



Service advancement strategy in analyzing the future of LTE-R for next-generation smart trains

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## **Abstract**

This research investigates and presents selected issues and aspects related to the railway mobile network (GSM-R) analysis and its shortcomings. Research studies show that millions of South Africans commuters are dependent on trains for daily movement activities, which significantly contribute towards economic growth. Over the two decades, the exponential growth in wireless broadband service indicates the need for GSM-R improvement so that it can support the modern IP based protocol. The principle of implementing the digital network in railway already demonstrated significant improvement in the railway environment, especially in communication and signalling. Train traffic and train communications are the most critical aspects of railway scenarios due to safety and reliability. Both features form fundamental content to this research thesis.

The exponential increase in Internet protocol (IP) based services and higher bandwidth requirements in modern technology applications have pushed the current Global system mobile for railway (GSM-R) technology to its maximum capacity as such the (GSM-R) platform is going to obsolete soon. There is a great need for the development of improved IP based networks for the future of the next generation network for fast smart trains to meet desired higher data low latency while improving quality of service (QoS).

The focus of the research study is on modelling of an effective sharing method between public LTE and LTE-R without addition mobile infrastructure by utilizing train access unit (TAU), the main purpose is for public network (LTE) to handle railway emergency service including drop calls to improve quality of service (QoS). The second focus is an improvement of signal reception by spreading signals over wide spectrum range by utilizing Orthogonal variable spreading factor (OVSF) technique where LTE-R is not deployed as noted that this technique is deployed in the 3G network.

The proposed scheme has adopted features in modern evolution communication and both scenarios were investigated modelled and simulated with comparison results showing better improvement in proposed conditions, there are many challenges in high-speed railway such as handover procedure and Doppler shift due to the velocity of the moving train. LTE-R has provided many solutions such as seamless handover, capacity availability as well as enhanced performance in both uplink and downlink. Digital evolution for railway GSM-R has been deployed in most developed countries in Europe and also expanded into Africa, there is a greater need for the seamless network to be developed due to an increased number of packet-

based services. Urban rail is the backbone of public transport in South Africa which is the Passenger Rail Agency of South Africa (PRASA). PRASA, and is the parent operator. Currently, PRASA has implemented digital railway network (GSM-R) to meet a high standard in railway. Modern demand and challenges require a cost-effective system to support IP orientated systems due to an increased number of packet-based services in the railway sectors.

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I hereby extend my sincere gratitude to all the people who assisted in the preparation of this research project.

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- My family, colleagues and friends.
- Lastly but not least the Passenger Rail Agency of South Africa (PRASA) for funding this project.

## **Dedication**

In loving memory of my late parents:

This entire work is dedicated to my late parents Nofanele Ligwa and Phofolo Dokwana-Ligwa may their soul rest in peace.

This work is also dedicated to Ligwa and Qayiso Family.

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## Publications

- Vipin Balyan, Mario Ligwa and Ben Groenewald (September 19th 2018). Mobile Broadband Scaling and Enhancement for Fast Moving Trains, Broadband Communications Networks Abdelfatteh Haidine and Abdelhak Aqqal, IntechOpen, DOI: 10.5772/intechopen.71782. Availablefrom:<https://www.intechopen.com/books/broadband-communications-networks-recent-advances-and-lessons-from-practice/mobile-broadband-scaling-and-enhancement-for-fast-moving-trains>.
- Mario Ligwa, Vipin Balyan, Ben Groenewald” Utilization of OVSF codes for service Enhancement of LTE-R” Accepted International Conference on Advanced Computation and Telecommunication (ICACAT) 2018.

## Acronyms- Nomenclature

<b>GSM-R</b>	<b>Global system mobile for railway</b>
<b>LTE-R</b>	Long Term Evolution for Railway
<b>MIMO</b>	Maximum input Maximum output
<b>OFDMA</b>	Orthogonal Frequency Division Multiplexing Access
<b>SC-OFDMA</b>	Single Carrier Orthogonal Frequency Division Multiplexing Access
<b>PRASA</b>	Passenger Rail Agency of South Africa
<b>UE</b>	User Equipment
<b>EnodeB</b>	Evolved node B
<b>MME</b>	Mobility Management Entity
<b>S-GW</b>	Serving gateway
<b>IP</b>	Internet Protocol
<b>FDD</b>	Frequency Division Duplex
<b>TDD</b>	Time Division Duplex
<b>PDN</b>	Packet Data Network
<b>QAM</b>	Quadrature Amplitude Modulation
<b>VIOP</b>	Voice over Internet Protocol
<b>EPC</b>	Evolved packet core
<b>ePDG</b>	Evolved packet data gateway
<b>HLR</b>	Home local Register
<b>GPRS</b>	General packet data service
<b>SISO</b>	Single input Single Output
<b>EPS</b>	Evolved Packet system
<b>PS</b>	Public Safety
<b>SGSN</b>	Serving GPRS Support Node
<b>GGSN</b>	Gateway GPRS Support Node
<b>PTSN</b>	Public Switch Telephone Network
<b>TETRA</b>	Terrestrial Train Radio System
<b>UIC</b>	International Railway Unit
<b>ERTMS</b>	European Radio Traffic Management System
<b>ETCS</b>	European Train Control System
<b>VLR</b>	Visitors Location
<b>HLR</b>	Home Local Register
<b>TCU</b>	Transceiver Coding Unit
<b>FDMA</b>	Frequency Division Multiple Access
<b>TDMA</b>	Time division multiplexing Access
<b>NSS</b>	Network Switching Sub-system
<b>BTS</b>	Base Transceiver Station
<b>MGW</b>	Media Gateway
<b>PCU</b>	Packet Control Unit
<b>GPRS</b>	General Packet Radio System
<b>MS</b>	Mobile Subscriber
<b>PDN</b>	Packet Data Network
<b>DHCP</b>	Dynamic Host Control Protocol
<b>EIR</b>	Equipment Identity Register

<b>IMEI</b>	International Mobile Equipment Identity
<b>BSS</b>	Base switching sub-system
<b>AuC</b>	Authentication
<b>LTE</b>	Long Term Evolution
<b>LTE-A</b>	Long Term evolution advanced
<b>CA</b>	Carrier Aggregation
<b>UTRAN</b>	Universal Terrestrial Radio Access Network
<b>3GPP</b>	3rd Generation Partnership Project
<b>PS</b>	Packet Switch
<b>ETSI</b>	European Telecommunication Standard Institute
<b>IP</b>	Internet Protocol
<b>QoS</b>	Quality of Service
<b>4G</b>	Fourth Generation
<b>HSS</b>	Home Subscriber Server
<b>MME</b>	Mobility Management Entity
<b>S-GW</b>	Serving Gateway
<b>P-GW</b>	PDN Gateway
<b>PCRF</b>	Policy and Charging Rules Function
<b>eNB</b>	Evolved NodeB
<b>EPC</b>	Evolved Packet Core
<b>EPS</b>	Evolved Packet System
<b>SCP</b>	SCP-Service Control Point
<b>QCI</b>	Quality Class Identification
<b>ARP</b>	Allocation and Retention Priority
<b>SIP</b>	Session initiation Protocol (Signalling protocol)
<b>eMBMS</b>	eMBMS - Evolved Multimedia Broadcast Multicast Service
<b>PTP</b>	PTP- Point to Point
<b>PTT</b>	PTT- Push to Talk
<b>SISO</b>	Soft input Soft output
<b>PDSCH</b>	Physical Downlink Shared Channel
<b>PMCH</b>	Physical Multicast Channel
<b>E-UTRAN</b>	Evolved Universal Terrestrial radio access network
<b>BSC</b>	Base Station Controller
<b>QPSK</b>	Quadrature Phase Shift Keying
<b>CS</b>	Circuit Switch
<b>PS</b>	Public Safety
<b>CSI</b>	Control State Information
<b>LOS</b>	Line of sight
<b>CoMP</b>	Co-ordinated Multipoint
<b>RRH</b>	Remote Radio Head
<b>RB</b>	Resource Block
<b>GMSC</b>	Gateway Mobile Switch Centre
<b>RAN</b>	Radio Access Network
<b>MCS</b>	Mission Critical Services
<b>OVSF</b>	Orthogonal Variable Spreading Factor
<b>TTT</b>	Time to Trigger
<b>UMTS</b>	Universal Mobile Telecommunication System

<b>3G</b>	3rd Generation Network
<b>TAU</b>	Tracking Area Update
<b>RSRP</b>	Reference Signal Receive Power





# Chapter 1

## General Concept of the Research

### 1.1 Introduction

South Africa railway transport is an imperative element of the country's transport backbone, statistics show that millions of South Africans are relying on trains for travelling especially in urban areas. With the rising cost in transportation urban railway is the key contributor in public transport backbone which significantly contributes towards economic growth. In railway train movement and communications are critical issues for safety and reliability which forms the fundamental concept of this research. Current trends indicate the exponential increase in mobile broadband services and that has an impact on railway organisation due to similar network version which was adopted by railway organisation, the implementation GSM-R network in railway environment has been significant improvement in the railway sector(Sniady & Soler, 2012).

Before railway network standardization analogue two-way radios systems were the mode of communication in the railway environment. Due to real-time and non-real time requirements that support the modern communication, there was a need for a suitable network to support this technology revolution. The key objective of the research project is to investigate and simulate and propose a suitable network that is capable of handling modern railway challenges. Orthogonal variable spreading factor (OVVSF) technique is proposed and simulated with its advantage to support call drop and increase network reliability. As the thesis unfolds, it focuses on LTE-R key features and continues explaining LTE-R by describing its various subsystem (smart antenna and OFDM), handover procedures, it also discusses the Multiple inputs multiple outputs (MIMO) which also become LTE-R's major characteristic. At the end of the research project, it summarizes by looking at LTE-R services and benefits.

### 1.2 Background

The first mobile two-way radio was developed in Australia in 1923 by Frederick William Downie of the Victoria police, and it was the first wireless communication used in cars. Two-way radios can transmit and receive signals (unlike broadcast). The current existing communication network operates in the UHF band between 450-465MHz using the MPT1327 standard for trunking. Two-way communication is a half-duplex analog communication. Most countries in

Africa including South Africa are still utilizing analog communication such as MPT1327 to communicate and convey a message.

The MPT1327 industry standard for trunked radio communication networks was developed in 1988 by a British telecommunication agency. It provides insufficient and less bandwidth availability and channel allocation.

Current South African railway communication still depend on UHF (Ultra High frequency) in the 450 MHz -465 MHz bandwidth which is known as Professional Mobile Radio (PMR) and Terrestrial Trunked Radio (TETRA) of which it has many disadvantages such as:

- Very restricted bandwidth and
- UHF spectrum is now overloaded and the best option is to go to the upper-frequency band in order to increase the number of available communication channels.

The South African railway Telecommunication infrastructure is part of the Transnet network which utilizes an old system for both signalling and telecommunication.

Due to the critically limited resources in (GSM-R) which is the most commonly used railway communication in European countries, with a growing increase in requirements associated with data. LTE-R is considered as a suitable alternative solution, GSM-R has been adopted as a representative rail communication standard, and although GSM-R has been chosen as the unique standard for integrated digital railway communication it has been more than a decade now as GSM-R has been deployed but due to its limited capability and capacity, LTE-R is considered as the future in high-speed railway for both practical benefits and best performance. In Korea's LTE-R implementation 700 MHz spectrum band has occupied same frequency band with public safety to avoid such problem there is a need to equip channel co-ordination for LTE-R control signal transmission, co-operative communication scheme such as CS Comp and dynamic ICIC can be introduced(Ahmad et al., 2017).

**Table 1.1:** GSM-R and LTE-R Comparison and their Core features

Parameter	Transnet Network(UHF) MPT1327	GSM-R	LTE-R
<b>Frequency</b>	450MHz -476MHz	Uplink 876-880 MHz Down link 921-925 MHz	450MHz,800MHz,1.4Mhz 1.8 MHz
<b>Bandwidth</b>	12.5 kHz or 24KHz	0.2 MHz	1.4-20 MHz
<b>Modulation</b>	FFSK	GSMK	QPSK/16-QAM
<b>Cell range</b>	High sites link	8 Km	4-12 Km
<b>Cell configuration</b>	Repeater old principle	Single sector	Single sector
<b>Peak data rate downlink/up Link</b>	28.8kbs/s	172/172 Kbps	50/10 Kbps
<b>Peak spectral efficiency</b>	1.2kbits/s	0.33 bps/Hz	2.55 bps/Hz
<b>Data transmission</b>	Voice call connection	Voice call connection	Packet switching (UDP data)
<b>Packet retransmission</b>	no	No ( serial data)	Reduced ( Packet data)
<b>MIMO</b>	no	No	2*2
<b>Mobility</b>	no	Max 500 km/h	Max 500 km/h
<b>Handover success rate</b>	< 50%	>99.5%	>99.9%
<b>Handover procedure</b>	Hard	Hard	Soft: no data loss
<b>All IP ( build in )</b>	No	No	Yes

As indicated from the comparison table above both handover success rate and bandwidth of LTE-R clearly indicate that it will be the future communication platform for the next generation high-speed smart trains, LTE-R provides excellent features which are very suitable to meet customer experience and current challenges.

From Table 1-1 in order to guarantee the peak data rate of 100 Mbps for a user on a train equipped with 2 TAUs, for instance, the system should use 16QAM and  $R = 3/4$  for modulation and coding, and guarantee a demodulator input SINR of 7.0 dB. Another important observation is that on table 1-1 above at maximum mobility the handover success rate accuracy becomes better in LTE-R which indicates suitability and ability of LTE-R network. It is also worth noting that only LTE-R utilizes MIMO to improve data capacity and continuous service availability. Based on the above-listed data LTE-R meets all required capability to be the future of railway communication.



**Figure 1.1:** MPT1327 Antenna with microwave dishes at Transnet in Bellville

As shown above, the current existing network antennas operating between 450MHz-465MHz are wired up along the roof courtesy of Transnet Telecoms, microwave Hub in Bellville linked with various high sites for network coverage.

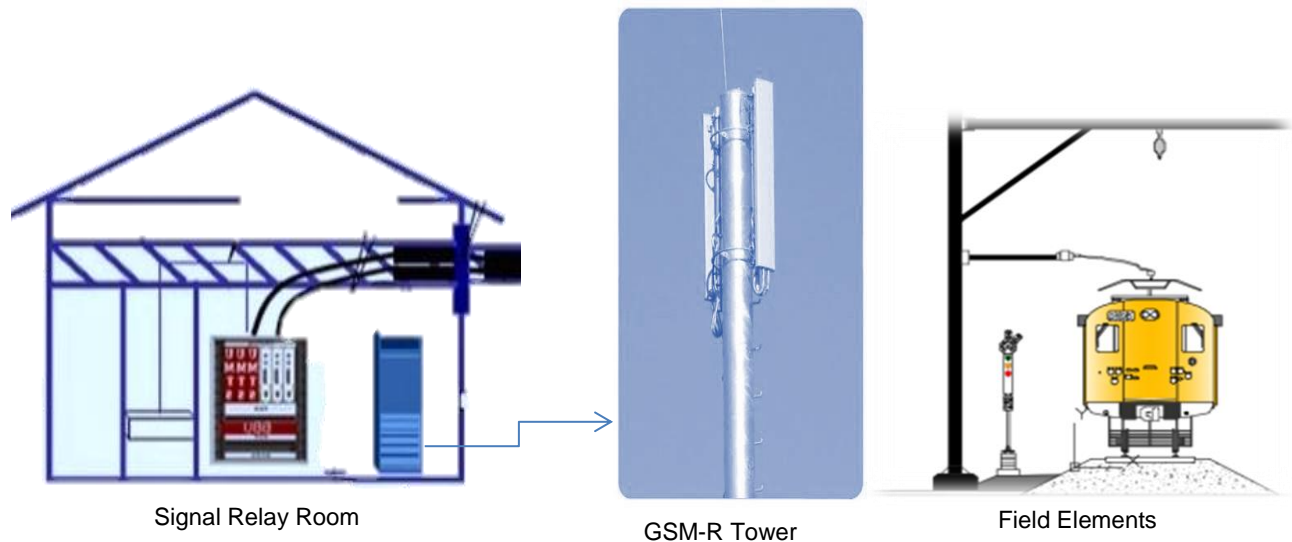
The MPT1327 network has been at the forefront of railway communication for more than two decades however it consists of various issues and received criticism such as limited bandwidth availability and fewer channel allocation which causes queuing process during a call including more drop calls and data cannot be sent on the control channel whilst it is in traffic mode.

