CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

The operators of Fourth Generation Long Term Evolution (4G LTE) in Nigeria usually deploy their network with excellent throughput performance and as subscribers grow over time within a region, the perceived great performance drops to regrettable throughput performance. This has been observed across board of operators in Nigeria, ranging from SPECTRANET, Smile network, SWIFT network, Nigerian Telecommunication (Ntel) etc. In the year 2013, many 4G LTE operators launched their service in the major cities of Nigeria with top speed of about six Mega Bits per Second (6Mbps), but today none of the operators can boast of an average cell throughput of 1.8 Mbps while some cells at various conditions, perform so poorly and unable to deliver data throughput greater than 800Kbps. However, in developed countries with similar technology, an average data throughput of 12 Mbps is maintained. Secondly, it has been observed that with less than hundred User Equipment (UEs) per eNodeB, congestion triggers as result of contention ratio against theoretical value of nine hundred UEs per cell. Furthermore, cost of limited data subscription in Nigeria remains very high against its counterpart in western world with unlimited data access per month for less than twenty five dollars. CNN World News, 22 October, 2019).

Recent development in the Nigerian telecommunications industry indicates that the operators engage in several marketing activities to ensure that their subscribers are satisfied and brand loyal rather than technical improvement. However, most subscribers complain about the Quality of Services (QoS) and some switch from one operator to the other or use numerous network lines. Identifying and solving low cell throughput performance of LTE network in Nigeria is the paramount task of this research. The spectrum licensing and diligent regulation of telecommunication operators as well as resolving performance standard disputes are the chief tasks confronting government in developing countries like Nigeria, (Masood, Khan, Naqvi, 2011). National Space Research and Development Agency (NASRDA), Nigeria Communication Satellite Limited, (NIGCOMSAT) and Nigerian Communications Commission (NCC) on a joint workshop, held in 2017 stressed that current communication problems in Nigeria may continue to worsen due to poor cell planning and dimensioning, none implementation of workable algorithm suitable for the country, invalid International Telecommunication Union (ITU) information on different regions of the country such as rain attenuation and land topologies. (Oghojafor, Ladipo, Ighomereho, 2014).

Mobile and cellular communication system have changed over the years from the way people communicate. Evolution of wireless access has gotten to the fourth generation (4G) and the 5G mobile networks which focus on the development of the user terminals where the terminals have access to different wireless technologies at the same time and combines different flows from different technologies. The first generation (1G) has delivered the basic mobile voice, while the second generation (2G) has introduced more capacity and increased cell coverage, the third generation (3G) which was designed with demand for data at higher speeds to open the gates for truly "mobile broadband" experience, which was further realized by the fourth generation (4G). The Fourth generation (4G) provides access to wide range of telecommunication services, including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet based, along with a support for low to high mobility applications and wide range of data rates, in accordance with service demands in multiuser environment. 4G LTE is an all-IP network initially meant for carrying data only, while carriers would be able to support voice traffic either by utilizing 2G or 3G systems or by using Voice over Internet Protocol (VoIP). Long Term Evolution (LTE) is the last step towards the 4th generation of cellular networks. This revolution is necessitated by the unceasing increase in demand for high speed data connection on mobile devices (Freescale Semiconductor, 2008). Hence the need for LTE networks arises due to fastness, smart, reliable, less complexity and fewer nodes processing. This provides for a downlink speed of up to 150Mbps and an uplink speed of up to 50 Mbps. Fixed wireless and wired standards are already approaching or achieving 100 Mbps or faster, and LTE is a way for cellular communications to operate at that high data rate (De-Gouveia and Magedanz, 2015).

However, to improve LTE cell throughput, cost effectiveness, optimal spectrum use, and Quality of Service (QoS), Differential Quality of Service (Diff-Serv QoS) technique was developed to efficiently manage the provisioned radio resource for the benefits of all subscribers and the network operator. The wireless network operator SPECTRANET Limited, Abuja (SLA) was used as case study and experimental testbed. According to Jia *et al*, (2015), the Long Term Evolution network gives total support to both end devices and network architecture. SPECTRANET limited, brought smiles to Nigeria populist and Abuja residents in particular when they observed the need for improved network architecture and for better data service delivery. They acquired 4G license and deployed a new set of network structure in the city at mid-year of 2013. It was a wonderful experience to all subscribers who got their service in the first 18th months of deployment. Their distinguished Quality of Service (QoS) was over 10 Mbps throughput on average at all corners of Abuja city, the Quality of Service started depleting as many users got into the network base. SPECTRANET Limited, Abuja today faces low cell throughput due to congestion and frequent exhaustion of Physical Resource Block (PRB) especially on data service as well as the voice service on the network. According to Olatokun, Sophia and Adegbola (2012), congestion remains a major challenge to telecommunications service provider especially to operators that witnessed huge influx of subscribers over short period of time. The LTE network by SLA is congested due to factors such as the use of various multimedia activities on the network by the end-users and increasingly number of users. Also according to Freeman (2014) external factors such as vandalism of network equipment, power supply, weather condition and high rise buildings also contributes negatively in varying degrees.

In order to provide for effective and Quality of Service (QoS) for 4G LTE network, this work investigated into the enhancement of cell throughput performance of the network. This will help to improve QoS provided by SPECTRANET Limited, Abuja (SLA) and other operators in the country. It also improved 4G LTE planning capability in future deployment to other cities in Nigeria. The obtained results on this work improved cell throughput performance through efficient, reliable and robust resource scheduler algorithm for the eNodeB(s). However, the research also enhanced End-to-End delay (E2E) of voice and data services provided by 4G LTE operators.

1.2 Problem Statement

One of the major challenges of 4G LTE network operators is the inability to adequately manage the provisioned radio resources according to their peculiarities, to this effect, there are incessant failures to deliver high data rate throughput and Quality of Service to their subscribers, remarkably after months of service deployment. There are unacceptable cell throughput performances by 4G LTE operators especially at severe radio channel conditions and during peak period where data rate drops below 0.8Mpbs. Nonetheless, the deployed eNodeB(s) get congested easily after accepting more than sixty UEs compared to average of 300 UEs in the developed countries. SPECTRANET Limited Abuja (SLA) as a testbed is one of the Long-Term evolution (LTE) network technology service providers in Nigeria, located at

Wuse II, Abuja. SLA provides voice and data services to individuals, cooperate organisations and government agencies. SLA is the first company to launch LTE service in Abuja in 2013; the company brought top speed internet broadband service and later voice service. As subscribers grew over time, it became obvious that user experience has dropped drastically to management situation. This is as result of increase in contention ratio or overbooking ratio over the provisioned bandwidth and available network element resources for each cell site which in turn give rise to delay and directly affects the network service throughput. The work employed field work and empirical methods to study each cell site and proffer implementable solution in order to enhance Quality of Service. The outcome of the work and the results obtained upon implementation will enhance cell throughput of LTE network that is obtainable from present study algorithms based on differential quality of service (Diff-Serv).

1.3 Aim and Objectives of the Dissertation

The aim of this dissertation is to enhance cell throughput performance of Long Term Evolution Service (LTEs) using differential Quality of Service technique. This aim was achieved using the following specific objectives:

1. To carry out an empirical test for data collection based on users experience for voice and data services through drive test and use of Huawei Imanager 2000 software tool.
2. To carry out performance evaluation on the empirical data and results obtained in order to validate it with the standard threshold of 3GPP standard chart on E-UTRAN and Cell Throughput Technical Specification TS.136.
3. To estimate and modify the existing Network capacity of LTE network based on the empirical data obtained using MATLAB software.

4. To develop Differential Quality of Service (Diff-Serv) technique based on Time Stamp Algorithm (TSA) and Traffic Volume Algorithm (TVA) for enhanced QoS using the measured data parameters.
5. To carry out comparative analysis to ascertain the level of throughput performance enhancement by TSA and TVA against the existing system.

1.4 Significance of the Work

This study quantified the quality of service of LTE network based on relevant standard specifications of International Telecommunication Union (ITU) and 3GPP technical Specification. The outcome of the study enhanced reliability and availability of LTE network services. Nonetheless, the work laid robust foundation for future network deployment and boosts economy of the industry significantly, more especially to the mobile users which ensured their monthly budget of data subscription and voice calls cut down by necessary percentage margin. The obtained results from the research became a source of scientific contribution on reliable communication network and efficient technique for improving 4G network cell throughput. The outcome of the study enhanced the process of improving communication engineering labour force. The work developed algorithm models based on Differential Quality of Service (Diff-Serv QoS) for both voice and data services for LTE network. The developed algorithm provided for multiple network service applications for efficiency and cost savings. The outcome of the study also provided performance improvement solution by means of efficient scheduling algorithm to the network architecture, hence avoiding underutilization of radio resources. Upon implementation of developed models, 4G network operators with similar challenge obtains competitive advantage through efficient radio resource scheduling, improved number of users per eNodeB and enhanced data rate throughput.

1.5 Scope of the Study

The dissertation target is to improve cell throughput of LTE network services provided and thus the study is limited to Radio Resource Scheduling for 4G LTE network services. The work understudied each cell site of the case study network SLA and proffered implementable solution in order to enhance Quality of Service. However, the study used available experimental voice and data obtainable from SLA over a period of five months starting from 12 November, 2018 to 28 February 2019, and from 1 April to 28 June 2019 in order to cover the both extreme weather conditions in Abuja, Nigeria. The results Obtained were used to characterize 4G LTE network and predicted network element behaviours as well as to develop an implementable Diff-QoS algorithm for enhanced Quality of Service.

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Framework of LTE System

This chapter presents the study framework on cell throughput enhancement of Long Term Evolution (LTE) service. The research reviewed theories of cellular communication system. The work also assessed the standards of LTE network and its architecture. The research reviewed different techniques used in optimizing the cell throughput performance of actively deployed Fourth Generation LTE (4G LTE) network. Recent and related works on Radio Resource Management (RRM) and Radio Resource Scheduler (RRS) as functions or techniques that can be adopted for 4G LTE cell throughput improvement were further reviewed and summarized. The most critical function in the Evolved Universal Terrestrial Radio Access Network (E-UTRAN) is the scheduling algorithm implemented in the Evolved NodeB (eNodeB). This function is decisive for cellular throughput and subscribers' Quality of Service (QoS). First, the research was empirically based where various experimental parameters (Data) were collected based on users' experience for services such as voice, data, video, game and transmission control protocol on LTE network service. The parameters were evaluated quantitatively and statistically analysed. Thenceforth, estimation and performance evaluation of existing network capacity to determine throughput and reliability of the services were carried out.

The study of the existing network capacity and the performances guarantees the technique best suitable to improve general network performance and Quality of Service. The modification was done by employing radio resource management and scheduling technique. The study subdivided the technique into two parts. The first part deals with radio resource scheduling as it relates to decision that include dynamic admission control of incoming volume of packet traffic into the Base Band Unit (BBU) of LTE eNodeB. The second part deals with admission control and radio resource scheduling as it relates to busy period of activities in the network. They are methods employed as enhancement technique to improve data rate and improve user's experience on 4G LTE cells. The conceptual framework developed an implementable algorithm that can be used to improve LTE network based on Quality of Service (QoS).

2.1.1 Trends of Cellular Network

First-generation mobile systems used analogue transmission for speech services. In 1979, the first cellular system in the world became operational by Nippon Telephone and Telegraph (NTT) in Tokyo, Japan. Two years later, the cellular epoch reached Europe. In the United States, the Advanced Mobile Phone System (AMPS) was launched in 1982. The two most popular analogue systems were Nordic Mobile Telephones (NMT) and Total Access Communication Systems (TACS). The system was allocated a 40-MHz bandwidth within the 800 to 900 MHz frequency range by the Federal Communications Commission (FCC) for AMPS. In fact, the smallest reuse factor that would fulfil the 18dB signal-to-interference ratio (SIR) using 120-degree directional antennas was found to be 7. Hence, a 7-cell reuse pattern was adopted for AMPS. Transmissions from the base stations to mobiles occur over the forward channel using frequencies between 869-894MHz. The reverse channel is used for transmissions from mobiles to base station, using frequencies between 824-849 MHz AMPS and TACS use the Frequency Modulation (FM) technique for radio transmission. Traffic is multiplexed onto a Frequency Division Multiple Access (FDMA) system, (NDI Communications, 2018). Second-Generation (2G) mobile systems were introduced in the end of 1990s. Compared to first-generation systems, second-generation (2G) systems use digital multiple access technology, such as Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA). Consequently, compared with first-generation systems, higher spectrum efficiency, better data services, and more advanced roaming were offered by 2G systems. In the United States, there were three lines of development in second-generation digital cellular systems. The first digital system introduced in 1991 was the North America TDMA Digital Cellular called Interim Standard- 54 (IS-54), of which a new version supporting additional services (IS-136) was introduced in 1996. Meanwhile, IS-95 (CDMA One) was deployed in 1993. 2G communications is generally associated with Global System for Mobile (GSM) services; 2.5G is usually identified as being fuelled by General Packet Radio Service (GPRS) along with GSM (Nikhil *et al*, 2017).

Third Generation (3G) uses Wide Band Wireless Network with Packet Switching. 3G telecommunication networks support services that provide an information transfer rate of at least 2Mbps. In EDGE, high-volume movement of data was possible, but still the packet transfer on the air-interface behaves like a circuit switches call due to inefficient packet delivery. 3G is not one standard; it is a family of standards which can all work together. An organization called 3rd Generation Partnership Project (3GPP) has continued the work by defining a mobile system that fulfils the International Mobile Communication-2000 (IMT-2000) standard. In Europe, it was called Universal Terrestrial Mobile System (UMTS), which is European Telecommunication Standard Institute (ETSI) driven. IMT2000 is the Telecommunication standardization Sector of the International Telecommunication Union (ITU-T) name for the third generation system, while Code Division Multiple Access 2000 (CDMA2000) is the name of the American 3G variant. Wide-Band Code Division Multiple Access (WCDMA) is the air-interface technology for the UMTS. The main components include Base Station (BS) or node B, Radio Network Controller (RNC), apart from Wideband

CDMA Mobile Switching Centre (WMSC) and Serving GPRS Support Node/ Gateway GPRS Support Node (SGSN/GGSN). 3G networks enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency. The first commercial 3G network was launched in Japan in 2001. (Raj, 2014).

The first successful field trial for 4G (All IP) was conducted in Tokyo, Japan on June 23rd, 2005. Nippon Telegraph and Telephone Mobile Communication Network (NTT DoCoMo) was successful in achieving 1Gbps real time packet transmission in the downlink at a moving speed of about Twenty meter per hour (20km/h). To use 4G services, multimode user terminals should be able to select the target wireless systems. In current GSM systems, base stations periodically broadcast signalling messages for service subscription to mobile stations. However, this process becomes complicated in 4G heterogeneous systems because of the differences in wireless technologies and access protocols. To provide wireless services at anytime and anywhere, terminal mobility is a must in 4G infrastructure. Terminal mobility allows mobile terminals to roam across geographic boundaries of wireless networks. There are two main issues in terminal mobility: location management and handoff management. With location management, the system tracks and locates a mobile terminal for possible connection. Location management involves handling all the information about the roaming terminals, such as original and current located cells, authentication information etc. On the other hand, handoff management maintains ongoing communications when the terminal roams (NOKIA Siemens Network. 2012). Mobile Internet Protocol version six (MIPv6) is a standardized IP-based mobility protocol for Internet Protocol Version six (IPv6) wireless systems. In this design, each terminal has an IPv6 home address. Whenever the terminal moves outside the local network, the home address becomes invalid, and the terminal obtains a new IPv6 address (called a care-of address) in the visited network. The design and optimization of upcoming radio access techniques and a further evolution of the existing system, the Third Generation Partnership Project (3GPP) had laid down the foundations of the future Long Term Evolution (LTE) advanced standards, the 3GPP candidate for 4G. The target values of peak spectrum efficiency for LTE advanced systems were set to 30bps/Hz and 15bps/Hz in downlink and uplink transmission respectively. Apart from the multiple access schemes, enhanced multiple-input multiple-output (MIMO) channel transmission techniques and extensive coordination among multiple cell sites called Coordinated Multipoint (CoMP) transmission/reception were accepted as the key techniques for LTE. (Kuang-Hao *et al*, 2008)

The 5G (Fifth Generation) Mobile and Wireless Networks can be a complete wireless communication with few limitations, which bring us perfect real world wireless named World Wide Wireless Web (WWWW). 5G denotes the next major phase of mobile telecommunications standards beyond the 4G/IMT-Advanced standards. 5G will champion the Internet of Things Technology, big data, Nano-technology and Pico-technology. 5G will come up with numerous benefits which include seamless mobile connectivity, home automation, smart transportation, smart malls, production, packaging industries, security system; e-books etc. 5G mobile technology has changed the means to use cell phones within very high bandwidth, (Jacob, 2016). Figure 2.1 presents the generation cellular network and their major technologies.

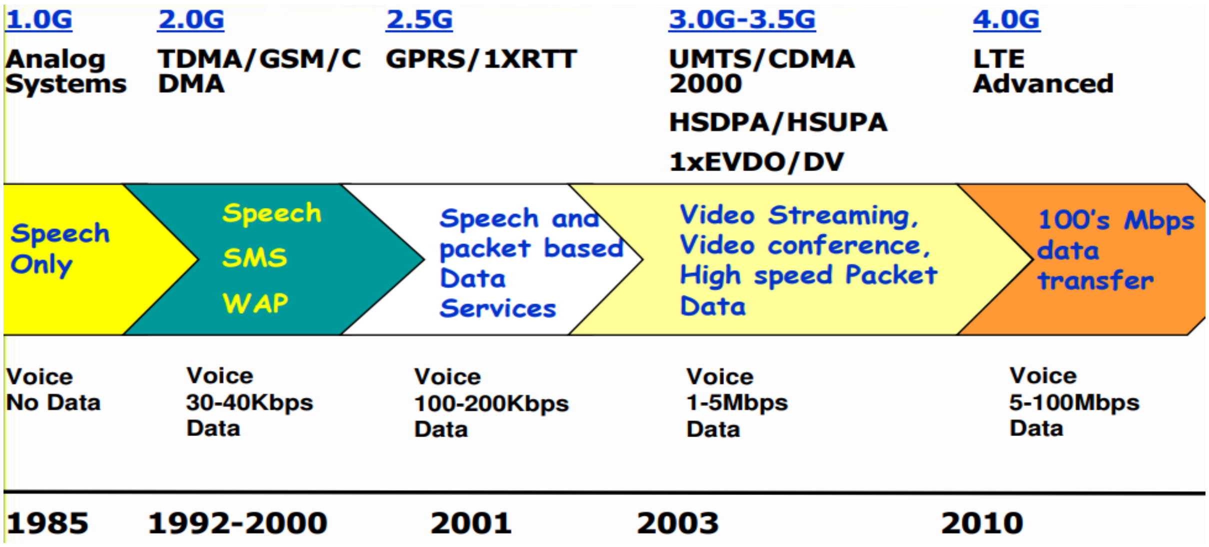

Figure 2.1: Trends in Cellular Network. (NDI Communications, 2018)

However, Figure 2.2 presented the different major parts of generation network architectures.

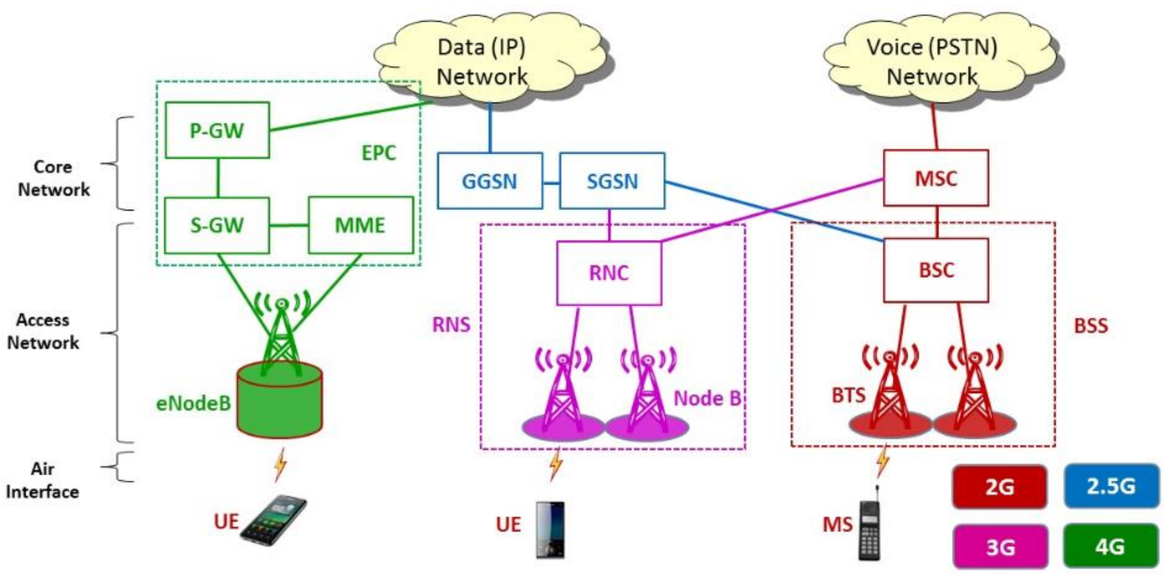

Figure 2.2: Comparison of 2G, 3G and 4G Network Architecture (Nikhil, Shivinder and Karamdeep, 2012)

The differences in the generation network architecture are majorly in the Core Network, Access Network, air interface and mobile terminals. Second generation (2G) network architecture makes use of Base Station Controller (BSC) controlling a set of Base Transceiver

Station (BTS) while 3G has Radio Network Controller (RNC) controlling a set of Node B while 4G has each eNodeB directly communicating with the core network.

2.1.2 Mobile Communication System

The creation of wireless communication systems paved the way for more efficient means of communications (Freeman, 2004). Today, one can communicate with other people on the other side of the planet in real time. Improved telecommunication systems are instrumental in the creation of more devices, mobile machines, smart phones, tablets, computers, cloud computing, Internet of Things, sensor networks, businesses, e-commerce, online payments, more opportunities and enhancement of people's lives.

Figure 2.3 presents generic cellular network structure.

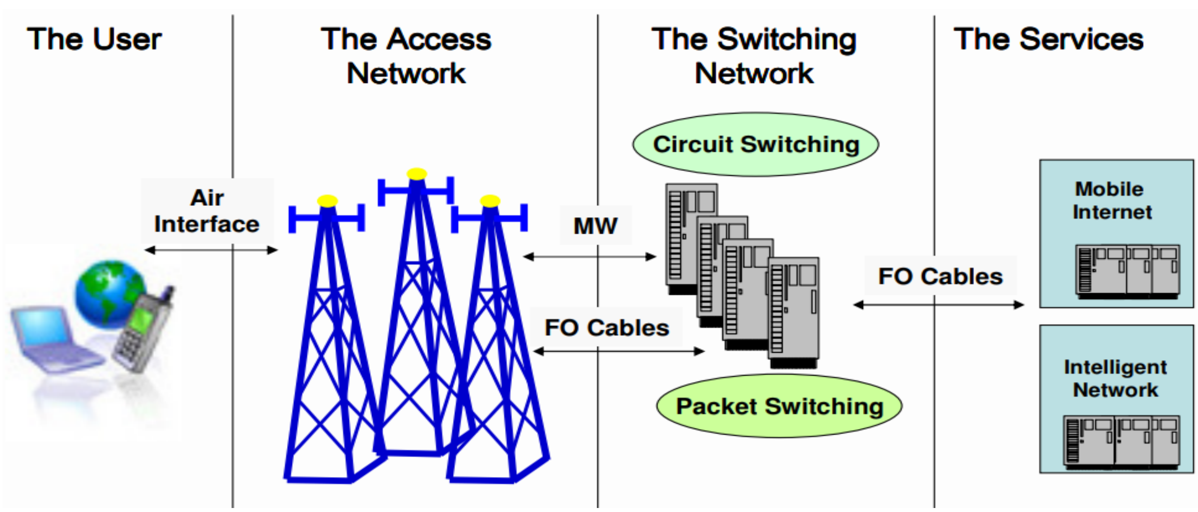

Figure 2.3: General Cellular Network Structure (Nikhil *et al*., 2012).

Figure 2.3 describes typical structure of Cellular network which formed the foundation for development to cellular generation from 1st to 4th generation. There are four major air interfaces or radio access technique in cellular network as applied at different generation network. Thus; Frequency Division Multiple Access (FDMA), Time Division Multiple Access

(TDMA), Code Division Multiple Access (CDMA), Orthogonal Frequency Division Multiple Access (OFDMA) and Space Division Multiple Access (SDMA).

A wireless communication link includes a transmitter, a receiver, and a channel. Most of telecommunication links are full duplex and include a transmitter and a receiver or a transceiver at each end of the link. Figure 2.4 portrays the block diagram of mobile communication system with major chain processes.

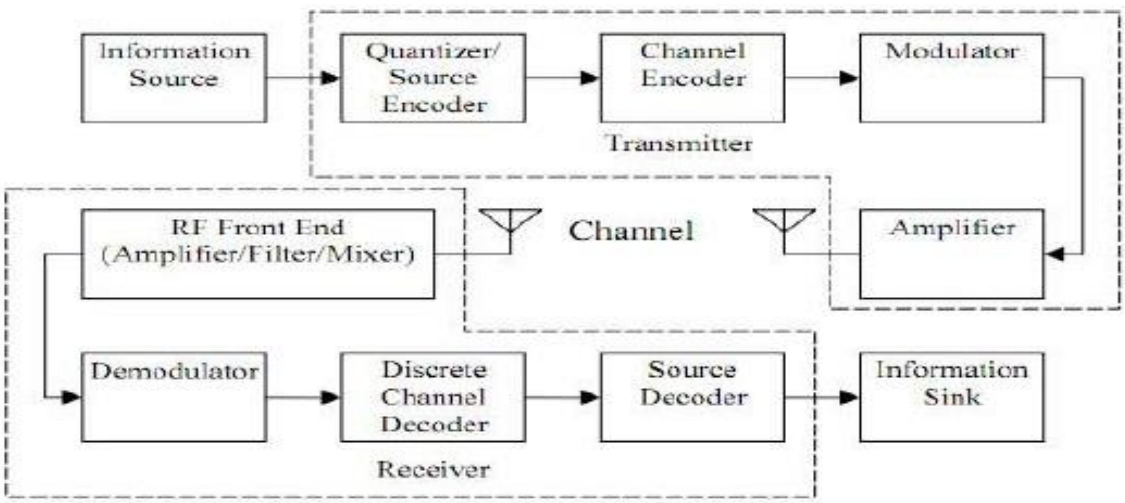

Figure 2.4 Block Diagram of Mobile Communication System (Akintoye, 2013)

The block diagram of figure 2.4 shows the duplex system telecommunication with transmit and receive Antennas. The processes involved in generating information bits to source encoder, channel encoder, modulation and amplification process to transmitter antenna and then unto radio frequency channel. The receive system processes are also defined.

2.1.2.1 Frequency Bands in Wireless Communication System

Cellular network/telephony is a radio-based technology, a wireless communication. Radio waves are electromagnetic waves that antennas propagate. Most signals are in a frequency bands ranging from 850 MHz, 900 MHz, 1800 MHz, 1900 MHz, 2300MHz, 2500MHz etc. Figure 2.5 shows the range of frequencies used for electromagnetic propagation in wireless communication of all class. Cell phones operate mainly on Ultra high Frequency range (300MHz to 3000MHz).

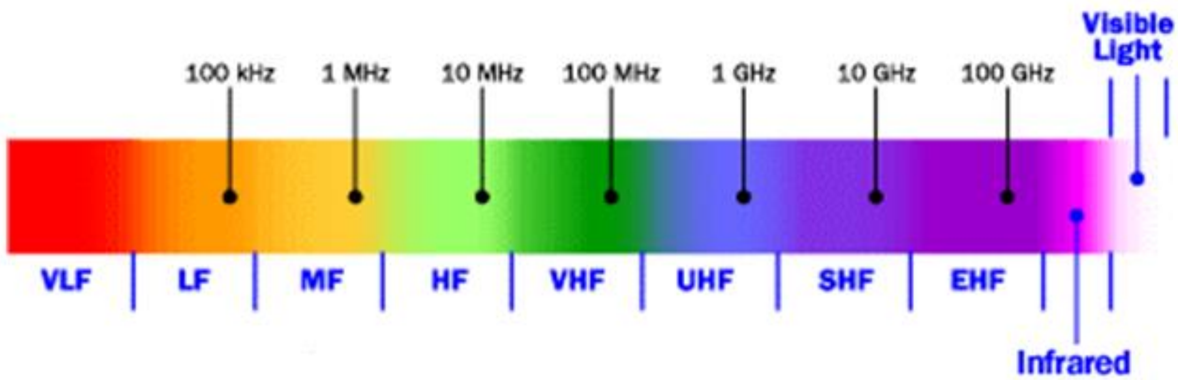

Figure 2.5: Frequency Range for wireless electromagnetic channel (Nikhil *et al*., 2012)

For good radiation efficiency, the antenna must be longer than one tenth of the wavelength of the operating frequency. If an antenna is transmitting at Amplitude Modulation (AM) band, with frequency F_c = 1MHz, which has a corresponding wavelength of $\lambda = C/F_c$ = 300m. C is the speed of light. Hence, the one tenth of the wavelength is 30m, meaning that the antenna for effective radiation will be 30m long or more. Consequently, if 10MHz is used, the required physical size is about 3meters.

2.1.3 Cellular Cell Design Techniques

There are numerous techniques employed in designing cellular cells for optimal coverage, overlapping cells, enhanced spectral efficiency, improved capacity etc. Traditional mobile service was structured in a fashion similar to television broadcasting where one very powerful transmitter located at the highest spot in an area would broadcast in a radius of up to 50Km. One antenna system will have limited coverage and number of users; Therefore, the idea of splitting into many low power transmitters of 100 Watts or less. Geographic areas are divided into cells, each cell served by its own antenna (Base Station). Band of frequencies are allocated to each cell and configured. Cells are set up such that antennas of all neighbours are equidistant (hexagonal pattern). Cellular network design employs Frequency Reuse technique, Cell

Splitting and cell sectorization to enhance the small number of radio channel frequencies available. Network engineers have to device a means of reusing radio channels in order to carry more than one conversation at a time.

