types of networks. The algorithm tries to utilize LTE-R capacity first and according to the preference of the calls.

The LTE-R is not totally equipped with carrier aggregation (CA) [19], which is widely employed in LTE-A. In this chapter, the CA is used in simulations to show the benefits of CA. The CA is used for higher data loads and leads to completion fast. With the use of CA in LTE-A, the networks are used again and the throughput increases considerably. With the employment of CA, UE can simultaneously use two or more frequency bands of 20 MHz, the complete description of which will be done in the sequel of this chapter.

5. Results and simulation

In this section, the performance of the proposed work is investigated using MATLAB. The results are compared for various scenarios for coexistence of public safety LTE, public mobile LTE network, and LTE-R. The resources of public mobile LTE network and public safety LTE are used to enhance the services of LTE-R. The LTE-R network runs parallel to railway track at a distance of 2.5 km from the track and with an antenna of height 45 m, a public mobile LTE network is placed at a distance of 4 km from railway track and public safety LTE network when used for simulations. *The call arrival rate is average from 0 to 6. The arrival of calls during high-passenger traffic scenario is LP calls (70%) and (MP + HP) calls 30%. In low-passenger traffic scenario, the call arrival is LP calls (20%) and (MP + HP) calls 80%. The average call duration of all traffic rates is exponentially distributed with normalized mean value 1. The LTE interface capacity used is 345.6 Mb/s and of UMTS interface 256*R (3.4 Mb/s). The same traffic is generated for network systems compared in **Figures 4** and **5**: LTE-R only (LTE-R), LTE-R + LTE public safety (LTE-RP), LTE-R + LTE public safety + LTE public mobile network (LTE-RPM), and reservation of capacity for handover in LTE-R systems. In **Figure 4**, the average throughput of the user calls is compared with average traffic load in Mbps, the throughput increases and after some time there is slight increase in throughput even though traffic load increases due to loss of the packets, for low passenger traffic condition throughput is higher as compared to high passenger traffic condition.

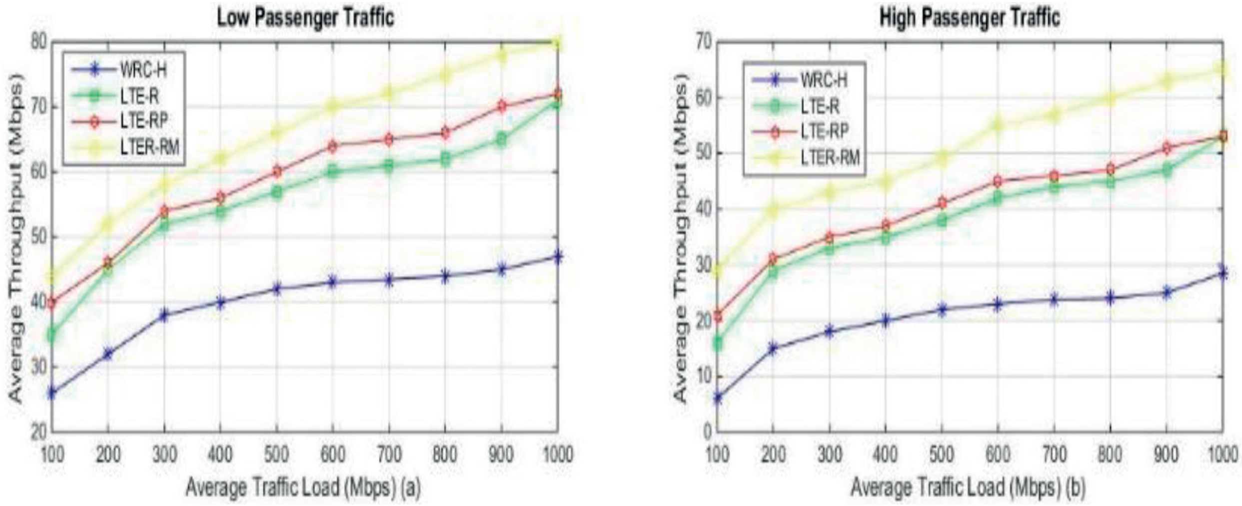

Figure 4. The average throughput comparison of different sharing method in: (a) Low passenger traffic scenario, (b) high passenger traffic scenario.