There are numerous problems with MPT1327 and its disadvantages are ever increasing as demand increase from people using this kind of technology, the numbering rules are classified and expanded and programmed according to fleet specified. This kind of technology can only accommodate less than 1000 subscriber per fleet; this also needs to be programmed in a prefix of three digits, the fleet number and the subscriber's call number.

Transnet's MPT1327 is an example of an analogue trunk network offering two basic trunking features, Conventional communication and Trunk system.

Trunk system is when the channel is assigned to a specific user automatically by the system and at least one channel per call must be a control channel, while conventional system uses manually selected channels, with no control channel, such that all channels are available to the users.

MPT1327 was developed and used in many countries by government agencies police, security, etc., because of its cost-effectiveness, however for safety reasons; channel limitations and



**Figure 1.2:** GSM-R Network tower built next to Signal Relay room.

signal quality, it did not become a good option for sustainability in railway communication.

To meet modern communication standard and digital evolution PRASA has adopted a new digital platform of telecommunication, which is (GSM-R) it offers similar features as GSM with additional capability specific for rail communication such as shunting and group calls including a push to talk, GSM-R is a very special rail network platform, it was developed for circuit switch capability with better audio quality.

### 1.3 Research focus

This research focuses on investigation and analysis with simulation for problems encountered in high-speed railway scenarios specifically in South African railway by proposing LTE-R and its features to meet those desired broadband requirements and customer experience. It also looks at a solution in which LTE-R is not deployed. The proposed solution must also meet critical challenges in the railway environment and also re-establish faith in public transport backbone.

## **1.4 Problem statement**

The high-speed railway can be affected by many problems such as mobility due to frequently handovers, Network interference with adjacent public networks and spectrum availability is also a major problem. Frequency planning needs to be carefully considered in order to improve spectrum allocation as well as excellent antenna alignment to avoid channel interference. In order to get better network coverage and handover procedure including cell reselection, there are some important tradeoffs needed to be taken into consideration by network planners.

## **1.5 Research Objectives**

The main aim of this research is to:

- a) Enhanced handover performance in high-speed railway scenario
- b) Investigate and modelling to Enhanced QoS by implementing network sharing with public network
- c) Improve throughput performance in railway low traffic and high traffic scenario.
- d) Providing a recommendation in the future broadband upgrade which can be regarded as future and solution for modern railway issues.

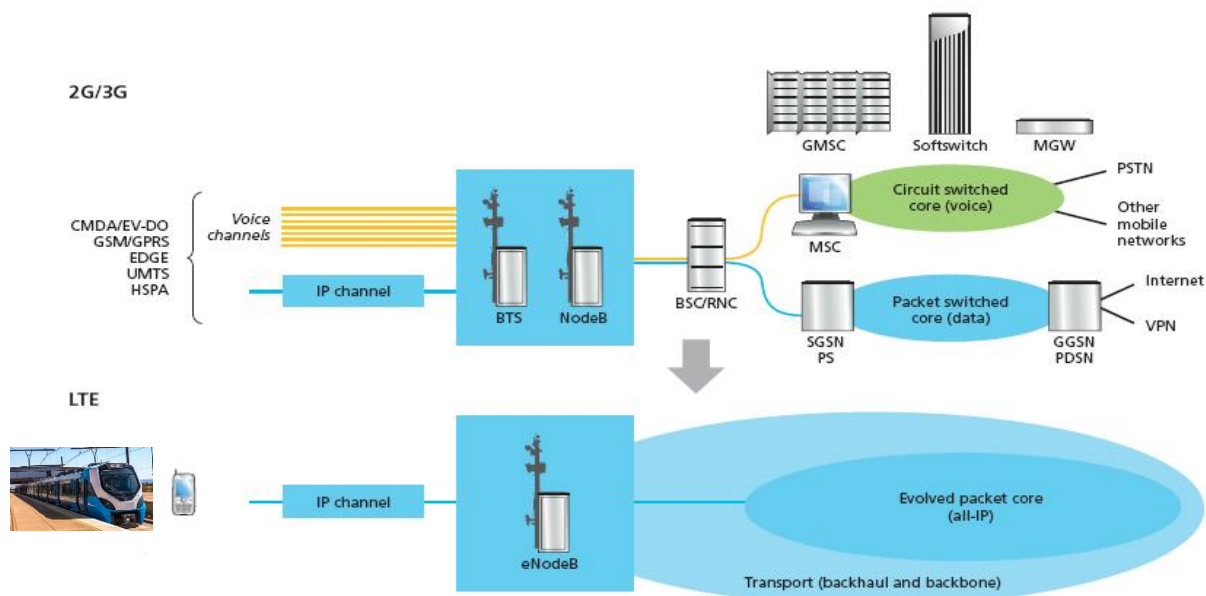
## **1.6 Sub-objectives**

- i) To study and define LTE-R features.
- ii) To introduce the simulation methodology using Vienna LTE-A simulator working with Matlab.
- iii) Introducing network sharing method to handle railway emergency calls and simulation.
- iv) Investigation and simulation of improvement in signal reception by introducing (OVSF) were LTE-R is not deployed.

## **1.7 Hypotheses**

From the stated research objectives and problem statement the following hypotheses can be identified:

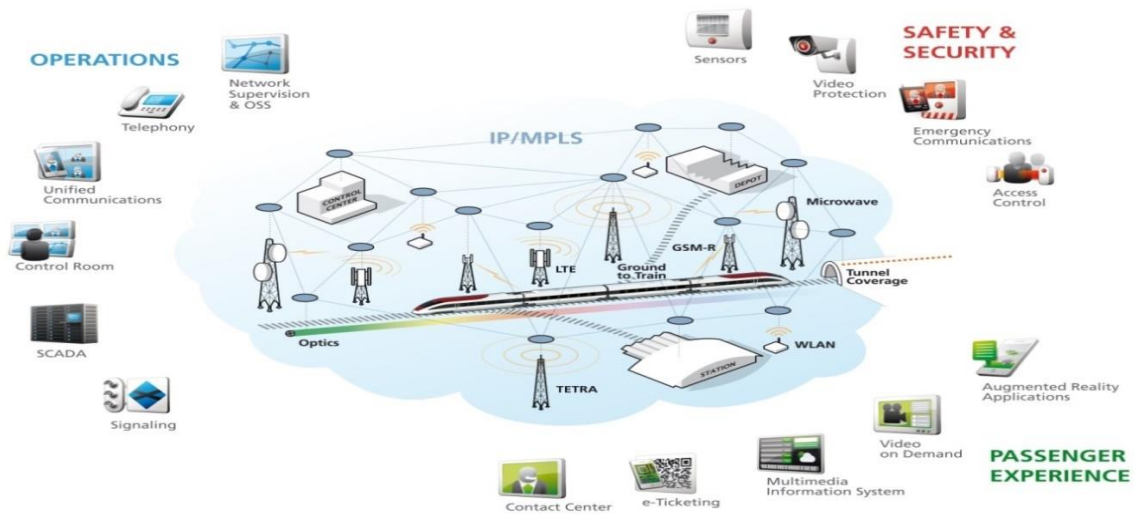
- a) Implementation of the seamless network (broadband) for the railway to improve customer experience and railway services.
- b) Enhance Voice over IP VoIP in order to reduce infrastructure vandalism and also ensuring security on board (inside carriage).
- c) Hypothesize the effectiveness in service reliability and availability.
- d) LTE-R improves desired broadband requirements such as high data rate while reducing packet loss and increases data throughput at the same time improving QoS.



**Figure 1.3:** Solution Approach network for GSM-R with LTE-R network, adapted from 3GPP

Both Figure 1.3 and Figure 1.4 provide the solution approach of the LTE-R, in order for the railway network to deliver a much-anticipated solution in railway challenges. Current railway challenges require broadband network which forms the railway service improvement for the next-generation smart railway. While voice communication becomes more essential evolved packet core which is all IP improves the entire railway efficiency, a combination of circuit switched core (voice) and packet switched core (data).

## 1.8 Solution Approach



**Figure 1.4:** LTE-R Services and Solution courtesy of Tecrail adapted from internet, [www.metromadrid.es](http://www.metromadrid.es)

As shown above, current GSM-R which is 2G network is guarantee of good voice quality with low data packet while LTE-R provides both voice and data with excellent quality. One of the services offered by LTE-R is Wi-Fi on board, in addition to that, it also provides excellent service which customers are expecting currently. Video on demand is also another service offered by LTE-R with closed-circuit television also known as video surveillance as one of the most imperative services to assist in mitigating robbery incidents which have become one of the biggest challenges in our railway service.

## 1.9 Delineation of Research

LTE-R logical operation won't be covered or analyzed in detail which includes the Cell configuration, interfaces also won't be discussed countermeasures which will be discussed throughout the research are those that form the core architecture of LTE-R and main features



and services, resource allocation mechanism and protocol, e.g. group paging won't be discussed.

### **1.10 Research Design and Methodology**

Methodology in this proposal includes the following stages:

#### **1.11 Literature review**

According to Jian Han and Kesheng Zhou in study "interference research and analysis of LTE-R", interference is the effect which causes signal interruption has been analyzed which states the importance of adding a cyclic prefix before transmission to prevent inter-symbol inference and inter-carrier interference(Zhou & Han, n.d.). The previous study such as "high-speed railway communication from GSM-R to LTE-R" by Ruisi He, Bo Ai, Gongpu Wang, LTE as the broadband network has better capability and capacity compared to narrowband GSM-R(He, Ai, Wang, Guan, Zhong & Briso-rodriguez, 2016).

Previous research studies propose many different handover mechanisms such as "A power distance based handover triggering algorithm for LTE-R using winnerII-D2a channel mode" by Ehab Ahamed Ibrahim, Ehab F Badran and MRM Rizk ,Lin Tian, Jaun Li, Yi Huang, Jiglin Shi, and Jihua Zhou on other hand proposed seamless dual-link handover scheme in broadband communication system for high speed railway(Ibrahim, 2016). In high-speed railway movement, there is a frequent handover occurrence which increases the possibilities of data loss. To improve the quality of service the study proposes a seamless handover scheme based on dual layer and dual-link system architecture. Mohamed Alaseli and Claes Beckman and Mats Karlsson researched about "providing internet to trains using MIMO in LTE networks", this study focuses on IP level using multiple communication connectivity. The main focus was also to support continuous connectivity without additional network infrastructure and also provide liability through redundancy connectivity of MIMO and carrier aggregation(Ab, 2014).

Planning on the spectrum allocation in LTE-R, based on the previous investigation, there is limited available spectrum recourse below 1 GHz for a high-speed train, so as to accelerate the application of LTE-R, the frequency planning is a priority. Tradeoff such as Spectrum requirement analysis must be done properly. Other critical considerations include frequency planning need to be reasonably evaluated carefully so that it supports to calculate the required capacity and frequency bandwidth(Zhang et al., n.d.).

Assessment of LTE-R has been presented based on the long-term evolution LTE standard and System Architecture Evolution (SAE). The major physical layer key technology of LTE-R refers to LTE, OFDM and MIMO are the core system parameters. The OFDM provides attractive solutions for meeting the requirement of next-generation wireless communication technology, all IP and support broadband services(Tingting & Bin, 2010).

In long-distance journey passengers are ready to use the internet, the current narrowband GSM-R network cannot meet this large capacity requirement of future high-speed railway demand. This needs improvement of spectrum efficiency by including massive MIMO and beamforming because bulk trains have more space to configure more antennas(Guan et al., 2011).

On the other hand the Evolved Packet System (EPS) which include long-term evolution (LTE) and System Architecture Evolution(SAE) represent the latest progress of the UMTS standard aiming to provide a unified architecture to real time and non-real time services and provide users with high data transfer rates, low latency and optimized packet wireless access technology(Tingting & Bin, 2010).

The GSM-R network security and reliability are both important issues for train traffic, however, there are significant challenges of handover in GSM-R network since the received signals may experience interference such as Doppler shift brought by fast-moving source (MS) speeds, instantaneous fluctuation caused by electric power traction, these are significant problems causing migration to LTE-R networking (Tang et al., 2011).

The GSM-R is an international wireless communication standard for railway communication and application based on GSM-R technology it has been developed as a platform for voice and data communication as well as traffic control system,(Jinn et al., 2010).

The handover problem in the high-speed environment is a key problem in GSM-R, hence dynamic handover margin evaluation (DHME) was proposed to reduce the call drop rate by changing the handover margin dynamically according to the speed of the train (Bhattacharya & De, 2012).

The access core network structure of the LTE-R is EUTRAN which consists of evolved node B (ended), while GSM-R has BTS and MSC, Core network of LTE-R is evolved packet core (EPC) precisely an all IP mobile core network (Date & Co, 2014).

The Modulation scheme for LTE-R is QPSK 16QAM and 64 QAM modulation technique both in the physical downlink shared channel (PDSCH) and physical multi-broadcast channel (PMCH), the coding technique for GSM-R are block convolution code fire code and parity code while LTE-R uses turbo code.

The long-term evolution for railway (LTE-R), multi-input multi-output MIMO technology is known to improve the efficiency and reliability of data transmission (Liu & Ai, 2016).

According to an article published in 2016, one of the essential target and motivation for LTE-R is to provide seamless and faster handover from one cell to another without losing any data while keeping management technique as simple as possible and improving latency (Ibrahim et al., 2016).

One of the key purposes of LTE-R is the establishment of multiple input multiple output antenna MIMO operation to improve efficiency, according to Hog Li, in conventional MIMO system liability is improved through diversity and channel capacity, that is, more than two antenna scheme belong to point to point MIMO whose attractive multiplexing gain are achieved by rich scattering environment and good SNR (Liu, Ai & Chen, 2016).

Deployment and implementation of LTE-R have key and positive benefits both in society and sectors, according to Ruisi He, Bo Ai, from the released article, LTE-R should provide series of services to improve security, QoS and efficiency compared with the traditional GSM-R network (Liu, Ai & Chen, 2016).

In Korea, the implementation and deployment of LTE-R work have started with some issues identified. Spectrum unavailability were both public safety and LTE-R occupy the 700 MHz band, having a resource allocation scheme is of vital importance for the careful design and spectrum allocation management(Choi et al., 2015).

Preventing interference in wireless communication becomes important; TD-LTE can reduce inter-carrier interference by increasing the size of the cyclic prefix, for band interference it is necessary to adjust the antenna position to reduce interference(Zhou & Han, n.d.).

Appropriate explanation of how GSM-R will evolve to support broadband requirements as well as LTE modulation access network and core network has been explained by Goa Tingting and Sun Bin in "high-speed railway mobile communication system based on LTE"(Tingting & Bin, 2010).

### **1.12 Simulation and significance of the Research**

Simulation is appropriate in order to obtain meaningful estimation both for data throughput and call drop approximation. From the software modelling perspective, Matlab is an appropriate tool. To facilitate better service in railway becomes a big challenge such as poor train service caused by signal issues, communication issues and monitoring issues. Improvement from the existing GSM-R to LTE-R will overcome modern problems such as customer experience (real-time), monitoring of infrastructure reducing vandalism of assets i.e. stealing of cables which improve delays problems. The emphasis is to restore public trust and establish better accessibility and reliability in public transportation.

### **1.13 LTE-R Services and Solution in Railway**

As indicated from the previous section LTE-R services offer incredible network solutions which are suitable for high-speed railway scenarios including the critical benefits. From the above LTE-R service diagram it has been proven that the challenges of next-generation smart trains and problems that are critical in railway can be something of the past, in metropolitan areas infrastructure improvement is necessary which is incorporated with public transport backbone that is a priority in economic development, the reason for that is how it directly impacts the economy, as shown from LTE-R services implementation of this network will resolve current issues affecting the railway.

### **1.14 Benefits of the Research**

One of the key benefits of the of the proposed project is to improve train services reliability and customer experience such as real-time issues including bandwidth availability and minimising maintenance problems, also including onboard monitoring to enhance safety by providing video surveillance, collision avoidance system with the aim of reducing train delays and improves signalling problems which forms a key factor in railway environment. Since there is a high increase in the packet switch optimized system this will assist to provide real-time and non-real time service support.

## 1.15 Thesis Outline

The rest of this thesis is organized as follows:

**Chapter 1:** provides a brief overview, background and introduction of the railway scenarios and the need to implement the modern digital network LTE-R.