Frequency Reuse: The concept of assigning to each cell a group of radio channels used within a small geographic area. Cells are assigned to a group of channels that are totally different from neighbouring cells. Note that a group of assigned cells is called Cluster. No frequency channels are reused within a cluster. Each cell has a footprint and boundary in order not to interfere and also for planners to adequately measure a distance good enough for the channel to reuse. Major advantages of frequency reuse includes; Improved coverage area, expanded cellular network capacity, reduced transmission power and reduced base station height while the disadvantage comes as Co-Channel Interference (CCI) when planning is poorly done and deployed.

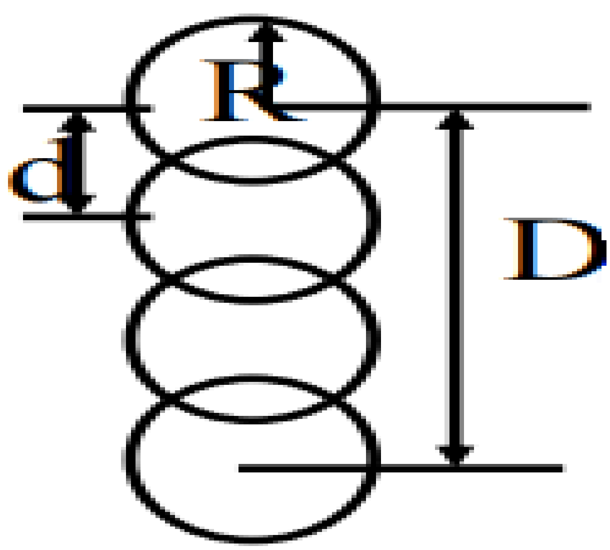

Figure 2.6: Cellular Cell and Frequency Reuse dimensions (Bao-Shuh, 2011)

Cluster of size $N = i^2 + ij + j^2$ (2.1)

Distance for Frequency reuse $D = R\sqrt{(3N)}$ (2.2)

Distance between centers of adjacent cells $d = R\sqrt{3}$ (2.3)

Where R is cell radius and D is distance at which a frequency can be reused with acceptable interference or minimum distance between centers of cells that use the same band of frequencies (called co-channels). N is the reuse factor or cluster size, explains the number of cells in repetitious pattern (Cluster). Each cell pattern uses unique band of frequencies.

Note; Possible values of N are 1, 3, 4, 7, 9, 12, 13, 16, 19, 21 …etc.

Simple example and solution for frequency reuse; the minimum distance between the centers of two cells with the same band of frequencies, if cell radius is 0.8 km and the reuse factor N is 7;

$D/R = \sqrt{3N}$ $D = (3\times7)^{1/2} \times 0.8$ km = 3.67km

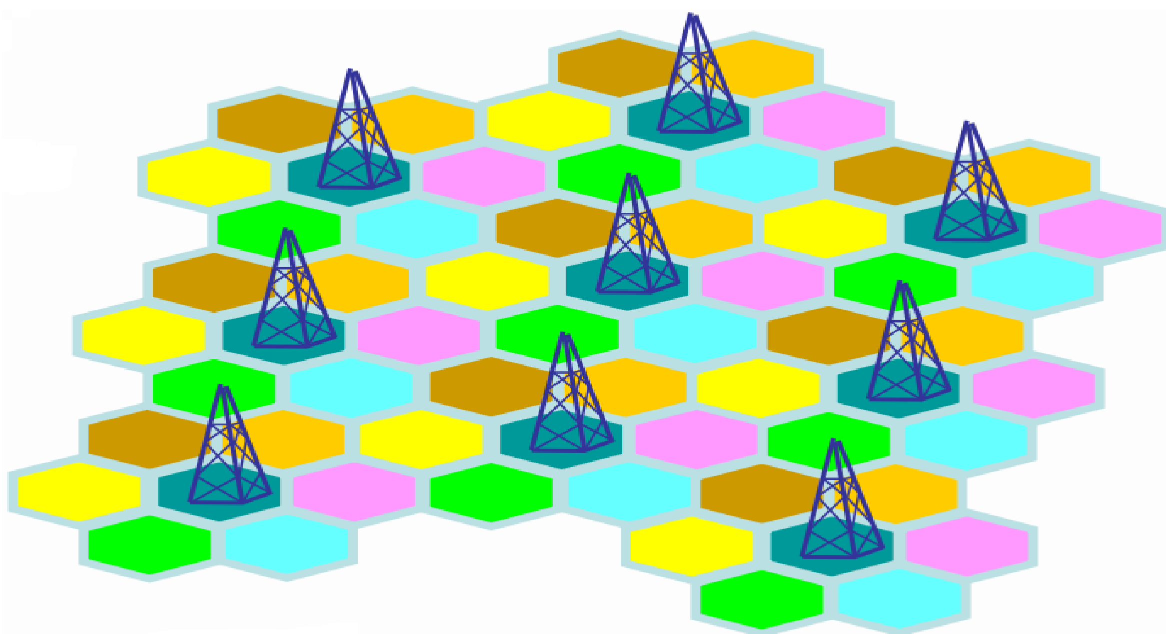

Figure 2.7: Typical Cell Layout and Group of Frequency band Reuse (Nikhil *et al.*, 2012)

Figure 2.7 shows a typical cell layout with different frequency band identifiable through colours, observe the layout cluster of seven with frequency reuse factor of 1/7

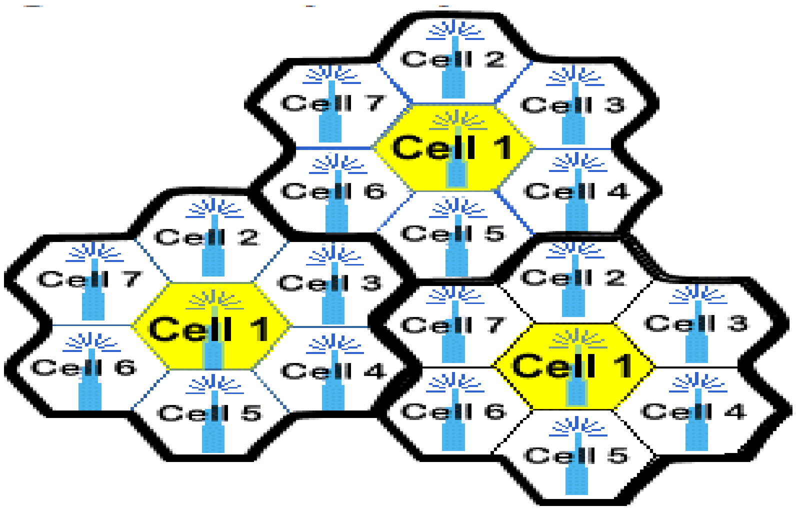

Figure 2.8: Frequency Reuse (Cell Cluster of seven Layout) (Bao-Shuh, 2011)

Cells with the same number has the same set of frequencies, since the number of available frequency is 7, hence the reuse factor becomes 1/7. That is each cell is using 1/7 of available cellular channels.

Cell Splitting**:** Is of the cellular concept of increasing capacity and performance of cellular network with respect to traffic. Cell splitting is an economic measure by network operators to decongest service area and enhance coverage. This technique is used to split a single area into a smaller area. Each of the serving cells in a populated zone is further divided into smaller cells known as microcell. R (Microcell) = ½ R (original cell). The radius of a microcell will become at least half of the original serving cell. In some situation, a micro cell can further be split into smaller cells known as Pico cell. This is illustrated at the figure 2.9, mostly witnessed at highly populated areas of a city. In such a way, urban centres can be split into many smaller cells in order to support required service level for heavy traffic zones, while larger and less expensive cells (Macro cell) can be used to provide service coverage in less populated areas such as remote rural areas.

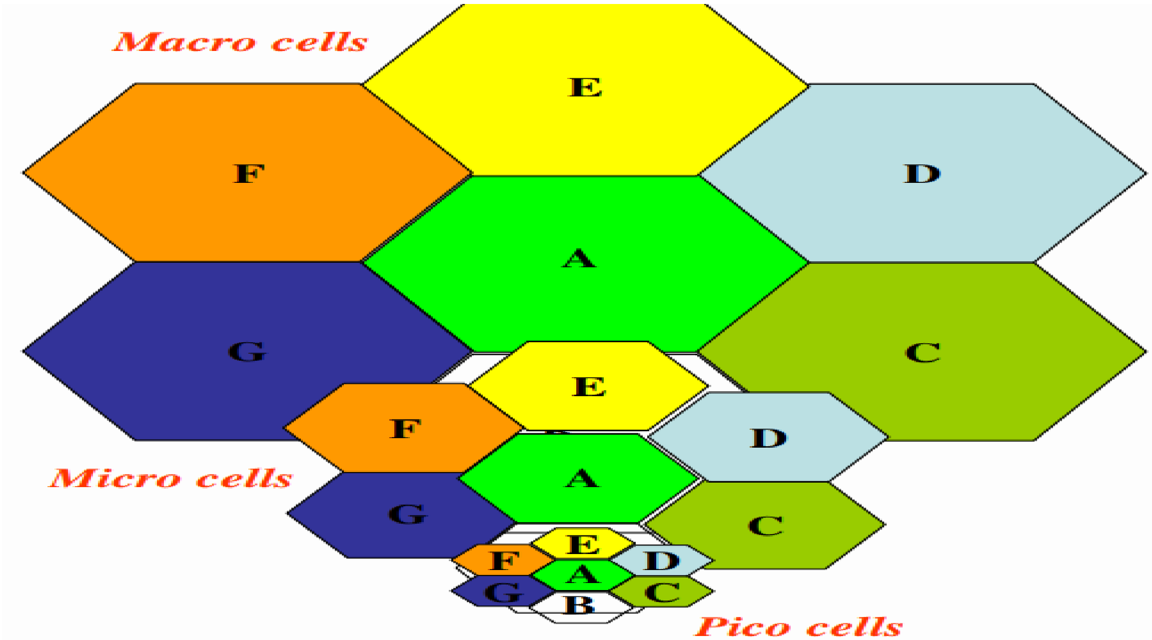

Figure 2.9: Cell Splitting Technique (Bao-Shuh, 2011)

Cell Sectorization**:** Is one of the techniques employed in cellular concept to maximize coverage and enhance blind spots coverage by adding extra antennas or transmitters. Normally, a standard cell is sectored into three (3) by 120 degrees separation from one sector. The three sector cell can be further expanded to six (6) sector cell with angle separation of 60 degrees. In some rural areas, cells can one or two sectored. Channel or frequency used in one cell can be reused in another cell few distances away to avoid co-channel interference. Cells can be added to existing cells in order to create expansion and build more capacity. New cell can be added to assist overlaying cells or to serve areas not covered initially.

2.2 Long Term Evolution Network System

Long Term Evolution (LTE), marketed as 4G LTE is a standard for wireless communication of high speed data for mobile phones and data terminals developed by 3rd Generation Partnership Project (3GPP). It is based on Global System for Mobile Communication (GSM)/ Enhanced Data for GSM Evolution (GSM/EDGE) and Universal

Mobile Telecommunication System/ High Speed Packet Data Access (UMTS/HSPA) network technologies. 4G LTE Increases the capacity and speed of cellular network using a different radio interface together with core network improvements. LTE is capable of peak download rate of 299.6 Mbps and upload speed up to 75Mbps (De-Gouveia and Magedanz, 2015). The mobile networks of most operators in both developing and developed countries are witnessing an unprecedented rise in data traffic, due to the increasingly demand by subscribers to access bandwidth with intense content on-the-go and the proliferation of a large number of mobile devices such as smart phones and tablets and computers (Capgemini, 2014). According to Jin *et al.,* (2014), the LTE system is designed to be a packet-based system containing lesser network elements, less complexity and also improves the system capacity and coverage. This provides high performance in terms of high data rates, low access latency, flexible bandwidth operation and seamless integration with other existing wireless communication systems. Forsberg, (2010) also stressed that LTE-A system specified by the 3GPP LTE Release 10 up till release 12 was developed to enhance the existing LTE systems to support much higher data usage, lower latencies and better spectral efficiency. Ever since LTE technology was established in 2008, the work on its enhancements and requirements had begun and this has been fulfilled successfully by LTE Advanced (LTE-A). However, the 3GPP Release 10 or LTE-A has proven to be one of the fastest developing mobile technologies in the world today (Sravanthi, Shubhrika, Deesha, Adwait and Mayur, 2013).

2.2.1 The Architecture of LTE Network System

Figure 2.10 presents LTE network architecture showing the interfaces between mobile terminals (UE), Evolved Universal Terrestrial Radio Area Network (E-UTRAN), Evolved Packet Core (EPC) and Internet Networks.

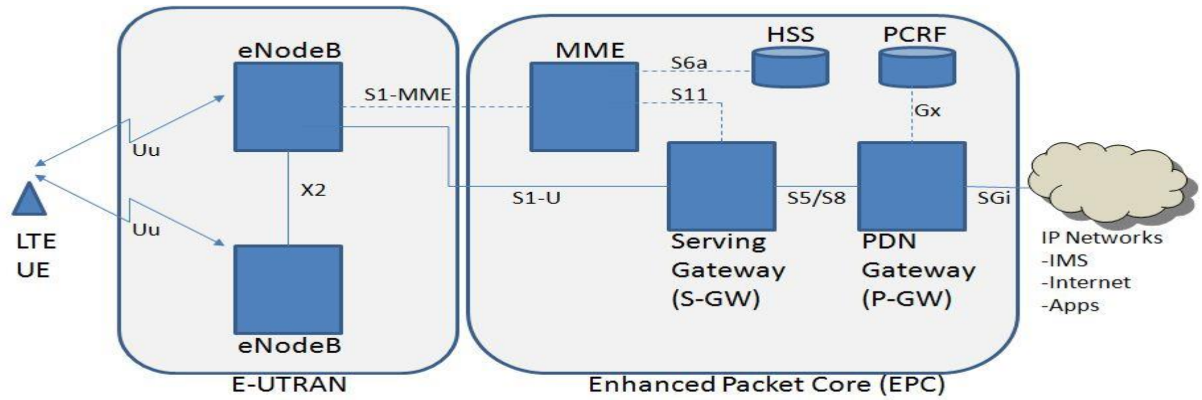

Figure 2.10: LTE Architecture (Jin *et al.*, 2014).

According to Pankaj Sharma, (2013). Illustrated LTE architectural design in Figure 2.11.

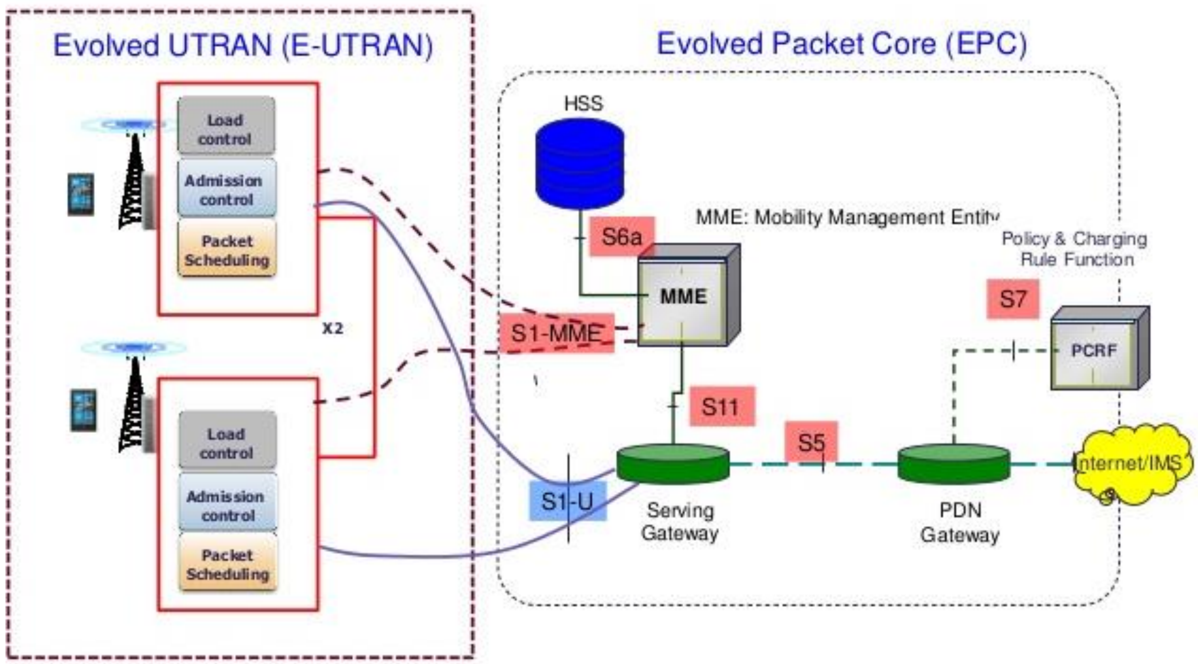

Figure 2.11: LTE architectural design (Pankaj, 2013)

LTE network architecture comprises mainly of four main parts,

1. The LTE User Equipment (UE),
2. The LTE Evolved Universal Terrestrial Radio Access Network (E-UTRAN)
3. The LTE Evolved Packet Core (EPC)
4. The Internet Protocol networks (Internet) or the cloud

1. *The LTE UEs* are also known as Mobile stations or LTE data terminals or devices that are of standard to access the internet via 4G LTE network, such as the mobile phones, smart TVs, WiFi devices, tablets etc. UEs have standard categories with different capacity for radio bearers. The interface link between the UEs and the eNodeB stations is called Uu interface.

Table 2.1: LTE UE Category

Category	1	2	3	4	5
DL	QPSK	QPSK	16QAM		64 QAM
UL					
DL Max RATE	10 Mbps	50 Mbps	100Mbps	150 Mbps	300 Mbps
UL Max RATE	5 Mbps	25 Mbps	30 Mbps	50Mbps	75 Mbps
TX- RX Diversity	Yes	Yes	Yes	Yes	Yes
2x2 MIMO TX-RX	N/A	Mandatory	Mandatory	Mandatory	Mandatory
4x4 MIMO TX-RX	N/A	N/A	N/A	N/A	Mandatory
Max RF Bandwidth	20Mhz	20Mhz	20Mhz	20Mhz	20Mhz

Source: (Aircom International, 2016)

2. *The LTE Evolved Universal Terrestrial Radio Access Network (E-UTRAN)*

This sector of LTE architecture consists mainly of the eNodeB, providing air interface for data traffic to and fro user equipment. eNodeB does several important functions such as: a) Radio Resource Management, such as Radio Bearer Control, Radio Admission Control, Mobility Connection Control, Radio Resource Scheduling etc., (b) Packet compression and Ciphering, (c) Routing of User Plane Data towards Serving Gateway (S-GW), (d) Scheduling and transmission of Broadcast information and paging messages, (e) Measurement, reporting, configuration and reconfiguration of E-UTRAN parameters and (f) Load control, admission control, packet scheduling etc. Major components of eNodeB are the LTE antennas, Remote Radio Unit (RRU), Base Band Unit (BBU), LTE Main Processing and Transmission Unit/ Universal Main Processing and transmission unit (LMPT/UMPT), LTE Baseband Processing Unit (LBBP) etc.

The eNodeB has four interface links, LTE Uu for data transmission to UEs, S1-U which is the non-dotted line for data traffic between serving Gateway and eNodeB, X1 link which is the dotted lines for control signalling between eNodeB and Mobility Management entity (MME) of Evolved Packet Core (EPC), while the fourth interface is the X2, serving as backhaul link between two eNodeBs. The eNodeB controls the mobility of UEs in Radio Resource Control connection (RRC-connected) mode while Mobility Management Entity (MME) controls UE mobility in Radio Resource Control (RRC-idle) mode. The Mobility in connected mode is governed by handovers which can be triggered by the eNodeB or the UE. UE triggers when certain measurement control criteria are met. The eNodeB does scheduling and Dynamic allocation of resources to UE for both Uplink and downlink interaction. This is done in every Transmission Time Interval (TTI) of one milli-second based on channel conditions. The eNodeB triggers state transition from Idle to connected mode and vice versa. If there is no data flow, eNodeB switches the UE to RRC-_idle state and saves power and network resources, however, when there is data flow, it changes the UE to RCC-connected mode. The eNodeB does buffering of data and forwarding of data to target eNodeB at the time of handover. eNodeB performs admission control and congestion control, during request for a service by UE to join an eNodeB, the eNodeB runs a congestion control algorithm checks to admit or not to admit the service based on current number of UEs and eNodeB load.

3. ***Evolved Packet Core (EPC):*** Also known as Enhanced Packet Core is an all-IP (internet protocol) and fully packet-switched backbone network in the LTE systems. Voice service is a digital circuit switched network service, and is handled by the Internet Protocol Multimedia Subsystem (IMS) Network. **EPC** consists of five major subsystems, namely;

(i) *Mobility Management Entity (MME):* Similar features are seen in UMTS and GSM architecture. Its main function is to manage movement and tracking of subscribers. MME is used for control planes only, and is connected to a database server called Home Subscriber Server (HSS) which is a central server that contains information of other network operator's subscribers through LTE interface known as S6a while MME connects to the serving Gateway through LTE interface known as S11. MME handles UE's Mobility in idle mode. MME and eNodeB are involved in connected mode during handover, so the MME knows which eNodeB a mobile is connected to. But if a mobile from one cell to another is in idle mode, neither the eNodeB nor the MME knows about this. MME only gets to know when there tracking area is updated by the UE. This is actually a challenge when it comes to paging a message or placing a call in such condition. The solution is provided for every cell in LTE with a code called tracking area identity. As soon as UE knows that it has got a new tracking area code, it triggers an RRC-_connection and sends the new tracking code to MME in a Non-Access Stratum (NAS). Every UE moves and decodes the cell broadcast information message and releases the RRC-_connection. This is the process through which MME learns about new tracking area code of UEs in a new cell. The process is called Tracking area updates or Periodic tracking Area updates by UE. MME also maintains UE context during RRC-_idle state of UE, State transition is solely controlled by eNodeB, and MME knows nothing about this. During idle state, power and network resources are saved over the E-UTRAN. UE context are vital information about the current service of UE. MME also does NAS signalling and NAS signalling Security. NAS signalling is present between UE and MME. Finally, MME does bearer management for UEs.

(ii) *Home Subscriber System (HSS):* is a central database that contains user related and subscription related information as well as helping in mobility management, call and session establishment. In GSM, similar function is to Home location Register (HLR) and Authentication Centre.

(iii) *Serving Gateway (S-GW):* This serves as a local mobility anchor for data bearers when UEs moves between eNodeBs. S-GW is responsible for user data flow and connects to the Packet Data Network gateway via S5/S8 interface. S-GW is an intermediary node between the mobile network and other external PDN network and internet. It collects data sent by the mobile terminals through various eNodeBs and forwards through Packet Data Network (PDN) to other external networks. S-GW distributes data coming from servers to the eNodeBs where the mobile terminals are located. When UE moves with a geographic location, it remains in same S-GW while registering and rerouting packet data over all eNodeBs under the given S-GW. When UE is in idle mode, there is no connection between UE and eNodeB, at this time, packets from PDN gets to the UE via S-GW. It buffers the downlink data when UE is in idle mode.

(iv) *Packet Data Gateway (PDN):* This gateway provides interconnectivity from UEs to external PDN networks. The gateway serves as a point of Entry and Exit of data traffic to and fro UEs. The PDN gateway does allocation of Internet protocol (IP) address to UEs. PDN gateway does filtering of downlink user IP packets into different Quality of Service (QoS) based bearers for different application services such as webcam, video streaming, browsing etc. These application services have different network requirement in terms of delay, because some services are delay sensitive while some are not sensitive. PDN does the lawful interception of packets, accounts for inter-operator charges, and is responsible to act as anchor for mobility between 3GPP and non 3GPP technologies.

(v) *Policy and Charging Rule Function (PCRF):* Service and network provider use the server for billing charges based on service level agreement. It could be on Pre-paid and post-paid agreement level. PCRF takes charging enforcement decision, places charges on Guarantee bit rate (GBR) and non-guarantee bit rate.

(vi) *Internet Protocol Networks/ Internet Multimedia Subsystem (IP/IMS):* IP multimedia Subsystem is a standard for telecommunication system which controls mobile multimedia services accessing different networks. IMS is based on the all-IP network. IMS model is implemented in 4G LTE to basically link classic mobile and fixed line network with all-IP based network, providing additional functionality which includes IP-based real time service such as voice, video-telephony, machine to machine communication, online gaming etc. IMS uses Session Initiation Protocol (SIP) as a protocol for signalling and establishing a connection in voice over IP-Telephony.

2.2.1.1 Performance Targets of LTE networks

1. Data rates: LTE should support downlink and uplink data rate up to 100 Mbps and 50 Mbps respectively.
2. Scalable bandwidth: The bandwidth allocation in LTE ranges from 1.4 MHz to 20 GHz. The higher bandwidth is used to acquire higher data rate.
3. Spectral efficiency: Spectral efficiency values of 5 Bps/Hz (downlink) and 2.5 Bps/Hz (uplink) are expected.
4. Mobility: LTE is optimized for mobility less than 15 km/h. It is still able to retain high performance until 120 km/h and preserving connection at 300 km/h.

5. Coverage: Within 5 km radius from base stations, the performance targets should be achieved. A slight degradation is acceptable within 30 km radius.

2.2.2 LTE Air Interface Protocols

Non Access Stratum (NAS) protocol is basically used to transport non-radio signalling messages between the User (UE) and the Mobility Management Entity (MME) of Evolved Packet System (EPS) core of LTE. NAS protocol procedures are grouped into two categories; Evolved Packet System Mobility Management (EMM) and Evolved Packet System Connection Management (ECM). Figure 2.12 describes the air interface protocol used in LTE system.

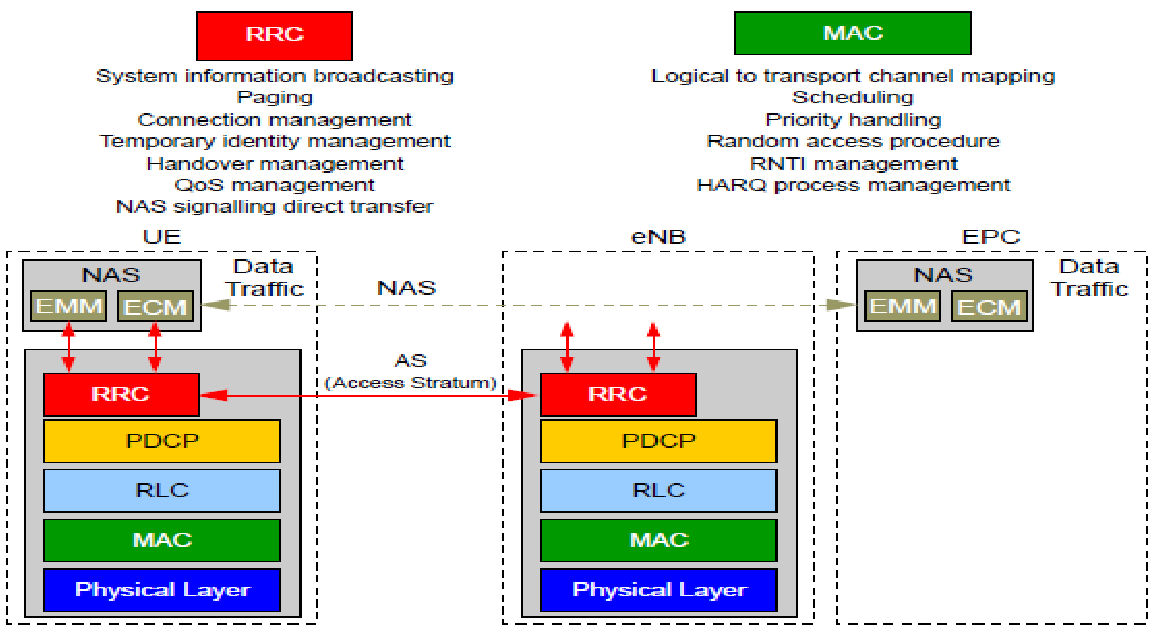

Figure 2.12: LTE Air Interface Protocols (Electronic Designs, 2016)

Evolved Packet System Mobility Management (EMM): EPS Mobility Management is a NAS protocol procedure basically initiated by the UE. These procedures define attach/detach (to/from the EPC) mechanisms. They also introduce the Tracking Area Update (TAU) mechanism, which update the location of the UE within the network. Tracking Area of EPS is the equivalent to Location Area in GSM and Routing Area in GPRS. In EPS, a UE initiates a Tracking Area Update when it detects that it enters into a new Tracking Area. EMM specific procedures also define periodic Tracking Area Update

Evolved Packet System Connection Management (ECM): EPS Connection management procedures provide several functions to support the connection of the UE to the core network EPS

- Service request: initiated by the UE to start the establishment of NAS signalling Connection.
- Paging: initiated by the network in case of downlink NAS signalling to indicate to the UE to start a service request
- Transport of NAS messages: used for Sort Message Service (SMS), and Circuit Switched (CS) fallback.
- Generic transport of NAS messages: Various other applications e.g. Location Services (LCS)

Packet Data Convergence Protocol (PDCP): Each radio bearer uses one PDCP instance. PDCP is responsible for header compression such as Robust Header Compression (ROHC); (RFC3095) and ciphering/deciphering of User plane data and Control plane data. PDCP Layer is responsible for Header compression and decompression of IP data, Transfer of data (user plane or control plane), Maintenance of PDCP Sequence Numbers (SNs), In-sequence delivery of upper layer PDUs at re-establishment of lower layers, Duplicate elimination of lower layer SDUs at re-establishment of lower layers for radio bearers mapped on Radio Link Control Acknowledged Mode (RLC-AM). Note that, Service Data Unit (SDU) is a packet unit from Radio Link Control (RLC) layer headed to upper layer through a process called concatenation.