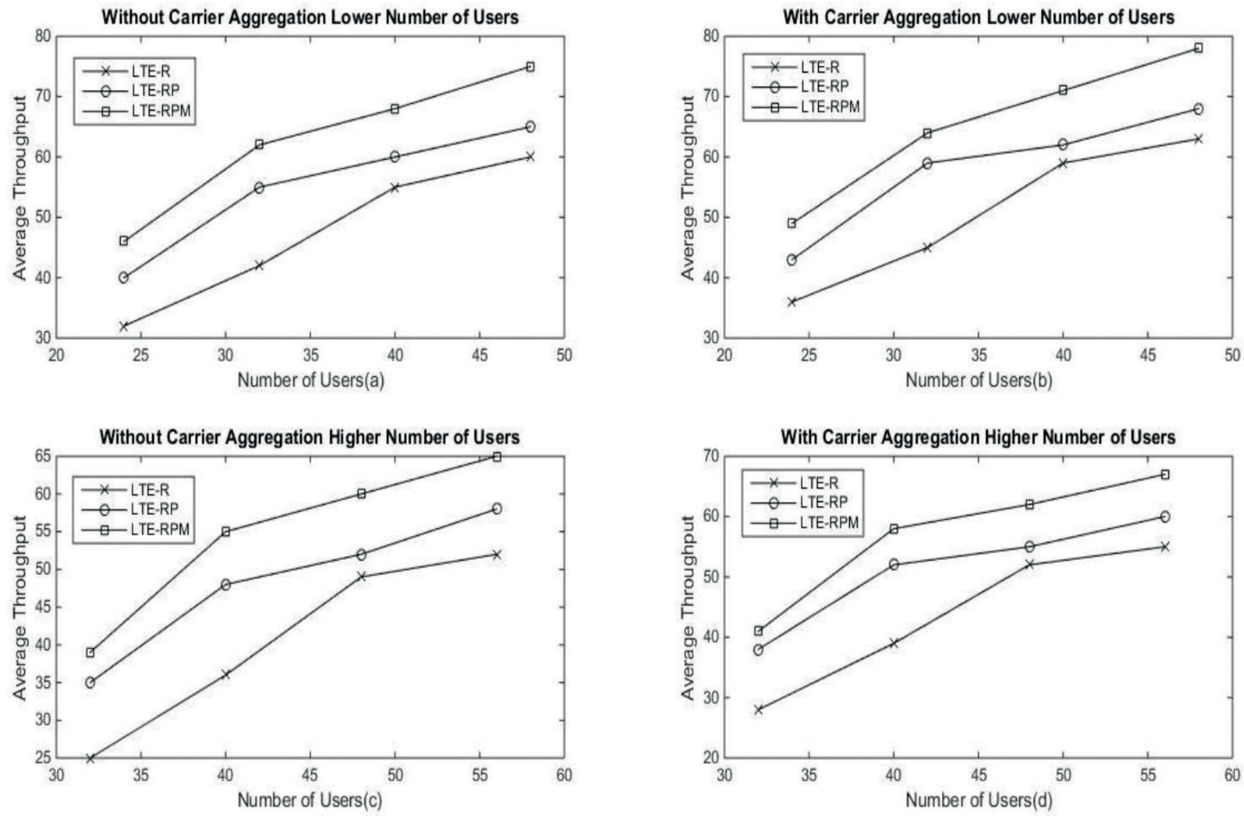

Figure 5. The average throughput comparison of different sharing method in: (a) and (b) lower number of UE with and without CA, (c) and (d) higher number of users with and without CA.

The network is simulated with CA capability means LTE-A is used and is compared with network without CA capability in **Figure 5**, the networks with CA and without CA are compared in lower user arrival **Figure 5(a)** and **(b)** and higher user arrival in **Figure 5(c)** and **(d)**. The network with CA provides better throughput, even though number of users are higher. The CA technique provides higher bandwidth and increases throughput.

6. Conclusion

The algorithm in this chapter provides analysis of LTE-R in coexistence with public safety LTE and LTE public mobile network. The main priority of the work is to handle emergency calls for railways in conjugation with other traffic on a train. The work is using existing network topologies without the requirement of any infrastructure changes. The LTE public mobile network has maximum coverage and its spectrum is not in fully utilized. Instead of deploying new BS, it is better to use the public mobile network for coverage in remote areas and for providing better QoS to on-board passengers. The work uses three networks alone and sharing modes. The throughput of users calls increases. Further, the simulations are done check the performance of the network. Moreover, RAN sharing is applied for the coexistence of two LTE network with CA. The use of CA keeps throughput closer to one achieved in without CA which provides greater benefit to users by achieving higher throughput in better channel condition.

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