**Chapter 2:** review the background of GSM-R and its shortcomings, it also describes the GSM-R classification including services offered by GSM-R it also indicates the limited capability to support broadband service.

**Chapter 3:** analyses the key factors which influence the implementation of LTE-R, it also describes the advantages of the newest generation of communication technology for railway environment.

**Chapter 4:** This chapter describes the main fundamental concept of the research the main industrial developments are described it presents the model for the proposed evolution network.

**Chapter 5:** this chapter presents the rise of the internet of things in railway scenarios by providing simulated results and comparison of the features (high traffic throughput, low traffic throughput) in the railway network.

**Chapter 6:** presents two scenarios as well as a final conclusion:

a) Seamless handover performance improvement.

b) In case LTE-R is not deployed this chapter introduces the utilization of OVSF codes to improve signal reception in 3G network.

## 1.16 Summary

Modern communication requires high bandwidth availability and low latency with good QoS, for instance, high-speed trains require the broadband network to meet desired requirements such as high bandwidth data throughput, onboard internet service and video streaming. LTE-R Evolved packet core and system architecture evolution which supports all IP technology which makes it be a recommended as a suitable network for the high-speed railway since the existing GSM-R network does not support the high bandwidth requirements which make it difficult to meet railway challenges and problems.

## Chapter 2

### Global System Mobile for Railway (GSM-R)

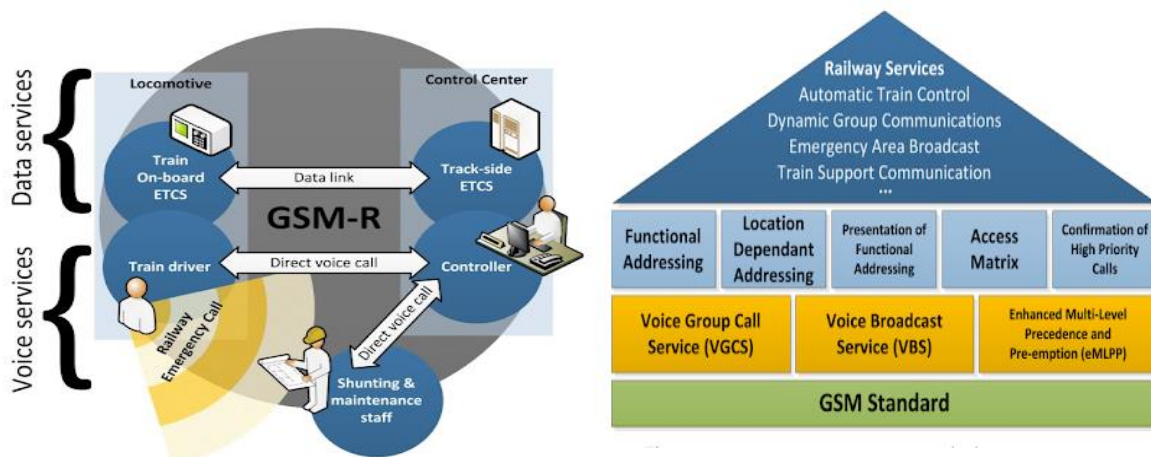
#### 2.1 Introduction

Global System Mobile for Railway communication GSM-R is a unified digital railway communication technology that has been adopted from GSM standard, due to its significant role in railway applications it carries in both voice and data it becomes more critical and imperative compared to that of commercial communication networks. These include signalling and control data as well as safety information it carries. Before the global standardization in railway communication technology, railway communication was dependent on analogue communication which was very limited in access.

In the late '80s through scientific study, a new digital railway radio communication was initiated, in which the primary candidate technologies were both GSM and TETRA. In 1990 international railway union UIC adopted GSM technology as a unified proven digital network for railway communication and MoU was signed, the same year with 32 railways organisation and in 2000 GSM-R specification (EIRENE) was released and the MORANE project was successfully finalised, this was supported by the European rail traffic management system (ERTMS) project which combines the European train control system (ETCS) the key purpose of digitizing railway network was interoperability, efficiency and safety in the railway network throughout the European rail network.

Further evidence shows that the motivation behind standardization was interoperability which consists of two types such as cross-border interoperability and multi-vendor interoperability. This means that trains must be able to cross any border in Europe without issues and vendors must be able to interwork with equipment without experiencing problems as such the proven technology must be accessibility, availability, maintainability.

The European continent started to deploy GSM-R as a railway communication network and later was adopted in places such as Saudi Arabia and Israeli and the Middle East. Because of its success, it expanded in Far East India and China since then also adopted throughout into Africa. Migration from analogue to GSM-R was better and necessary step towards railway innovation since analogue systems were ageing and it was becoming very difficult to get spare, as migration to the digital network was getting a massive boost, with GSM-R preferred due to its efficiency and reliability.



**Figure 2.1:** GSM-R is built on the same GSM 2G standards for public cellular communication in both architecture and technology(Sniady & Soler, 2012).

## 2.2 GSM-R overview

GSM-R is built on the same GSM 2G standard for public cellular communication in both architecture and technology, that means existing vendors can modify it can suit railway functionality and also it can operate on the GSM platform.(Sniady & Soler, 2012). the Characteristic of the GSM-R network, even though it's similar and identical to commercial GSM it has an exclusive characteristic which specifically supports railway environment. The GSM-R network requirements are supplemented by special services, such as ASCI(Advanced speech call items).

The main applications of GSM-R are:

### 2.2.1 Voice group call service VGCS and Voice broadcasting service VBS

These two types of service can offer an almost identical type of service in railway communication. VGCS is been a number of group of users can participate in a conversation one person can talk while the rest listen and vice versa that means everyone can participate in the entire conversation while VBS service is when the message is being sent to everyone such as for alerting no one is allowed to participate everyone can just listen.

### **2.2.2 Push to talk**

Push to talk is special GSM-R service with its advantage of spectrum flexibility this can do in either group communication or two people in conversation this type of service is also available in the current MPT1327 network.

### **2.2.3 Functional addressing**

Functional addressing this type of service offer real time and train numbers and coach numbers including setting up a call and display call party function, it also offers automatic and manual test mode with fault indication.

### **2.2.4 Railway emergency**

Railway emergency calls, this feature enables the setup of group calls for alerting in case of dangerous areas and this is set up in high priority mode.

### **2.2.5 Automatic train control**

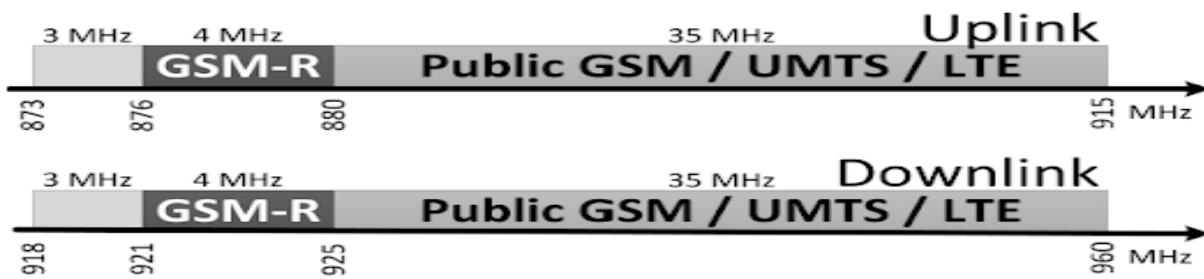
Automatic train control ATC is one of the unique services offered by GSM-R which is designed with the fail-safe mode.

Additional functionality of GSM-R including:

- i) Communication for speed up to 500KM/h.
- ii) Guaranteed capability to handle handover in fast mode.
- iii) Fast and guaranteed call setup.

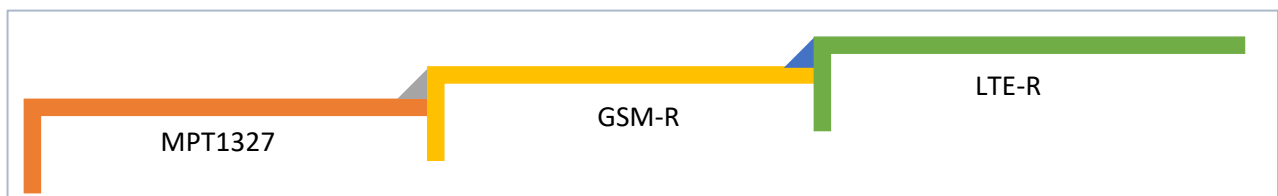


## 2.2.6 The GSM-R frequency bands



**Figure 2.2:** GSM-R Frequency Band(Section et al., n.d.)

- a) Data transmission used for Uplink is: 873-880 MHz
- b) Data reception used for Downlink is: 918-925 MHz
- c) E-GSM channel for guard band
- d) 19 channels available with 200 kHz line spacing
- e) In China and South Africa
- f) Uplink: 885-889 MHz
- g) Downlink: 930-934 MHz



**Figure 2.3:** Exponential increase in technology representation from MPT1327 to LTE-R

Figure 2.3 denotes a perfect representation of the GSM-R network with another network in an ascending format. The development of digital railway network by European Train Traffic Management System ERTMS together with international railway union UIC has sparked many

opportunities in both academic institutions and in railway organisation. It also brought many advantages in the railway organisation such as safety and better quality in communication while reducing many challenges.

In South Africa, the Department of Transport operates the most developed railway network in Africa. As a matter of fact, the digitized network has been developed to attract more passengers and provide more efficient, comfortable and convenience services. To enable this, PRASA selected Huawei and Siemens Convergence Creators' GSM-R solution as it supports LTE evolution and provides support across the following three key areas:

I) Enables PRASA's control centres to conveniently manage its frontline staff and assets through a Siemens Convergence Creator train dispatcher system, which uses converged voice communication.

II) Enhances on-board communications as the GSM-R solution features voice recording technology, which improves the post-incident analysis of railway accidents.

II) Helps railway operators communicate during long-distance journeys as the GSM-R solution features a real-time dispatching capability.

**Table 2.1:** GSM-R 19 channel frequency availability –frequency allocation

	<b>ARFCN</b>	<b>Uplink</b>	<b>Downlink</b>
<b>1</b>	<b>955</b>	<b>876.200</b>	<b>921.200</b>
<b>2</b>	<b>956</b>	<b>876.400</b>	<b>921.400</b>
<b>3</b>	<b>957</b>	<b>876.600</b>	<b>921.600</b>
<b>4</b>	<b>958</b>	<b>876.800</b>	<b>921.800</b>
<b>5</b>	<b>959</b>	<b>877.000</b>	<b>922.000</b>
<b>6</b>	<b>960</b>	<b>877.200</b>	<b>922.200</b>
<b>7</b>	<b>961</b>	<b>877.400</b>	<b>922.400</b>
<b>8</b>	<b>962</b>	<b>877.600</b>	<b>922.600</b>
<b>9</b>	<b>963</b>	<b>877.800</b>	<b>922.800</b>
<b>10</b>	<b>964</b>	<b>878.000</b>	<b>923.000</b>
<b>11</b>	<b>965</b>	<b>878.200</b>	<b>923.200</b>
<b>12</b>	<b>966</b>	<b>878.400</b>	<b>923.400</b>
<b>13</b>	<b>967</b>	<b>878.600</b>	<b>923.600</b>
<b>14</b>	<b>968</b>	<b>878.800</b>	<b>923.800</b>
<b>15</b>	<b>969</b>	<b>879.000</b>	<b>924.000</b>
<b>16</b>	<b>970</b>	<b>879.200</b>	<b>924.200</b>
<b>17</b>	<b>971</b>	<b>879.400</b>	<b>924.400</b>
<b>18</b>	<b>972</b>	<b>879.600</b>	<b>924.600</b>
<b>19</b>	<b>973</b>	<b>879.800</b>	<b>924.800</b>
<b>20</b>	<b>974</b>	<b>880.000</b>	<b>925.000</b>

As indicated by the GSM-R channel availability, in order for network planners to appropriately plan and design network accurately spectrum allocation per channels becomes a special priority, also to avoid any network interference. These channels guarantee network availability and also improve QoS since railway network takes higher priority.

**Table 2.2:** BCCH and TCH Huawei GSM-R documents

Channels/Cell	Cell A	Cell B	Cell C	Cell D	Cell E	Cell F	Cell G	Cell H
BCCH	955	963	967	971	956	962	966	970
TCH	957	965	969	973	958	964	968	972

- a) Co-channel interference protection ratio/ $I \geq 12$  dB
- b) Adjacent frequency interference protection ratio  $C/I \geq 6$  dB
- c) 400 kHz space used for TCH and 600 kHz space for BCCH
- d) Frequency can be reused every 4 cells

BCCH-Broadcasting control channel

TCH-Traffic Channel

Absolute radio frequency channel number is a code that specifies a pair of the physical radio channel used for transmission & reception in GSM-R uplink and downlink.

GSM-R uses GMSK modulation scheme and GSM-R is a TDMA (Time Division Multiple Access) systems, it also occupies 4 MHz wide range of the E-GSM band (900 MHz-GSM)

Europe: 876-880 MHz, 921-925 MHz With channel spacing of 200 KHz. The GSM-R technology comprises GSM-R access infrastructure nodes such as the base station controller (BSC), the Trans-Coding unit (TCU) and the Base Transceiver station (BTS).

GSM-R network infrastructure shares the same aspect as that of a public network (GSM) excluding user equipment (UE) which in this case is a train with a sim card.(Sniady & Soler, 2012)Mobile switching centre MSC with home local register (HLR) visitor's local register (VLR) and authentication centre (AUC). The call routing procedure with operational and maintenance GSM-R is pre-dominantly similar to that of the public network.

Radio transmission which includes physical channels, logical channels, and packet burst structures, as well as radio subsystem including the A-bis, interface the A interface the x.25 interface, BTS and BSC are all the same with public network infrastructure(Sniady & Soler, 2012). The Network subsystem NSS both in public network and GSM-R network share same

similar functionality which has the following database: home local register HLR, visitor's local register VLR, authentication centre AUC and equipment identity register (EIR).

As it was mentioned previously since GSM-R has adopted similar technology as that of the public network the following aspects remain identical both commercial and GSM-R network.

- a) Cellular concept
- b) Radio interface
- c) Radio resource management
- d) Mobility and security management
- e) Communication management and
- f) Network management

### **2.2.7 Cellular concepts**

- a) Frequency re-use
- b) Mobility
- c) Network architecture
- d) Radio interface

### **2.3 TDMA & FDMA**

Time division multiplexing access (TDMA) and frequency division multiplexing access (FDMA) and it uses both combinations.

- a) Radio resource management
- b) Handover preparation
- c) Radio channel management

GSM-R logical operation is not going to be covered in this thesis both GSM-R and GSM shares the same radio resource procedure such as paging handover execution call establishment, radio resource session release, and load management procedure. Handover preparation in both GSM-R and GSM has the possibility to change the cell during call time as this role is a very imperative function in the cell system, that decision to trigger a handover and the choice of targeting next cell is based on a number of parameters. Various reasons may trigger this reason both criteria and handover purpose(Bhattacharya & De, 2012).

Mobility and security management which include location management, location update, procedure architecture, cell and PLMN selection.

- a) Security management.
- b) The signalling mechanism.
- c) Architecture and protocols.
- d) Communication management.
- e) The call control function and call release.
- f) Routing of mobility terminating calls.
- g) The mobility originating call establishment procedure.
- h) The mobile terminating call establishment procedure.

### **2.3.1 Network management.**

The network management includes subscriber management with billing and accounting mobile, management as well as engineering, operation, management.

- a) Cellular planning.
- b) Cellular configuration.
- c) Network change control.
- d) Network optimization and validation.

Since train movement is of paramount importance, therefore reliability and availability. become very critical.

### **2.3.2 Reliability.**

- a) It must be a proven technology in commercial operation.
- b) It must be very robust products due to maturity.
- c) High immunity against interference.

### **2.3.3 Availability**

- a) It must provide a full internal redundant solution with no failures.
- b) It must provide a full geographical redundant solution.
- c) Dual radio coverage functionality.
- d) Fall back into the public network.

GSM-R provides two types of services voice applications and data both these applications can be provided in critical applications and non-critical application.

#### **2.3.4 Voice application critical.**

- a) Train dispatching communication.
- b) Shunting communication.
- c) Emergency voice communication.
- d) Freight dispatching communication.