This process adds header and concatenate more than one RLC SDU to form RLC Packet Data Unit (PDU). Padding of RLC SDUs also produces RLC PDU for upper layers. This is a process of adding filter bits to small SDU to make a complete PDU. Segmentation is a process in RLC layer where a Packet Data Unit (PDU) is received from upper layer and splits into SDUs. Packets received from upper layer are SDU while packet output of a layer is PDU.

Radio Network Temporary Identifiers (RNTIs) are used to differentiate/identify a connected mode UE in the cell, a specific radio channel, a group of UEs in case of paging, a group of UEs for which power control is issued by the eNB, system information transmitted for all the UEs by the eNodeB.

Radio Resource Control (RRC) is the access stratum specific control protocol for EUTRAN. It provides the required messages for channel management, measurement control and reporting while the NAS protocol is running between UE and MME of EPC and thus must be transparently transferred via Evolved UTRAN (E-UTRAN).

The Access Stratum (AS) is a functional layer in the UMTS and LTE wireless telecom protocol stacks between radio network (eNodeB) and user equipment. Access stratum is very different between UMTS and LTE; in both cases the access stratum is responsible for transporting data over the wireless connection and managing radio resources. The radio network is also called access network.

*Radio Link Control (RLC) layer***:** RLC operates in 3 modes of operation: Transparent Mode (TM), Unacknowledged Mode (UM), and Acknowledged Mode (AM).

RLC Layer is responsible for transfer of upper layer PDUs, error correction through Automatic Repeat Request (ARQ) only for Acknowledged Mode (AM) data transfer. Concatenation, segmentation and reassembly of RLC SDUs only for Unacknowledged Mode (UM) and Acknowledged Mode (AM) data transfer. Radio Link Control segments (divides) and reassembles higher layer data or concatenates higher layer data into data chunks suitable for transport over transport channels which allow only a certain set of transport block size. RLC also enhances radio bearer with Automatic Retransmission on Request (ARQ) with the help of sequence numbered frames and status reports to trigger retransmission.

Media Access Control (MAC): This unit is very significant on LTE network, one of the major factors determining the performance of the network. MAC protocol supports multiplexing and de-multiplexing between logical channels and transport channels. The MAC protocol supports QoS by scheduling and prioritizing data from logical channels. Recall that MAC layer is a sub layer in Open System interconnection (OSI) model layer 2 (Data Link Layer). Data link layer comprises of Media Access Control (MAC) which primarily provides flow control and multiplexing for transmission medium while the second sub layer thus; Logical Link Control (LLC) which primarily provides flow control and multiplexing for the logical link.

Physical Layer carries all information from the MAC transport channels over the air interface. The layer oversees the link adaptation based on Adaptive Modulation and Coding (AMC), power control, cell search in order to acquire initial synchronization and in cases handover process. Physical layer also defines other measurements receivable inside the LTE system and systems in-between for the RRC layer perusal. Physical link is the lowest layer of the OSI reference model. It is responsible for the actual physical connection between the devices. The physical layer contains information in form of bits. When receiving data, this layer will get the signal received and convert it into 0s and 1s (digital form) and send them to the Data Link layer, which will put the frame back together. The physical layer offers the following functions:

*Bit synchronization***:** This synchronization is achievable through clock provision which is set to control timing between the sender and the receiver hence providing synchronization at the level of bits.

Bit rate control: The Physical layer by its function specifies the transmission rate, thus the number of bits sent per second to be carried.

*Transmission mode***:** Physical layer by its function describes the manner in which the data flows and moves between two connected devices. Recall the various transmission modes used in telecommunication systems are: Simplex, half-duplex and full-duplex. Any of these modes is applied for device to device network connectivity

2.2.3 LTE Communication Channels

The way information are carried and processed across different layer protocols of LTE communication channels are characterized by Logical, Physical and Control Channels. These three channels coordinates and controls flow of information.

Logical Channels: Define **what-type** of information is transmitted over the air, e.g. traffic channels, control channels, system broadcast, etc. Data and signalling messages are carried on logical channels between the RLC and MAC protocols.

Transport Channels: Define **how-is** something transmitted over the air, e.g. what are encoding, interleaving options used to transmit data. Data and signalling messages are carried on transport channels between the MAC and the physical layer.

Physical Channels: Define **where-is** something transmitted over the air, e.g. first N symbols in the DL frame. Data and signalling messages are carried on physical channels between the different levels of the physical layer.

2.2.3.1 LTE Logical Channels

Logical channels define what type of data is transferred. These channels define the data-transfer services offered by the MAC layer. Data and signalling messages are carried on logical channels between the RLC and MAC protocols.

Logical channels can be divided into control channels and traffic channels. Control Channel can be either common channel or dedicated channel. A common channel means common to all users in a cell (Point to multipoint) while dedicated channels means channels can be used only by one user (Point to Point).

Logical channels are distinguished by the information they carry and can be classified in two ways. Firstly, logical traffic channels carry data in the user plane, while logical control channels carry signalling messages in the control plane. Below are lists of logical channels that are used in LTE. Broadcast Control Channel (BCCH), Paging Control Channel (PCCH), Common control Channel (CCCH), Dedicated Control Channel (DCCH), and Multicast control Chanel (MCCH). While Logical TRAFFIC Channels are Dedicated Traffic Channel (DTCH) and Multicast Traffic Channel (MTCCH)

2.2.3.2 LTE Transport Channel

Data and signalling messages are carried on transport channels between the MAC and the physical layer. Transport Channels are distinguished by the ways in which the transport channel processor manipulates them and they divided into Downlink Channels and Uplink Channels as used by LTE. LTE Transport channels for Downlink services are (1) Broadcast Channel (BCH), (2) Downlink Shared Channel (DSCH), (3) Paging Channel (PCH) and (4) Multicast Channel (MCH). LTE Transport Channels for UPLINK services are (1) Uplink Shared Channel (UL-SCH) and (2) Random Access Channel (RACH)

2.2.3.3 LTE Physical Channel

These are very crucial channels in LTE system, they are mostly used as TRANSPORT and CONTROL channels purposes. They carry with them information blocks received from MAC Physical layer and upper layers. Data and signalling messages are carried on physical channels between the different levels of the physical layer and accordingly they are divided into two parts: Physical Data Channels and Physical Control Channels.

On physical Data Channels, there are channels for Downlink such are Physical Broadcast Channel (PBCH), Physical Downlink Shared Channel (PDSCH) and Physical Multicast Channel (PMCH) and for Uplink operations are Physical Uplink Shared Channel (PUSCH), Physical Uplink Control Channel (PUCCH) and Physical Random Access channel (PRACH)

2.2.4 LTE Reference Signals

There are two types of reference signals, downlink reference signals and uplinks reference signals

a) *LTE Downlink Reference Signals*:

Reference symbols are also known as pilot symbols inserted in the OFDM time frequency grid to provide for channel estimation. This is done to allow for coherent demodulation at user equipment. Downlink reference symbols are inserted within the first and third last OFDM symbol of each slot with a frequency domain spacing of six (6) sub-carriers, this corresponds to the fifth and fourth OFDM symbols of the slot in case of normal and extended Cyclic Prefix (CP) mode respectively. Recall that the normal Cyclic Prefix (CP) mode has 7 OFDM symbols and extended 6 OFDM symbols. See figure 2.13

For one antenna system of normal CP mode in LTE, there are four reference symbols in each Resource block to estimate the channel, the user equipment interpolates over the multiple reference symbols. For two transmit Antenna System of normal CP mode, reference symbol signals are placed on both antennas, while the one in the second (2nd) antenna serves as an offset in the frequency domain by three sub-carriers. For adequate channel coefficient estimations on the UEs, the second (2nd) antenna transmits nothing at the same time-frequency location of reference signals.

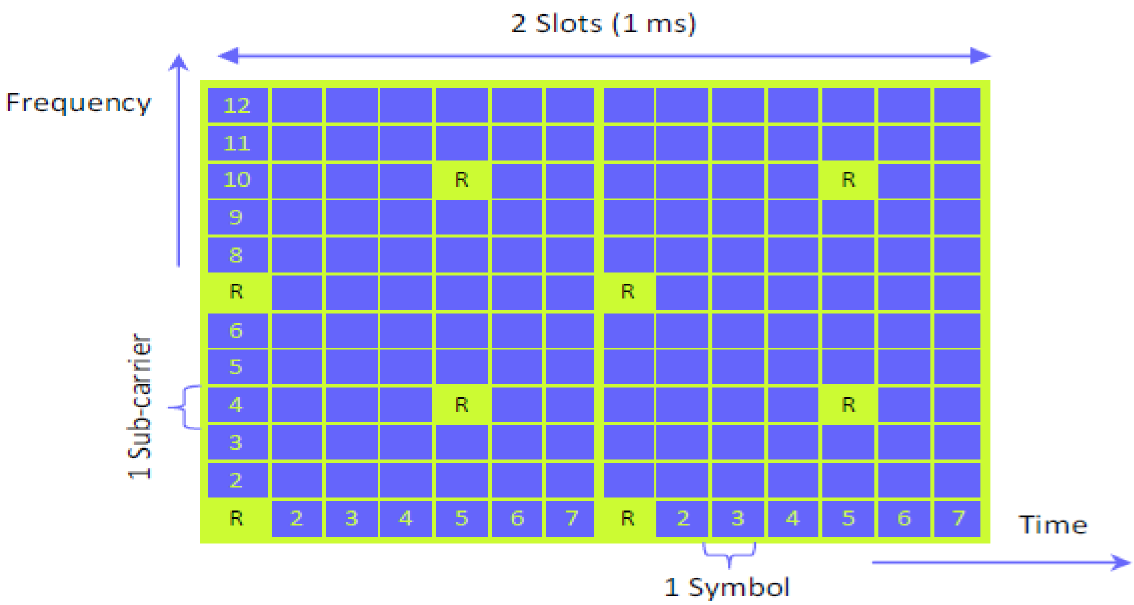

Figure 2.13: Reference Symbol locations in Resource Block (Telesystem, 2010)

b) LTE Uplink Reference Signals

Demodulation Reference signal (DM-RS) and Sounding Reference Signal (SRS) are two uplink reference signals in LTE. DM-RS is placed in the fourth or third Single Carrier Frequency Division Multiple Access (SC-FDMA) symbol of an uplink slot for normal or extended Cyclic Prefix (CP) respectively to enable coherent signal demodulation at the eNodeB. When using same bandwidth as the data, note that these symbols are time multiplexed with uplink data. The Sounding Reference Signals (SRS) are for channel dependency, in other words frequency selective on uplink scheduling. DM-RS cannot be used for this purpose since they are allocated over the assigned bandwidth to a UE. The SRS is introduced as a wider band reference signal typically transmitted in the last SCFDMA symbol of a 1 ms sub-frame. User data transmission is not allowed in this block which results in about 7% reduction in uplink capacity. Although the SRS is an optional feature and is highly configurable to control overhead, it can be turned off in a cell. Users with different transmission bandwidth share this sounding channel in the frequency domain. Figure 2.14 shows the locations of DM-RS and SRS in SC-FDMA symbol of Normal CP mode.

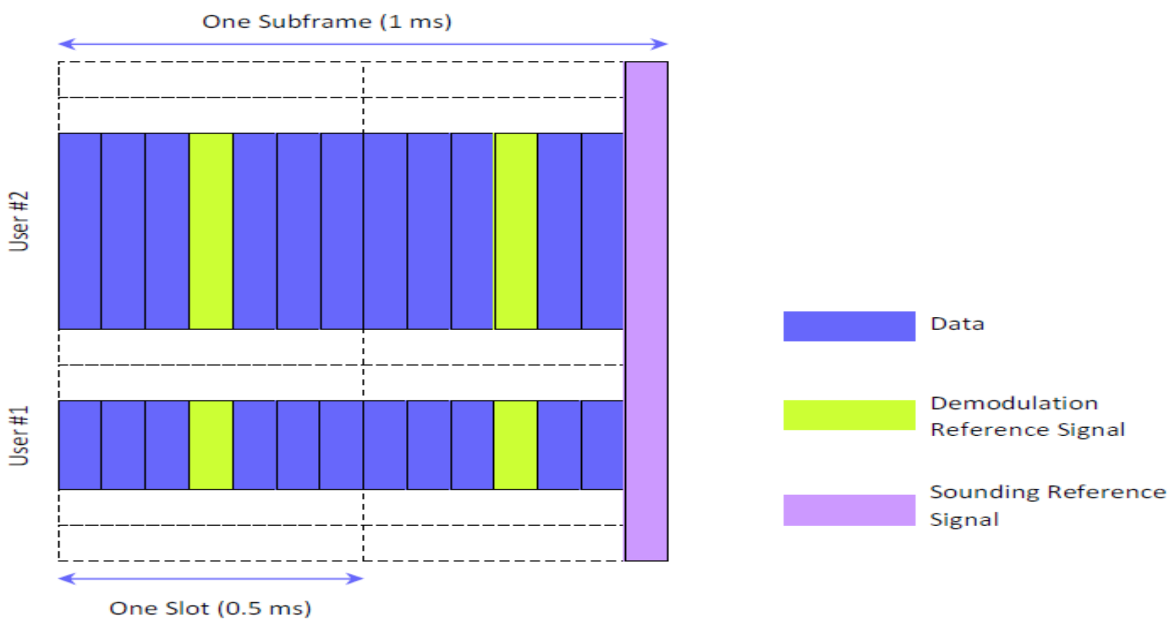

Figure 2.14: Uplink DM-RS and SRS in SC-FDMA Symbol of Normal CP mode (Telesystem, 2010)

c) LTE Synchronization Sequences

User Equipment (UE) access to LTE system follows stages of synchronization sequences in order to determine adequate time and frequency parameters needed to obtain downlink signals and also to transmit uplink signal at good timing and to obtain necessary system parameters. In LTE system, there are three requirements for synchronization.

1. Acquisition of symbol Timing: this determines where correct symbol begins
2. Synchronization of Carrier Frequency: This helps to eliminate frequency errors coming

from Doppler shift and system electronics.

3. Sampling Clock Synchronization

In LTE system, there are two types of cell search procedures: one for initial synchronization and another for detecting neighbour cells in preparation for handover. In both cases, the UE uses two special signals broadcast on each cell: Primary Synchronization Sequence (PSS) and Secondary Synchronization Sequence (SSS). The detection of these signals allows the UE to complete time and frequency synchronization and to acquire useful system parameters such as cell identity, cyclic prefix length, and access mode (FDD/TDD). At this stage, the UE can also decode the Physical Broadcast Control Channel (PBCH) and obtain important system information (Telesystem, 2010)

2.3 Orthogonal Frequency Division Multiplexing (OFDM)

OFDM technique is based on using multiple narrow bands sub-carriers spread over a wide bandwidth. The sub carriers are mutually orthogonal in the frequency domain, hence mitigates Inter Symbol Interference (ISI). OFDM supports FDD and TDD systems, (NTNU, 2015). OFDM modulates a block of data symbols simultaneously over one OFDM symbol, where one OFDM symbol is the time used to transmit all of subcarriers (12 subcarriers for one OFDM Symbol). At the transmitter side the baseband modulator modulates the input block data using different modulation formats such as Quadrature Phase Shift Keying (QPSK) or 16 or 64 Quadrature Amplitude Modulation (QAM). Hence, LTE makes use of either QPSK, 16QAM (4 bits per symbol) or 64QAM (six bits per Symbol). These modulated symbols are then mapped to subcarriers in case of Orthogonal Frequency Division Multiple Access (OFDMA) for forward link operation (Downlink). While in the case of reverse link (Uplink), Single Carrier-OFDM (SC-OFDM), an N-point Discrete Fourier Transformer (DFT) transforms these symbols in to frequency domain before mapping. An inverse DFT is used to transform the modulated subcarriers in frequency domain into time domain samples. A cyclic prefix copies a portion of the samples at the end of the time domain samples block to the beginning. The block of samples are then serialized in the time domain and converted to analog signals, finally the RF section modulates the In-Phase Quadrature (I-Q) samples to final transmission radio frequency. An exact inverse operation is performed at the receiver side, starting from Received RF to Analogue Digital Conversion (ADC), to removal of Cyclic Prefix etc. (Daniel, 2016). Note that I-Q samples are samples that are converted from a polar coordinate system to a Cartesian(X, Y) coordinate system. **OFDM** technique avoids need for complex frequency equalizer as used in 3G technology. Inter symbol interference is prevented using a guard interval (Tg) or Cyclic Prefix (CP) between subcarriers at the beginning of each OFDM symbol. The OFDM symbol duration (Tu) is termed useful symbol, when total symbol length (Ts) is equal to the sum of OFDMA symbol (Tu) and the guard interval (Tg). Thus:

$$T_s = T_u + T_g T_s \quad (2.4)$$

The above equation makes the OFDM symbol sensitive to time dispersion. Recall, time dispersion is a type of fading in wireless communication caused by multipath time delay spread $\delta\tau$ which either gives flat fading (situation where all signal is received correctly thus $\delta\tau << Ts$) or Frequency selective fading (situation where signal received is distorted thus $\delta\tau >> Ts$).

2.3.1 Orthogonal Frequency Division Multiple Access (OFDMA)

The LTE downlink employs OFDMA as the multiple access technique because of its efficiency in managing allocated resources and low latency in sending packets, OFDMA single user equipment communicates on all the sub carriers at any time. UEs are allocated specific number of sub carriers for a predetermined amount of time by the base station called the eNodeB in LTE, so that the multiple UEs can be scheduled for data transmission simultaneously. The scheduling resource unit is known as the physical Resource block (PRB). A PRB is the smallest unit of resource that can be allocated to a user. Also PRB has both time and frequency dimension. The OFDMA signal used in LTE downlink consist of 2048 different sub carriers at maximum while operating 20MHz bandwidth with sub carrier spacing of 15 KHz. One resource block (RB) consists of 12 sub carriers irrespective of the overall LTE bandwidth

In OFDMA, the RB is 180 kHz wide in frequency and 0.5ms long in time domain. In frequency, the standard number of subcarriers used per RB is 12 for most channels. The minimum unit of the time domain is a Symbol, which amounts to 66.7 μs. Regardless of bandwidth, the symbol length does not change. The largest unit in time domain is a frame, each of which is 10 ms in length. Each of the frame consists of 10 sub frames, each of which is 1 ms in length. Each of sub frames consists of 2 slots, each of which is 0.5 ms in length. Each of slots consists of 7 symbols or 6 symbols for normal and extended cyclic prefix respectively, each of which is 66.7 μs.

Standard LTE radio frame format is shown in Figure 2.15 has time duration of 10 ms, consisting of 20 slots of each 0.5 ms, two adjacent slots form a sub-frame of 1 ms duration, which is also one Transmission Time Interval (TTI). Each slot consists of seven OFDM symbols with short/normal Cyclic Prefix (CP) or six OFDM symbols with long/extended CP. CP is the process of extending each symbol to avoid inter-symbol-interference by duplicating a portion of the signal at the symbol ends, which is removed at the receiver.

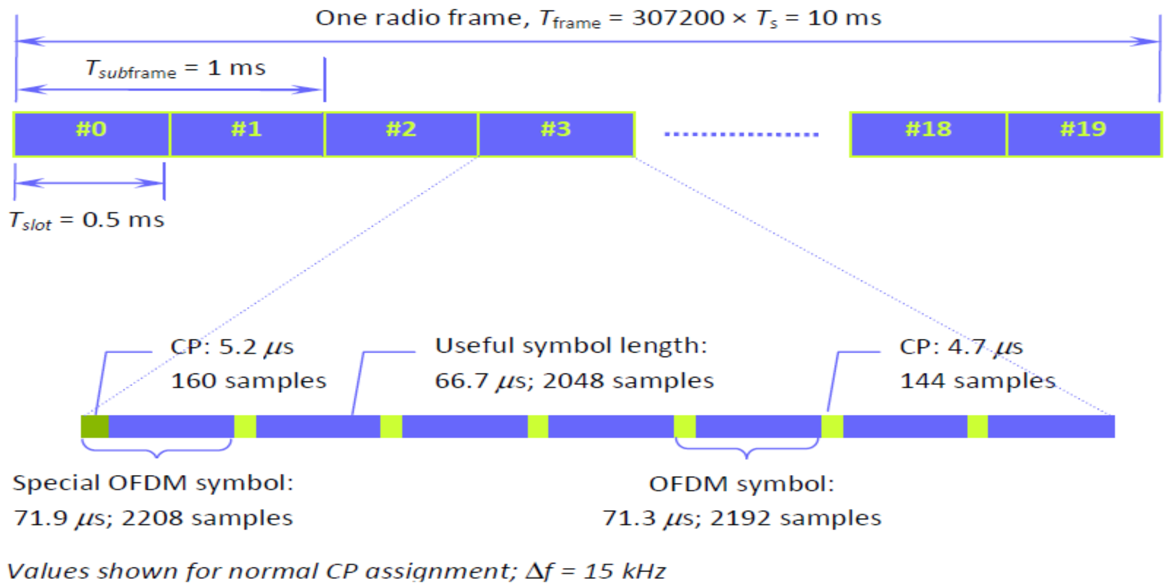

Figure 2.15: Standard LTE Radio Frame (Telesystem, 2010)

In the time domain, different time intervals within LTE are expressed as multiples of a basic time unit *T*s = 1/30720000. The radio frame has a length of 10 ms (*T*frame = 307200 ・*T*s). Each frame is divided into ten equally sized sub-frames of 1 ms in length (*T*sub-frame = 30720 ・*T*s). Scheduling is done on a sub-frame basis for both the downlink and uplink. Each sub-frame consists of two equally sized slots of 0.5 ms in length (*T*slot = 15360 ・*T*s). Each slot in turn consists of a number of OFDM symbols which can be either seven (normal cyclic prefix) or six (extended cyclic prefix).

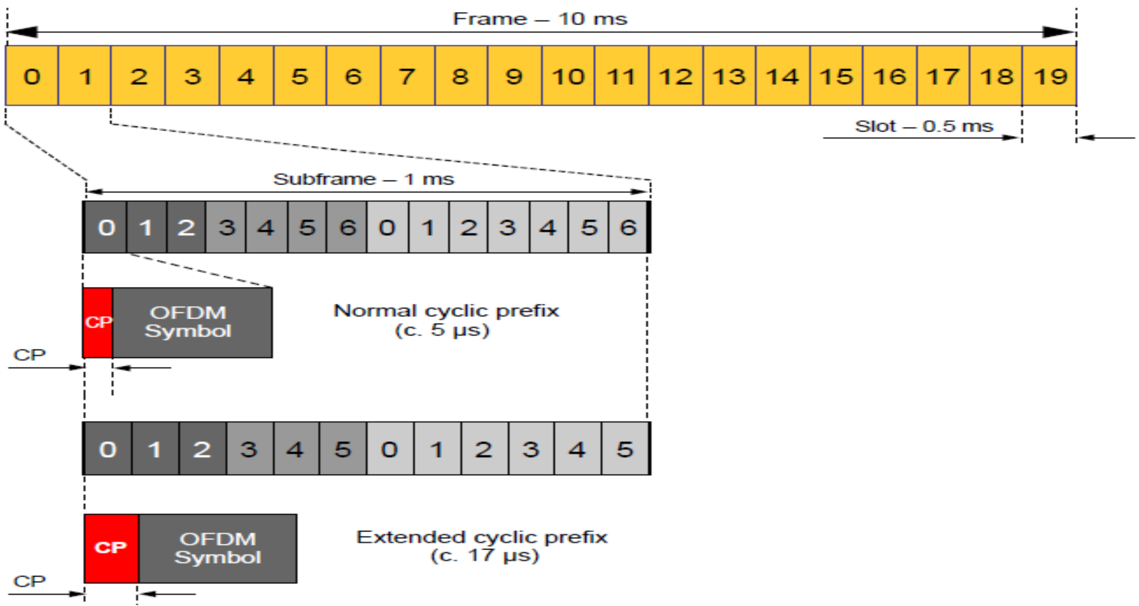

Figure 2.16: LTE FDD Mode Frame Structure (Wrey, 2011)

Figure 2.16 represents FDD radio frame. Recall, the frequency channel is common for both uplink and downlink. One FDD frame is 10 ms and is subdivided into 20 slots; each slot is 0.5ms duration. For most information transmission, two slots are combined to form a sub-frame which gives 1ms and corresponds to one TTI (Transmission time interval). Scheduling occurs during one TTI, up to the first three symbols in the sub frame can be used for carrying control and scheduling messages. Then the remaining symbols of the first slot and the second slot of the sub-frame are made available be used for data traffic by users.

The useful symbol time is $T\text{u} = 2048 \times T\text{s} \approx 66.7\ \mu\text{s}$. For the normal mode, the first symbol has a cyclic prefix of length $T\text{CP} = 160 \times T\text{s} \approx 5.2\ \mu\text{s}$. The remaining six symbols have a cyclic prefix of length $T\text{CP} = 144 \times T\text{s} \approx 4.7\ \mu\text{s}$. The reason for different CP length of the first symbol is to make the overall slot length in terms of time units divisible by 15360. For the extended mode, the cyclic prefix is $\text{TCP-e} = 512 \times T\text{s} \approx 16.7\ \mu\text{s}$. The CP is longer than the typical delay spread of a few microseconds typically encountered in practice. The normal cyclic prefix is used in urban cells and high data rate applications while the extended cyclic prefix is used in special cases like multi-cell broadcast and in very large cells (e.g. rural areas, low data rate applications).

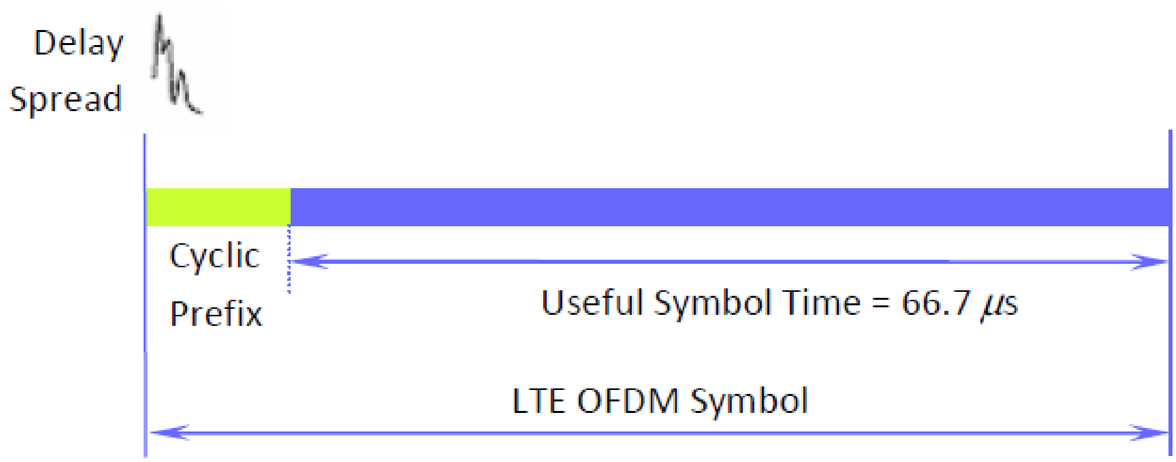

Figure 2.17: LTE Symbol Structure (Telesystem, 2010)

The CP uses up part of the physical layer capacity: 7.5% in the case of normal cyclic prefix. One way to reduce the relative overhead due to cyclic-prefix insertion is to reduce the sub-carrier spacing D*f*, with a corresponding increase in the symbol time *T*u as a consequence. However, this will increase the sensitivity of the OFDM transmission to frequency instability resulting from fast channel variations (i.e. high Doppler spread) as well as different types of frequency errors due to electronics.

In the frequency domain, the number of sub-carriers *N*, ranges from 128 to 2048, depending on channel bandwidth with 512, 1024 and 2048 for 5MHz, 10MHz and 20 MHz, respectively.

The sub-carrier spacing is D*f* = 1/*T*u = 15 kHz. The sampling rate is *f*s = D*f* · *N* = 15000 *N*. This result in a sampling rate that's multiple or sub-multiple of the Wideband Code Division Multiple Access (WCDMA) chip rate of 3.84 Mcps: LTE parameters have been chosen such that Fast Fourier Transform (FFT) lengths and sampling rates are easily obtained for all operational modes while at the same time ensuring the easy implementation of dual-mode devices with a common clock reference. In a macro cell, the coherence bandwidth of the signal is in the order of 1 MHz. LTE carrier bandwidth of up to 20 MHz, there are some sub-carriers that are faded and other are not faded. Transmission is done using those frequencies that are not faded. The transmission can be scheduled by Resource Blocks (RB) each of which consists of 12 consecutive sub-carriers, or 180 kHz, for the duration of one slot (0.5 ms). This granularity is selected to limit signalling overhead. A Resource Element (RE) is the smallest defined unit which consists of one OFDM sub-carrier during one OFDM symbol interval.

Each Resource Block consists of 12 x 7 = 84 Resource Elements in case of normal cyclic prefix (72 for extended CP)

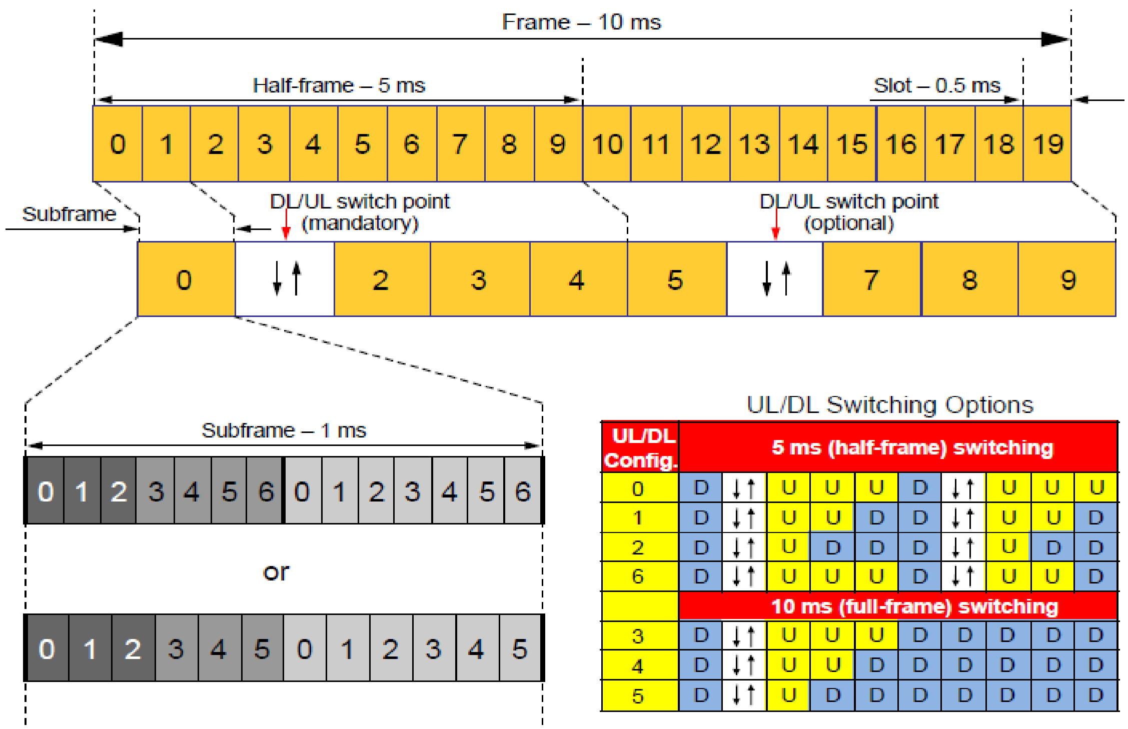

Figure 2.18: LTE TDD Mode Frame Structure (Telesystem, 2010)

Figure 2.18 depicts the frame used for LTE TDD configured systems, they share 10 ms frame structure and 1 ms sub frame like in FDD but with a demarcation known as a half frame. Each of the half frames carries 5 sub frames and each of them can be used for TDD downlink to Uplink switching. The switching point in the first half is mandatory while in the second is optional. In the configuration parameter, it is flexible to set or allocate more slots for uplink or downlink

2.3.2 Single Carrier Frequency Division Multiple Access (SC-FDMA)

Single Carrier Frequency Division multiple Access (SC-FDMA) is the technique used for LTE uplink channels, although very similar to OFDMA implementation but some factors made considerably efficient for uplink use rather than OFDMA. SC-FDMA is a modified form of OFDMA. It has similar throughput performance and complexity as OFDMA. OFDMA has a very high Peak to Average Power Ratio (PAPR). High PAPR requires expensive and highly efficient power amplifiers with good linearity capability, which increases the cost of the terminal and drains the battery life faster. One key factor that affects all user equipment UEs or Mobile terminals is the battery life, minimal use of the battery span is very important to stay connected. RF power amplifier is noted to consume most UE battery life, as it is required to transmit RF signal through mobile antenna to eNodeB, LTE system requires more power for higher modulation order such as 64QAM to gain robust RF signal format. SC-FDMA brings the benefit of low peak-to-average power ratio compared to OFDMA making it suitable for uplink transmission by user terminals. SC-FDMA solves this problem by grouping together the resource blocks in such a way that reduces the need for linearity, and so lowers power consumption in the power amplifier. A low PAPR also improves coverage and the cell-edge performance

In OFDMA each subcarrier only carries information related to one specific symbol while in SC-FDMA contains information of all transmitted symbols. For a single sample in time the signal being transmitted is composed of the summation of all symbols, due to mapping of the symbols' frequency domain samples to subcarriers. Thus, SC-FDMA offers spreading gain in frequency selective channels (Joe et al, 2014). The main difference between OFDMA and SC-FDMA transmitter is the Discrete Fourier Transform (DFT) mapper. After mapping data bits into modulation symbols, the transmitter groups the modulation symbols into a block of N symbols. An N-point DFT transforms these symbols in time domain into frequency domain. The frequency domain samples are then mapped to a subset of M subcarriers where M is typically greater than N.

Table 2.2: Downlink Parameter for LTE OFDMA Fame

Transmission BW	1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Sub-frame duration	0.5 ms					
Sub-carrier spacing	15 kHz					
Sampling frequency	1.92 MHz (1/2 × 3.84 MHz)	3.84 MHz	7.68 MHz (2 × 3.84 MHz)	15.36 MHz (4 × 3.84 MHz)	23.04 MHz (6 × 3.84 MHz)	30.72 MHz (8 × 3.84 MHz)
FFT size	128	256	512	1024	1536	2048
Number of occupied sub-carriers†, ††	76	151	301	601	901	1201
Number of OFDM symbols per sub frame (Short/Long CP)	7/6					
CP length (µs/samples) – Short	(4.69/9) × 6, (5.21/10) × 1*	(4.69/18) × 6, (5.21/20) × 1	(4.69/36) × 6, (5.21/40) × 1	(4.69/72) × 6, (5.21/80) × 1	(4.69/108) × 6, (5.21/120) × 1	(4.69/144) × 6, (5.21/160) ×1
CP length (µs/samples) – Long	(16.67/32)	(16.67/64)	(16.67/128)	(16.67/256)	(16.67/384)	(16.67/512)

Source: (Bao-Shuh, 2011)

Table 2.3: Uplink Parameters for LTE SC-FDMA Frame

Transmission BW		1.25 MHz	2.5 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Timeslot duration		0.675 ms					
Sub-carrier spacing		15 kHz					
Sampling frequency		1.92 MHz (1/2 × 3.84 MHz)	3.84 MHz	7.68 MHz (2 × 3.84 MHz)	15.36 MHz (4 × 3.84 MHz)	23.04 MHz (6 × 3.84 MHz)	30.72 MHz (8 × 3.84 MHz)
FFT size		128	256	512	1024	1536	2048
Number of occupied sub-carriers†, ††		76	151	301	601	901	1201
Number of OFDM symbols per Timeslot (Short/Long CP)		9/8					
CP length (μs/samples)	Short	7.29/14	7.29/28	7.29/56	7.29/112	7.29/168	7.29/224
	Long	16.67/32	16.67/64	16.67/128	16.67/256	16.67/384	16.67/512
Timeslot Interval (samples)	Short	18	36	72	144	216	288
	Long	16	32	64	128	192	256

Source: (Bao-Shuh, 2011)

2.4 Multiple Input Multiple Output (MIMO) and LTE Capacity

In wireless communication system, multiple-input and multiple-output (MIMO) technology is adopted method for multiplying the capacity of a radio link using multiple transmit and receive antennas to advantage of multipath propagation. MIMO has been featured in a number of wireless communication standards such as IEEE 802.11n (Wi-Fi extension, 2008), IEEE 802.11ac (Wi-Fi), HSPA+ (3G), IEEE 802.16e (WiMAX), and Long Term Evolution (4G LTE). Multiple Input- Multiple Output (MIMO) systems are one of the major enabling technologies for LTE. They allow higher data rate transmission through the use of multiple antennas at the transmitter and receiver to provide simultaneous transmission of multiple parallel data streams over a single radio link.

The Single-Input Single-Output system (SISO) system is the most commonly used one due to high power consumption of MIMO systems. In SISO the maximum channel capacity is given by the Shannon-Hartley relationship:

$$C = B \times log_2 (1 + SIN\,\mathrm{R}avg) \qquad (2.5)$$

Where C is the channel capacity in bits per second, B is the channel bandwidth in Hz and SINRavg is the average Signal to Interference and Noise Ratio (SINR) at the receiver.

For MIMO system the capacity is given by:

$$C = B \times log_2 (1 + M_T \times N_R \times SIN\mathrm{R}avg) \qquad (2.6)$$

Where M_T is the number of transmitting antennas and N_R is the number of receiving antennas. Thus, obtaining an M_TN_R fold increase in the SINRavg and increasing channel Quality (Tewelde et al, 2015).

2.4.1 Formats of Multiple Input Multiple Output

There are Spatial Diversity and Spatial Multiplexing formats.

Spatial Diversity: This form of MIMO refers to transmit and receive diversity methodology. These two methods are used to improve Signal to Noise Ratio (SNR) and link reliability with respect to fading mitigation. Transmit diversity radiates data stream signal to be transmitted over all available and configured transmit antennas. The same data signal that is sent on all transmit antennas reaches the receiver and the combined signal level will be higher gain than the case of only one transmit antenna. This makes transmit diversity more interference resistant. Transmit diversity will increase the Carrier-to-Interference plus Noise Ratio (CINR) level and is used at cell locations with low CINR (i.e., further from eNodeB toward the cell edges).

Spatial Multiplexing: This form of MIMO tends to provide more data capacity by taking advantage of different paths or multiple paths to carry additional data traffic. This gives direct improvement on data throughput of the network. Different data stream signals are transmitted or sent to different transmit antennas following this multiplexing technique. If the transmit terminal has *M* antennas and the receive terminal had *N* antennas, the throughput through transmit and receive link can be increased by [min (*M*, *N*)]. This technique tends to provide more data capacity by taking advantage of numerous of data traffic, this gives arise to increased channel throughput provided that good CINR levels exist over the link

Note that MIMO generally, improves wireless capacity of a given channel while still obeying Shannon Hartley's theory as relates to Channel capacity, Channel bandwidth and link.

2.4.2 LTE Channel Estimation

Channel estimation is a technique used in order to estimate the channel characteristics. Signal recovery process requires knowledge of channels, which are estimated from pilots. To increase the data rate of the wireless communication, the spatial multiplex is used in the MIMO system with Nt transmitted antennas and Nr received antennas. Assuming that the signal $X^i(t)$ represents the i-th of Nt transmitted vector pass through the channel response (Nr x Nt) matrix H, which is dependent on the transmitted angle, the incidences of received antennas and the number of multi-path in varied channel. The main functionality of OFDM system is to ease the frequency selection effect. After FFT block as described in Lin-Chang (2012) the received signals at the k-the subcarrier $X_k(n)$ can be obtained in frequency domain, as indicated in equation 2.4.

$$Y_k = H_k X_k + n_k \tag{2.7}$$

for k = 1, 2, 3…... N

The MIMO system is presented as equation. (2.4) with Nt transmitted antennas and Nr received antennas, and the QR decomposition of Hk is derived from computing the known preambles or known training sequences of wireless communication system by channel estimation. (Lin Chang, 2012).

In recent times, most of the modern MIMO-OFDM data-detecting methods are combined with QR decomposition algorithm. The main reason is that, after QR decomposing the channel response, the data is kept orthogonal and simplified the signal processing procedures. When the channel response H, is QR decomposed, it will be transformed into an up-triangular matrix R. Therefore, the interference of every received signal is reduced. Since using QR decomposition algorithm can decrease the complexity of equalizer, the total size will not be increased due to the additional QR decomposition. The common QR decomposition algorithms are Gram Schmidt Orthogonalization.

2.5 Cell Throughput in Long Term Evolution Network

The deployment of new Radio Access Technologies (RAT) has paved the way for fast mobile broadband services (Buenestado, Ruiz-Avilés, Toril, Luna-Ramírez, Mendo, 2014). With these services commercially available, network operators now face the challenge of meeting rising user expectations in an increasingly complex environment. Rapid adoption of smartphones and tablets has generalized the use of applications always connected to the network, increasing both signalling and user data significantly. The 3rd Generation Partnership Project (2010) group has defined five classes of performance indicators.

i. Service availability

ii. Accessibility

iii. Retainability

iv. Mobility

v. Integrity

This Long term evolution (LTE) is telecom technology specified by 3GPP for 4G wireless communication. Ajay and Samar (2017) stressed that LTE provides high spectral efficiency, high data rates, high throughput, low latency and less propagation delays as well as high frequency stability and flexibility. The user throughput is an important indicator to check the integrity of data services in all radio access technologies (RAT). Likewise, average cell throughput is used to estimate the maximum cell capacity for network dimensioning (Buenestado *et al.*, 2013). The LTE throughput performance is widely reported in the literature, based on simulation tools or field tests. The present study adopts field test analysis based on data obtained from SLA LTE networks. The comprehensive analysis of several widely accepted indicators of overall network throughput performance in LTE.

i. User Throughput

ii. Cell Throughput

iii. Radio link throughput

However, throughput is the data rate that is successfully delivered over a channel for a given time (seconds). The unit for throughput is usually bits per second. By comparing the throughput of each scenario, it is easy to determine the QOS of each scenario (Ajay *et al.*, 2016).

2.5.1 Quality of Service (QoS) in LTE Network

According to Ross and Bambos (2005) the Quality of Service (QoS) in the field of telecommunications can be defined as a set of specific requirements provided by a network to users, which are necessary in order to achieve the required functionality of an application (service). The users specify their performance requirements in form of Quality of Service (QoS) parameters such as delay or packet loss and the network commits its bandwidth making use of different QoS schemes to satisfy the request. Each service model has its own QoS parameters. An increase in bandwidths and processing capabilities of future packet switched networks is necessitated dramatic rise to types of applications using them. Many of these applications will require guaranteed quality of services (QoS) such as a bound on the maximum end-to-end packet delay and/or on the probability of packet loss. According to De-Gouveia and Magedanz (2005), Quality of Service (QoS) refers to several related aspects of telephony and computer networks that allow the transport of traffic with special requirements. Quality of Service is the ability to provide different priority to different applications, users, data flows in order to guarantee a certain level of performance. For example, a required bit rate, delay, jitter, packet dropping probability or bit error rate may be guaranteed. QoS involves measurements and guarantees of buffer capacity. Drop rates of packets and expected delay are examples of Quality of Service quantities which are of great importance to network managers and customers. (Ross and Bambos, 2005). Quality of Service guarantees is important if the network capacity is insufficient, especially for real-time streaming multimedia applications such as voice over IP, online games and IP-TV. Since these often require fixed bit rate and are delay sensitive.

In packet-switched networks, Quality of Service is affected by various factors, which can be divided into "human" and "technical" factors (Naoum and Maswady, 2012). Many things can happen to packets as they travel from origin to destination, resulting in the following problems as seen from the point of view of the sender and receiver. Human factors include: stability of service, availability of service, delays, user information. Technical factors include: Reliability, Scalability, Effectiveness, Maintainability and Grade of service

Freeman (2004) states that there are a number of generic impairments that will directly or indirectly affect Quality of Service of voice, data, images etc. in telecommunication transmission systems. The following forms basic impairments in telecommunication networks and they include: Signal-to-Noise Ratio, Voice Transmission Rating, Amplitude (or attenuation) distortion and Phase distortion

Signal-to-Noise Ratio: Signal-to-noise ratio (S/N or SNR) is the most widely used parameter for measurement of signal quality in the field of transmission. Signal-to-noise ratio expressed in decibels which indicate the amount by which signal level exceeds the noise level in a specified bandwidth. The types of material to be transmitted on a network each will require minimum S/N to satisfy the user or to make a receiving instrument function within certain specified criteria. The following are S/N guidelines at the corresponding receiving devices (Freeman, 2004):

i. Voice: 40 dB;
ii. Video (TV): 45 dB;
iii. Data: ∼15 dB based upon the modulation type and specified error performance.

2.6 Key Performance Indicator (KPI) of LTE Network

According to Vasseur, Pickavet, Demeester (2004) the performance of network is affected by parameters such as latency (delay), jitter, throughput, packet loss, scalability, recovery time, and network reliability, percentage of coverage, stability and signal requirement.

Delay/Latency: The delay is a parameter that is intrinsic to communications, since the end points are distant and the information will consume some time to reach the other side. Delay is also referred as to latency. Delay time can be increased if the packets face long queues in the network (congestion), or cross a less direct route to avoid congestion. The delay can be measured either one-way (the total time from the source that sends a packet to the destination that will receive it), or round-trip, the one-way latency from source to destination plus the one-way latency from the destination back to the source (Vasseur *et al.,* 2004). Latency is experienced when it takes a longer time than expected for each packet to reach its destination. This is different from throughput, as the delay can build up over time, even if the throughput is almost normal. In some cases, excessive latency can render an application such as VoIP or online gaming unusable and directly affects the performance of network throughput.

*Throughput***:** This is the amount of data which a network or entity sends or receives the amount of data processed in one determined time space. It has basic units of measurement, the bit per second (bit/s or bps). Due to varying load from other users sharing the same network resources, the bit rate (the maximum throughput) that can be provided to a certain data stream may be too low for real time multimedia services if all data streams get the same scheduling priority (Vasseur *et al.*,2004).

*Jitter***:** Jitter is the delay variation and is introduced by the variable transmission delay of the packets over the networks. This can occur because of router's internal queues behaviour in certain circumstances such as flow congestion and routing changes. This parameter can seriously affect the quality of streaming audio and/or video. To handle jitter, it is needed to collect packets and hold them long enough until the slowest packets arrive in time, rearranging them to be played in the correct sequences (Vasseur *et al.,* 2004).

*Packet loss***:** Packet loss occurs when one or more packets of data being transported across the internet or a computer network fail to reach their destination. Wireless and IP network cannot provide a guarantee that packets will be delivered at all, and will fail to deliver (drop) some packets if they arrive when their buffer is already full. This loss of packets can be caused by other factors like signal degradation, high loads on network links, packets that are corrupted being discarded or defected packets in network element (Vasseur *et al.*, 2004).

Dropped packets: The routers might fail to deliver (drop) some packets if their data is corrupted or they arrive when their buffers are already full. The receiving application may ask for this information to be retransmitted, possibly causing severe delays in the overall transmission (Vasseur et al., 2004).

Errors: Sometimes packets are corrupted due to bit errors caused by noise and interference, especially in wireless communications and long copper wires. The receiver has to detect this and, just as if the packet was dropped, may ask for this information to be retransmitted (Vasseur *et al.*, 2004).

Out-of-Order Delivery: When a collection of related packets is routed through a network, different packets may take different routes, each resulting in a different delay. The result is that the packets arrive in a different order than they were sent. This problem requires special additional protocols responsible for rearranging out-of-order packets to an isochronous state once they reach their destination. This is especially important for video and VoIP (Voice over Internet Protocol) streams where quality is dramatically affected by both latency and lack of sequence.

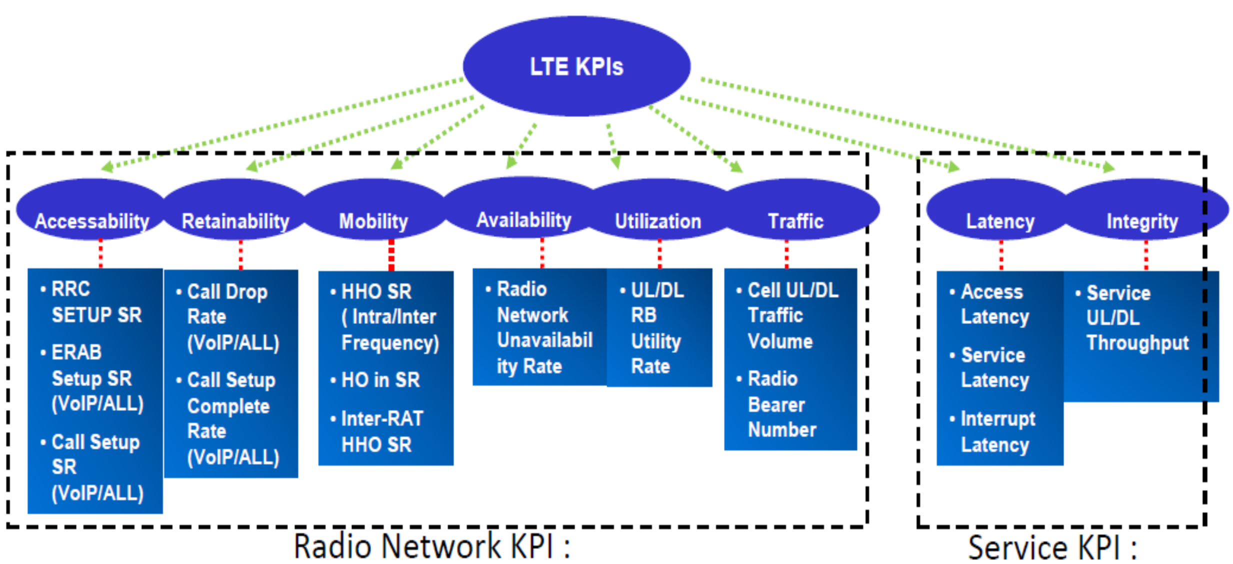

Figure 19: Overview of LTE Network Key Performance Indicator (Huawei Tech. Ltd. 2012).

Radio network KPI comprises elements that define the performances of the radio network while the Service KPI defines the elements focuses on users' experience.

RRC SETUP SR: Radio Resource Control Connection setup Success Rate

ERAB Setup SR (VoIP, VoLTE/ALL): E-UTRAN Radio Access Bearer setup Success Rate. (Voice over Internet Protocol, Voice over Long Term Evolution)

Call Setup SR (VoIP, VoLTE/ALL): Call Setup Success Rate Inter –RAT HHO SR: Inter Radio Access Technology Hard Handover Success Rate

Other Key Performance Indicators (KPIs) as employed by the SPECTRANET limited are as follows:

(i) Average Uplink (UL) and Downlink (DL) Throughput (Mbps)

(ii) Average Physical Resource Block Utilization Rate Per Cell (Percentage)

(iii) Average number of User

(iv) Reference Signal Received Power (RSRP)

(v) Reference Signal Received Quality (RSRQ)

(vi) Signal to Noise Ratio (SNR)

(vii) Intra-eNodeB Handover Success and Failure Rate

(viii) Average Downlink Channel Quality Indicator (DL CQI)

(ix) Average DL and UL Spectrum Efficiency

(x) Average DL and Uplink Traffic Volume per Cell

(xi) Average Service Drop Rate

(xii) Average DL and UL Transmission Block Retransmission Rate

2.7 LTE Radio Resource Management (RRM)

The aim of Radio Resource Management (RRM) in wireless communication networks such as LTE is to share the available and often limited radio spectrum between users as efficiently as possible (Vesa, 2007). The efficiency in RRM refers to the use of capacity in the sense of maximizing the data traffic load with respect to satisfying the QoS requirements. To ensure an efficient use of radio resources, several techniques are used as part of RRM. The main RRM algorithms/technique in LTE includes Admission Control, Power Control and Interference Control, and Packet Scheduling. (Dinesh, 2016):

***Admission control**:* The first Radio Resource Management mechanism that a user new encounter is the admission control process, which decides whether the services of the new user can be supported in the current traffic situation. Care in the admittance process is necessary, since admittance of several users demanding services could result in unacceptable outage and dropping potential for the users already in the network. If overload in the system should occur anyway, use of connection removal algorithms is obligatory to remove as few users as possible to guarantee the desired QoS level to the others (Vesa, 2007)

Power Control and Interference Control (PCIC): Since 3GPP only defines signalling regarding these procedures, they can be vendor and operator dependent. To overcome the fundamental difficulties of radio wave propagation in the environment of cellular networks, PCIC can be employed for monitoring and controlling the network traffic. Vesa (2007) generalised radio resource management algorithm/techniques as three they include:

i. *Transmission Power Control*: power control in wireless communication refers to intelligent setting and balancing of the transmission powers in respect of the available radio resources in the system.

ii. *Adaptive Beam Forming*: Adaptive beamforming provides a way to do spatial filtering of the signals in multiple-antenna systems in order to amplify the desired waveforms in respect to the interfering signals.

iii. *Transmission Rate Allocation*: Transmission rate allocation controls communication speeds of all connections with variable transmission rates in the system

Packet scheduling*:* An efficient mechanism is necessary to take advantage of a cell's capacity, ensuring high spectral efficiency while guaranteeing the defined QoS to the connected users. LTE's solution resides in the scheduling of resources for both downlink and uplink channels in an intelligent and weighted way. Its main goal is the allocation of Resource Blocks (RBs) and transmission powers for each sub-frame in such way that a determined set of performance metrics is optimized. For the instance maximum/minimum/average throughput, maximum/minimum/average delay, total/per-user spectral efficiency or outage probability.

According to Ralf and Karstan (2011) the most critical function in the Evolved Universal terrestrial Random Area Network (E-UTRAN) is the Packet scheduling which is a sub-function and major function of Radio Resource Management (RRM) system. This sub-function can only be efficient with adequate scheduling algorithm. Adequate in this context means that it has to be handling network resources based on peculiarities because network behaviours, environment, topologies, deployment, capacity, users etc. differ, hence the importance of understanding adequate scheduling algorithm to suit each network operator. Adequate Scheduling algorithm ensures provisioned radio resources are utilized efficiently and Quality of Service is maintained across board. Scheduler is a very crucial tool in wireless communication in order to support increasing demand on data services such as mobile Television (TV), web. 2.0 services, content streaming, online video games etc. Schedulers tend to provide adequate priority and fairness to all UEs, thereby improving and enhancing the cell throughput performance.

In International Telecommunication Union Radio communication Sector (ITU-R), scheduling algorithm is proprietary to network operator. Major kinds of scheduling algorithm or technique employed in LTE are (1) Best Channel Quality Indicator, (2) Round Robin (RR), (3) Proportional Fair Scheduler and (4) Max-Rate Scheduler.

2.7.1 Scheduling Algorithm in 4G LTE

Best Channel Quality Indicator (CQI): This scheduling algorithm is used strategically to assign resource blocks (RB) to the user with the best radio link conditions. The resource blocks assigned by the Best CQI to the user will have the highest CQI on that RB. The Mobile Station or UE must feedback its Channel Quality Indication (CQI) to the eNodeB to perform the Best CQI. UEs scheduling proceeds after eNodeB must have assessed the terminals Channel Quality condition instantaneously. Basically in the downlink, the BS transmits reference signal (downlink pilot) to terminals. These reference signals are used by UEs for the calculation of the CQI. A higher CQI value means better channel condition and more resource blocks from the scheduler

Round Robin (RR): The scheduler developed with this technique provides resources cyclically to the users without considering channel conditions into account. It goes in cycles, first come, first served and on equal proportion. The simple nature and procedure of this technique gives the best fairness to all users. However, the technique would propose poor performance in it comes to cell throughput and cell edge throughput. Round Robin technique meets the fairness to all by providing an equal share of packet transmission time to each user. In Round Robin (RR) scheduling the terminals are assigned resource blocks (RB) in turn thus;

one after another without considering CQI values or any form of channel conditions. This means that the terminals are equally scheduled. However, throughput performance degrades significantly as the algorithm does not rely on the reported instantaneous downlink SNR values when determining time and radio frequency to be assigned as well as the number of bits to be transmitted.

Proportional Fair Scheduler (PF): Main purpose of Proportional Fair algorithm is to balance between throughput and fairness among all the UEs. The technique tends to maximize total wired and wireless network throughput while at the same time providing resource to all users at least at minimal level of acceptable service. Proportional Fairness was designed to maintain best access data rate. The scheduler applies Proportional Fair (PF) scheduling by allocating more resources to a user with comparatively better channel quality. This is done by giving each data flow a scheduling priority that is inversely proportional to its anticipated resource consumption. Users are scheduled based on the value of R/r, where R is the maximum data rate corresponding to the channel quality, and r is the average data rate of the user. Based on the radio channel quality of an individual user, the PF scheduler provides the user with an average throughput proportional to its average channel quality. In most cases, this algorithm is used to ensure fairness among users while achieving a moderate cell capacity.

Max-Rate Scheduler: UEs with higher data rate gets priority and preferential treatment, hence having more resource blocks assigned to than others with low data rate of consumption.

2.8 Parameters and Methods of LTE Optimization

Optimization Process is a process or technique employed to enhance effectiveness of a system or a process to minimize inefficiencies of a system, in order to make the system function at its best, taking best advantage of the system as well as delivering optimal usage. In any engineering system, in this case 4G telecommunication, a computer programming instructions can be written to perform the task of optimization in LTE. This process follows practical oriented guide to resolving common mechanical and electrical configuration of deployed cells. In order to meet subscriber's requirement for high quality networks, LTE networks must be optimized during and after project implementation. Radio frequency (RF) optimization is very necessary in the entire optimization process since it is provides the interface to User Equipment (UEs).

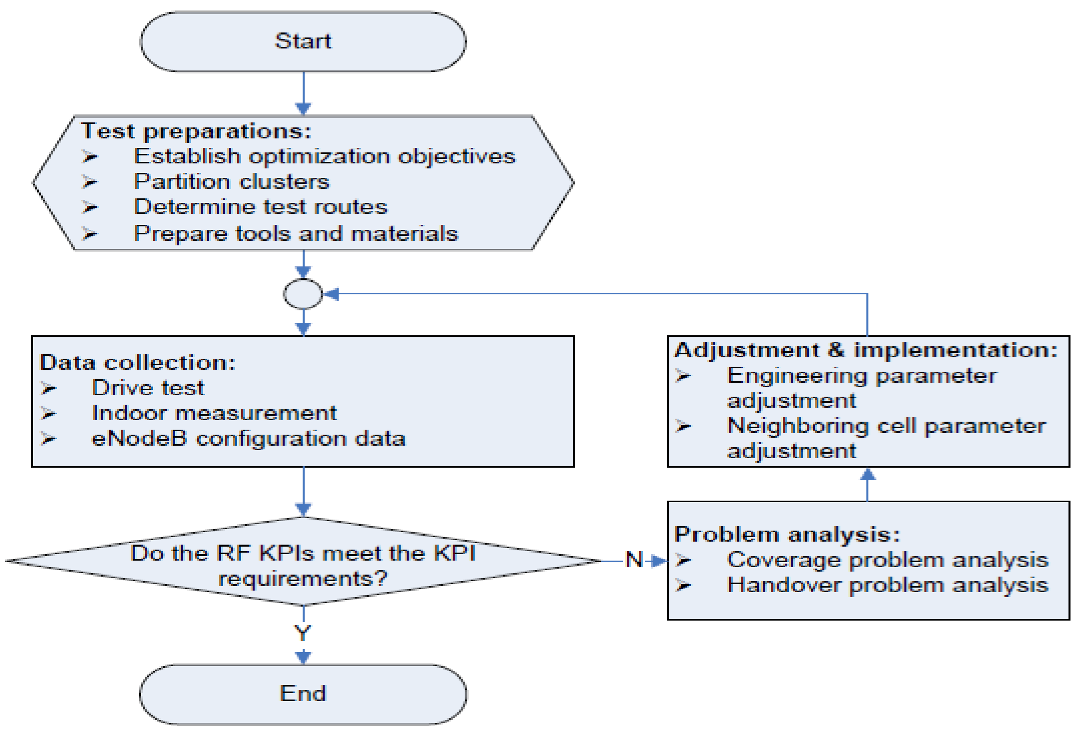

Figure 2.20: Flow Chart for LTE RF Optimization Steps (Huawei Technology Ltd. 2012).