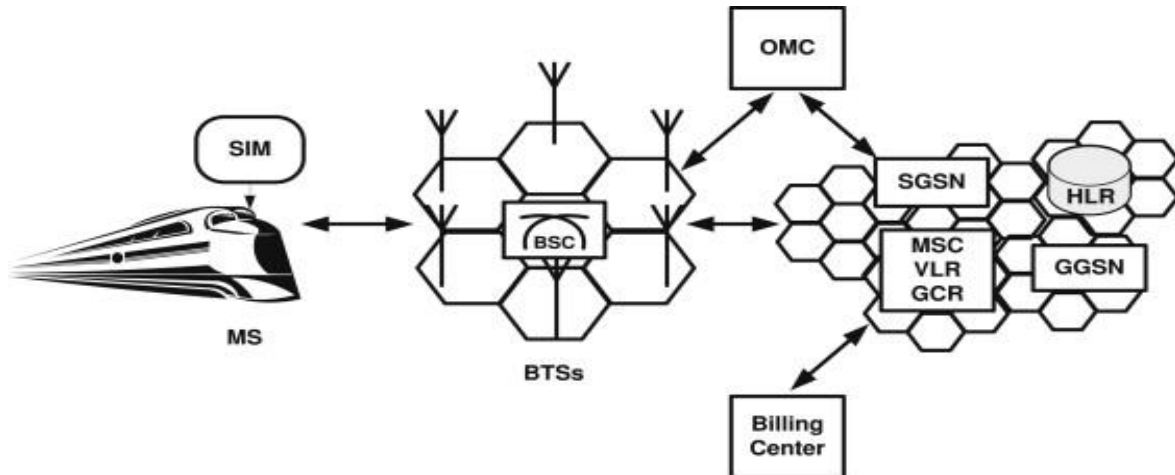
#### **2.3.5 Voice application non-critical.**

- a) Public addresses.
- b) Construction and maintenance communication.

#### **2.3.6 Data application.**

- a) Automatic train control.
- b) Transfer of maintenance data to rolling stock.
- c) Transfer of the train and equipment info.
- d) Passenger information services and.
- e) Customer support service information.

Other applications offered by GSM-R including general radio application at the Depots and stations, also onboard communication.



**Figure 2.4:** GSM-R Network architecture(Ljubic & Simunic, 2009).

As shown in Figure 2.4 the GSM-R core architecture consists of the main parameters such as network switching sub-system which is accountable for mobility management, base station sub-system which is responsible for the RF part, handling of traffic channels cell reselection, and also General Packet Radio Services (GPRS) which provide packet-switched data services.

The Network switching sub-system NSS carries out the switching protocol and mobility management functions, other functions such as roaming on the networking switching system NSS allows mobile subscriber MS to communicate with each other and with external networks such as PTSN PBX and another GSM-R network.

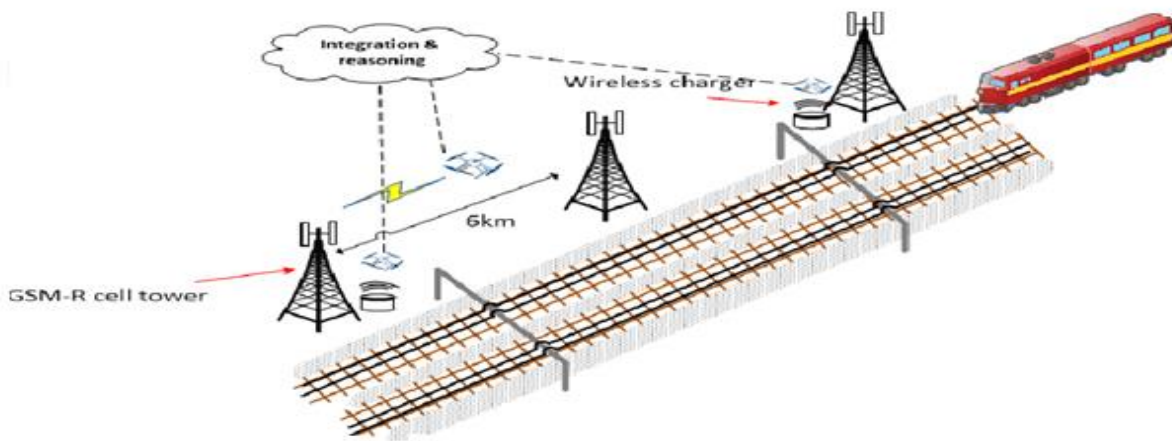
The Base station Sub-system BSS is responsible for Traffic handling capability and signalling between the Mobile Subscriber MS and the NSS. The BSS is also responsible for the allocation of radio channels to Mobile Subscriber MS, transcoding of speech channels, data channels management, paging location update, transmission.

The detailed function of the network element and terminals of GSM-R

BSS a combination of BSC and BTS.

Functions of the BTS in network





**Figure 2.5:** GSM-R BTS has been built along the railway(Flammini et al., 2017)

The Base Transceiver Station BTS is responsible for transmits and receives of radio signals from mobile subscriber MS (with modulation /demodulation between baseband signals and RF signals), the BTS is controlled by BSC.

## 2.4. The function of the BSC in the network

The Base station controller BSC controls BTS, the other role is to handle the allocation of radio channels for VGS/GCS/VBS between BSC and BTS. The BSC controls inter BTS handover and receive various measurements from the MS (traffic, radio link). The BSC is also responsible for transcoding the voice channels between mobile and PTSN as well as controlling the data channel (PCU).

### 2.4.1 Functions of the Network switching sub-system NSS

$$MCS + MGW + HLR = NSS$$

The NSS is a core element of the GSM-R network; it manages and controls the functional entities of the GSM network. The NSS is responsible for routing voice calls and other services such as charging authentication, collection. The MSC is built into MSC server that has the control function such as completes processing of all signalling and protocols and MGW that has

the bearer function such as completes access and bearing of all services under the control of the MSC server) in 3GPP R4 architecture.

#### **2.4.2 Function of HLR in the network**

The Home local register HLR is a central database of the GSM-R system. The HLR stores the information about all GSM-R mobile subscribers such as IMSI, access capability, subscriber type, group call services data and supplementary service data. The HLR is also responsible for storing dynamic data of the MSC areas where some roaming mobile subscriber are located.

The function of the Follow me function node FFN. Follow me function node FFN provide the FA function in the GSM-R system and it stores the mapping between FN and subscriber numbers. Based on the mapping information, the FFN can translate the FN into the real subscriber number during the FA process.

#### **2.4.3 Function of the Authentication (HLR)**

Authentication stores the authentication algorithms and encryption keys to prevent illegal subscribers from accessing the network. It also provides and ensures secure verification during communication of mobile subscriber over the air interface.

#### **2.4.4 Function of EIR**

The function of the Equipment Identity Register EIR stores the international mobile station Equipment Identities (IMEI)

It provides clarification on:

- i) IMEIs that not allowed.
- ii) IMEIs that are prohibited.
- iii) IMEIs that are abnormal and need to be monitored.

All of them are on whitelist blacklist and greylist respectively, railways are also putting security measures in ensuring uniqueness and encryption in the network. General Packet Radio Services GPRS consists of two core network elements GGSN and SGSN.

#### **2.4.5 Function of the Serving GPRS Support Node SGSN**

The SGSN is a network access control that provides authentication and IMEI checks the MS. SGSN is also responsible for Logical link management between the SGSN and the MS (attach /detach). SGSN is also responsible for mobility management and session management, route and tunnel management, compression/decompression, encryption /decryption data storage and forwarding of subscriber data and routing selection.

It also provides data routing as well as scheduling and determining the speed of the data network. The function of the Gateway GPRS support node GGSN. GGSN provides routing and encapsulating the data between the GPRS network and the external network (PDN).GGSN is also responsible for route selection, address translation and mapping, encapsulation, tunnel transmission it is also responsible for Dynamic allocation of IP addresses (DHCP).

The GGSN provides network access control at the external Packet Data Network PDN side. It also provides session management, charging, and collection.

#### **2.5 Advantages of GSM-R network.**

Even though GSM-R has some limitation such as high bandwidth availability and flexibility in both passengers and safety. GSM-R has fulfilled its desired requirements it was developed for. GSM-R is a unified railway communication with better capability such as voice communication interoperability as well as roaming features higher bandwidth availability compared to an aged analogue system that was in use(Bhattacharya & De, 2012).

#### **2.6 GSM-R limitation capabilities.**

GSM-R support the most important and critical railway services, however, the limited capability of GSM-R define a barrier for the introduction of new services this technology is not flexible enough in terms of throughput and delay to provide railway's modern services and also to adapt to new requirements both those that are predictable and unpredictable (Hui et al., n.d.).

GSM-R is not capable of delivering services such as video surveillance, internet for on-board passengers these services becomes a priority to be provided to passengers and also for security and safety.

## **2.7 Capacity problem and Spectrum availability.**

Capacity problem in GSM-R such as limited radio is huge concern in railways, in the available 4Mhz band 19 channels are placed with 200Khz channel spacing, however, GSM-R cell only uses few of the channels because of the same channel cannot be reused by adjacent cell due to avoid interference but this is sufficient for railway voice communication.

It has been noted from the previous study of GSM-R that voice calls are limited in time and therefore they do not occupy resources continuously.

## **2.8 Interference.**

There is interference between GSM-R and other public networks due to cell overlapping and to receive good coverage, this mostly happens along the railway line, from the previous study it was revealed that this problem can be avoided if the public network does not use frequency band adjacent to those of GSM-R (Hammi et al., 2009)

## **2.9 Capability.**

GSM-R is a narrow band system and it cannot provide modern services and adapt to the latest railway requirements which need broadband requirements. It was noted from the previous study that the maximum transmission rate of GSM-R per connection is 9.6kb/s which is sufficient only for application with low demand.

## **2.10 Conclusion**

In this chapter, the architecture including the overview as well as limitation associated with GSM-R network has been outlined. In addition, its key features have been demonstrated. The basic advantages of GSM-R are also stated which forms the motivation for the deployment. In some countries including South Africa GSM-R is on an optimization and test stage (2018) while in developed countries especial in Europe and China it was implemented tested and the next step is to evolve. Even though GSM-R did meet its desired prime objective such as roaming, speech quality, interoperability the increase data in railway operations, safety and security and passenger experience has pushed the railway operators to evolve to LTE-R.

## **Chapter 3**

### **Long Term Evolution and Long Term Evolution Advanced**

#### **3.1 Introduction**

This chapter review the latest developments on the existing mobile broadband wireless telecommunication technology long-term evolution LTE and long-term evolution advanced LTE-A. Both LTE and LTE-A represents a very imperative step which forms the platform in which future of mobile wireless telecommunication system will be developed. Long-term evolution LTE is a fourth generation standard for high-speed wireless communication for mobile devices. LTE is developed for packet data communication with the aim of improving high spectral efficiency, high data bandwidth, minimum latency and better frequency flexibility.

The high demand for wireless data traffic has caused the exponential increase in broadband services which are also growing rapidly over the three decades, ever since 2G network was deployed it has contributed very positively in wireless networks, this change has a positive impact on the development of LTE, the goal and aim behind the implementation of LTE is to increase and improve capacity and speed using different radio interface such as digital signal processing technique DSP, and high order modulation. The other goal was to re-design and simplification of the network architecture to support all IP based system which significantly reduced transfer latency while improving quality of service QoS compared to its predecessor 3G system.

The long-term evolution advanced LTE-A is the next major steps in the development of LTE networks with the emphasis to improves the massive increase in mobile data demand and deliver high data speeds for all users as well as better network coverage. “The major emphasis of evolving LTE is to improve data throughput good network stability and faster performance with excellent quality of service QoS minimum latency”.

#### **3.2 Background**

The long-term evolution LTE and the long-term evolution advanced LTE-A is a Third generation partnership project 3GPP standard term for a complete latest air interface – based on OFDM and smart transmission that is incorporated with all IP networks, according to Dave Wisely from British Telecommunication BT, UK (IP for 4G), the long-term evolution LTE core is all IP based technology meaning that there is no circuit switch (CS) part all service including voice is transmitted over the packet core, the interesting approach reveals that some LTE system was

demonstrated at the mobile world congress ( formerly 3GSM) in Barcelona in February 2008 this is where release 8 was initiated. LTE was standardized in 3GPP release 8 but it kept evolving over the multiple releases to meet the highest standard and to improve data throughput as specified in the 3GPP document specification.

Third generation technology 3G is obvious a predecessor of LTE, even though 3G did meet its desired requirements it was developed for but it fails to meet the current higher demand in packet data such as capacity and wider bandwidth. The exponential rise in the packet data system spark the utmost need for higher competitive network, wider bandwidth and seamless access technology to handle the increasing demand, this is inclusive need of minimum latency and better spectrum efficiency due to the increase of broadband services, video streaming and also to meet required bandwidth availability which seems almost impossible to be achieved in the existing 3G network, IP for 4G by Dave Wisely BT, UK.

Scientific evidence has proven that LTE is capable of providing better system reliability QoS, including wider bandwidth seamless access to the multimedia teleconference full video image also uninterrupted global roaming with easy access in the integrated standard, mobile ultra-broadband internet accessibility.

### **3.3 Key Features of Long-Term Evolution (LTE)**

- OFDM
- SC-FDMA
- FDD and TDD
- MIMO

The LTE-A which is evolved LTE has provided the following features in order make sure that LTE remains the reliable and competitive network of choice and to be at the highest in the global standard for mobile broadband technology.

- Carrier aggregation ( CA)
- The improved base station(BS) to user equipment (UE) multiple antenna transmission (MIMO)
- Higher spectrum efficiency
- Higher data throughput

### **3.3.1 Multicarrier technology - Orthogonal Frequency Division Multiplexing (OFDM)**

The Orthogonal Frequency Division Multiplexing OFDM is multiple carrier modulation technique that was first introduced over 50 years ago according to Sassan Ahmadi from LTE-A, A practical system approach to understanding the 3GPP LTE release 10 and 11 radio access technique. The basic principle of OFDM is to transmit data bits in parallel quadrature amplitude modulation QAM modulation subcarrier using frequency division multiplexing.

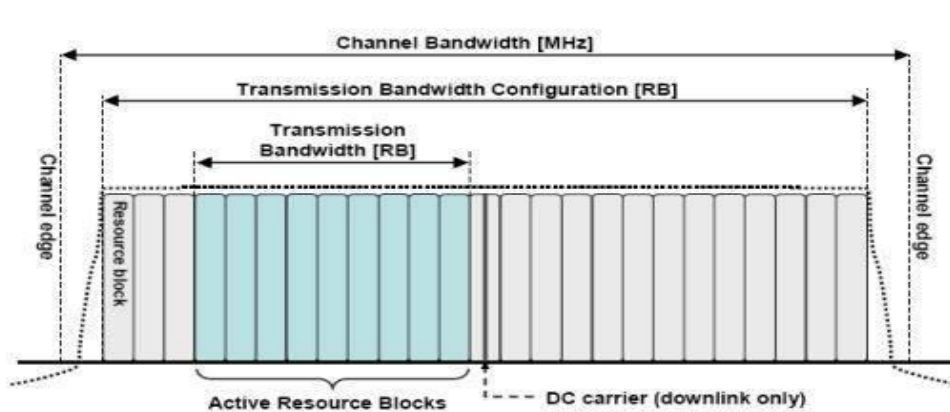
In order to facilitate the proper functionality of OFDM the carrier spacing must be appropriate selected such that each sub-carrier is situated on other sub-carrier zero-intersection points in the frequency domain, this kind of system allows multiple access through channel division that must be in a set of orthogonal subcarriers which are in distributed groups depending on each user need, this process happens in the downlink.

### **3.3.2 Single Carrier Orthogonal frequency division multiplexing (SC-OFDM)**

In the uplink position, the LTE uses SC-OFDM, in order to achieve better multi-user orthogonality at the receiver there is a need for enabling of efficient frequency domain equalization.

One of the main disadvantages of OFDM is the existence of a significant variation of power in the output signal that requires to use linear amplifier which has low efficient, power consumption is important for the uplink that is why SC- OFDM is regarded as a suitable technique which has better efficient alternative in terms of power that preserves most of the OFDM advantages.