RF optimization involves adjustment of azimuths, tilts, antenna height, eNodeB transmit power, feature algorithms, and performance parameters. Optimization methods in different standards are similar, but each standard has its own measurement definition. The four major performance parameters to use for baseline targets for optimal and good operation are:

(i) Reference Signal Received Power (RSRP)

(ii) Reference Signal Received Quality (RSRQ)

(iii) Signal to Interference Noise Ratio (SINR)

(iv) Handover Success Rate

Reference Signal Received Power (RSRP): When UEs moves from cell to cell and performs cell selection/reselection and handover. It measures the signal strength/quality of neighbouring cells, basically the RSRP, RSSI and RSRQ.

RSRP is the average power of resource element (RE) that carries a cell specific reference signal (RS) over the entire bandwidth, so RSRP is only measured in the OFDM symbol carrying reference signal. Recall in Time division–Long Term Evolution (TD-LTE) systems have multiple subcarriers multiplexed. Therefore, the measured pilot signal strength is the RSRP of a single subcarrier (15 kHz) not the total bandwidth power of the frequency.

The RSRPs near a cell, in the middle of a cell, and at the edge of a cell are determined based on the distribution of signals on the entire network. Generally:

The RSRP near a cell is -85 dBm,

The RSRP in the middle of a cell is -95 dBm, and

The RSRP at the edge of a cell is -105 dBm.

Currently, the minimum RSRP for UEs to camp on a cell is -120 dBm, beyond which the UE will request for handover.

SPECTRANET empirical RSRP at the edge of a cell is at average of 116dB

Reference Signal Received Quality (RSRQ): This performance parameter provides additional information when RSRP is not sufficient to make a reliable handover or cell reselection decision, RSRQ depends on serving cell power and number transmit antennas. The measured RSRQ values will range between -3 to -20 dB

$$RSRQ(dB) = \frac{(N\ X\ RSRP)}{RSSI} \tag{2.8}$$

RSSI is the received strength indictor measured over the same bandwidth; N is number of resource blocks

Signal to Interference Noise Ratio (SINR) is given as follows:

$$SINR(dB) = \frac{S}{(1+N)} \qquad (2.9)$$

S: indicates the power of measured usable signals. Reference signals (RS) and physical Downlink Shared Channels (PDSCHs) are mainly involved.

I: indicates the power of measured signals or channel interference signals from other cells in the current system and from inter-Radio Access Technology (RAT) cells.

N: indicates background noise which is related to measurement bandwidths and receiver noise coefficients. SPECTRANET empirical SINR at cell edge is at average of -3dB

*Handover Success Rate***:** Referring to the signalling process in (3GPP TS 36.331. 2010).

$$Handover\ Success\ Rate = \frac{(\text{No of Handovers})}{(No\ of\ Handover\ attempts)} X\ 100\% \qquad (2.10)$$

Where Number of handover attempts refers to the number of eNodeB -transmitted RRC-Connection-Reconfiguration messages for handovers. Number of handovers refers to the number of eNodeB-received RRC-Connection-Reconfiguration-Complete messages for handovers. SPECTRANET empirical handover success rate at cell edge is at average of 98%.

2.8.1 Troubleshooting LTE Network Problems

Optimizing an existing network requires proper and deep troubleshooting to find out the root cause of any given problem, there are three areas of concentration while troubleshooting for RF Optimization, namely Coverage, Signal Quality, Handover success Rate

2.8.1.2 Troubleshooting for LTE Network Coverage Problems

There are well known coverage problems to look out for, in connection with coverage troubleshooting; in this case RSRP plays important role.

Weak Coverage: weak coverage is observed when a signal quality in cells goes below the optimization baseline or threshold in a service area. As a result, UEs cannot be registered with the network or accessed services cannot meet QoS requirements. Engineers must ensure there is continuous coverage at the service area as designed and deployed.

Coverage Holes: This is a situation where by some areas will be witnessing no cell coverage or the coverage level is extremely low and can't easily establish connection and stay connected. If receive level of a UE is less than its minimum access level (RXLEV_ACCESS_MIN) because downlink receive level in a weak coverage area are unstable. In this situation, the UE is disconnected from the network. After entering a weak coverage area, UEs in connected mode cannot be handed over to a high-level cell, and even service drops occur because of low levels and signal quality.

Cross Coverage: This is situation where coverage scope of an eNodeB exceeds the planned footprint or coverage. The actual coverage must be consistent with the planned one to prevent service drops caused by isolated islands during handovers.

Imbalance between Uplink and Downlink coverage: This is coverage problem where UE transmit power (dB) is less than eNodeB transmit power as preconfigured, UEs in idle mode may receive eNodeB signals and successfully register in cells. However, the eNodeB cannot receive uplink signals because of limited power when UEs perform random access or upload data. Uplink and downlink losses must be balanced to resolve uplink and downlink coverage problem.

Lack of Dominant Cell: Each cell in a network must have a dominant coverage area to prevent frequent reselection or handover caused by signal strength changes.

Factors affecting Coverage in downlink direction (eNodeB to UE) may differ from factors affecting coverage in reverse link (UE to eNodeB).

2.8.1.3 Applicable Solutions to Weak Coverage in Uplink and Downlink

There are number of things to check, change and adjust to improve weak coverage, the first set of things are as follows:

1. Analyse geographical environments and check the receive levels of adjacent eNodeBs.
2. Analyse the Effective Isotropic Radiated Power (EIRP) of each sector based on parameter configurations and ensure EIRPs can reach maximum values if possible.
3. Increase pilot power, and adjust antenna azimuths and tilts, increase antenna height, and use high-gain antennas

The Second set of techniques to apply is as follows:

1. Deploy new eNodeBs if coverage-hole problems cannot be resolved by adjusting antennas.
2. Increase coverage by adjacent eNodeBs to achieve large coverage overlapping between two eNodeBs and ensure a moderate handover area. Note: Increasing coverage may lead to co-channel and adjacent-channel interference.

The third stage of solution to employ is as follows: Use Radio Remote Units (RRUs), indoor distribution systems, leaky feeders, and directional antennas to resolve the problem with blind spots in elevator shafts, tunnels, underground garages or basements, and high buildings. Finally, analyse the impact of scenarios and terrains on coverage.

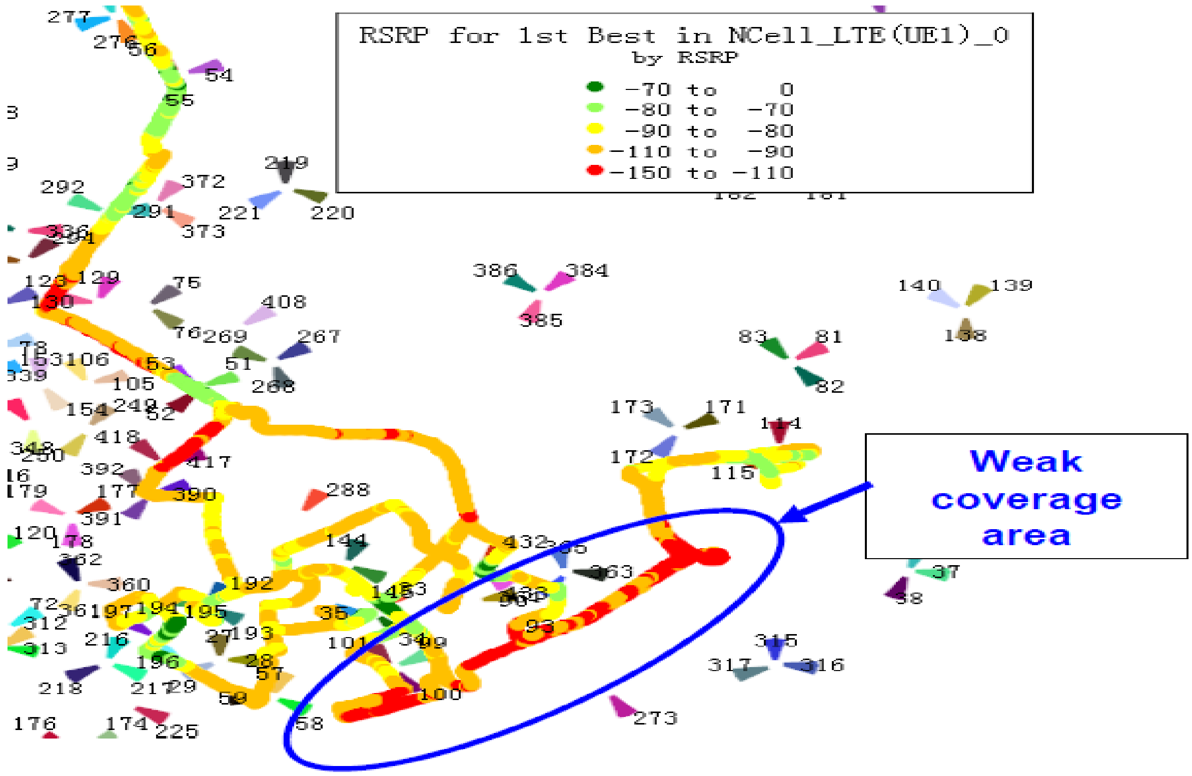

Figure 2.21: Troubleshooting Weak Coverage through Drive Test (Huawei Tech. LTD. 2012).

Drive test was performed in zero load environments to obtain the distribution of signals on test routes, a network scanner can be used also. Then a weak coverage distribution was found as circled in (figure 2.21) and observe the corresponding RSRP values at strong and weak coverage areas. RSRP for weak coverage areas ranges from -110dB to -150dB.

2.8.1.4 Troubleshooting and Applicable Solution for LTE Cross Coverage Problems

Cross coverage means that the coverage scope of an eNodeB exceeds the planned footprint, hence generates discontinuous dominant areas in the coverage scope of other eNodeBs. Observe that if a height of a site is much higher than average height of surrounding buildings, the signal the antenna transmits tends to propagate far along hills or roads and form dominant coverage in the scope of other eNodeBs, in such case, it is referred as an island. If a call is connected to an island that is far away from the eNodeB but is still served by the eNodeB, and the cells around the island are not configured as neighbouring cells of the current cell, when cell handover wants to occur, it won't be possible and there will be service drop. Recent study have shown that there are major two cases of cross coverage, first improper tilting of serving Antenna and secondly, inverse or improper connection involving RRU and antenna systems.

Applicable Solution: First, tilt adjustment is the most effective approach to control cross coverage; Tilting mechanism could be electrical or mechanical. Adjust antenna azimuths properly so that the direction of the main lobe slants from undesired direction to designed area of coverage. This reduces excessively far coverage by electric waves because of reflection from buildings on two sides of the street. Decreasing the antenna height for a high site also decreases transmit power of carriers when cell performance is not affected. Problem of inverse or improper connections involving RRU and antenna system are noticeable when in a given area, RSRP of a first cell in a sit, for instance cell 0 is low in its directed lobe or foot print and the next cell, say cell 2 is having a stronger RSRP is the supposed footprint of cell 0 and the signal quality of cell 0 is strong in the footprint of cell 2, this is a case of inverse connection, In order to diagnose properly, first disable one of the cells, say cell 0, measure the RSRP while keeping cell 2 enabled. If the RSRP in cell 2 is normal and the SINR is higher than that tested in cell 0. Swap the optical fibre on the baseband board and re-diagnose

Figure 2.22: Case of Inverse Connection between Two Cells (cell0, 2) (Mohammad, 2016)

2.8.1.5 Troubleshooting and Solutions to Imbalance between UL and DL Coverage

Uplink (UL) and Downlink (DL) coverage problem occurs when User Equipment (UE) transmit power is less than eNodeB required transmit power for UEs. UEs in idle mode may receive eNodeB signals and successfully register in cell. However, the eNodeB cannot receive uplink signals because of limited power when UEs perform random access or upload data. In this situation, the UE uplink coverage distance is less than the downlink coverage distance.

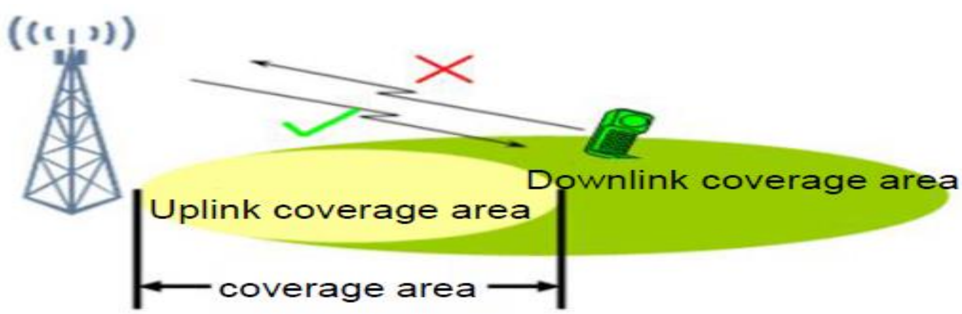

Figure 2.23: Troubleshooting Imbalance Coverage Areas (Mohammad, 2016)

Imbalance coverage caused by limited uplink coverage, it will be observed that UE transmit power stretches to its maximum power and still cannot meet the required Block Error Rate (BLER) for uplink service. Imbalance between uplink and downlink coverage leads to service drops. The most common cause is limited uplink coverage because the eNodeB is usually equipped with high power amplifiers.

***Applicable Solutions to Imbalance Coverage Areas*:** The use of Key Performance Indicator (KPI) data is very important here to observe the imbalance between uplink and downlink coverage, but in situation where there is no KPI data, the use of Operation, Maintenance and Control (OMC) equipment in network centre to trace single user and obtain its uplink measurement reports on the Uu interface. Then analyse the measurement reports and drive test files. But if KPI data is available, check each carrier in each cell for imbalance between uplink and downlink based on uplink and downlink balance measurements. Secondly, check if uplink interference leads to imbalance between uplink and downlink, monitor eNodeB alarms to check for interference. Finally, run a check to see if equipment works properly and whether alarms were generated.

2.8.1.6 Troubleshooting and Solutions to Lack of Dominant Cell Coverage in LTE

This is one of LTE coverage problems; every enabled cell is designed to have a dominant footprint, but in an area without a dominant cell can be regarded as a weak coverage area because of frequency handovers or service drops that occur on UEs in connected mode and cell selection and reselection in idle mode. In an area without a dominant cell, the receive level of the serving cell is similar to the receive levels of its neighbouring cells.

***Applicable Solutions to Lack of Dominant Cell Coverage*:** First is to diagnose properly by probing the receive level of designated serving cell and its neighbouring cell, observe if the receive level is close to each other or even same, adjust antenna tilts and azimuths to increase coverage of the designated cell (Cell with strong signal) and decrease coverage of the neighbouring cell with weak signal. Adjusting engineering parameters of cells correctly during site design and deployment to ensure optimal coverage of desired area

2.8.1.7 Troubleshooting and Solutions to Signal Quality in LTE Network

When troubleshooting for signal quality, Signal to Noise Interference Ratio (SINR) is most important empirical parameter to consider. There are processes of analysing SINR problems: Frequency planning, Cell layout, Site selection, Antenna height, Antenna Azimuths and Antenna tilts. Secondly, wrong parameter setting can cause signal quality problems in cases where radio frequency needs optimization, engineers can change and optimize frequencies based on drive test report and KPI performance measurement data obtained. If antenna systems are wrongly adjusted, engineers should adjust antenna azimuth and tilts to change the distribution of signals in an interfered area by increasing the level of a dominant sector and deceasing levels of the other sectors. If dominant coverage lacks, engineers should ensure and provide for dominant coverage by increasing power of a cell and decrease power of other cells to form a dominant cell. If the antenna pattern is distorted because of large antenna tilt, Power adjustment and antenna system adjustment can be used together.

***Solutions to Poor Signal Quality in LTE Network*:** Situation where there is severe Signal to Interference Noise Ratio (SINR) degradation, first check and change Physical Cell Identifier number (PCIs) of Intra-frequency cells to observe reduction in interference. For instance, a situation where UEs access a cell whose PCI is 3 and SINRs are low (24 dB), however the UEs are about 200 meters away from the serving eNodeB. This problem may be caused by co-channel interference but in reality, the problem may not be caused by co-channel interference but lack of neighbouring cell with the same frequency as the current cell. Secondly, adjusting antenna tilt to decrease coverage and stop island coverage that causes severe handover failure.

SPECTRANET LTE SINR EMPIRCAL Values: 20 -50 dB (Excellent), 10 – 20 dB (very Good), 5 – 10 dB (good), (-5) – 5 dB (bad), (-20) – (-5) dB (very bad)

2.8.1.8 Troubleshooting and Solutions to Handover Success Rate in LTE Network

Handover problems can be can caused by invalid handover parameter configuration such as neighbouring cell validity, average receive level for handovers, average receive quality for handovers, ratio of the number of handovers to the number of cells. In LTE network optimization process, cells and neighbouring cell optimization must be performed to ensure that UEs in idle or connected mode can promptly perform reselection to or be handed over to optimal serving cells. This helps achieve continuous coverage. In addition, problems with delay, ping-pong, and non-logical handovers can be resolved by optimizing coverage, interference, and handover parameters. In summary, handover troubleshooting is best done with drive test apparatus and analysing the reports before effecting improved and positive changes.

2.9 Review of Related Literature

Packet scheduling is one of the Radio Resource Management (RRM) mechanisms and it is responsible for intelligent scheduling of user's packets over the available system resources such that specified performance metrics are satisfied. The need to support diverse QoS requirements of different applications whilst maximizing system throughput is one of the major challenges in the design of packet scheduling algorithms in the downlink 3GPP LTE system.

Enhancing cell service throughput of 4G LTE as regards to existing solution for scheduling and resource allocation schemes are of great importance. The essence of scheduling strategies based on deployed network peculiarities are to best utilize the radio resource by guaranteeing QoS, throughput, and ensuring that every user is served and served properly, irrespective of radio condition, mobility, distance to the eNodeB or class of User Equipment.

Mahfoudi *et al*. (2014) considered congestion avoidance as a means of boosting the capacity of LTE network as well as improving the cell throughput. The research showed that the LTE network is capable of avoiding network congestion phenomena by choosing for each traffic type the suitable scheduling algorithm and by configuring in corresponding Base Station (eNodeB) exact parameters. The performance evaluation was conducted in terms of system throughput, delay and Packet Loss Ratio using different scheduling algorithms implemented at the LTE base station employing Proportional Fair (PF), Maximum-Largest Weighted Delay First (MLWDF) and Exponential/Proportional Fair (EXP/PF) schedulers. The result concluded that the Maximum-Largest Weighted Delay First (M-LWDF) Scheduling algorithm is the most suitable for all the flows while the EXP/PF algorithm did not show a big capacity to avoid congestion for VoIP flows. Finally, due to PF scheduling high delays, big packet loss ratio and low throughput, PF algorithm did not demonstrate high performances as regards to congestion avoidance but in fairness to users.

Tshiteya (2015) studied the impact of the downlink resource scheduling algorithm on the cell throughput of 4G LTE and investigated the fairness of each scheduling scheme. The researcher considered that 80% of all mobile broadband users will be served by LTE in the nearest future. The time and frequencies are scarce radio resources. Tshiteya (2015) stated that packet scheduler is a key element in the eNodeB since it determines to which user the resource blocks should be assigned to, as well as the amount of resource to be assigned. The research developed a new scheduling algorithm that combined the algorithm of Best Channel Quality Indicator (B-CQI) scheduling algorithm and Round Robin (RR) scheduling algorithm to improve the cell throughput performance of LTE network. The developed novel algorithm compromised between the throughput and the fairness of LTE network system. The result were tested for two International Telecommunication Unit (ITU) channel types, the Pedestrian B model and the Vehicular A channel model. The developed and implemented new model that allows Best CQI algorithm to schedule on the first slot (first TTI) and Round Robin algorithm to schedule for second slot of a sub-frame. Result showed that Round Robin scheduling performed worst since it does not take the channel conditions into account in terms of overall cell throughput. The maximum cell throughput for the Round Robin scheduling was 12 Mb/s. The developed new scheduling algorithm achieved better throughput (33 Mb/s) than the Round Robin scheduling. The Best CQI scheduling achieves the highest throughput of 43Mbps but at the expense of the fairness. Pedestrian B and the Vehicular A channel model were tested, RR scheme presented similar throughput performance for both models, while the best CQI observed difference in throughput performance as result of delay spread witnessed with vehicular A channel model.

Varum and Shikha (2016) stated that mobile broadband networks like LTE, the high performance of the radio network can be realized with proper scheduling of resources for different types of services. According to Varum and Shikha (2016) the choice of scheduling algorithms is pivotal for optimum usage of LTE radio resources, however proper scheduling of resources in the radio network alone is not sufficient to guarantee a good End to End performance. Transport network between the radio and core networks needs proper dimensioning and scheduling of resources for various types of services in order to improve overall performance of the service that is offered to the user especially in time of severe congestion in the link. The research implemented Internet (IP) based QoS technique. Since the transport network is not aware of the QoS architecture of LTE. This implies that the various bearers that are used to classify the services in LTE domain needs to be mapped to IP based

QoS techniques. The Differentiated services architecture (Diffserv) which is commonly used in IP based networks is used to classify the various types of services in the LTE transport network. The research integrated Diffserv architecture with the LTE QoS architecture to guarantee good end to end performance.

Fadil, Akhmad, Yuliza and Ulil (2019) adopted the method of bandwidth expansion as a means of optimizing Quality of Service for LTE network. Fadil et al stated that bandwidth expansion increases network accessibility, retainability, downlink PRB utilization, number of users as well as improves congestion avoidance. The work conducted network performance evaluation by monitoring the performance of the key parameters and assessment of the performance concerning capacity and coverage. Fadil et al used drive test method to collect the KPIs parameters from the field of measurements. The selection of those KPIs parameters were made in such a way that both the end user performance and the resource utilization were captured. Results from the work showed that bigger scale of bandwidth offered higher number of Users, better accessibility, higher data rate.

Basukala, Mohd, and Sandrasegaran (2009) studied the service applications of LTE and observed that solution to multimedia type of service is the key to general network performance in terms of Quality of Service (QoS). Hence, an adequate scheduling algorithm should be employed to handle real time service on the network while best effort method is deployed to Non real time service. This method ensures efficient sharing the radio resources. Basukala *et al.* (2009) investigated different scheduling algorithm as relates to Real Time (RT) application and Non-Real Time (NRT) application. The simulation results showed that in the downlink system supporting Real Time and Non-Real Time services given 150 m radius cell, MLWDF algorithm provided better performance as compared to EXP/PF algorithm with lower number of users ranging from 50 to 160. Required Packet Loss Ratio (PLR) of 1% and average RT throughput of 100 kbps were maintained by M-LWDF in that range providing better system throughput. However, as the number of users increased, EXP/PF algorithm showed sustained performance in terms of average RT throughput and PLR requirements for RT service loads of up to 250 users. However, some system throughput is sacrificed in this particular scenario when EXP/PF is used, as it prioritizes RT video streaming whose throughput is capped by video source encoder data rate. On the whole, it is recommended to employ simpler M-LWDF algorithm for lower loads and use computationally complex EXP/PF algorithm for higher loads in downlink LTE system supporting multimedia services.

Tchao, Gadze and Jonathan (2018) adopted large Multiple Input, Multiple Output Antenna configuration to improve cell throughput of 4G LTE network. The work implemented empirical methods and simulation (Genex UNET) of field measurement to aid evaluation on 4G network coverage and throughput performance of 2X2, 4X4 and 8X8 MIMO configurations of the deployed networks. The results showed that average simulated throughput per sector of 4X4 MIMO configuration was better than 2X2 configuration, conversely, the percentage coverage for users under the 2x2 MIMO simulation scenario was better than adaptive 4x4 MIMO configuration with 2x2 MIMO achieving 60.41% of coverage area having throughput values between 1 - 40Mbps as against 55.87% achieved by the 4x4 MIMO configuration in the peculiar deployment terrain.

Deepak and Balaji (2015) carried out research work on techniques of improving 4G LTE networks, the research reviewed many authors techniques while exploring the open issues, emerging trends and significant research gap. The work described mobility management technique as a definite approach to improving cell throughput performance of 4G network. The paper furnishes better comparative analysis of the techniques and highlights their effectiveness in improving the LTE network for the future wireless communication systems where e-UTRAN system design principles consider OFDM for downlink transmission, single carrier FDMA for uplink transmission and employ MIMO to further enhance the throughput under various dynamic traffic conditions. The authors recommended user's mobility aware scheduling algorithm as the best method of improving overall cell throughput of LTE network.

Mohana , Mohankumar and Devaraju (2014) studied and experimented on the performance of LTE system with different spectrum configuration for a Constant Bit Rate (CBR) traffic scenario in the downlink channel. The research identified number of users on eNodeB density, delay and jitter as major factors affecting throughput performance of 4G LTE network. The performance metrics considered for the simulation work were aggregate bytes received; average throughput, average delay and average jitter for different bandwidths of LTE system using QUALNET SIMULATOR. From the results, the author concluded that 20 MHz bandwidth achieved the highest throughput performance across the metrics used over other scales of bandwidths (1.4 MHz, 3 MHz, 5 MHz, 10 MHz, and 15 MHz).

Maria and Chairunisa (2019) studied and tested the level of users mobility performance on 4G LTE network using drive test method and pilot pioneer software for data generation and analysis, she concluded in her research that the use of Reference Signal Received Power (RSRP) values analysis, researchers can narrate vividly the performance of a network and users experience especially in mobility state and recommended future research on ways of improving users RSRP. Jose et al (2015) described network dimensioning as a critical task in mobile network management. In such a process, operators need to estimate future traffic demand and upcoming network capabilities to detect capacity bottlenecks in advance. Unfortunately, traffic growth and radio capabilities are not easily predictable, causing operators to constantly revisit their planning forecasts to guarantee an adequate quality of service (QoS). Jose et al (2015) stated that estimating the maximum capacity of the radio access network is a very first step towards QoS. Cell capacity is defined as the maximum traffic demand for satisfying some QoS constraint. When cell capacity is exceeded, QoS reaches unacceptable levels. Thus, an accurate cell capacity estimate is needed to guarantee an adequate QoS with minimal investment. The research modelled and implemented technique of several multivariate linear regression equations to estimate the value of different service-specific QoS indicators from network performance statistics collected on a cell basis to estimate and evaluate the maximum traffic cell capacity, Jose et al (2015) considered service specific constraints such delay and throughput in the research, the obtained result showed a strong correlation between QoS performance and the average number of active users in the Physical Downlink Control Channel (PDCCH),

Garcia, Buenestado, Luna-Ram´ırez, Toril and Ruiz (2018) worked on optimization of LTE network, recognized the complexity of physical layout in a real cellular networks as great challenge to obtaining a good estimate of the nominal cell range on a cell-by-cell basis. Garcia et al (2015) developed and implemented a novel geometric method of estimating cell ranges in 4G LTE as a key parameter for network planning and optimization using Voronoi tessellation while empirical data are collected. Cell coordinates, antenna azimuths, antenna horizontal and beam widths are considered in this model as input parameters, the results showed the method has less complex algorithm of estimating nominal cell range over classical approach and also improves the accuracy of previous approaches.

Kamran (2015) described packet level scheduling as one of the core functionality of

LTE and plays an important role in the optimization of the network. A scheduling scheme can be designed to allocate each UE a portion of the available resources i.e. resource blocks (RBs). However, Kamran (2015) identified the impact of Channel Quality Indicator (CQI) uplink feedback delay and mobility as major factors hindering scheduling algorithm from delivering optimal QoS performance. The work studied the overall network performance under different scheduling algorithms (Best CQI, Round Robin, and Proportional Fair) and mobility patterns (5km/hr, 30Km/Hr, 70 Km/Hr, 120Km/Hr). The author considered average User Equipment (UE) throughput, average cell-edge UE throughput and average cell throughput under Vehicular mobility model of 3GPP and concluded that for an efficient LTE-Advanced scheduling algorithm, UE speed and CQI feedback delay must be taken into account. The varying channel response at very low speed showed better throughput performance for all scheduling algorithm, while at high speed, the throughput degraded. B-CQI gives superior performance in terms of average UE throughput and average cell throughput compared to other scheduling algorithms. This is an expected result as BCQI schedules the users with the best channel conditions. Higher throughput of BCQI translates into the fact that the distribution of resources among users is not fair. While on the other hand, RR and PF average throughput is low (compared to BCQI) but distribution of resources among users is fair, and scheduling algorithm assigns resources to cell-edge users are as well as other users with poor channel conditions. Nevertheless, the average UE throughput at cell edge showed Zero throughput for Best CQI algorithm model.

Hsu-Chieh, Lin, Fan, and Ozan (2015) worked on mobility effect on performance of LTE internet access network in a moving vehicle. There are challenges of providing reliable Internet access through in-cabin wireless networks and the research delved into a new approach to improve the performance of current Transmission Control Protocol (TCP) under the use case. The modified TCP approach incorporates the information directly as relates to the vehicle and the Round Trip Time (RTT) ratio and adaptively adjusts the parameters such as the congestion window size to optimize the overall throughput and delay. Hsu-Chieh et al (2015) demonstrated an approach utilizing direct information of the vehicle such as current speed and historical channel condition to adaptively adjust TCP parameters for optimal throughput and latency performance. The result showed that the approach increased the LTE downlink throughput by 41% to 82% with different parameters and the variance of Round Trip Time (RTT) of packets.

Yildiz and Sokullu (2018) maintained that the major approach to coping with the intensified mobile traffic of limited bandwidth is efficient scheduling of the available radio resources. The work stated that the design of the scheduling algorithm is crucial for accurate and efficient resource planning and allocation. The operation is performed by the packet scheduler residing in the Media Access Control (MAC) layer of eNodeB. The objective of the scheduling algorithms is for efficient resource allocation, ensuring fairness among users while achieving high system throughput as well as transmission of data within acceptable error and delay limits. Yildiz and Sokullu (2018) implemented a novel scheduling algorithm called Mobility Aware Scheduling (MAS) considering real-time and non-real-time traffic users for different network configurations. During the first step of the algorithm the number of real-time (VoIP, video, game) and non-real-time (http, ftp) users is determined. If the users are only real-time (rUE) or non-real-time traffic users (nrUE), the algorithm considers this "uniform traffic" and allocates resources by specifying the users with the best channel conditions for each RB during a TTI. If some of the users are real-time and some are non-real-time traffic users, the algorithm detects "mixed traffic" and prioritizes real-time users. For this purpose the number of real-time users waiting for service in that TTI (NtbrUE) is considered. 10 % of the resource added for real time users while the rest of resources are given to users with best spectral Efficiency. The developed algorithm maximizes the average user throughput and performs very close to the B-CQI algorithm while also providing service to edge users similar to the RR algorithm while robust against high user mobility with poor BLER.

Osman and Vehbi (2015) maintained that meager throughput and high delay in the LTE network for UEs at cell edge are major concern for overall network degradation and researched on best scheduling algorithm to alleviate the performance. Osman and Vehbi (2019) developed QoS-aware downlink scheduling algorithm (QuAS) to enhance the QoS experience of mobile network users. In mobile networks, users are spread in the covering area of a base station. The quality of communication channel of a user depends on the communication distance and obstacles between the user and the base station. This affects the signal-to-noise ratio (SNR), bit error rate (BER), transmission delay, and achieved throughput. As the communication distance increases, that is, the user is closer to the cell edge; SNR and throughput tend to decrease while BER and delay increase. QoS-aware downlink-scheduling algorithm (QuAS) employed techniques based on the metrics of PF scheduling algorithm where factors such as he UE's current achievable throughput (through instantaneous CQI report) and the average throughput of the UE in a predefined past window to enhance the QoS experience of mobile network users especially the cell edge users with QoS Fairness metric that takes delay needs of each user's packets into consideration. If a packet is delivered in time, the fairness index of the user is incremented; else it is increased by the amount of transmitted data divided by the packet size. The results indicated that QuAS algorithm provides very good results about edge throughput especially when the number of users is smaller. QuAS algorithm showed in 10% higher edge throughput, 2% higher fairness, and 6% higher QoS fairness when compared to PF algorithm

Hussain (2009) worked on dynamic resource management by means of equal and fair sharing of radio resources to users, incorporating round robin scheduling method, also this method is best for network operators with huge radio resource. The method reduces management complexity in radio resource sharing, reduces time of processes and gives throughput service to users already latched to the cell network but the proposed solution reduce the general network efficiency and throughput owing to the fact that that round Robin does not take the user's channel condition into consideration. Some allotted resource over the period of usage will be redundant and underutilized as result of non-critical applications and poor channel of the user. However, the proposed method would not in any way improve the network of whose radio resources are limited.

Nasim, Mohamed, Ali and Kweh (2015) presented study on throughput-aware resource allocation for QoS classes in LTE networks. LTE systems prefer using multicast services to deliver efficient response for strong QoS support. This requires Class of Quality of Services (CQoS) requirements to be satisfied. These quality constraints limit the scheduling flexibility, and the LTE downlink resource allocating algorithms need to assimilate these constraints while trying to maximize system performance in terms of fairness and throughput. Nasim et al (2015) addressed the fundamental problems of LTE downlink scheduling by adopting the time domain Knapsack algorithm over the traffic overload patterns. The efficient performance can be achieved in terms of fairness index and system throughput, which were evaluated using simulation results. The desired solution, the effect of past experienced throughput awareness is more prominent for prioritizing the bearers with the same QoS characteristics. The simulation results shown that; the time domain Knapsack algorithm improved the performance of high priority bearers by sacrificing the transmission performance of the other bearers' results in several fluctuations. However, this is a guide for the present study by help in understanding the effect of QoS parameters in LTE network throughput.

The study of radio resource management strategies in LTE Networks by Ricardo (2016) stated that to efficiently manage the available radio resources, this necessitate to maintain Quality of Service (QOS) levels while sustaining economic viability. Ricardo (2016) study was based on priority based call admission control algorithm. Then, the study combines methods such as forced handovers, queue list and service degradation to allow a customisable approach for admission control. This occurs between rigid QOS limits and high capacity in the number of simultaneously active users. The analysis parameters include services penetration rates, frequency band, available bandwidth and network layout-urban and suburban. The results showed that there were improvements regarding the increase in capacity, with the trade-off of slightly hindering Key Performance Indexes (KPIs) such as throughput, delay, jitter and signal-to-interference-plus-noise ratio (SINR).

Sharmila and Vera (2014) on their work on enhancement of QOS in LTE downlink systems using frequency diversity selective scheduling, The work suggested a scheduling algorithm for different mobility in LTE downlink systems using frequency diversity selectivity scheduling, upon implementation, the algorithm increases spectral efficiency and favours the network capacity for mobility users. The algorithm shows increase in continuous rate adaption, throughput and capacity improvement over other scheduling techniques especially for mobility users.

Huang, Subramaniani, Agrawand and Berry (2009) researched on best technique test for downlink radio resource allocation for OFDM system. Huang et al considered the problem of gradient-based scheduling and resource allocation for a downlink OFDM system, which essentially reduces to solving a convex optimization problem in each time-slot. They studied this problem for a model that accommodates various choices for user utility functions, different sub-channelization techniques, and self-noise due to imperfect channel estimates or phase noise. Using duality theory, they first gave an optimal algorithm for solving a relaxed version of this problem in which users can timeshare each sub-channel. This involves finding a maximum of a per user (closed-form) metric for each sub-channel and a one-dimensional search of an optimal dual variable.

Mateusz (2018) developed a custom eNodeB scheduler for better network performance. The customized eNodeB schedulers that should be pluggable into any compliant eNodeB stack depending on peculiarities. It was presented to small cell forum. Femto application platform interface, 2018. Mateusz (2018) adopted proportional fair scheduling algorithm. In addition he recommended that UEs with lower throughput application events should be prioritized and cell edge user should be considered also. The custom algorithm considers CQI and UEs throughput history and schedules appropriately. Thereby increasing fairness, cell throughput and cell capacity. This method is implementable, after understudying the network's KPI and architecture and users handover. There should be dynamic QoS differentiation with respect to higher data rate user and low data user, hence accommodating more users while improving service experience and cell throughput.

Lakshmikishore, Prect, Singh and Rachel (2014) described packet scheduler as the backbone of intelligence in LTE networks. The work proposed classification of schedulers to be dynamic, persistent or semi-persistent algorithm depending on the type of application it serves. Real time service such as conversational voice, video phony (conversational video), real time gaming etc., or non- real time service such as voice messaging, buffered streaming, FTP, WWW, email, interactive gaming etc. The proposed semi-persistent as best algorithm for real time service because it is a hybrid system covering up for lapses found in dynamic and persistent algorithm, especially for conservational voice payloads which uses resource assigned only at the period of activeness. However, the resources are underutilized during inactive period or pause time during conversation.

Gochev, Poulkov, Iliev, (2013) worked on methods of improving cell edge throughput for LTE network using combined uplink power control. The developed power control is used to maximize desired received signals while limiting the interference. Gochev et al (2013) analysed two power control mechanisms namely; factional power control (FPC) and interference Based power control (IBPC). The work then proposed a way of combining the two mechanisms in order to develop an efficient algorithm to control the transmitted power spectral density which has the capacity to make up poor channel conditions, hence obtaining better call throughput especially for users at cell edge.

Pandiaraj (2013) worked on Power control optimization as model of improving cell throughput for LTE relay networks. Pandiaraj (2013) proposed two kinds of LTE relays, type-I and Type-II thus; Non transparency and transparency respectively. Type-I is to be distanced from eNodeB which transmits common signal and the control information from eNodeB to UEs thereby helping to increase network coverage (reaching remote UEs) and capacity by performing IP-packet forwarding in the network layer. The type-II will be located in the eNodeB coverage area and does not transmit control signal. The major aim is to increase capacity by achieving multipath diversity and transmission gains for UEs thereby improving data rate and cell throughput. Pandiaraj (2013) techniques equally have its disadvantages, which is cost, complexity and processing delay.

Nokia Siemens network (2018) on one of the researches on Smart packet Scheduler for LTE Network; LTE radio is designed for frequency re-use of one where all the cells use the same frequency. The challenge with re-use on is the high inter-cell interference when UE is located between two cells, there will be poor throughput performance in this case. They proposed a means of boosting the cell edge performance through smart scheduling which tend to enhance the average data rates and system capacity by considering signal fading and interference in the packet scheduling decisions. LTE radio is highly standardized by 3GPP when it comes to interfaces but not the network algorithm for link adaption, power control and scheduling, hence differences in network performances depending on applied scheduling algorithm and network peculiar desire and challenges. They proposed that multipath propagation in the mobile environment results in frequency selective fading, hence their choice of using frequency selective scheduling as the most important factor of the smart scheduler. The information about channel fading is obtained from UE's CQI reports in downlink and from Sounding Reference Symbols (SRS) in the uplink. The method achieves high throughput while transmitting on these carrier bandwidth (resource block) that are not faded. Frequency Selective Surface (FSS) minimizes fading impact. Improves cell edge data rate, mitigates against inter cell interference. Nokia solution is targeted at FDD deployed network and more effective for cell edge users. FSS consists of channel aware scheduling (CAS) and interference aware scheduling (IAS). The Field measurement demonstrates 30% gain for the cell edge data rates.

Avishek , Volker, Lang (2017) presented a packet scheduling algorithm for real-time communication over LTE system, novel mobile radio research which developed dynamic scheme for non-voice packets because they are large, infrequent and non-periodic but suggested the use of Semi-Persistent Scheduling (SPS) for voice packets that are small, frequent, and periodic. The use of Dynamic scheduling (DS) will limit capacity due to limited control Channels. In Ds, Multiple users need PRBs in same Transmission Time Interval (TTI). The DS grants PRBs to number of users available Physical Downlink Control Channel (PDCCH) per TTI. This results in high call drop rate and QoS reduction. In Persistent Scheduling (PS): there is fixed PRB allocation, PDCCH only required for initial allocation but here capacity are limited to available PRBs. No link adaption, Same Modulation and Coding Scheme (MCS). Semi-Persistent scheduling PRBs are reserved for extended period (for instance, Talk Burst), PDCCH required for initial allocation capacity are less dependent on PRBs or PDCCHs. MCS/PRB change possibly with talk burst. But the major disadvantage comes in if PRB required is greater than PRB available, then queuing increases, latency increases, packet drops increases after number of HARQ, throughput decreases, hence reduction in overall network QoS.

2.9.1 Summary of the Reviewed Related Literature

Cell throughput performance is a major concern to all Fourth Generation Long Term Evolution (4G LTE) operators. Literatures reviewed showed that many researchers are working towards improving the cell throughput performance through diverse scheduling techniques for peculiar cases. However, some authors techniques which may not necessarily be efficient for given unique situations. Most studies did not exclusively consider the problems with high data rate users, users' mobility in multipath environment and the number of users per eNodeB. Some of the reviewed works has a limited number of active eNodeB sites, few meters of coverage and mobility Pattern of the user is not well defined.

According to Fedil *et al* (2019), cost implication of the method will be unbearable to any 4G LTE operators to implement as measure of optimizing Quality of Service (QoS). It will entail obtaining new spectrum license, network equipment. Techniques to maximize the available resource will be more cost efficient while improving QoS. Mahfoudi *et al* (2014) recommended Maximum-Largest Weighted Delay First (MLWDF) as an algorithm best to improve network capacity and QoS over Proportional Fair Scheduling in terms of congestion avoidance. However, the algorithm is not implemented by good number of Telecommunication Vendors. Huawei and other notable vendors implements Maximum Carrier to Interference (Max-C/I) and Proportional Fair (PF) algorithm; Secondly, MLWDF has limited throughput performance when the number users are increased per eNodeB. However, Basukala *et al*. (2009) recommended same technique but it was observed that the technique does not perform well with increase in mobility speed as well as in increase with number of UEs per eNodeB.

Tchao *et al* (2018) recommended more transmit antennas to improve performance, however, this is not cost effective and the research failed to address the real circumstance that improves the performances of deployed 2x2, 4x4 or 8x8 MIMO when they fall short of desired performance with respect to interferences, number of users, coverage range, congestions etc. Tshiteya (2015) recommended combination of Best CQI and Round Robin scheduling scheme where each of the algorithm serves one time slot of a sub-frame and the other serves the subsequent time slot. Best CQI scheduling optimizes the user throughput by assigning the resource block to the user with the good channel quality and the Round Robin scheduling is fair in the long term since it equally schedules the Mobile Station in turns, without taking channel condition into consideration but on first come first served basis. However, Best CQI scheduling can increase the cell capacity at the expense of the fairness. Mobile terminals located far from the base station (i.e. cell-edge users) are unlikely to be scheduled. Also, Round Robin scheme is easy to implement, achieves fairness to all users but results in low user throughput. The algorithm is too complex and would not serve the network peculiarities in Nigeria. Mohana *et al* (2014) recommended deployment of 20 MHz bandwidth but did not state measures to maximize data throughput or performance over downlink channel networks that have deployed 20MHz bandwidth when number of users increase to cause delays, jitter and low data rate. In the work of Jose et al. (2015) Multi-Service Multiple Linear Regression (MS-MLR) model can only estimate the values of a predefined set of specific QOS indicators, this will limit other variation services offered by 4G network other than Voice over LTE (VoLTE).

Garcia *et al* (2015) method of Voronoi tessellation did not address the process of using the result to improve network performance especially in urban populated regions where cell ranges are very small to next serving cell and the method has lesser or no effect on short cell to cell distances. The methods deployed by Kamran (2015) improves link reliable but results in a tremendous uplink control signalling overhead leading to complexity, processing delays and degradation in data rate. Yildiz and Sokullu (2018) technique differentiates radio resource whenever there is congestion and mixed traffic in favour of real time application users and pays best effort services to non-real time application users. The implemented algorithm according to Osman and Vehbi (2015) is applicable and efficient to a network deployment with little number of users and secondly, the algorithm also showed degradation on overall cell throughput by 1.8%. The reason of this decrease is result of more resources to the edge users instead of the users closer to eNodeBs in order to fulfill their QoS objectives. Lastly, from the reviewed works, some authors proposed enhancement algorithm for real time services for conservational voice payloads which uses resources assigned only at the period of activeness, but the resources are underutilized during inactive period or pause time during conversation, hence will not offer spectral efficiency.

2.9.2 Research Gaps Established

The review of related literatures suggests that a number of studies have been carried out in order to improve the cell throughput performance of 4G LTE network throughout the world with focus on functional packet scheduling technique. Effective method to maximize the provisioned radio resources of the network is of great importance. However, from the various related works reviewed, the following research gaps were observed.

i. There are no stringent or standard rules governing packet scheduling techniques of 4G LTE network. It solely depends on the network operators.

ii. Techniques to analyse the behavioural trends of subscribers of 4G LTE network in terms of data consumption rate using empirical Key Performance Indicators obtained. This helped to predict effective packet scheduler algorithm best suited for peculiar cases.

iii. A reliable extrapolation method and analysis are required in order to accurately estimate and modify existing network capacity within the standards of 3GPP based on the empirical KPI data and 4G LTE network configuration parameters.

iv. Requirement for fairness, cost effective, less complex and scalable packet scheduling algorithm for cell throughput enhancement of 4G LTE network during peak periods and at high number of high data rate users per eNodeB.

CHAPTER THREE

METHODOLOGY

The study used quantitative analysis to analyze experimental voice and data Key Performance Indicator (KPI). The voice and data KPIs were carried out using Huawei Imanager 2000 tool. Drive test technique was employed across troubled regions. The performance evaluation of the existing network capacity was done and the outcome was validated using standard threshold of International Telecommunication Unit (ITU) ITU-R and 3GPP TS. 136 chart on cell throughput. The two algorithms employed for differential quality of service include Time Stamped based (TSA) and Traffic Volume based (TVA) algorithms. The algorithms helped enhance cell throughput of Long Term Evolution Service (LTEs) upon implementation. However, the supplied Key Performance Indicators (KPI) is limited to the SLA network configuration metrics and preprocessed data.

3.1 Experimental Measurement Environment

SPECTRANET Limited Abuja (SLA) is one of the Fourth Generation Long-Term Evolution (4G LTE) network technology services providers in the heart of Abuja located at Wuse II (9.069170, 7.480446). SLA provides voice and data services to individuals and cooperate organisations. SLA is the first company to launch LTE service in Abuja in 2013. The company brought top speed internet broadband service and later voice service to their numerous subscribers. The research used SLA network elements as a case study and testbed for empirical data collection, network configuration setup and measurements. SLA operates an average of 145 eNodeB sites in Abuja metropolis, with an average subscriber base of 15,200. The Abuja city is capital of Nigeria, with land mass of 7,315 square KM, located almost in the center of the country and North of the confluence (Lokoja) of River Niger and River Benue. The last census taken in 2006 put the population at 776,298. However, between 2000 and 2010, the population grew by almost 140%, with more recent estimates showing that the population now exceeds 3.9 million (World Population Review, 2019).

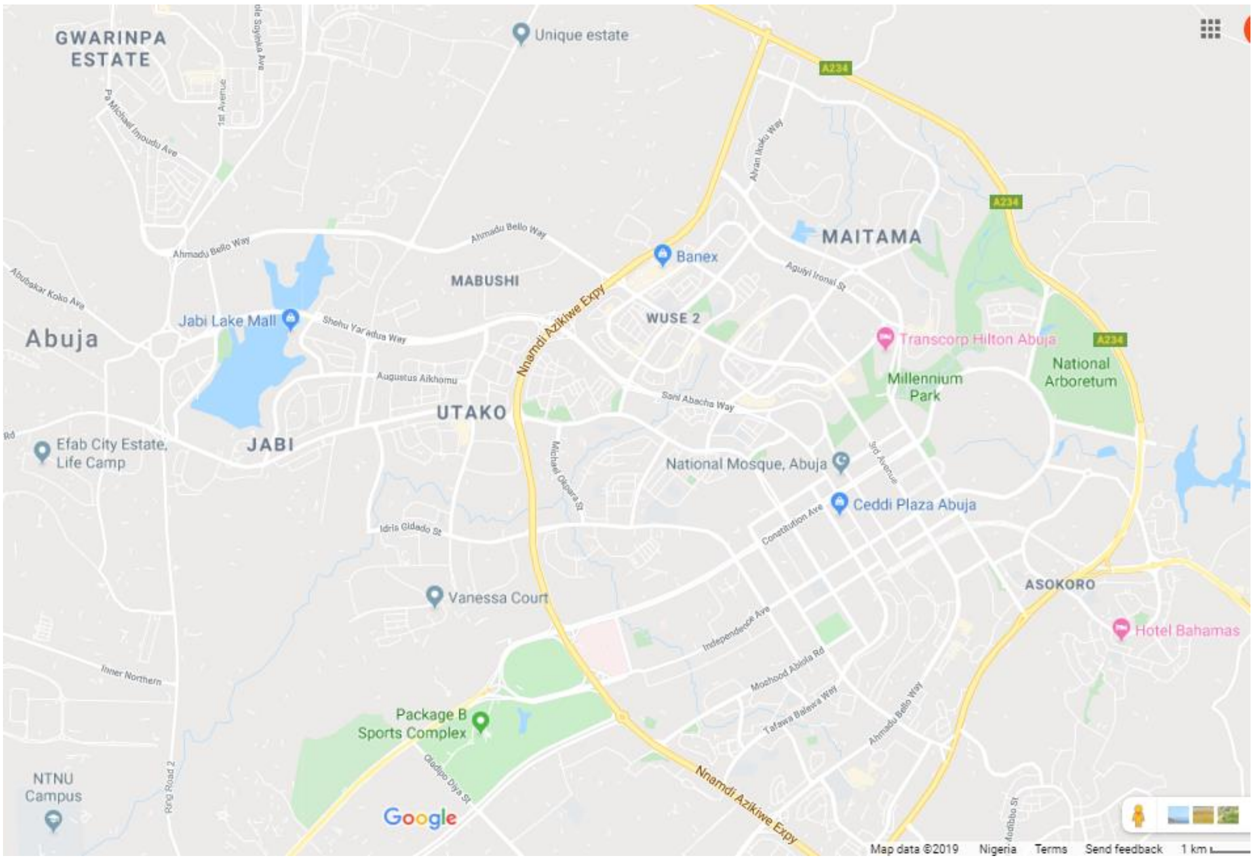

Figure 3.1 Map of Environment under Study (ABUJA)

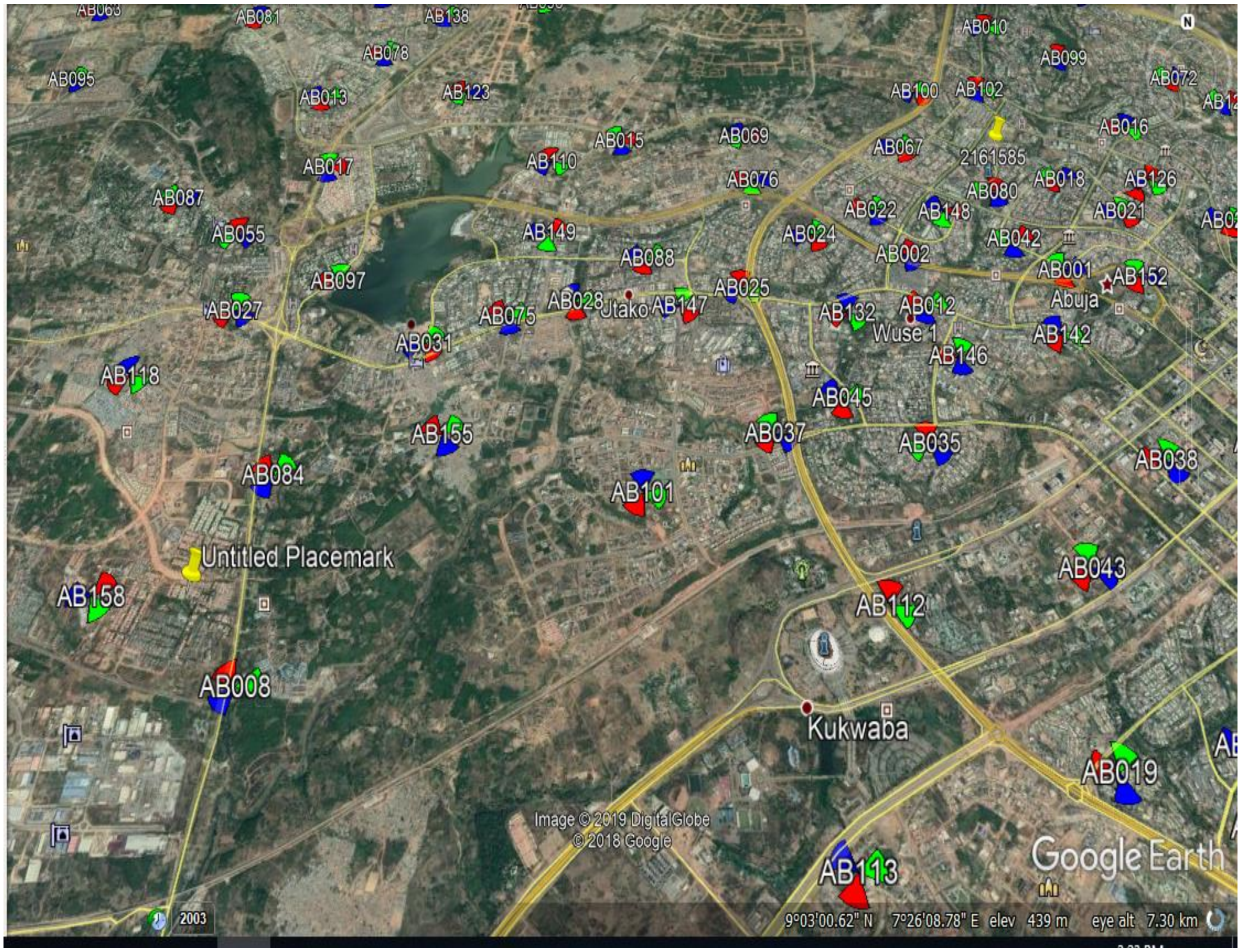

Figure 3.2: Overview of SPECTRANET eNodeB Sites in Abuja Metropolis

3.2 Test Equipment Configuration

Huawei is an active participant and contributor to 3GPP specification development. This high-level involvement improves Huawei product development. Long Term Evolution Time Division Duplex (LTE TDD) eRAN2.0 was developed based on Third Generation partnership Project (3GPP) Release 8 specifications. Huawei provides users with high performance service to improve operator’s competitiveness. 3GPP specification defines Frequency Division Duplex (FDD) and TDD modes in the UL and DL. FDD mode uses different frequency bands, whereas TDD mode uses the same frequency band for UL and DL. Huawei eNodeB supports Scalable channel bandwidth including 5MHz, 10MHz, 15MHz, and 20MHz.

3GPP specification defines Cyclic Prefix (CP) length for LTE OFDM symbols. In an OFDM symbol, the CP is a time-domain replication of the end of the symbol and is appended to the beginning of the symbol. It provides the guard interval between OFDM symbols to decrease inter-symbol interference due to multipath delay and synchronization error. There are two classes of CP: normal CP and extended CP. SPECTRANET LTD applied Normal CP. In the case of 15 kHz subcarrier spacing, the normal CP corresponds to seven OFDM symbols per slot in the downlink and seven SC-FDMA symbols per slot in the uplink. The normal CP length (time) is calculated as follows:

In the downlink

Normal CP: T_{CP} = 160 x Ts (OFDM symbol #0), T_{CP} = 144 x Ts (OFDM symbol #1 to #6)

In the uplink

Normal CP: T_{CP} = 160 x Ts (SC-FDMA symbol #0), T_{CP} = 144 x Ts

(SC-FDMA symbol #1 to #6)

Where $Ts = 1/(2048 \times \Delta f)$, Δf = 15 kHz

Huawei SPECTRANET eNodeB supports multiple modulation schemes in the UL and DL channels depending on the network channel conditions. In most cases, the eNodeB applies QPSK in DL/UL; 16QAM in DL/UL, 64QAM in DL only (which allows a maximum of six information bits modulated per symbol). This is achievable under excellent channel conditions in order to attain high data rates, which improves system throughput and spectral efficiency**.** The choice of order of modulation is dependent on quality of channel condition and gives best trade-off between the user data rate and the Frame Error Rate (FER) during transmission. The trade-off mechanism is a functional tool of LTE Adaptive Modulation and Coding (AMC) which provides a suitable modulation order and coding rate at every point in time with respect to channel condition based on Channel Quality Indicator (CQI) report presented by UEs. The signal to interference plus noise ratio (SINR) of the uplink Reference Signal (RS) measured by the eNodeB. AMC technique improves the spectral efficiency when the system resource and transmit power are fixed. Cell throughput can therefore be maximized and QoS requirement can be achieved. Huawei SPECTRANET eNodeB supports different UL and DL sub-frames configuration which gives operators the flexibility to configure the ratio of uplink and downlink sub-frame based on different service requirement. Huawei SPECTRANET eNodeB also supports different special sub-frames for UL and DL configuration such as sub-frames for Downlink Pilot Timeslot (DWPTS), Guard Interval (GP), and Uplink Pilot timeslot (UPPTS). These configurations are scenario based such as applied to different deployed cells. Table 3.1 show the network setup parameters and network configuration used at a glance from SLA operational manuscript.

Table 3.1: Network and eNodeB Configuration

S/N	Features	Configuration
1	Network Structure	UE, eNodeB, MME/SGW/PDNGW
2	Duplex Mode (Mode of operation)	TDD
3	Radio Frame Structure	10ms
4	Access Technique	DL (OFDMA), UL (SC:FDMA)
5	Channel Bandwidth	20 Mhz
6	Operational Frequency	2.3Ghz
7	TX Diversity (MIMO)	4x4
8	No of Physical Resource Block	100
9	Average PRB Utilization	50%
10	Modulation Schemes	QPSK ,16QAM , 64QAM
11	Average No of nodes (eNodeBs):	145
12	Antenna Maximum Tx Power	46 dBm
13	UEs Maximum TX Power	23dBm
14	Average No of Active Subscribers	15200
15	Antenna Models (BBU)	BBU 3900
16	Microwave Radio System (RTN)	OptiX 950, 905

Source: SPECTRANET Parameters and Configuration Manual

The Key Performance Indictors (KPI) data of 4G network were captured using Huawei Imanager 2000 software tool for both voice and data for all different site locations (145 LTE base stations) covered by SPECTRANET within Abuja metropolis. The study used available experimental voice and data obtainable from SLA over a period of five months starting from 12

November, 2018 to 28 February 2019, and from 1 April to 28 June 2019 (total of 29 weeks) in order to cover both extreme weather conditions in Abuja. KPI data were collected on daily basis between Mondays to Fridays with exclusion of Saturdays and Sundays only. This provides an average of Twenty (20) data sets per month. Subsequent site location with customer's complaints or cells observed to be performing below company's desired threshold or standards, further test were carried out in such areas using Drive test tools, Google-Earth Pro, and Open-Signal Software. The data obtained was used to modify the existing network architecture using discrete events modelling and simulation tool MATLAB R2015a. Refer to section 4.2.