<b>Channel BW [MHz]</b>	<b>1.4</b>	<b>3</b>	<b>5</b>	<b>10</b>	<b>15</b>	<b>20</b>
<b>Number of RBs</b>	6	15	25	50	75	100

**Figure 3.1** LTE Resource Blocks and Bandwidth which has up to 20 MHz

### 3.3.3 Time division duplex (TDD) and frequency division duplex (FDD)

The long-term evolution LTE is capable of operating in both duplex scheme bands paired frequency division duplex FDD and unpaired time division duplex TDD, time division duplex both uplink and downlink allocated in the same frequency for transmission but differ in time slots while frequency division duplex both  $F_{c1}$  and  $F_{c2}$  are assigned in two separate frequencies but utilize the same time slots for transmission. In the case of adjacent frequency bands, it uses guard bands. Both data transmission and received data happen at the same time.

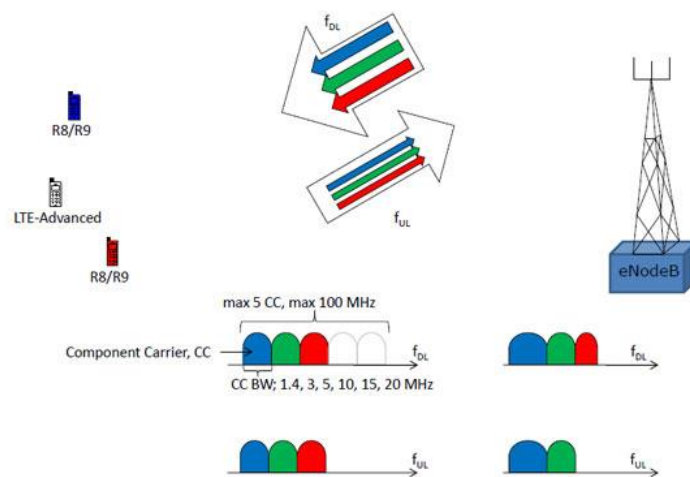
By contrast, however, the choice between FDD and TDD is driven by spectrum availability most operators and vendors can deploy both networks in contrast to achieve bandwidth availability.

### 3.4 Carrier Aggregation

The idea behind the implementation carrier aggregation (CA) was to improve system capacity and that can be achievable through the addition of more bandwidth, there is no doubt that there is faster acceleration increase in data being needed due to the highest number of increase to broadband services such faster internet connection, video download, this has forced 3GPP to seek other methods for further evolve LTE.

LTE-A was developed which is evolved LTE, one of the major features of LTE-A is Carrier aggregation. CA is technology to combine up to five separate LTE carriers in one data channel

in order to improve data capacity, transmission bandwidth and bitrate. Carrier aggregation can be done in both FDD and TDD this also enables LTE to increase the peak user data rate and overall capacity and exploit fragmented spectrum allocation. Scientific evidence proved that the number of uplink component carriers is never larger than the number of downlink component carriers.



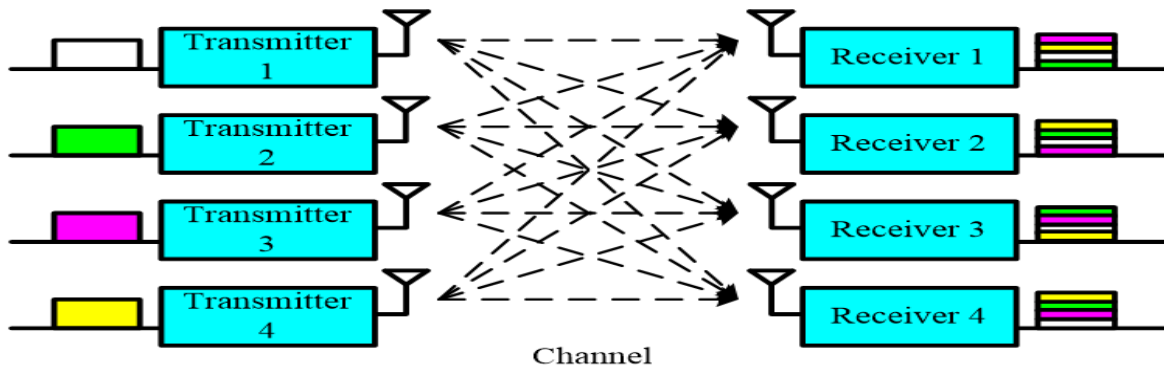
**Figure 3.2** CA in the downlink (DL) and uplink (UL) with aggregated CC, adopted from 3GPP website (internet), [www.3gpp.org](http://www.3gpp.org)

LTE-A has the following benefits:

- The high peak data rate
- Spectrum flexibility
- Both uplink and downlink transmission improvement
- Backward compatibility to support older technology

### 3.5 Multi-input multiple outputs MIMO

In wireless communication, MIMO can be defined as a method to multiply radio capacity through



**Figure 3.3:** Multi input Multi output MIMO is shown to increase Data capacity adapted from the internet communication DSP logarithm. [www.ee.nthu.edu.tw](http://www.ee.nthu.edu.tw)

transmission by using multiple antenna scenarios to improve channel capacity and transmission reliability which it can be  $4 \times 4$ ,  $2 \times 2$  or  $2 \times 4$ . Multiple inputs and multiple output system MIMO systems consist of a MIMO transmitter with  $n_{xt}$  transmitter antenna and receiver.

Or channel between transmitter and receiver antenna putting  $x_k(t)$  represents the transmitted data signal from the  $k$ th transmitted antenna at time  $t$  the received signal (Rx) at the  $L$ th antenna can be written as:

$$y_l(t) = \sum_{k=1}^{N_t X} h_{lk}(t) * x_k + n_l(t) \quad (3.1)$$

In frequency domain it can be written as follows:

$$Y_l(\omega) = H_{lk}(\omega) X_K(\omega) + N_l(\omega) \quad (3.2)$$

Multiple antenna transmission can be written mathematically as follows:

$$n + Hx = Y \quad (3.3)$$

$Y$  and  $x$  represent the  $n$ th receive and transmit vectors while  $H$  and  $n$  represent the  $n$ th matrix and the noise vector respectively.

High spectrum efficient and high data throughput in LTE-A

The most straightforward way to define high spectrum efficient and data throughput including frequency flexibility in LTE-A is to discuss the benefits and characteristics of LTE-A, as it was explained in the previous discussion that the purpose of providing MIMO, CA and higher

modulation scheme in LTE-A is to achieve better data throughput and high spectrum efficient including frequency flexibility.

### 3.6 LTE Deployment

Long-term evolution LTE deployment is very similar to the older version of GSM but differs in terms of implementation where base station becomes eNodeB, LTE deployment must support carrier aggregation, in LTE deployment the following consideration needs to be taken in account:

- All base-station need to provide sufficient coverage

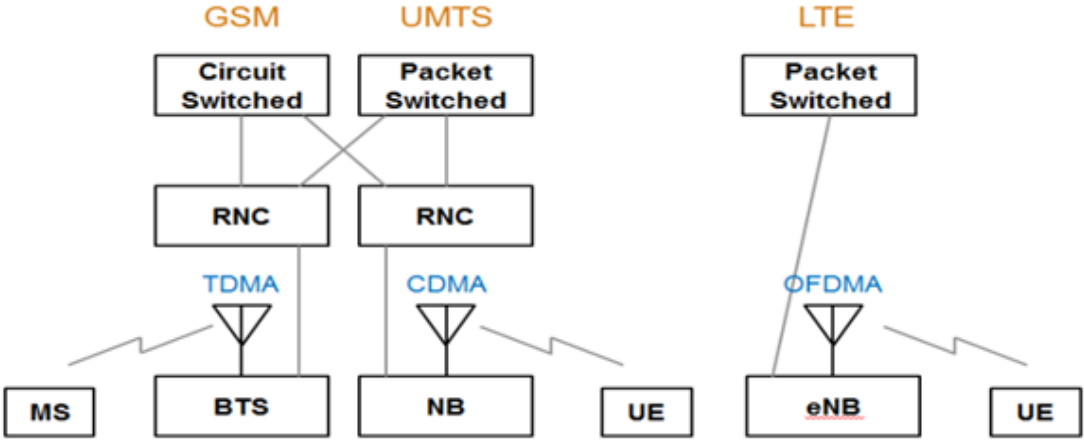


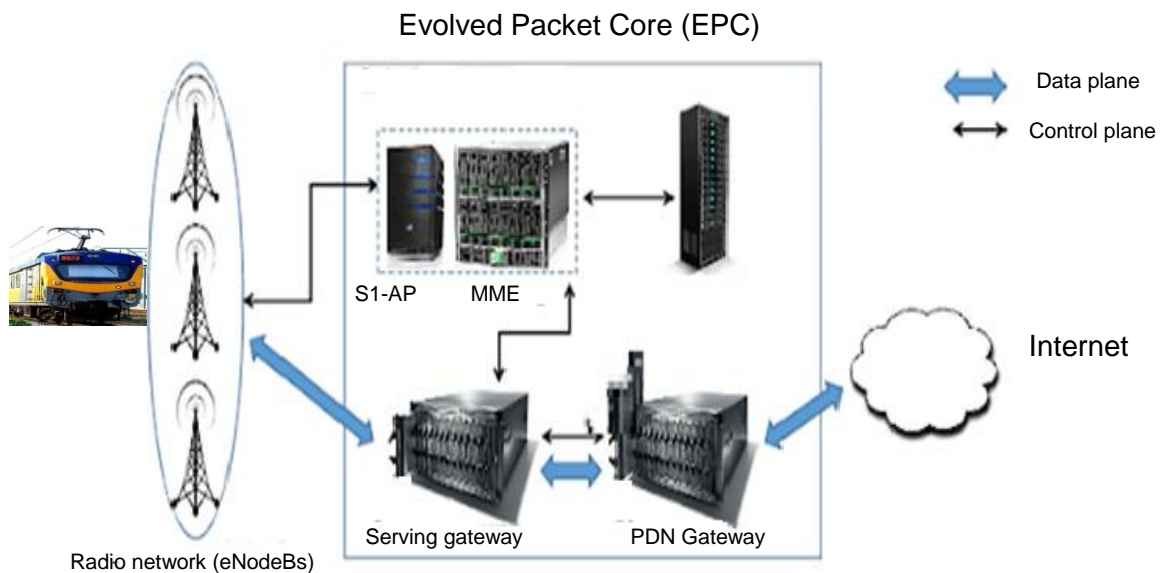
Figure 3.4: Network Solution GSM-UMTS and LTE adapted from the internet maths works

- Cell interference management mechanism Handover management
- Improve data rates in the hotspot

### 3.7 The bandwidth scalability of LTE

From the following carriers (1.4, 3, 5, 10, 15, 20) MHz the bandwidth scalability enables the user to access multiple channels to achieve high peak data rate. According to Moustafa M Nasralla, Ognen Ognenoski and Maria G Martin LTE has more advantage in larger bandwidth to maximize the data rates and achieve optimum spectral efficiency(Nasralla et al., 2015).

Network solutions from GSM to LTE adapted from math works. As it has been illustrated above the first implementation of the digital network was GSM with only circuit switch capability (voice). The Invention of UMTS in the mobile industry has added communication technology to have packet switch. While the demand for data usage started to increase the mobile networks were no choice to evolve into Long-term evolutions (LTE) which has better ability to accommodate more data users. As shown from fig 13 there are various multiple access technologies that were implemented in the development of digital wireless technology such as in GSM with TDMA and



**Figure 3.5:** Architecture of the EPC with Radio network elements (eNodeBs) (Raza et al., 2017)

UMTS with CDMA while in LTE OFDMA and SC-FDMA was deployed. The core network of LTE is Evolved Packet Core (EPC) which has been implemented and developed as all IP. In previous section it was discussed the development stages which indicates the first improved digital network GSM-R and the current period which has adopted the packet switching system due to the increasing and growing number of data services, the development of UMTS was to provide cost-effective data transmission with the aim of better flexibility and data accessibility and availability all the time(Raza et al., 2017).

Through current scenario and the predictions of the future in growing data demand and services network providers and pushed to higher technology that supports more data effectiveness and

better spectrum efficiency with low latency and improved quality of service that how LTE was born.

### **3.8 Advantages of LTE**

- As already been specified in previous discussion LTE support all IP as such it is a packet-oriented network while also support voice calls.
- The LTE support MIMO which provide higher data throughput and reduction of bit error rate (BER) since it uses advanced signal processing algorithm.
- In the uplink position, it uses SC-FDMA which has less power consumption to extend battery life.
- In the downlink, it supports FDMA so downlink channel resources can be utilized effectively as such capacity can be increased so that many users utilize many different channels.
- It has higher bandwidth availability and low latency to improve the quality of service (QoS).
- Since it has improved architecture such that handover is better smoother which it has fewer interruptions during streaming and downloads.

### **3.9 Disadvantages of LTE**

- Even though scientific evidence shows that LTE is reliable and better enhanced but it has some disadvantages such as.
- Most of the existing handset (GSM handset) does not support LTE, so users need to purchase the one that supports LTE.
- Network deployment very costly since it needs to support FDD and TDD.
- Since LTE is the latest network it needs to be matured and be very stable so multimode is needed to support the older system such as 2G, 3G in case LTE is not available.
- The LTE is very sophisticated it needs skilled engineers to maintain which is very costly.
- It consumes more data and battery when in use.

### **3.10 Conclusion**

This chapter presented the most obvious view of the LTE and LTE-A which development emphasis requirements is to increase bandwidth and data efficiency flexibility accessibility and availability, there is no doubt that the deployment of these networks brought better challenges to wireless telecommunication were data is on higher demand and the exponential number increases rapidly. Even though there is nothing wrong with 3G technology, and it did meet its mandate and the desired specification. The initial growth and increasing demand for data users show that 3G is not capable of handling the current demand without any network interruptions and also providing better results.

## Chapter 4

### The Long Term Evolution for Railway (LTE-R)

#### 4.1 Introduction

This chapter presents the most fundamental part of the entire research project, the long-term evolution for railway (LTE-R). Through scientific study, it has been proven that LTE-R is the best suitable network for high-speed railway (HSR). LTE-R has adopted a similar version of 4<sup>th</sup> generation LTE commercial broadband technology. Due to the increase broadband services to improve quality of services QoS in railway operations including higher bandwidth improved data capacity to enable it to transmit onboard video surveillance, data for train control, enhanced security systems, improved data throughput.

Current developments in High-Speed Railway (HSR) allows the train to reach a speed of 350Km/h and that must be achieved without any data loss with high throughput and in fact this is an associate of novel broadband mobile communication system for high-speed railway (HSR), LTE-R has been proven as best candidate for broadband requirements to provide users with high data rate minimum data delay compared to the existing global system mobile for railway GSM-R(Mart et al., 2013).

The LTE-R is an all IP network, with evolved packet core network and access radio network UMTS terrestrial radio access network (UTRAN). LTE represents a very imperative step which forms the platform in which the future of railway communication network is built. The evolved packet core (EPC) is the core network of LTE-R, which has been implemented and developed as an all IP oriented network. The current scenario and the predictions of the future by looking at the number of growing data services and data on demand in railway operations maintenance services as well safety and security pushed to higher technology that supports more data and service effectiveness including better spectrum efficiency with low latency and improved quality of service (QoS).

The Evolved UMTS Terrestrial Radio Access Network E-UTRAN is access network structure of LTE-R which is the radio access interface and Evolved Packet Core EPC which is known as System Architecture Evolution (SAE) which both forms the major component of the Evolved Packet System (EPS).LTE-R has enhanced LTE-R features to support high encryption and authentication for security purposes(Tingting & Bin, 2010).



## **4.2 Background**

Before the implementation of GSM-R as a railway standard for communication, railway operators invested in different analog communication technology which it was very problematic such as less channel availability network congestion, short-range transmission, and ageing system (very problematic in maintenance issues). In the early 90s, the European Railway Traffic Management System ERTMS and International Union railway (UIC) agreed to adopt the digital commercial communication network GSM as a suitable replacement of GSM-R in railway environment around European countries. The agreement was motivated to improve issues such as speech quality, network channel congestion, roaming and interoperability. Ever since such time GSM-R has been deployed in many different countries in Europe, Middle East, Asia and Africa.

During mid-90s Global system mobile for railway GSM-R was deployed, implemented and tested in many different countries in Europe and China, so far it has provided a wonderful improvement in railway scenarios such as speech quality and railway communication.