3.3 Measurement Site and Drive Route Selection

Huawei Imanager 2000 is a very essential tool kit used for Operation Maintenance and Control (OMC). It is a desktop application for remotely generating KPI of all deployed cells of the network. I-Studio Software is also Huawei Desktop application for network measurement. It detects serving eNodeB, the cell ID, measures the current Receiver Sensitivity, Transmit (Tx) Power, Received Signal Strength Indicator (RSSI), Reference Signal Received (RSRP), Reference Signal Received Quality (RSRQ) etc. While Open Signal Software is a mobile phone application, Open Signal Software is a renowned tool for network performance measurement. It provides coverage maps of the area, the coordinate of serving cell, the Physical Cell Identifier (PCI), the RSRP, RSRQ, SNR, Tx power, RX sensitivity. The cell throughput performance data were collected over period of five months, drive test was on particular days as approved by SLA administrators during the experimental period. Drive Test Areas includes: Mbora District, Maitama District, and Wuse Zone 7 District. The process of selection of experimental data in this work was dependent on specific number of size. The site population of this study comprises of one hundred and forty five different locations with presence of LTE network services provided by SLA. The locations with great and stable performance were considered randomly to observe the network elements behaviour as well as the traffic demands from subscribers. However, the cell sites observed to be poorly performing were considered one hundred percent (100%) in evaluations as sample size. The drive test for each area selection takes about twenty five minutes driving through the planned paths/routes, each of the drive test areas generates above (463,883) points of data. Average of each cell throughput was determined. The work uses statistical method to analyze experimental voice and data KPIs. The cell throughput enhancement is achieved by adopting Radio Resource Management (RRM) technique which necessitated the developed algorithm based of Quality of Service Differentiation (Diff-Serv QoS).

The study consists of experimental work as well as simulation part, all the 145 sites of SPECTRANET in Abuja were captured and studied using Huawei Imanager 2000 tool which generated on daily basis, the Key Performance Indicators (KPI) of all deployed cells. Experiments and data collection within network zone was for a period of twenty nine weeks, but for the purpose of this research. Nonetheless, only Monday through Friday data collection were considered which includes working and public holidays. This means 20 days of experimental data were considered per month and lasted for a period of five months. The experimental procedure was strictly followed through extraction of daily KPI data from computer system installed with Huawei Imanager 2000 tool belonging to RF and network optimization unit of SPECTRANET LTD. Understudying of the generated data discloses cells with poor Quality of Service and the possible causes as well as applicable solutions. However, when the possible causes cannot be identified through the KPI data, further investigation on the affected sites can be carried out physically, employing drive test kits or the use of google earth Pro for virtual measurement, diagnosis and analysis. The following processes were carried out in this section to actualize the objectives of the research, first is the analyses and performance evaluation on the empirical data obtained in order to validate the standard threshold of ITU-R standard chart on Cell Throughput, using Microsoft Excel, MapInfo etc,. Secondly, estimation and modification of the existing network capacity and network parameters of SLA based on the empirical data obtained was done using MATLAB in order observe event parameters that best suits and improves SLA network performance. Finally, an enhancement algorithm developed and validated for the SLA network for better QOS using the measured data characteristics, with the aid Visual Studio2015 (Enterprise). Theoretical results of the cell throughput were compared to experimental results of the study. Equations were employed in the theoretical analysis while both theoretical and experimental analyses were both analytical based on research design. Graphs were plotted in chapter four to show the nature of cell throughput in both theoretical and experimental. The two enhancement functional flow chart algorithms developed are shown in the flow chats of Figures **3.7 and 3.8.** The algorithms helped in differentiating users based on Time Stamps (TSA) scales and Traffic Volume (TVA) scales in order to be fair to all subscribers against high users that tend to consume about 80% of the available radio resources. The Primary KPIs defined by the network operators are the Round Trip Time (RTT) (Milliseconds), Throughput (Mbps), Signal to Noise Interference Ratio (SNIR) (dB), Reference Signal Received Power (RSRP) (dBm), Reference Signal Received Quality (RSRQ) (dB). The following Key Performance Indicators (KPI) was considered on daily basis by Huawei Imanager 2000 for the experimental period experiment.

(i) Average Uplink (UL) and Downlink (DL) Throughput (Mbps)

(ii) Average Physical Resource Block Utilization Rate Per Cell (Percentage)

(iii) Average number of User

(iv) Reference Signal Received Power (RSRP)

(v) Reference Signal Received Quality (RSRQ)

(vi) Signal to Noise Ratio (SNR)

(vii) Intra-eNodeB Handover Success and Failure Rate

(viii) Average Downlink Channel Quality Indicator (DL CQI)

(ix) Average DL and UL Spectrum Efficiency

(x) Average DL and Uplink Traffic Volume per Cell

(xi) Average Service Drop Rate. (xii) DL and UL Transmission Block Retransmission Rate

All deployed active cell's KPI were monitored and studied on daily basis. The average performances of each cell for the period under study were analyzed. The following data were collated, computed and recorded. Huawei Imanager 2000 helped in generating KPI data for active cells across Abuja metropolis. Table 3.3 - 3.5 present the sample of the KPI data logs as generated per day (24Hrs) and the Key performances are organized per site, sector(eNodeB), Busy Hour (BH), Evening Hour (EH), Congestion Hours, Network Traffic. Table 3.2 depicts Abuja KPI Data Log sample for 24Hrs performance per Site. The key performance parameters record for 10 December, 2018. Measured average Downlink throughput (Mbps), the average Throughput on Uplink (Mbps), the Maximum Throughput on Downlink (Mbps), are shown for each site or Network Element (NE).

Table 3.2: KPI Data Log sample for 24Hrs –Site Record on 10 December, 2018

Start Date	NE Name	Avg_ThPut_DL (mb/second)	Avg_ThPut_UL (Mbit/s)	Max_ThPut_DL (mb/second)
10/12/2018	AB001	16.02	3.05	37.54
10/12/2018	AB022_Wuse_II	24.80	3.63	55.36
10/12/2018	AB024_Wuse_I	10.56	1.61	26.82
10/12/2018	AB043_FCT_Abuja	19.94	2.01	37.44
10/12/2018	AB050_Garki_1	8.22	1.05	23.75
10/12/2018	AB054_Garki_2	6.75	1.83	31.35
10/12/2018	AB057_Apo	16.49	1.48	32.57
10/12/2018	AB066_Apo	9.33	0.93	23.53
10/12/2018	AB032_Wuse_IV	14.95	2.01	36.84
10/12/2018	AB068_Apo	9.77	1.36	29.70
10/12/2018	AB059_Kaura	9.33	0.95	24.27
10/12/2018	AB062_Gudu	14.12	2.27	29.74
10/12/2018	AB025_Utako	21.45	2.81	44.22
10/12/2018	AB030	13.02	1.61	46.88
10/12/2018	AB037_Wuse_7	13.76	2.38	28.28
10/12/2018	AB031_Jabi	15.94	1.93	32.20
10/12/2018	AB027_Gwarimpa	20.23	2.95	35.41

However, Table 3.3 represents continuation of Table 3.2, Abuja KPI Data Log sample for 24Hrs performance per Site, provides average performance data record for 10 December, 2018. The following Key Performance parameters were measured per site (three sectors) such as the Maximum throughput in Uplink (Mbps) direction, the average number of User for each site, the Maximum number of Users recorded for the given day, the Maximum Total Throughput.

Table 3.3: KPI Data Log sample for 24Hrs –Site Record on 10 December, 2018 Cont'D

Max_ThPut_UL (Mbit/s	Max user	Average user	Max of Average User	Max of Total Thput	Total Max Th_F
6.95	132.00	70.80	112.854	41.55802246	44.48
6.51	175.00	102.54	150.858	59.4575	61.87
4.48	76.00	49.46	62.134	28.48500488	31.30
5.53	128.00	60.84	102.664	38.48475879	42.96
3.09	58.00	32.66	47.363	26.57396289	26.84
4.88	52.00	26.54	42.716	34.90667676	36.23
4.29	100.00	62.89	85.123	36.7410625	36.86
2.73	76.00	42.27	62.981	25.92776172	26.26
4.79	105.00	49.66	86.673	40.48328223	41.62
3.76	77.00	42.37	66.164	31.83210742	33.46
3.84	89.00	49.39	69.585	26.3165459	28.11
6.37	113.00	67.41	96.446	32.26981543	36.11
6.43	172.00	101.11	147.502	48.70860547	50.64
4.79	103.00	52.45	88.621	48.94161914	51.67
5.49	79.00	54.81	65.791	31.40805664	33.77

Significantly, Tables 3.2 and 3.3 present the first sub sheet of the KPI data set, providing the performance parameters for each site. 145 sites were actively deployed. The sample starts with date of event, name of site, the average throughput DL for each site, Average throughput UL for each site, Maximum throughput DL for each site, Maximum throughput UL for each site, Maximum number of Users per site, Average Users per site, Maximum of Average Users per site, Maximum of total Throughput per site, Total Maximum throughput per site etc.

Successively, Table 3.4 presents performance data log recorded per cell showing the measured average Downlink and uplink throughput performance, average and maximum users per cell etc.

Table 3.4: KPI Data Log sample for 24Hrs –Sector Record on 10 December, 2018

Start Time	Cell	Avg_ThPut_DL (mb/second)	Avg_ThPut_UL (kbit/s)	Max_ThPut_DL (mb/second)	Max_ThPut_UL (mbit/s)	Max user	Average user	Max of Average User	Max of Total Thput
10/12/2018	ID=2, Cell Name=AB_12001_2, eNodeB ID=12	5.54	1.09	15.32	4.78	46.00	23.76	38.793	16.20557422
10/12/2018	ID=1, Cell Name=AB_12001_1, eNodeB ID=12	6.28	0.81	15.41	2.32	53.00	26.96	46.891	16.60594531
10/12/2018	ID=0, Cell Name=AB_12001_0, eNodeB ID=12	4.21	1.15	14.19	4.52	38.00	20.08	30.976	17.65100586
10/12/2018	Cell ID=2, Cell Name=AB_12022_2, eNodeB ID	3.91	1.37	21.85	3.78	27.00	15.84	22.316	23.29597363
10/12/2018	Cell ID=1, Cell Name=AB_12022_1, eNodeB ID	8.05	0.84	24.13	2.33	57.00	30.24	49.463	25.64508398
10/12/2018	Cell ID=0, Cell Name=AB_12022_0, eNodeB ID	12.84	1.42	24.82	2.85	98.00	56.47	88.16	26.7222207
10/12/2018	Cell ID=2, Cell Name=AB_12024_2, eNodeB ID	3.07	0.35	10.68	3.40	31.00	17.62	26.719	12.84141602
10/12/2018	Cell ID=1, Cell Name=AB_12024_1, eNodeB ID	4.81	0.97	15.34	3.07	33.00	19.47	26.833	17.56819922
10/12/2018	Cell ID=0, Cell Name=AB_12024_0, eNodeB ID	2.68	0.29	13.57	1.58	22.00	12.37	16.982	13.96843066
10/12/2018	al Cell ID=2, Cell Name=AB_12043_2, eNodeB	4.02	0.66	15.94	4.93	31.00	18.68	26.477	17.11560449
10/12/2018	al Cell ID=1, Cell Name=AB_12043_1, eNodeB	7.15	0.47	22.43	2.26	31.00	15.61	26.491	22.98940039
10/12/2018	al Cell ID=0, Cell Name=AB_12043_0, eNodeB	8.76	0.88	16.55	4.25	69.00	26.55	55.022	18.09471289
10/12/2018	Cell ID=2, Cell Name=AB_12050_2, eNodeB ID	1.21	0.12	8.83	1.46	14.00	4.51	10.489	9.037625977
10/12/2018	Cell ID=1, Cell Name=AB_12050_1, eNodeB ID	6.25	0.83	21.18	2.48	38.00	25.56	33.679	22.02745215
10/12/2018	Cell ID=0, Cell Name=AB_12050_0, eNodeB ID	0.76	0.11	16.69	1.90	6.00	2.59	5.071	18.01558691
10/12/2018	Cell ID=2, Cell Name=AB_12054_2, eNodeB ID	2.05	0.62	13.82	2.52	14.00	7.88	11.326	14.68037109
10/12/2018	Cell ID=1, Cell Name=AB_12054_1, eNodeB ID	2.46	0.51	13.77	2.90	25.00	10.02	21.819	16.26057324

However, Table 3.5 represents continuation of Table 3.4, Abuja KPI Data Log sample for 24Hrs performance per Sector (Cell). Record of 10 December, 2018. Measured parameters such as Maximum Downlink and Uplink Physical Resource Block (PRB) Used Rate (%), Downlink and Uplink PRB utilization rate above eighty percent (> 80%) etc.

Table 3.5: KPI Data Log sample for 24Hrs–Sector Record on 10 December, 2018 Cont'D

MAX DL PRB Used Rate(%)	MAX UL PRB Used Rate(%)	DL PRB Used Rate(Busy Hour)(%)	UL PRB Used Rate(Busy Hour)(%)	Average 24 hrs DL PRB Used Rate	Average 24 hrs UL PRB Used Rate	DL PRB>=80 Count(Busy Hour)	UL PRB>=80 Count(Busy Hour)	DL PRB>=80 Count(24 Hour)	UL PRB>=80 Count(24 Hour)
95.65	85.45	62.45	48.49	44.36	44.31	10	0	21	4
97.76	75.52	84.87	55.33	50.24	43.44	23	0	24	0
89.80	81.80	46.13	54.15	31.21	42.66	2	1	2	1
95.30	81.09	32.12	49.84	32.86	46.91	1	0	9	1
97.60	84.86	84.36	60.57	57.33	47.86	18	2	30	2
97.64	88.00	90.72	71.53	62.70	55.23	29	9	42	10
69.92	68.62	30.04	32.09	19.93	28.05	0	0	0	0
89.66	77.51	30.65	45.52	26.19	41.98	0	0	2	0
93.45	63.04	28.05	31.54	22.80	28.69	0	0	1	0
94.30	77.70	35.02	33.36	28.12	33.22	3	0	6	0
59.09	59.84	29.45	32.15	25.46	27.28	0	0	0	0
99.30	83.72	79.19	56.05	65.56	43.17	20	1	35	1
59.72	41.23	11.21	21.61	10.69	19.58	0	0	0	0
79.68	67.75	43.91	48.13	37.73	39.89	0	0	0	0
51.96	72.07	8.66	18.36	4.09	15.43	0	0	0	0
74.81	87.42	14.77	35.66	16.39	44.16	0	0	0	4
84.40	72.31	33.78	41.17	16.82	29.44	1	0	1	0

Consequently, Table 3.4 and 3.5 show the 24-Sector Data set of the KPI, it presents the performance in smallest units for sectors; there are three sectors or cells in one site. 405 sectors were covered. The sample starts with date of event, name of the cell, Average throughput in DL per cell, Average throughput UL per cell, Maximum throughput DL for each cell, Maximum throughput UL for each cell, Maximum User per cell, Average Users per cell, Maximum of Average Users per cell, maximum of total Throughput per cell, Total Maximum throughput per cell, Maximum DL PRB utilized per cell, Maximum UL PRB utilized per cell etc.

Drive test were deployed to further investigate the root causes of poor performing cells, Tables 3.6 and 3.7 present a sample of extracted drive data and its most important empirical measurement parameters for further analysis as carried on 6 May, 2019. Note that for each drive test path (2 – 3Km) for 15 to 20 minutes generates huge amount of data points up to 468, 000.

Table 3.6: Sample of Filtered Data for District Drive Test

	A	B	C	D	E	F	G
1	Date	Latitude	Longitude	PCI	RSRP	RSRQ	SINR
2	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
3	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
4	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
5	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
6	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
7	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
8	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
9	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
10	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
11	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
12	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
13	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
14	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
15	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
16	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
17	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
18	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
19	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
20	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
21	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
22	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
23	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
24	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4
25	Monday, May 6, 2019	9.054835	7.456753333	95	-97.6875	-11.1875	1.4

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However, Table 3.7 depicts the continuation of Table 3.6 of extracted data obtained during drive test on same day 6 May, 2019.

Table 3.7: Sample of Filtered Data for District Drive Test Cont'D

B463883 fx 9.051896787

	A	B	C	D	E	F	G
463856	Monday, May 6, 2019	9.05189997	7.4471206	197	-117.813	-19.875	-13.2
463857	Monday, May 6, 2019	9.05189997	7.4471206	197	-117.813	-19.875	-13.2
463858	Monday, May 6, 2019	9.051899429	7.447120562	197	-117.438	-20.125	-9.8
463859	Monday, May 6, 2019	9.051899429	7.447120562	197	-117.438	-20.125	-9.8
463860	Monday, May 6, 2019	9.051899429	7.447120562	197	-117.438	-20.125	-9.8
463861	Monday, May 6, 2019	9.051899429	7.447120562	197	-117.438	-20.125	-9.8
463862	Monday, May 6, 2019	9.051899369	7.447120558	197	-117.438	-20.125	-9.8
463863	Monday, May 6, 2019	9.051898949	7.447120529	197	-117.438	-20.125	-9.8
463864	Monday, May 6, 2019	9.051898949	7.447120529	197	-117.438	-20.125	-9.8
463865	Monday, May 6, 2019	9.051898949	7.447120529	197	-117.438	-20.125	-9.8
463866	Monday, May 6, 2019	9.051898408	7.447120491	197	-117.438	-20.125	-9.8
463867	Monday, May 6, 2019	9.051898408	7.447120491	197	-117.438	-20.125	-9.8
463868	Monday, May 6, 2019	9.051897928	7.447120458	197	-117.438	-20.125	-9.8
463869	Monday, May 6, 2019	9.051897928	7.447120458	197	-117.438	-20.125	-9.8
463870	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463871	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463872	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463873	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463874	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463875	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463876	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463877	Monday, May 6, 2019	9.051897327	7.447120416	197	-117.438	-20.125	-9.8
463878	Monday, May 6, 2019	9.051896787	7.447120379	197	-117.438	-20.125	-9.8
463879	Monday, May 6, 2019	9.051896787	7.447120379	197	-117.438	-20.125	-9.8
463880	Monday, May 6, 2019	9.051896787	7.447120379	197	-117.438	-20.125	-9.8
463881	Monday, May 6, 2019	9.051896787	7.447120379	197	-117.438	-20.125	-9.8
463882	Monday, May 6, 2019	9.051896787	7.447120379	197	-117.438	-20.125	-9.8
463883	Monday, May 6, 2019	9.051896787	7.447120379	197	-117.438	-20.125	-9.8

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Ready

The filtered samples show the important parameter needed for further analysis in MapInfo, such as the date of event, the coordinates, the Physical Cell Identifier (PCI) numbers, Reference signal Received Power (RSRP) values, Reference Signal Received Quality (RSRQ) values, Signal to Interference Noise Ratio SINR values etc.

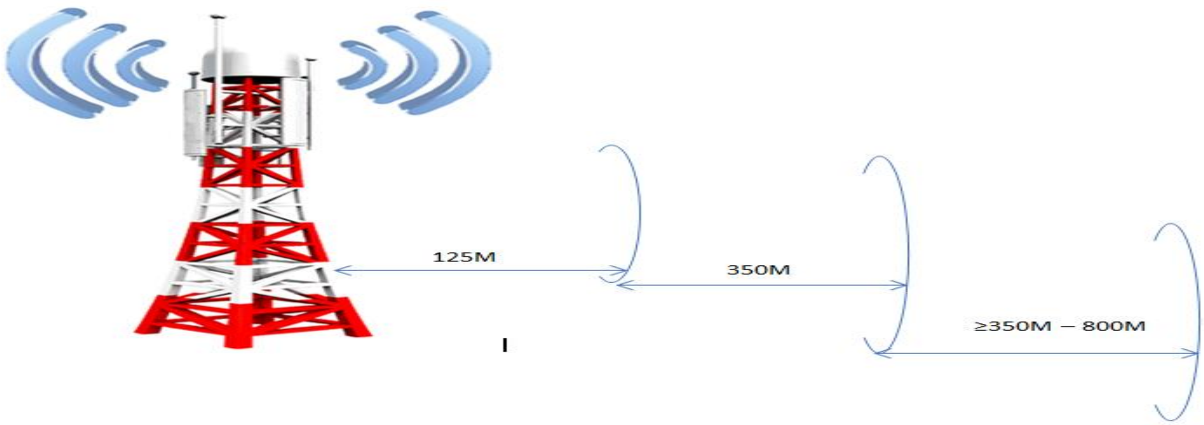

Figure 3.3: Measurement Distances from the Serving eNodeB

Measurement Dates: 12th of November, 2018 – 28th June, 2019

Measurement Distances (Meters)

Cell Centre Radius = 0 - 125 M

Middle of Cell Radius = 125 – 350 M

Cell Edge Radius = > 350 M

Table 3.8 SPECTRANET LTE Empirical SINR, RSRQ, and RSRP Values

S/N	Performance Remark	SINR (dB)	RSRQ (dB)	RSRP (dBm)
1	Excellent	20 -50	-10 – 0	-70 - 0
2	Very Good	10 – 20	-12 – (-10)	-80 – (-70)
3	Good	5 – 10	-14 –(-12)	-90 – (-80)
4	Bad	(-5) – (5)	-16 – (-14)	-110 – (-90)
5	Very Bad	(-20) – (-5)	-20 – (-16)	-150 – (-110)

3.4 Models for Estimation and Modification of Network Capacity

The parameter listed in section 3.1 of this chapter was analysed empirically and average of the data determined before employing it over various analysis in the study. The average analysis of same quantity is stated in equation (3.1) (Forsberg, 2010).

$$\text{Average } (\bar{x}) = \frac{\sum x}{n} \tag{3.1}$$

Where

$x =$ Collected data of various parameters, $n =$ Number of collected data

The network capacity and throughput of the existing network of LTE service provided by SLA were determined. According to Shannon's theory the network capacity is given as (Onald, Marius, Simon and James, 2013):

$$C = Blog_2(1 + N_T N_R SINR) \tag{3.2}$$

Where: $C =$ Channel capacity in bits per second

$N_T =$ Number of transmitting antenna

$B =$ Channel bandwidth in Hz, $N_R =$ Number of receiving antenna

$SINR =$ Average signal to interference and noise ratio at the receiver end

Signal to-interference and noise ratio is given by (Onald *et al.*, 2013).

$$(SINR)_{m,k} = \frac{P_r}{P_I + P_n} \tag{3.3}$$

Where: $P_n =$ Noise power, $P_r =$ External radar interference, $P_I =$ Total interference power

$m =$ Signal terminal unit in downlink, $k =$ Sub-carrier unit with total number of K. Throughput is defined as the amount of packets transmitted and received successfully over a given time. Usually measured in Kilo-bits per second (Kbps) or Mega Bits per second (Mbps). Throughput is the actual bandwidth measured in a particular time and in a certain LTE network conditions that are used to transfer files of a certain size. The throughput in bit per second of a network is stated in (3.4) and (3.5) respectively (Jia, Mao, Sontineni and Kwong 2015).

$$T_r = (1 - BER) \times T_i \quad (3.4)$$

$$T_i = 14\, N_{rb} N_{sc}\, M \quad (3.5)$$

$$BER = \frac{1}{N} \sum_{k=1}^{N} P_{b,k}\,(E) \quad (3.6)$$

Where: BER = Bit error rate

$T_i =$ Ideal throughput in a single input and single output, $T_r =$ Real throughput

$M =$ Modulation order (Refer to Table 3.9)

$N_{rb} =$ The number of resource blocks based on bandwidth specification in Table 3.10

$N_{sc} =$ Number of subcarriers in resource blocks, $N =$ Total number of subcarrier

$P_{b,k}(E) =$ Raleigh Fading channel in subcarrier, k out of N

The selection of physical layer of LTE network capacity is based on modulation technique shown in Table 3.9:

Table 3.9: LTE Standards on Channel and Quality Indicator (CQI)

	Before Rel.12		Rel.12 and beyond	
CQI	Modulation	Code rate	Modulation	Code rate
0	Out of range			
1	QPSK	0.0762	QPSK	0.0762
2	QPSK	0.1172	QPSK	0.1885
3	QPSK	0.1885	QPSK	0.4385
4	QPSK	0.3008	16QAM	0.3691
5	QPSK	0.4385	16QAM	0.4785
6	QPSK	0.5879	16QAM	0.6016
7	16QAM	0.3691	64QAM	0.4551
8	16QAM	0.4785	64QAM	0.5537
9	16QAM	0.6016	64QAM	0.6504
10	64QAM	0.4551	64QAM	0.7539
11	64QAM	0.5537	64QAM	0.8525
12	64QAM	0.6504	256QAM	0.6943
13	64QAM	0.7539	256QAM	0.7783
14	64QAM	0.8525	256QAM	0.8634
15	64QAM	0.9258	256QAM	0.9258

Source: (3GPP Technical Specification Release 8, 2008)

In Table 3.9 the following are defined:

QPSK: Quadrature phase shift key

M- Quadrature amplitude modulation, M= 16 and 64 respectively.

CQI, 0 = the poorest channel quality

CQI, 15 = the most best channel quality

Table 3.10: LTE Standards on Bandwidths and Corresponding Resource Blocks

Bandwidth (MHz)	Resource Blocks	Sub-carriers Downlink	Sub-carriers Uplink
1.4	6	73	72
3.0	15	181	180
5	25	301	300
10	50	601	600
15	75	901	900
20	100	1201	120

Source: (Das, Bhuvaneswari, Ezhilarasi, 2015).

Table 3.10 defines all operating bandwidth (MHz) of LTE network with their corresponding number of resource blocks as well as the number of sub-carriers assigned in the forward and reserve links. The higher the operating bandwidth the higher the capacity of the network, SPECTRANET LTD (SLA), Abuja employs 20 MHz bandwidth as well as other cities they operate in Nigeria.

Tables 3.11, 3.12, and 3.13 are defined tables by 3GPP Technical Specification Release 8, (2008) for determining data rate (Throughput) of any given User Equipment (UE). From the Channel Quality Indicator (CQI) of UE, eNodeB uses the tables to calculate the amount of radio resource to be assigned to the UE. This translates to Transport Block Size (TBS) deciding the real amount of bits that can be transmitted in one mili-second (1ms) of LTE Transmission Time Interval (TTI)

Table 3.11: Modulation and Coding Scheme (MCS) Index for Physical DL Shared Channel (PDSCH)

MCS Index I_{MCS}	Modulation Order Q_m	Target code Rate R x [1024]	Spectral efficiency
0	2	120	0.2344
1	2	157	0.3066
2	2	193	0.3770
3	2	251	0.4902
4	2	308	0.6016
5	2	379	0.7402
6	2	449	0.8770
7	2	526	1.0273
8	2	602	1.1758
9	2	679	1.3262
10	4	340	1.3281
11	4	378	1.4766
12	4	434	1.6953
13	4	490	1.9141
14	4	553	2.1602
15	4	616	2.4063
16	4	658	2.5703
17	6	438	2.5664
18	6	466	2.7305
19	6	517	3.0293
20	6	567	3.3223
21	6	616	3.6094
22	6	666	3.9023
23	6	719	4.2129
24	6	772	4.5234
25	6	822	4.8164
26	6	873	5.1152
27	6	910	5.3320
28	6	948	5.5547
29	2	reserved	
30	4	reserved	
31	6	reserved	

Source: (3GPP Technical Specification Release 8, 2008)

Modulation and Coding Scheme Index, (MCS Index) ranges from 0, 1, 2,…, 31. The parameter is used by eNodeB to signal to the mobile terminal the modulation and coding to use for receiving or transmitting a certain transport block. Each MCS index stands for a certain modulation order and transport block size index. MCS index tells the UE the coding rate to use not only for the downlink but also for the uplink. The target code rate is used to determine the spectral efficiency, for instance, from the Table 3.11, the target rate of MCS index number of 15 is 616. Then the corresponding spectral efficiency can be derived as MCS divided by a kilobits data, multiplied by the corresponding modulation order, thus: $S\epsilon = \frac{616}{1024} \times (0.4) = 2.4063$.

Where $S\epsilon$ represents spectral efficiency

Table 3.12: Modulation Coding Scheme/Transport Block Size (MCS-TBS) index for PDSCH

MCS Index I_{MCS}	Modulation Order Q_m	TBS Index I_{TBS}
0	2	0
1	2	1
2	2	2
3	2	3
4	2	4
5	2	5
6	2	6
7	2	7
8	2	8
9	2	9
10	4	9
11	4	10
12	4	11
13	4	12
14	4	13
15	4	14
16	4	15
17	6	15
18	6	16
19	6	17
20	6	18
21	6	19
22	6	20
23	6	21
24	6	22
25	6	23
26	6	24
27	6	25
28	6	26
29	2	reserved
30	4	
31	6	

Source: (3GPP Technical Specification Release 8, 2008)

MCS index (***I**mcs*) is the index factor of Modulation and Coding Scheme (MCS), while (***Q**m)* is the corresponding modulation order and finally, the Transport Block Size (TBS) index (I_{TBS}) Transport Block Size. The factors are major determinant of data throughput of any given UE, the factors can be used to determine how much bits are transferred in this 1ms transport block size?

Solution; It depends on the MCS and the number of resource blocks assigned to the UE.

If eNodeB assigns MCS index 22 and 4 Resource Blocks (RBs) on the basis of Channel Quality Indicator (CQI) and other information for downlink transmission on Packet Data Shared Channel (PDSCH). Now the value of TBS index is 20 as seen in modulation and TBS Index Table (Table 3.12).

Code rate is simply defined as how efficiently and successfully data payload can be transmitted in one sub-frame of 1ms transport block. Similarly, it is defined as the ratio of actual amount of bits transmitted to the maximum amount of bits that could be transmitted in one transport block.

Code rate = (TBS + CRC) / (RE x Bits per RE) (3.7)

However,

TBS = Transport Block Size (TBS) as calculated from TBS Table (Table 3.13)

CRC = Cyclic Redundancy Check (CRC) i.e. Number of bits appended for error detection

RE = Resource Elements assigned to PDSCH or Physical Uplink Shared Channel (PUSCH)

Bits per RE = Modulation scheme used.

After obtaining the values of TBS, CRC and bits per RE (modulation order), Then the precise amount of RE used for PDSCH or PUSCH since some of the REs are also used by control channels like Physical Downlink Control Channel (PDCCH), Physical Hybrid Automatic Repeat Request Indicator Channel (PHICH) etc.