## **4.3 Developing literature**

The inception of smart railway started with the evolution of GSM-R, which is considered as the key basis in which railway communication standard is built. Currently, the GSM-R remains the most popular and best digital communication technology used between trains and train control operations (TCO) for such as operations and maintenance within railway infrastructure. It operates in many countries in Europe including all associate states members of the European Union (EU), Asia, America and Africa. The railway industries began to develop more progress after 2005 with the advent of the internet of things (IoT). This also has projected to the development of smart city projects which led to the development of smart ticketing, passenger information, rail analytics and route scheduling and planning. IoT enhancement based solution provided railway operators with a better solution and competitive advantages and also discovered improved business models that were already impacted railway industry negatively. Technology such Wi-Fi represents the most obvious implementation of onboard internet access. The supply of broadband internet access to public trains is already been discussed in detail in the chapter on broadband scaling and enhancement for fast-moving trains.

Due to the continuous changes in modern technology railway networks will have to evolve in order to adapt to the increasing pace and to provide reliable transmission of video and high

data. To support seamless mobility high data throughput, better spectrum flexibility, faster handover with no data loss and minimum latency. LTE-R a version of LTE has been adapted to the railway technology of the future. LTE-R represents the biggest step towards the future of railway communication.

#### 4.4 Long-term evolution for railway (LTE-R) critical services

- The LTE-R has been adopted which is a similar version with that of the commercial network the following services are applicable:
- Information transmission of a control system must compatible with European Train Control Services (ETCS-3)
- Real-time monitoring such as video monitoring mechanism to provide track conditions bridges and tunnels in case of a natural disaster
- Train multimedia dispatching to improve dispatching data (dispatching efficiency)
- Railway emergency communication when a natural disaster occurs
- Railway internet of things (IoT) to provide train tracking and goods train.

#### 4.5 Railway network progression from analog Network to LTE-R network



**Figure 4.1:** The network progression from MPT1327 to LTE-R

From the two decades ever since the development of digital railway communication technology, railway network has produced a positive growth and exponential progression. With the support of European railway traffic services (ERTS) and International railway union (UIC) to adopt third generation partnership project release 8 specifications, the railway network has evolved in order to support railway communication issues and to adapt with the current high spectral efficiency.

#### **4.6 The Access network**

The Evolved universal terrestrial radio access network E-UTRAN is the access network structure of LTE-R, unlike GSM-R with base transceiver station BTS and base station controller BSC, LTE-R has evolved nodeB (eNodeB) which is the only network equipment deployed, the eUTRAN has the flat architecture of all IP network(Tingting & Bin, 2010).

#### **4.7 Core Network**

The primary network of LTE-R is Evolved packet core (EPC) with fully IP switched network devices and a backward mechanism to support existing GSM-R network(Ibrahim et al., 2016).

#### **4.8 Main LTE-R Technology**

- a) Modulation Technology
- b) Coding Technology
- c) OFDMA and MIMO

##### **4.8.1 Modulation Technology**

Modulation Technology of LTE-R is very identical to that of commercial network LTE. Downlink modulation quadrature phased shift keying (QPSK),16Quadrature amplitude modulation and 64Quadrature amplitude modulation technology are being used in both physical downlink shared channel (PDSCH) and physical Multi broadcasting channel (PMCH).

**Table 4.1:** LTE-R extended features to support railway backward compatibility

Parameter	GSM-R	LTE-R
Data type	Circuit switch data	Packet switch data
PTP Call	Circuit switch voice	SIP-based Voice call
PTT	VDCS/VBS	eMBMS-based LTE group Communication
Emergency call	VGCS	eMBMS-based LTE group Communication
Priority	eMLPP	QCI, ARP
Functional Addressing	SCP	SCP
Local Depended Addressing	SCP	SCP
Access Matrix	SCP	SCP

Figure 4-1 illustrates backward compatibility features which are necessary for LTE-R, the main aim is for LTE-R network to support circuit switched operation while its core mandate is all IP. Compatibility is imperative to avoid network interruptions, improves network continuous availability. The main purpose is to improve QoS and network reliability.

#### 4.8.2 Coding Technology

While GSM-R uses fire code and parity code, LTE-R makes use of turbo code to achieve high data throughput. The turbo coding works by combining both random interleave and convolution code method called soft input and soft output SISO decoding algorithm. Component decoder requires three different types of soft input which are applicable in decoding processes which are data bits, parity information and prior information.

#### 4.8.3 OFDMA and MIMO

Unlike GSM-R orthogonal frequency division multiplexing Access OFDMA can be used in LTE-R network in order to increase high data rate, OFDMA is a method of higher order digital signal modulation that splits data rate modulation stream across several separate narrowband channels at different frequencies to increase bandwidth flexibility. It is obvious that to achieve high data throughput, system capacity and frequency flexibility LTE-R has been developed to support multiple carriers such as multiple inputs and multiple outputs MIMO technology. In LTE-R downlink position 2x2 configuration is applicable which means two transmit antenna and two

receiving antennae. In uplink position, 1x2 configuration is applicable which is one transmit and two receiving antennas(Liu & Ai, 2016).

#### 4.9 Long Term Evolution (LTE-R) main features and solution

The fact that LTE-R has adopted similar version with that of commercial technology (LTE) similar features has been implemented to meet 3GPP specification requirements and also to be regarded as a better wireless broadband technology that is suitable for faster speed with the spectrum flexibility seamless handover and improved mobility. It needs to meet a peak data rates required including download rates. It also needs to be flexible in both duplex scheme such as TDD and FDD with access scheme OFDM (downlink) and SC-FDMA (uplink). Downlink modulation QPSK, 16QAM, 64QAM while uplink modulation QPSK, 16QAM. Frequency range is 700MHz-2.6GHz (FDD) and 2.3GHz 3.5 GHz (TDD) in a bandwidth that ranging from 1.4MHz-20MHz, according to Samsung LTE-R the peak downlink can reach a speed of 150mbs/s for 20MHz and peak uplink can reach a speed of 50mbs/s also for 20MHz. Samsung has been chosen to develop the first-ever LTE-R network in South Korea for the preparations for the Winter Olympic Games (2018).

#### The LTE-R network architecture

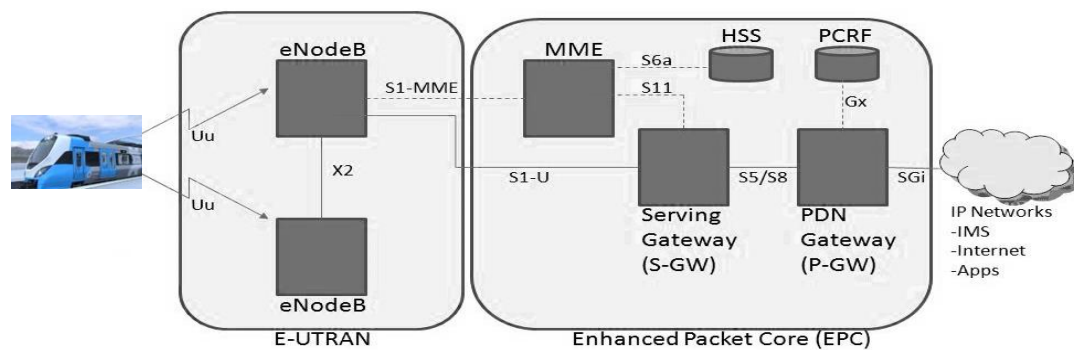


Figure 4.2: The LTE-R network architecture

The evolved packet core (EPC) is the primary network architecture of LTE-R which is IP based system, EPC can support multicast and broadcast streams, it also supports scalable bandwidth ranging from 1.4 to 20 MHz in both frequency division duplex (FDD) and time division duplex (TDD) duplex scheme. LTE-R network architecture has been designed to support seamless handover for both voice and data.

**4.11 Long Term Evolution for Railway Deployment**

The Evolution of wireless broadband for railway scenarios deployment is very similar to the older version of GSM-R but differ in terms of implementation were base station becomes eNodeB, in LTE-R deployment the following consideration needs to be taken in high

**Table 4.2:** Major parameters of LTE and LTE-R

Parameter	LTE	LTE-R
Frequency	900MHz, 1.8MHz, 2.6MHz	450MHz,800MHz,1.4MHz,1.8MHz
Bandwidth	1.4-20 MHz	1.4-20MHz
Modulation	QPSK/M-QAM/OFDM	QPSK/16-QAM
Cell range	1-5Km	4-12Km
Cell configuration	Multisector	Single sector
Peak data rate,DL/UP	100/50Mbs/Hz	50/10 Mbps
Peak spectral efficiency	16.32bps	2.55bps/Hz
Data Transmission	Packet switch	Packet switching(UDP data)
Packet retransmission	Yes(IP packet)	Reduced ( UDP packet)
MIMO	2×2, 4×4	2×2
Mobility	Max.350Km/h	Max.500Km/h
Handover success rate	≥99.5	≥99.9
Handover process	Hard/Soft	Soft no data loss
Native ( all IP)	Yes	Yes

consideration:

- All base-station need to provide sufficient coverage
- Cell interference management mechanism, Handover management
- Improve data rates in the hotspot

**Table 4.3:** Long-term evolution for Railway (LTE-R) entities

Entity	Description
<b>EU</b>	It links to eNodeB via LTE-Uu interface
<b>eNodeB</b>	It provides the subscriber with radio interface and performs radio resource management RRM functions such as radio admission control including eNodeB Measurement configuration control.
<b>MME</b>	A mobility management entity is the key control entity for E-UTRAN. It provides subscriber authentication and subscriber profile download EPS mobility management and EPS session management.
<b>S-GW</b>	The Serving gateway performs functions such as terminating the interface towards and E-UTRAN. It also serves as a local point for a data connection for inter-eNode(intra-E-UTRAN).
<b>P-GW</b>	The Market data network PDN gateway provides user equipment with access to PDN by allocating an IP address from the address space of the PDN, the P-GW also responsible for handover between 3GPP and non-3GPP system (Intra RAT).
<b>HSS</b>	Also known as a core network architecture, home subscriber server is central database where all subscriber profile is being stored, it provides subscriber verification to assign permission including user profile download for mobility management entity (MME).

Table 4-3 indicates Major system parameters of LTE and LTE-R adapted from high-speed railway communication from GSM-R to LTE-R by Ruisi He, Bo Ai, System entities are the key from the system functionality and to the entire LTE-R network architecture, in order for the system to perform optimum and effective those entity need to be interworking accurately.

#### **4.12 Advantages of LTE-R**

- LTE-R support MIMO which means higher data throughput
- It also Support SC-FDMA uplink and FDMA access technology to improve effectiveness reliability and efficient
- It improves Frequency flexibility (spectrum availability/bandwidth) low latency and better quality of service QoS which it has fewer interruptions during connection.

#### **4.13 Disadvantages of LTE-R**

- In LTE-R Network deployment very experience
- LTE-R still new not matured yet multimode equipment is required to support existing GSM-R to avoid inconveniences (backward compatibility).
- LTE-R is a very sophisticated network it requires skilled personnel for maintenance which very costly
- Battery life does not last in the portable LTE-R handset.

#### **4.15 Conclusion**

The current limitation in the Global system mobile for railway has pushed to the evolution of railway wireless broadband network to support the latest railway services and challenges. Long-term evolution for railway LTE-R is regarded as a suitable network to replace global system mobile for railway (GSM-R). The idea is to enhanced railway services .in order to achieve services effectiveness efficient and reliability and quality of QoS LTE-R is mandatory to be implemented. There is no problem in GSM-R to support voice calls and normal shutting. That also means GSM-R met its development requirements such as normal voice calls, better speech quality, interoperability and roaming.



## Chapter 5

### Mobile Broadband Scaling and Enhancement for Fast Moving Trains

#### 5.1 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 (Choi et al., 2015). 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 (Calle-Sanchez et al., 2013). The public safety network mainly used by firefighters, 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 onboard passengers also require high rate data services which are 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.

#### 5.2 Related Work

The work in the literature on the LTE-R communication technology is related to the modelling of channels with a layout of LTE-R network (Institute, 2011; Liu et al., 2012; Guan et al., 2011). In (Chen et al., 2017), Co-existence 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 (Ren et al., 2016) uses co-ordinated multipoint (Comp) by utilizing a 2-step precoding in presence of a multi-user Comp. The paper in (Saad et al., 2016) and (Sun et al., 2013) proposes scheme related to power control and interference

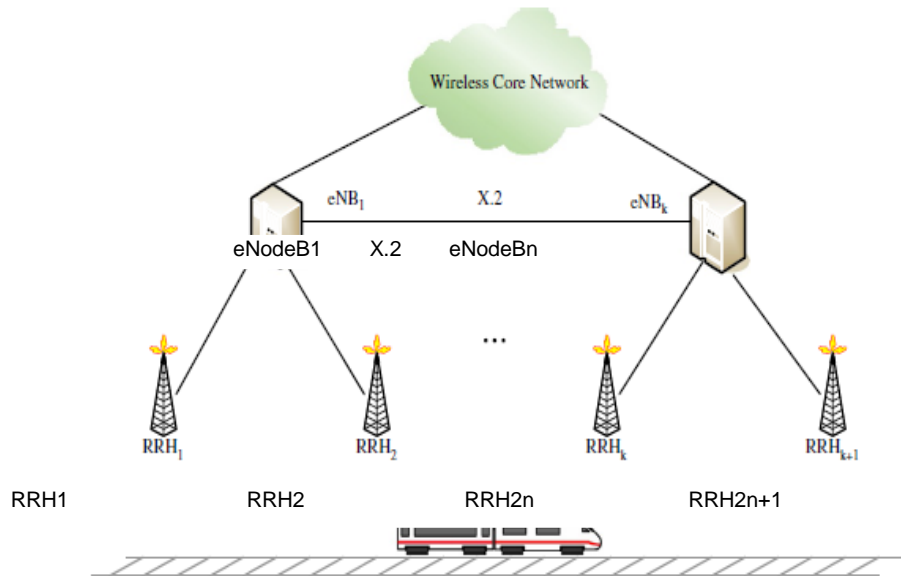
management in 3<sup>rd</sup> Generation partnership project (3GPP). For all the schemes proposed (6-9), in order to achieve benefits in form of better quality of service (QoS), fairness in assignment and load balancing a complex feedback mechanism is required to provide channel state information (CSI) additionally. The work in (Chen et al., 2017) employed enhanced inter-cell interference cancellation (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 anodes. In (Ahmad et al., 2017), 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 anodes, public safety LTE anodes, and LTE-R anodes. The radio resource assignment management is investigated like a resource sharing scheme which is aware of interference in (Zhang et al., 2013), a joint scheduling mechanism in (Wang et al., 2013), and a game based resource allocation in (Wei et al., 2016). 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 (Ai et al., 2014). The high-speed railway unique property (Ai et al., 2015), the presence of the line of sight (LOS) component. Due to the unique characteristics of high-speed railways (Chen et al., 2011), for instance, the existence of the LOS component and the deficiency of scattering in a series of bridges which seriously influence the MIMO performance (Bhagavatula et al., 2010). The work needs to be done on enhancing characteristics of antenna arrays in order to enhance the LTE-R efficiency (Bhattacharya-De, 2012-Raza et al., 2017). The LTE-R (Tingting & Bin, 2010), 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 took 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 gets 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) (Liao et al., 2014) 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 by the conclusion.

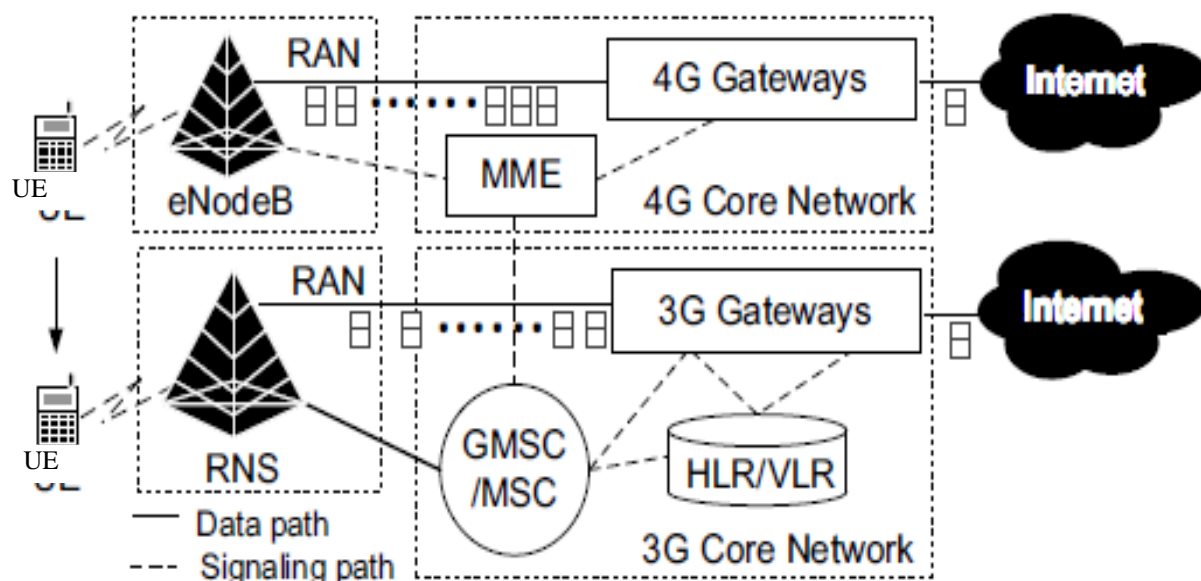
### 5.3 Problem Statement and Network Parameters



**Figure 5.1:** LTE-R system based on RRHk,RRH2n+1

The LTE-R is a solution for 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, 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 anodes which are connected to each other by X.2 line and in the backbone connected to the wireless core network as shown in Figure 5.1 The RRH is used in all the three types of cellular systems. The railway communication system which uses RRH to deploy fibre network to send information along the track. The LTE-R, LTE public mobile network and LTE public safety deployed are equipped with the anode of two interfaces UMTS and LTE. The anode provides access to user equipment's (UE) with different traffic requirements and different mobility. The 4G LTE network

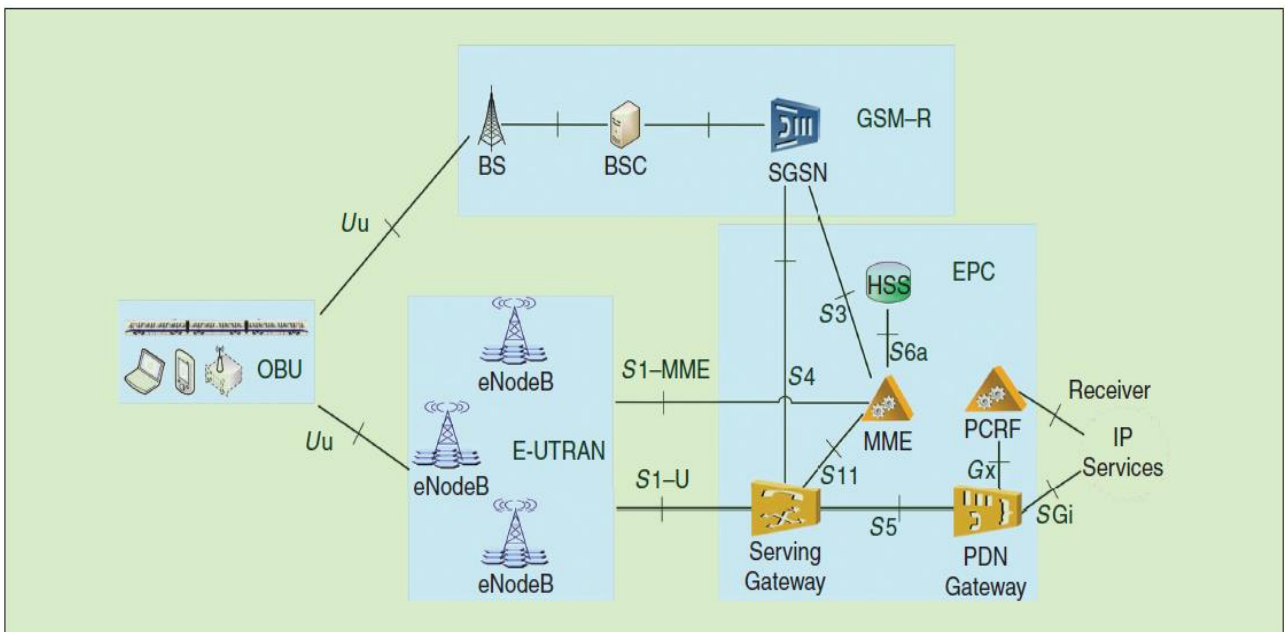


**Figure 5.2:** 4G-3G core network architecture (Bhattacharya & De,2012).

structure and its 3G network are explained in this section. The LTE network with its 3G interface is illustrated in Figure 5.2 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 anode 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 which provides data (packet) service and provides a route between the RAN and the internet.

The UMTS (Balyan, 2017) interface adopts VSF-OFCDM in order to allocate OVSF codes of a code tree spread in two dimensions: time and frequency. The LTE/LTE-A uses orthogonal



**Figure 5.3:** The LTE -R architecture for HSR communication(He, Ai, Wang, Guan, Zhong, Molisch, et al., 2016).

frequency division multiplexing access (OFDMA) which uses a fixed frame for downlink transmission. The size of a radio frame in OFDMA is of 10 Ms which is divided into 1ms, 10 subframes. Each subframe is further divided into 2 slots of 0.5ms. Each slot has 7 or 6 consecutive OFDM symbols. A basic scheduling unit in LTE is a resource block (RB) which is composed of a time slot in the time domain. And in frequency domain 12 consecutive subcarriers. The RB(s) are allocated to a call(s) when a call arrives or may vary at each transmission time interval (TTI).

## 5.4 LTE-R Services

The LTE-R communication architecture for railways is given in Figure 5.3 (3GPP, 2016). 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), a packet data network (PDN).

The LTE-R communications are used to provide services with minimum latency and least failure. The suggestion is given in the E-Train project (Tang et al., 201) LTE-R must provide the services given below with a 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 of less than 50 Ms. The information related to the location of the train is detected by radio block centre (RBC) and radio equipment on the train. This will enhance the accuracy of the 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 centre and the train in real time with a delay not greater than 300 Ms.

3) *Multimedia dispatching:* The LTE-R provides information about drivers and yards to the dispatcher and improves dispatching efficiency(He, Ai, Wang, Guan, Zhong, Molisch, et al., 2016).

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 two of the railway authorities but to public safety departments like ambulance, fire-fighters, police etc., for the faster rescue operation. The communication needs to be fast, accurate and may contain images or videos with a delay not greater than 100ms when containing videos or images.

5) *Internet of Things (Iota) of Railway Communications*: The railway Iota 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.

## 5.5 Proposed Work

The LTE system consists of train access units (TAU) which are the onboard 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 fibre. The passenger 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:

- i. Generate a call.
- ii. Check the call type (A, B, C)?
- iii. For HP (Check whether a voice or data call?) Data call assigns the 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. When a voice call assign UMTS interface.
- iv. For MP (Check whether a voice call or data call) Data call assigns the 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 to assign UMTS interface.

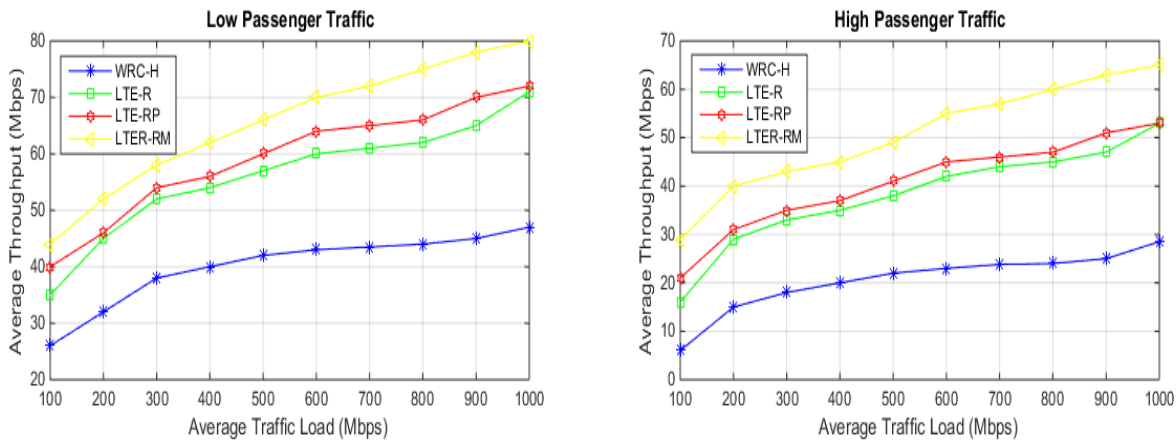


- v. For LP (Check whether a voice call or data call) data call assigns the LTE interface of LTE-R network. If no RBs available in LTE-R network, use mobile LTE network which is supporting the LTE-R network to handle LP calls. Voice call assign UMTS interface.
- vi. End the call and release the resources.

The calls are served by onboard wireless units, which request for capacity from TAUs. The TAUs request for capacity from RRHs which are connected to the eNodeB. The algorithm works fine for any type of call, any location when a number of users are limited and it's in the 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 centre will facilitate the e 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 request to LTE public mobile network eNodeB, which may be placed at a larger distance as compared to LTE-R anode placed closely. These calls handled will be will be at higher latency. When the capacity of LTE-R becomes available, some of the calls 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 this TAU, the handover request is not between the user equipment and anode. The TAU request for handover to RRH (anode), 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 anodes 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 anode 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 TAU 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)(Liao et al., 2014), 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

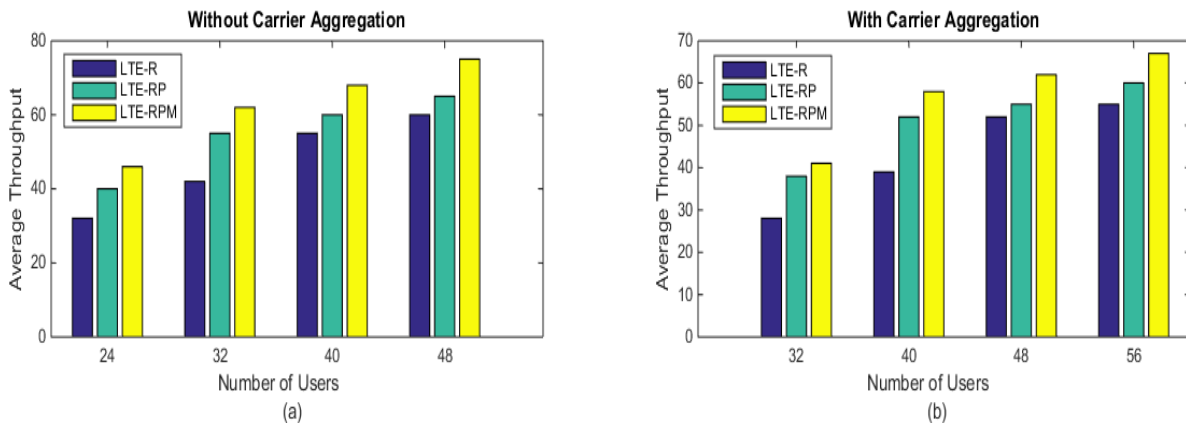


**Figure 5.4** The average throughput comparison of different sharing method in: (a) Low passenger traffic scenario, (b) high passenger traffic scenario.

employment of CA, UE can simultaneously use two or more frequency bands of 20MHz, the complete description of which will be done in the sequel of this chapter.

## 5.6 Results and Simulations

In this section, the performance of the proposed work is investigated using Matlab. The results are compared for various scenarios for the 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 2.5Km from the track and with the antenna of height 45m, a public mobile LTE network is placed at a distance of 4Km 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 a normalized mean value 1. The LTE interface capacity used is 345.6 Mb/s and of UMTS interface 256R (3.4Mb/s). The same traffic is generated for network systems compared in Figure 5.4 and Figure 5.5: LTE-R only (LTE-R), LTE-R+LTE public safety (LTE-RP), LTE-R+LTE public safety + LTE public mobile network (LTER-RM), reservation of capacity for handover in LTE-R systems. In Figure 5.4, the average



**Figure 5.5:** Traffic Load with Carrier Aggregation and without Carrier Aggregation

throughput of the user calls is compared with average traffic load in Mbps, the throughput increases and after some time there is a 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.

The network is simulated with CA capability means LTE-A is used and is compared with the network without CA capability in Figure 5.5, the number of users used is more in CA capability systems. The throughput is almost similar to the throughput achieved in the network without CA, even though a number of users are higher. The CA technique provides higher bandwidth and increases throughput.

## 5.7 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 fully utilized. Instead of deploying new BS, it's better to use the public mobile network for coverage in remote areas and for providing better QoS to onboard passengers. The work uses three networks alone and sharing modes. The throughput of users calls increases. Further, the simulations are done to 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. .

## Chapter 6

### Utilization of OVSF codes for service Enhancement of LTE-R

#### 6.1 Introduction

Providing internet in trains becomes a huge challenge, especially in trains moving at a velocity of up to 350km/h(Ab, 2014). The work done in (Ab, 2014) proposes providing internet in trains using multiple input multiple (MIMO) in LTE networks has been presented, aggregation and handover IP level using multiple communication links. The legacy of GSM-R which is the currently installed railway network is unable to support the required data. The recent spark in data required to support high demand in current railway services has pushed railway operators to evolve existing network to LTE-R(Tingting & Bin, 2010). The 3GPP has adopted a specified MIMO scheme for LTE specifications because it offers significant increases in data throughput and link range without any increased bandwidth(Nsiri & Nasreddine, n.d.). Current services require an increase internet capacity in railway services to support the current demand for data transmission such as safety and security, operations, required maintenance data as well as on-board wireless connectivity. The Long Term Evolution for railway (LTE-R) has adopted a similar version of 4<sup>th</sup> generation LTE commercial broadband technology. Due to the increase broadband services to improve quality of services QoS in railway operations including higher bandwidth improved data capacity to enable it to transmit onboard video surveillance, data for train control, enhanced security systems, improved data throughput. The current developments in High-Speed Railway (HSR) allows them to reach a speed of 350Km/h and that must be achieved without any data loss with high throughput and in fact, this is an associate of a novel broadband mobile communication system for HSR(He, Ai, Wang, Guan, Zhong, Molisch, et al., 2016).

Recent studies about LTE-R has proven that only long-term evolution (LTE) is the best candidate for broadband requirements to provide railway operators with high data rate with minimum delay compared to the existing global system mobile for railway GSM-R(Mart et al., 2013). The LTE-R is an all IP network, with evolved packet core network and access radio network UMTS terrestrial radio access network (UTRAN). LTE represents a very imperative step which forms the platform in which the future of railway communication network is built. The evolved packet core (EPC) is the core network of LTE-R, which has been implemented and developed as an all IP oriented network. The current scenario and the predictions of the future

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by looking at the number of growing data services and data on demand in railway operations maintenance services as well safety and security pushed to higher technology that supports more data and service effectiveness including better spectrum efficiency with low latency and improved quality of service (QoS). The Evolved UMTS Terrestrial Radio Access Network E-UTRAN is access network structure of LTE-R which is the radio access interface and Evolved Packet Core EPC which is known as System Architecture Evolution (SAE) which both forms the major component of the Evolved Packet System (EPS). LTE-R has enhanced LTE-R features to support high encryption and authentication for security purposes(Tingting & Bin, 2010).

## **6.2 Related work**

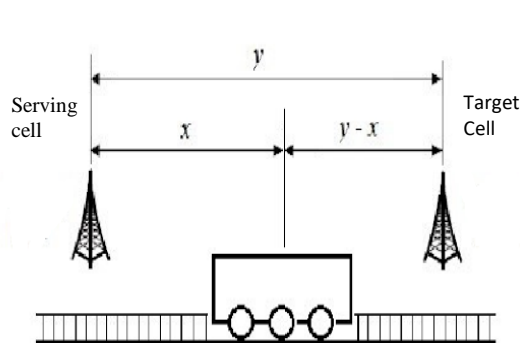
The work in the literature on the LTE-R communication technology consists of two sections and is related to key features of LTE-R such as high mobility support scheme handovers and data throughput analysis over MIMO. Scientific study has proven that LTE-R is a suitable network that is capable to support seamless mobility in high-speed railway (HSR). The LTE-R consists of two essential features such as multiple inputs and multiple outputs (MIMO) and handovers which are the key elements for future research in broadband wireless communication. As a matter fact the MIMO technique enhance the reliability, availability and efficiency method to increase peak data rates including multiple data transmission this means it supports high coverage high data throughput better robustness low bit error rate and better spectral efficiency(Mohandas et al., n.d.) in both transmitting antenna method and receiving antenna method such as MIMO technique. Multiple inputs multiple outputs MIMO enhanced the efficiency and reliability of data transmission is considered (Li et al., n.d.). The work in literature also features on LTE-MIMO performance improvement when using antenna arrays. In high-speed railway (HSR) there is a need to increase high data capacity and enhance systems throughput in order to meet the critical network challenges such as network congestion and spectrum efficiency(He, Ai, Wang, Guan, Zhong, Molisch, et al., 2016). The LTE-R support wide bandwidth and all IP architecture(Zhang et al., n.d.). One of the essential requirements to provide high speed, data throughput and spectrum efficiency is to employ MIMO technique(Alexa et al., 2013). In (Liu, Ai, Chen, et al., 2016) the impact of mutual coupling for antenna array configuration in high-speed railway scenario is studied while on another hand in (Li et al., n.d.) the multi-antenna transmission scheme in high-speed railway communication has been studied. In this chapter, we discuss the impact of mutual coupling in high-speed railway

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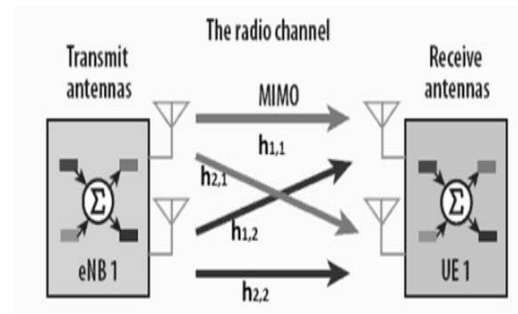
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and multi-antenna transmission without coupling. Antenna transmission can either be conventional MIMO or massive MIMO.

A different number of mechanism with transmission schemes and receiver designs have been proposed to effectively utilize the additional spatial dimension obtained by multiple antennas at the transmitter and receiver (Bhagavatula et al., 2010). Mobility is another key element in wireless communication especially railway scenario where there is a need of guarantee of seamless service (Ge & Lu, 2009). In wireless communication quality of service is very critical which is determined by the service interruptions occurred. When the handover process took place the key outputs is to avoid data loss or service interruption including drop calls. This has a bigger impact on the quality of services (QoS) which also it can contribute to network performance. If there is a loss of data and too many drops call due to handover capability the quality of service becomes bad, while if the handovers are planned properly in accordance with



**Figure 6.2:** Network Architecture for power distance handover (Ibrahim et al., 2016).



**Figure 6.1:** Block diagram of typical 4x4 MIMO antenna system (Nsiri & Nasreddine, n.d.)

cell edges and cell coverage's the network can function optimally.

Since 3GPP propose LTE under release 8 which was published in 2008 with the aim of increasing data, speed and better coverage LTE key features such as Handover became the area of research (Ibrahim et al., 2016). LTE handover support hard handover which breaks

before connecting BBC (Tomasov et al., 2013) The handover of calls is a critical issue, which

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becomes more critical for real-time calls as the probability of handover failure is 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 design accurately to avoid non-disruption and drop of calls during the handover procedure.

As shown in Figure 6.1 handover procedure happens between the serving cell and target cell (Ibrahim et al., 2016). In(Ibrahim et al., 2016) it has been demonstrated that A train moves between both anodes with constant speed either 120 km/h or 250 km/h. While the train is moving, UE measures RSRP and sends them back to the serving anode. Based on the measurement report and results, the serving anode will send a handover request to the neighbouring anode when the measurement report of neighbour anode is considered as better than serving anode with the value of hysteresis, A3 event is triggered. After the event is triggered, the UE continues to measure the environment for duration equals Time to Trigger (TTT).

### **6.3 Problem statement**

In high-speed railway, mobility becomes a huge challenge due to many factors such frequently handover occurrence (Liu, Ai & Chen, 2011-Choi et al., 2015). The railway BS is deployed more often compared to commercial LTE. Another problem is network availability (coverage) in rural areas were LTE deployment is less compared to cities.

### **6.4 Propose work**

The collaboration of LTE-R with UMTS (3G network) in areas where signal reception is weak to provide LTE-R full coverage. Improved handover connectivity which is the key factor in mobility and customer satisfaction and better quality of services Comparisons in previously researched handover mechanism and evaluate the suitable one which is suitable in High-speed railway Comparisons in previously researched MIMO technique as shown in Figure 6.2 and evaluate the suitable one which is suitable in High-speed railway.

The HSR system equipped with LTE and 3G interface require train access units (TAU) on the board, these TAU provide access in bogies of the trains. In this paper, we are using three TAUs,

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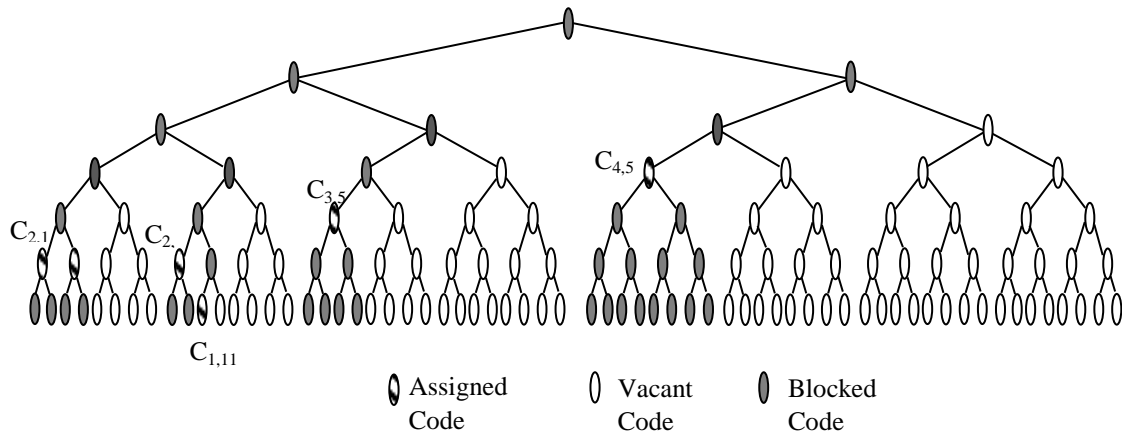
one placed on top of driver bogy, one in middle bogy and third in the last bogy. The driver bogy TAU is the main access point with respect to the public mobile network and the railway network. This TAU borrows capacity from base stations (BSs), assigns capacity to other TAUs. These TAUs are using optical fiber to connect with the inboard access points.

The radio resources are available and the network provides connectivity depending on the type of connection request. The data calls are handled using LTE-R resources and voice calls using 3G resources. The LTE radio resources can be borrowed from nearby public mobile networks (PMN) BSs. In the worst case, the 3G interface is used for data calls. The voice calls are always priority calls and the network uses 3G resources for them. The calls can be generated in railway communication by the railway safety people (RSP) and passengers. The calls generated by RSP are priority calls. The LTE-R or more specifically HSR network also works differently in urban and rural areas. In the context of this paper, the urban areas mean the BS has both LTE and 3G interface while rural areas mean the BS has an only 3G interface. Consider the generation of a call of rate  $qR$ . For 3G the interface, the orthogonal variable spreading factor (OVSF) codes are quantized and the rate of each code is  $2^{l-1}R, 1 \leq l \leq 9$ .

## 6.5 Urban Areas

The algorithm works as follow.

- a. Check the type of call: *data* or *voice*?
- b. For voice call use 3G interface of a HSR network and assign a code from the OVSF code tree using code assignment scheme propose in next section.
- c. For a data call:
  - i. Check the resources of LTE-R interface available, assign the required number to the call.
  - ii. If LTE-R interface resources are already used, borrow RBs from the nearby public mobile networks and assign those RBs to the new call.

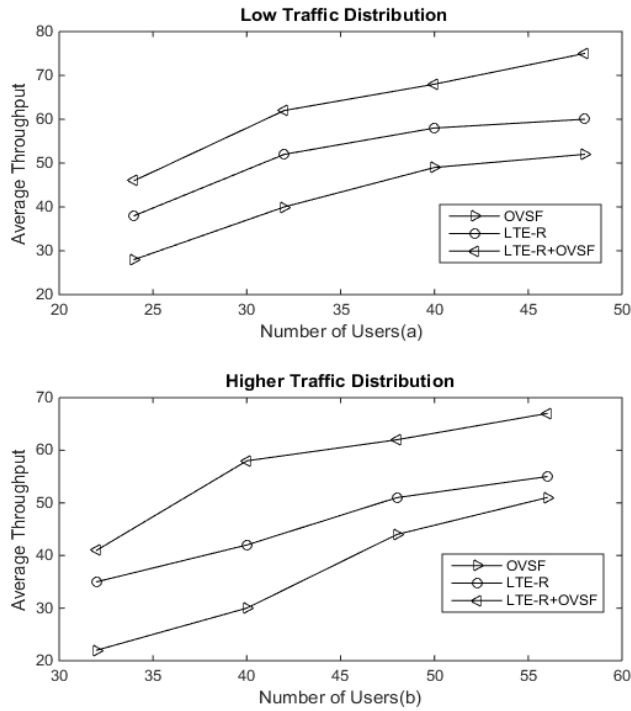


**Figure 6.3:** Illustration of fast top down Approach.

- iii. If the nearby PMN base stations LTE resources are also utilized, find the value of  $l = \log_2 q + 1$  use 3G interface to handle the new call.
- iv. If the train is not moving very at a high speed, it will stay in the same BS for a longer duration
- v. And will keep on checking the available LTE resources in LTE-R network or PMN for those calls which are using 3G interface. The call(s) will be transferred to these resources.
- vi. If the train is moving at higher speed it will be continuously changing the BSs, the algorithm will request for the number of resources it's currently handling using TAU on drivers bogey before it enters the new BS service area. If the LTE resource required is higher than the available some of the calls have to fall back on 3G interface otherwise call will be handled normally. The call that will fall back must be passengers generated.

## 6.6 Rural areas.

The base station is equipped with a 3G interface only. The OVSF codes are limited as they suffer from code blocking problem. The code assignment scheme needs to be fast and must be



**Figure 6.4:** The average throughput comparison of the system equipped with OVSF

prioritized based. The fast top-down code search algorithm proposed in (Bhattacharya & De, 2011) is used which considers the priority of the call.

The algorithm works as follow.

a. For an incoming call of rate  $qR$ , find the value of  $l = \log_2 q + 1$  6.1

b. If currently used capacity in the tree  $+qR \leq 2^{L-1}R$ , total tree capacity, where  $L=9$ .

Find the number of optimum codes defined in  $C_{l_1, n_{l_1, opt}}, l \leq l_1 \leq (L - 1)$  6.2

Assign code  $C_{l_1, n_{l_1, opt}}$  to the new call. Do code assignment and blocking. Update code

indices defined in (Bhattacharya & De, 2011)  $I_{l_1, n_{l_1}}^{l''}, C_{l_1, n_{l_1, opt}},$  6.3

$l \leq l_1 \leq (L - 1), l_1 \leq l'' \leq (L - 1)$  6.4

Go to step 1.

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Mario Ligwa, Vipin Balyan, Ben Groenewald "Utilization of OVSF codes for service Enhancement of LTE-R" IEEE 2018 International Conference on Advanced Computation and Telecommunication (ICACAT).

- c. *Else*  
Reject call.  
Go to step 1.
- d. *End*

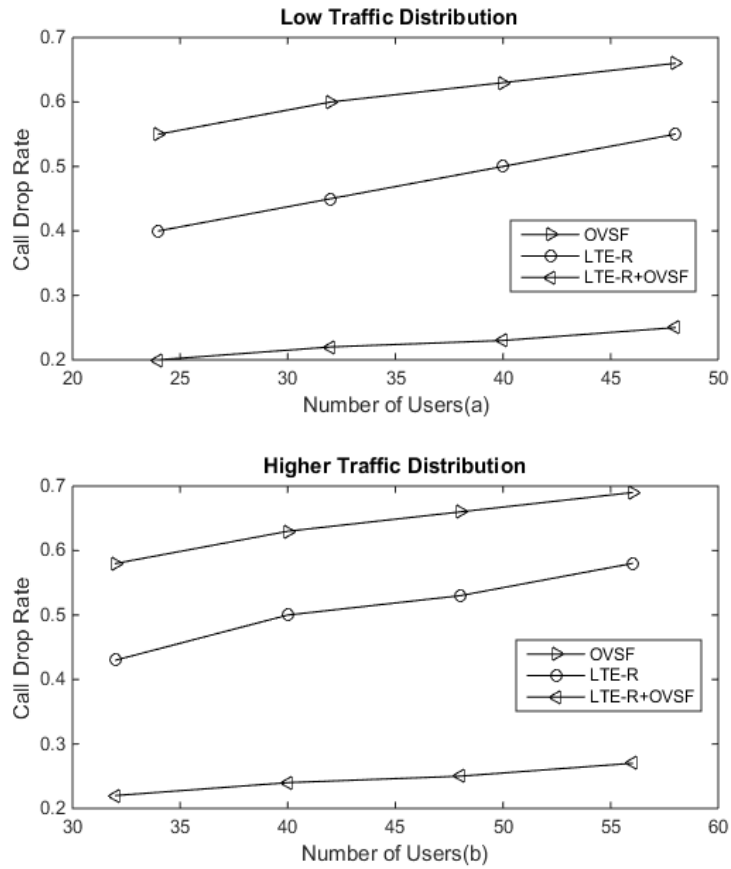
For illustration, consider the status of the OVFSF code tree of 7 layers as shown in Figure 6.3 Let the TAU request a call of rate  $16R$ , the fast top-down approach will assign the complete capacity of  $C_{5,4}$ . If TAU request for another  $16R$  for priority calls the call assigned to  $C_{4,5}$  will be shifted  $C_{4,4}$  and  $C_{4,5}$  capacity will be assigned to TAU.

## 6.7 Results and Simulation

In this section, the performance of the proposed work is investigated with the help of simulations on MATLAB. The work is compared to different traffic conditions and resources.

- LTE-R only denoted as LTE-R in urban areas
- LTE-R and OVFSF codes denoted as LTE-R+OVFSF in urban areas.
- OVFSF codes in rural areas.

The system equipped with the above resources are compared in heavy traffic distribution scenarios and low traffic distribution scenarios. In all conditions, the public mobile network resources are



**Figure 6.5:** The call drop rate comparison of the system equipped with OVSF

borrowed, these resources are considered limited and can handle 10% of the traffic. The LTE-R network is considered to be placed parallel at a 2.5Km distance from railway lines having an antenna height of 45m. The call arrival rate is average from 0 to 6. The average call duration of

all traffic rates is exponentially distributed with a normalized mean value 1. The LTE interface capacity used is 345.6 Mb/s and of UMTS interface 256R (3.4Mb/s).

From the results of Figure 6.4 and Figure 6.5, it is clear that when the railway communication services use OVSF codes on the 3G interface, the throughput increases and call drop rate decreases. However, the fast top-down assignment scheme keeps the call drop rate close to 0.7 and throughput close to 40 in rural areas.

## 6.8 Conclusion

This research proposed a framework for providing broadband services to highly mobile users. Within this framework, we propose various algorithms such as sharing method with the commercial network to handle railway emergency calls, we also propose handover improvement which mitigates the impact of conventional handover failure and guarantees continuous services. The proposed framework may not only overcome the challenge of high call drop rate due to frequent handover failures at high mobility but also achieve quality broadband communications under strong Inter Channel Interference due to a severe Doppler frequency shift in the scenario of high-speed train communications.

Generally, as the train speed increases and the location changes fast, the framework we propose can efficiently select the RRHs for service accessing and smoothly transport the user traffic to receivers with little change in user-perceived quality. Currently the existing communication infrastructure does not fully comply with high communication standard even though GSM-R has been deployed. As technology moves towards the internet of things (IoT) the future scope will also enhance commuter requirements and service.

The proposed framework and algorithm could be a strong candidate for high-speed train communications. As the research unfold the OVSF codes was proposed as a radio resource on the 3G interface. In rural areas mostly 3G services are implemented due to less demand for speed and data. However, the train running on the long route may pass through such areas. In addition, the use of OVSF codes as 3G resources leads to improved throughput and connectivity in rural areas also in some areas in urban areas, In future work can be done to find complexity in handover when a train enters from urban areas to rural areas, the effect of fallback.

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