In SPECTRANET case, 10% of RE's are assigned for control channels then

TBS = 1864

CRC = 24 CRC length (3GPP TS 36.212, section 5.1.1)

RE = 4 (RB) x 12 (subcarriers) x 7 (assuming 7 OFDM symbols) x 2 (slots per sub-frame) x 0.9 (10% RE for control) = 604.8 REs

Bits per RE = 6 (Modulation order of assigned MCS 22, refer to table 3.12)

Consequently; Code rate = (1864 + 24) / (604.8 X 6) = 0.52

Therefore 0.52 coding rate is achieved for the radio bearer with MCS of 22 and 4 RBs.

Table 3.13: Transport Block Size (TBS) Index and Equivalent N_{PRB}

I_{TBS}	N_{PRB}									
	1	2	3	4	5	6	7	8	9	10
0	16	32	56	88	120	152	176	208	224	256
1	24	56	88	144	176	208	224	256	328	344
2	32	72	144	176	208	256	296	328	376	424
3	40	104	176	208	256	328	392	440	504	568
4	56	120	208	256	328	408	488	552	632	696
5	72	144	224	328	424	504	600	680	776	872
6	328	176	256	392	504	600	712	808	936	1032
7	104	224	328	472	584	712	840	968	1096	1224
8	120	256	392	536	680	808	968	1096	1256	1384
9	136	296	456	616	776	936	1096	1256	1416	1544
10	144	328	504	680	872	1032	1224	1384	1544	1736
11	176	376	584	776	1000	1192	1384	1608	1800	2024
12	208	440	680	904	1128	1352	1608	1800	2024	2280
13	224	488	744	1000	1256	1544	1800	2024	2280	2536
14	256	552	840	1128	1416	1736	1992	2280	2600	2856
15	280	600	904	1224	1544	1800	2152	2472	2728	3112
16	328	632	968	1288	1608	1928	2280	2600	2984	3240
17	336	696	1064	1416	1800	2152	2536	2856	3240	3624
18	376	776	1160	1544	1992	2344	2792	3112	3624	4008
19	408	840	1288	1736	2152	2600	2984	3496	3880	4264
20	440	904	1384	1864	2344	2792	3240	3752	4136	4584
21	488	1000	1480	1992	2472	2984	3496	4008	4584	4968
22	520	1064	1608	2152	2664	3240	3752	4264	4776	5352
23	552	1128	1736	2280	2856	3496	4008	4584	5160	5736
24	584	1192	1800	2408	2984	3624	4264	4968	5544	5992

Source: (3GPP Technical Specification Release 8, 2008)

Long Term Evolution (LTE) Transport Block Size (TBS) Index Table 3.13 gives details of number of bits as it corresponds to Number of Physical Resource Blocks (N_{PRB}) and TBS value assigned to a given UE. It is important to understand how much bits are transferred in 1ms transport Block size in LTE network, although this depends on the MCS index, and number of resource block assigned to the UE. For 20MHz bandwidth which corresponds to 100 resource blocks (3GPP standard).

If an MCS of 24 is sent, it corresponds to TBS of 22, as observed from TBS index table 3.13.

Secondly, if the number of allocated Physical Resource Blocks (PRB) is one (1), then the Transport Block for the condition is 520. Refer to TBS Table 3.13.

Also observe from Table 3.13, if the number of allocated PRB is two (2), the corresponding Transport Block size is 1064.

Furthermore, observe that there is reduced performance or number of Transport Block Size when UE is assigned TBS index of 5, consider when one (1) PRB or two (2) PRBs are allocated to UE; it will corresponds to 72 and 144 transport block size respectively Table 3.13.

Consider a radio scenario where eNodeB assigns MCS index of 12 and 2 Resource Blocks to UE, The transport block size will be calculated as follows:

This value goes a long way determining the application speed. First, from the MCS index of 12, corresponds to TBS index of 11 (Refer to Table 3.12), then from TBS index Table 3.13, 2 PRB corresponds to 376 Transport Block Size.

Hybrid Automatic Repeat Request (HARQ) process reduces throughput performance but improves reliability. If there is bad radio interface or congestion, there will be retransmission which does affect the physical speed but the application speed.

Consider a single UE, 20 MHz bandwidth and ideal radio conditions (to get peak throughput),

Then, number of RBs =100,

MCS Index = 28 and TBS index = 26 (Table 3.12)

Based on that TBS = 75376 bits. (Table 3.13)

Throughput = (75376 X 1000) = 75.376 Mbps.

Assuming MIMO 2x2, then Throughput equals (75.376 X 2) = 150.752 Mbps

Assume 4 x 4 MIMO, throughput will be (75.376 X 4) = 301.504 Mbps

3.4.1 Estimation of LTE Data Rate using Field /Measured Data

Applying the obtained parameters

20MHz bandwidth has 100 resource blocks

1 resource blocks (One time Slot) have 12 sub-carries

1 frame packet has 10 sub-frames (10ms)

1 sub-frame has 1ms (TTI)

1 sub- frame has two time slots (0.5ms each)

1 time –slot has 7 OFDM symbols (when Normal CP is used)

1 OFDM symbol has 6 data bits, when 64QAM modulation order is used

Number of Data bits in a sub frame(2 time slot) = 100 RBS x 12 sub-carriers x 2 slots in sub frame x 7 modulation symbol in a time slot x 6 bits in 1 OFDMA symbol = 100800 bits

Data Rate = 100800 bit/1ms = 100.8Mbps

4x4 MIMO system, then the peak date would be 4x 100.8Mbps = 403 Mbps

In very good condition, ¾ coding rate is used to protect the data, obtain ¾ x 403 Mbps = 300Mbps as data rate on downlink.

However, Performance of existing network is determined by comparing the delay experience in the cell throughput with LTE QoS class identifier. The throughput performance (P) of the network is calculated as (Ferdosian *et al.*, 2015):

$$P_T = \frac{T_e}{T_{QCI}} \tag{3.8}$$

Where: T_e = Experimental throughput

T_{QCI} = Expected throughput by QCI standard

However, Spectral efficiency (ε_s) of the network is determined using modified Alpha-Shannon Formula given as:

$$\varepsilon_s = \alpha log_2(1 + 10^{\frac{SNR}{10G_f}}) \tag{3.9}$$

Where: $\alpha =$ Bandwidth efficiency factor

$G_f =$ Geometry distribution factor in dB

The average signal-to-noise ratio (SNR) in decibel is the measure of the ratio of average of signal power and average of noise power (Sayantan *et al.*, 2015).

$$SNR = \frac{P_s}{P_n} \tag{3.10}$$

Where: $P_s =$ Signal transmission power of serving base station (eNodeB) in Watt

Pn = Noise power

The packet error and delay is shown in Table 3.14 for achieving good cell throughput. .

Table 3.14: LTE QOS Class Identifier (QCI) Characteristics

S/N	Resource Type	Packet Error	QCI priority	Packet Delay Budget	Service Type
1	GBR	10^{-2}	2	100ms	Conversational voice
2	GBR	10^{-3}	4	150ms	Conversational video
3	GBR	10^{-3}	3	50ms	Real timing game
4	GBR	10^{-6}	5	300ms	Non-Conversational video
5	NGBR	10^{-6}	1	100ms	IMS signaling
6	NGBR	10^{-6}	6	300ms	Buffered video, email
7	NGBR	10^{-3}	7	100ms	Voice, Radio transmission, video
8	NGBR	10^{-6}	8	300ms	TCP Based service
9	NGBR	10^{-6}	9	300ms	TCP Based service

Source: (3GPP Release 13, 2014)

Where: GBR: Guaranteed bit rate and NGBR: Non-guaranteed bit rate, QCI is QOS Class Indicator.

3.4.2 Key Performance Indicators (KPI) and Empirical Data Evaluation

Fact forming the basis of research has it in SPECTRANET LTD, Abuja report that 20% or less of the users/ subscribers that latches into the Cell Radio (eNodeB) consume about 80% or more of the network resources (PRB) than the rest of subscribers. Analyzing the empirical data will validate the aforementioned fact, hence, solution of Differential Quality of Service (dQOS) for better Quality of Experience and improved network performance.

The Essence of KPI data is to be able to detect the sites, cells in a particular region that are performing well or underperforming at every given time. It captures all the cell and site locations, presents the data of performances. The KPI data can easily tell areas or sites that have good and poor throughput of Network. The KPI also shows us the amount of the network resources (PRB= Physical Resource Block)-used per one cell for given period of time. It helps to observe when and where congestion triggers on & off in the network etc. Refer to section 3.3 for list of KPIs captured.

SPECTRANET LTD, Abuja uses Huawei Imanager2000 for daily generation and log of key performance indicator involving all the deployed eNodeB. Imanager2000 presents the KPI data log in Microsoft Excel with 6 sub-sheets summarizing site performances during Busy Hour(BH), Evening Hours(EH), 24hrs-Site Performance, 24Hrs-Sector performance, Congestion and Network Traffic in one Excel Data Sheet .

In 24-Sector Data, this is the most important sub data sheet, because it's the performance in smallest units for cells, or sectors. Recall, there are three sectors or cells in one site or NE. Recall SPECTRANET network has about 403 serving cells. It shows each as follow, Refer to table 3.4.

eNodeB Function Name=AB022_Wuse_II,

Local Cell ID=1,

Cell Name=AB_12022_1,

eNodeB ID=12022,

Cell FDD TDD indication=CELL_TDD

Cell FDD TDD indication = Cell_ TDD means Time Division Duplex is a duplexing technique for isolating uplink and downlinks traffic. It means is that uplink and downlink share same frequency band but different time Slots. But if it were to be FDD, the UL and DL will have different frequencies bands. Another important column in table 3.4 is the PRBs for Uplinks and downlinks. It shows in percentage when the Physical Resource blocks are almost consumed (Above 80% usage) for each cell. Once it gets to 90%, there will be congestion and packet data starts to drop after number of HARQ sequence, and there will be increase in delay in delivering packets successfully.

It should be stipulated that the SPECTRANET network operates the bandwidth capacity of 20 Mhz, that will give 100 PRBs (Refer to Table 3.1) and one PRB has 12 sub-carriers, and each sub-carrier corresponds to one User Equipment (UE) allotment. Theoretically, the maximum number of user each cell can have or contain at every given point in time is 1200 subscribers. Other Sub sheets or Tab shows the average of what is happening or performances at Evening Hours (EH) (4pm to 7pm) and Busy Hours (BH) (9am to 11:30) in each site. The Congestion Tab shows the performance as at the set Busy Hour. Good to monitor and observe changes for each tab.

3.4.3 Estimation and Modification of Existing Network

Third objective of this research is to estimate and modify the existing Network capacity of LTE network based on the empirical data obtained using MATLAB software. Modelling, simulating and visualizing the performance of the communications in 4G LTE. The Main purpose is to use MATLAB Tool box for LTE and build a 4G LTE network depicting the network using the information from collected data. Clearly, the simulation incorporated the chain blocks and characteristics of 4G LTE wireless communications System such as;

Transmitter: There are processes for Code-word generation, Amplification, channel coding, code-word scrambling, modulation, Orthogonal Frequency Division Multiplexing (OFDM) transmission, and Inverse FAST Fourier Transform (IFFT).

Communication Channel: Here there are effect of Doppler (path delay, 0. 30, 60 90,), multipath Propagation, AWGN Noise etc.

Receiver: There are processes for OFDM reception, Fast Fourier Transform (FFT), Channel Estimation, Equalizer (Minimum mean square error, or Zero forcing), Demodulation, code-word descrambling, channel decoding, and detection.

The parameters of the network configuration are strictly followed from data obtained and studied: Network Structure: UE, eNodeB, MME/SGW/PDNGW

We observed the performance effects of generated LTE Signal on PDSCH, when transmitted and received via different channel condition (low, medium, and high mobility for same modulation scheme say 64QAM and 16QAM or QPSK) as well as at Different SNR (Say, 0, 3, 6, 9 dB). If possible, The Spectral Power Density for the Signals before transmission and reception for different network scenarios, Downlink Reference Measurement Channel (RMC) generator, RMC spectrum, generated downlink evolved universal terrestrial radio access "E-UTRA TEST MODEL (E-TM) Waveforms. We shall able to identify Parameters/factors that INCREASEs OR DECREASES the network congestion, Delay {RRT: Round trip time}, Packet drops, SNR, Inter Symbol interference (ISI), Inter channel interference (ICI), Multi-path effect etc.

The parameters of the network configuration: Network Structure: UE, eNodeB, MME/SGW/PDNGW, Duplex Mode (Mode of operation) TDD, Radio Frame Structure: 10 ms, Access Technique: Downlink (OFDMA), UPLINK (SC:FDMA), Channel Bandwidth: 20 Mhz, Frequency: 2.3Ghz, MIMO: 4x4, Number of Physical Resource Block: 100, Modulation Schemes: QPSK, 16QAM, 64QAM, Average number of nodes (eNodeBs): 145, Average number of Cells: 403, Average Number of users per cell: 50 UEs, Average Throughput of the Network: 1.8 Mbps, Poor performing cells average throughput: 0.8mbps

3.4.3.1 LTE Downlink Waveform Generation

The LTE Toolbox can be used to generate standard compliant LTE/LTE-Advanced downlink baseband waveforms which could be used for a number of end user applications including end-to-end simulations, static waveform generation, and performance analysis. The toolbox provides functions for flexible and easy generation of the full link, adaptable to user requirements. LTE network operators have different configuration to suit their subscriber's need, the toolbox also provides a means to generate pre-defined parameter sets corresponding to standard defined measurement channels which can be used as such or further modified to suit specific waveform generation and end-to-end simulations. The pre-defined parameters are referred as Radio measurement Channel (RMC) and specified in 3GPP technical specification, TS 36.101. The table 3.15 shows some of the characteristics of pre-defined RMC. The marked RMCs [R.6, R.9, R.12, R.13, and R.14] are the ones with parametrization set closest to SPECTRANET configuration and serve the best interest of the research upon modification. Generating LTE downlink waveform using MATLAB tool requires two major call functions. Namely; lteRMCDL and lteRMCDLTool. The combination provides for LTE downlink waveform generation for different user requirements. The corresponding uplink call functions are lteRMCUL and lteRMCULTool. lteRMCDL function helps to establish a full parameter set while lteRMCDLTool function helps to generate the downlink waveform.

Table 3.15: Pre-defined LTE Reference Measurement Channel (RMC)

Reference channels	Reference channels (continued)
R.0 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)	R.31-3A FDD (CDD, 50 RB, 64QAM, CellRefP=2, R=0.85-0.90)
R.1 (Port0, 1 RB, 16QAM, CellRefP=1, R=1/2)	R.31-3A TDD (CDD, 68 RB, 64QAM, CellRefP=2, R=0.87-0.90)
R.2 (Port0, 50 RB, QPSK, CellRefP=1, R=1/3)	R.31-4 (CDD, 100 RB, 64QAM, CellRefP=2, R=0.87-0.90)
R.3 (Port0, 50 RB, 16QAM, CellRefP=1, R=1/2)	R.43 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.4 (Port0, 6 RB, QPSK, CellRefP=1, R=1/3)	R.43 TDD (SpatialMux, 100 RB, 16QAM, CellRefP=4, R=1/2)
R.5 (Port0, 15 RB, 64QAM, CellRefP=1, R=3/4)	R.44 FDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.6 (Port0, 25 RB, 64QAM, CellRefP=1, R=3/4)	R.44 TDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)
R.7 (Port0, 50 RB, 64QAM, CellRefP=1, R=3/4)	R.45 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)
R.8 (Port0, 75 RB, 64QAM, CellRefP=1, R=3/4)	R.45-1 (Port7-14, 39 RB, 16QAM, CellRefP=2, R=1/2)
R.9 (Port0, 100 RB, 64QAM, CellRefP=1, R=3/4)	R.48 (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/2)
R.10 (TxDiversity|SpatialMux, 50 RB, QPSK, CellRefP=2, R=1/3)	R.50 FDD (Port7-14, 50 RB, 64QAM, CellRefP=2, R=1/2)
R.11 (TxDiversity|SpatialMux|CDD, 50 RB, 16QAM, CellRefP=2, R=1/2)	R.50 TDD (Port7-14, 50 RB, QPSK, CellRefP=2, R=1/3)
R.12 (TxDiversity, 6 RB, QPSK, CellRefP=4, R=1/3)	R.51 (Port7-14, 50 RB, 16QAM, CellRefP=2, R=1/2)
R.13 (SpatialMux, 50 RB, QPSK, CellRefP=4, R=1/3)	R.6-27RB (Port0, 27 RB, 64QAM, CellRefP=1, R=3/4)
R.14 (SpatialMux|CDD, 50 RB, 16QAM, CellRefP=4, R=1/2)	R.12-9RB (TxDiversity, 9 RB, QPSK, CellRefP=4, R=1/3)
R.25 (Port5, 50 RB, QPSK, CellRefP=1, R=1/3)	R.11-45RB (CDD, 45 RB, 16QAM, CellRefP=2, R=1/2)
R.26 (Port5, 50 RB, 16QAM, CellRefP=1, R=1/2)	
R.27 (Port5, 50 RB, 64QAM, CellRefP=1, R=3/4)	
R.28 (Port5, 1 RB, 16QAM, CellRefP=1, R=1/2)	

Source: (3GPP Technical Specification 36.101, 2010)

There are numerous scenarios where different waveform configuration may be desired other than the pre-defined set of RMCs. In such scenario, customizing the parameter sets starting with one of the pre-defined RMCs and modifying variable(s) which require different values to create the full customized parameter set. However to generate PDSCH reference Measurement Channel (RMC) waveforms, there are parameters that must be defined:

The reference Channel (R.12, R.13, etc); RMC parameters such as number of downlink resource blocks 15, 50, 100 etc., Number of transmits ports: (1, 2, 4).

Modulation scheme: QPSK, 16QAm, 64QAM.

Transmission layer and Total Information bits per frame per code-words.

Duplex mode: (FDD or TDD) and Transmission Scheme: (Spatial MUX, TX Diversity).

Cell Identity: Physical layer cell identity (PCI) usually from 0 to 503, Radio network temporary identifier (RNTI) value (16 bits) it is usually a scalar integer (0 default, 1,). RNTI helps distinguish/recognize a connected UE in the cell, a specific radio channel, a group of UEs in case of paging, broadcast etc., a group of UEs for which power control is issued by the eNodeB

RV Sequence [0, 1, 2, 3,], This specifies the sequence of Redundancy Version (RV) indicators for each HARQ process. The number of elements in each row is equal to the number of transmissions in each HARQ process. If RV-Seq is a row vector in a two code-word transmission, then the same RV sequence is applied to both code-words.

Rho (dB): PDSCH resource element power allocation, in dB it is usual a scalar integer (0 default, 1) and OFDM Channel Noise Generator (ON/OFF),

Number of Sub frames: (2/5/10): It is a non-negative scalar integer, usually set to determine the number of sub-frames to generate and Number of Code-words (1/2),

Precoder Matrix Indication (PMI) set is an Integer vector with element values usually from 0 to 15. If it is a single value, corresponds to single PMI mode, or multiple digits corresponding to multiple or sub-band PMI mode. The number of values depends on transmission layer and transmit scheme.

Number of HARQ (8 for FDD, 7 Max for TDD): It provides for the number of HARQ processes per component carrier or subcarrier.

Windowing (samples): This is usually set as non-negative scalar integer, it shows number of time-domain samples over which windowing and overlapping of OFDM symbols is applied.

Finally, Waveform variables, Resource Grid output variable, RMC configuration output variable etc., can be generated (Mathworks, 2015).

I

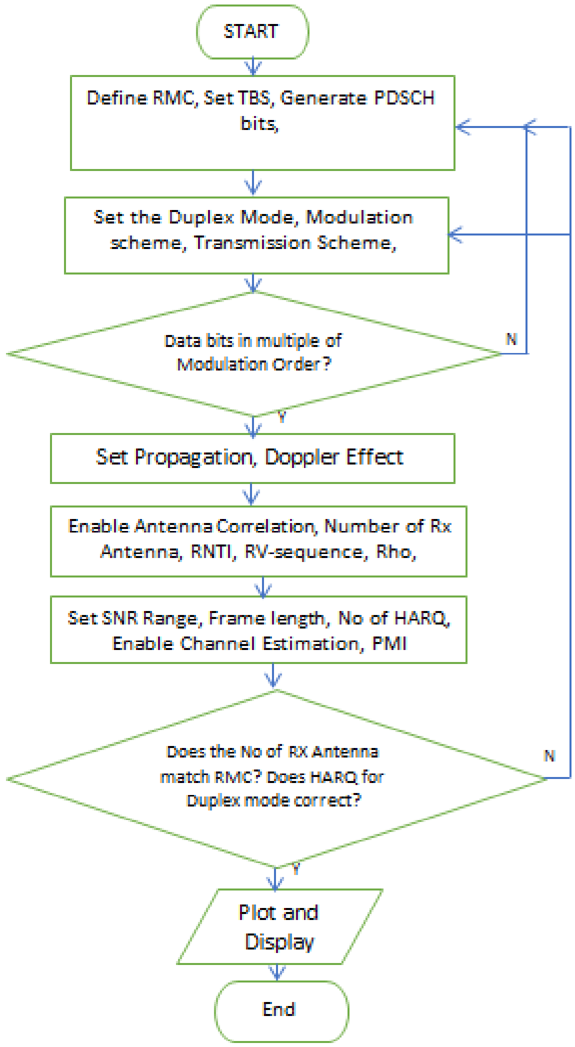

Figure 3.4: Flow Chart Algorithm for Throughput Performance against SNR

The performance analysis and necessary effects were observed for throughput performance against effect of fading or attenuation on the network. Also throughput performance against Speed of UEs on the network (1, 3, 5, or 10km/hr), finally LTE downlink resource grid and spectrogram were developed and generated, as well as BER (Bit-Error-Rate) curve analysis for different network configuration. LTE PDSCH throughput conformance test for Throughput against SNR were carried out and presented. The full results and analysis are seen in chapter four of this work.

3.4.3.2 Bit-Error-Rate Testing and Evaluation

Bit error rate, (BER) is a key functional parameter in telecommunication that is used in evaluating systems that transmit digital signal (data) from one transmitting station to one or more receiving stations. BER can be used to assess the performance of radio link as well as Ethernet and fibre optic links for data transmission. The major causes of transmitted data bits to be in error are the channel imperfection, noise, phase jitter, interference etc but mainly noise and changes in propagation path (multipath). These factors causes degradation on the quality of signal demodulated or received. According to Irfan and Jagan (2013):

$$\boldsymbol{BER} = \frac{\mathbf{NBerr}}{\mathbf{TBtr}} \qquad (3.11)$$

Where: NB_{err} is the number bits Received in errors; TB_{tr} is the total number of bits sent.

BER = number bits Rxed in errors / total number of bits sent

Bit-error-rate testing and evaluation requires an end to end network system, transmitter, receiver, and channel model. First, a long sequence of random bits has to be generated, which serves as input to the transmitter unit. The transmitter modulates (depending on the modulation order, gives the number of bits that are mapped onto one OFDM symbol of data before transmission) these random data bits are being bundled onto a transmission channel (simulated channel) in form of digital signalling and the Bit error-rate performance is evaluated and presented on a two dimensional graph. The X coordinate is the normalized signal-to-noise ratio (SNR) expressed as Eb/N0: the energy-per-bit divided by the one-sided power spectral density of the noise, expressed in decibels (dB). (Irfan and Jagan, 2013).

3.4.3.3 Relationship between Eb/No and SNR

The energy per bit to noise power spectral density ratio (E_b/N_0) is an important parameter in digital communication. It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit". It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account. (Mills, lister, Vos, and Ji, 2010).

$$\text{SNR}_{abs} = E_b/N_{0\,abs} \cdot R \qquad (3.12)$$

Where R represents the modulation and coding rate in use; for instance, if QPSK modulation and coding rate 1/3 is used, R value will be (2 X (1/3)) equal to 2/3. The subscript abs indicates that the units are in an absolute domain. Expressed in dB domains or Logarithmic domain. (Mills et al, 2010).

$$\text{SNR (dB)} = E_b/N_0 \text{ dB} + 10 \log_{10}(R) \qquad (3.13)$$

E_b is the energy in one bit, and N_o is the noise power spectral density which is the noise power in 1 Hz bandwidth of the signal. It should be noted that each type of modulation has its error function value. This is because each type of modulation performs differently in the presence of noise. In particular, higher order modulation schemes (e.g. 64QAM, etc) that are able to perform higher data rates transmission but they are not as robust in the presence of noise as the lower order modulation formats (e.g. BPSK, QPSK, etc.). Lower modulation orders offer lower data rates but are more robust to noise and interference.

The energy per bit, Eb, can be determined by dividing the carrier power by the bit rate, it is a measure of energy in Joules. N_o is a power per Hertz and therefore this has the dimensions of power in joules per second. Energy-per-bit is the total energy of the signal, divided by the number of bits contained in the signal. We can also express energy-per-bit can also be expressed as the average signal power multiplied by the duration of one bit: (Irfan and Jagan, 2013).

$$E_b = \frac{1}{(\text{N}.F\text{bit})} \sum_{n=1}^{N} x^2(n) \qquad (3.14)$$

Where: N is the total number of samples in the signal, and F_{bit} is the bit rate in bits-per-second. Signal, x(n), is in units of volts, the units of E_b are Joules.

The power spectral density of the noise has units of Watts per Hertz. (Irfan and Jagan, 2013).

MATLAB LTE System toolbox has a function that provides used in simulating different BER curves for given SNR values and modulation schemes. **hPDSCHBER.m** is the main call function in command line, input network parameters as desired, then simulate the Physical Downlink Shared Channel (PDSCH) Bit Error Rate (BER) curves under Additive White Gaussian Noise (AWGN). The process follows a random stream of bits; the size of the desired transport block that undergoes Downlink Shared Channel (DL-SCH) coding rate to match the transport block to the available PDSCH bits. Scrambling, modulation, precoding and layer mapping are then applied to form the complex PDSCH symbols. AWGN is added to these symbols after which channel decoding and demodulation are performed to recover the transport blocks upon which the BER curve is plotted, the essential parameters required to be provided for the MATLAB to simulate the effects of SNR and its corresponding BER in graphic format (Mathworks, 2015).

- TransportBlockSize - Size of transport block
- AvailablePDSCHBits - Size of coded transport block after rate matching (codeword size)
- Modulation - Modulation scheme string {'QPSK', '16QAM', '64QAM'}
- SNRRange - Eb/No range in dB
- RVSeq - Redundancy version indicators sequence
- NTurboDecIts - Number of turbo decoder iteration cycles

The ratio of values assigned to the transport block size and available PDSCH bits should fit the range of target turbo code rates defined by LTE (1/3, 1/2, 3/4). Furthermore the value assigned to the available PDSCH bits are governed by the modulation scheme selected, for instance, PDSCH bits for 16QAM must have a value that in multiple of four (4). Higher symbol modulation orders are more sensitive to noise interference and thus will suffer degradation in performance when compared to lower symbol modulation orders schemes at similar SNR values. The redundancy version must come from the range {0,1,2,3}.

The toolbox provides control over the configuration of the number of turbo decoder iteration cycles to be used in the decoder algorithm. This helps to perform an extended cycles of turbo decoder algorithm under AWGN. Turbo codes are in form of forward error correction (FEC) codes that provide high performance in error correction within channel capacity. This feature trades off data rate by increasing robustness of transmitted data against noise in a given channel. To compare the effect of the various parameters, all the curves can be plotted onto the same graph by prompting graph overlay function.

3.4.4 Modification of Network Capacity using Radio Resource Management Technique

Radio resource related decision was considered using the following approach

Radio admission control: This is possible by using handoff. Packet flow and delivery is done through radio bearer in LTE and mostly is by evolved packet system (EPS) also called LTE system bearer from user equipment (UE). This helps in treating packet in terms of QoS. However, the radio bearer EPS is classified into GBR and non-GBR. The present study classified resources are allocated to the bearer as follow;

i. Complete sharing scheme: all users share the same resources and all calls are treated equally. Therefore, there is no Quality of Service (QoS) priority admittance class. This means that the available resources are shared in the ratio of 50:50 and is applicable when there is no network congestion.

ii. Complete partitioning scheme: The radio resources are split up into GBR and non-GBR to enables different classes of service to have a set resource allocation. However, if resources for a particular class are used up, then the packet is not admitted. In this study, the available is shared as 60:40 for GBR and non-GBR bearers respectively whenever there is light network congestion.

iii. Virtual partitioning scheme: This divides traffic flow of packet into GBR and non-GBR bearers. But if there are available resources from non-overloaded group in the LTE network, the overloaded group can use non-overloaded resources. This study will first apply complete portioning scheme if network congestion persist then decongestion will be applied by using this rule. This allows the shielding of the networking from packet loss due to congestion.

The radio admission control is determined as:

$$0 \leq S \leq C_t(1 - \rho) \tag{3.15}$$

If the network utilisation is S (Hillier and Lieberman, 2015):

$$S = \frac{\lambda}{s\mu}(S < 1)\ for\ stability \text{ Or else congestion exist} \tag{3.16}$$

Where s = number of node (server)

λ = arrival rate (number of packet arriving per unit time) in identified class (GBR or non-GBR)

μ = service rate per unit node (server) or (number of packet forwarded per unit time) in identified class

$S =$ Network utilisation bandwidth by group of service (GBR or non-GBR bearer)

$C_t =$ Total system capacity bandwidth

$\rho =$ Utilisation factor of resources bandwidth based on sharing of resources

- **Packet scheduling**: This is the most critical task of Evolved Universal Terrestrial Radio Access Network (E-UTRAN) implemented by eNodeB. It is a decisive for subscriber's Quality of Service (QoS) and Quality of Experience (QoE). eNodeB Packet scheduler provides UE with appropriate Resource Block (RB) and transport format to use upon request on Physical Uplink Shared Channel (PUSCH). LTE schedulers employ link adaption to its decision algorithm, which gives LTE edge on higher data rate through effective utilization of radio resource. Channel Quality Indicator (CQI) is a major metric used by LTE Scheduler, it tells the eNodeB scheduler the data rate an UE expects to be able to receive at a given point in time. The UE periodically sends a CQI to the serving eNodeB on the uplink control channel (PUCCH). CQI is equivalent carrier to Noise spectral density (Ec/No) metric as used in 3G networks. CQI gives true and better assessment of network channel condition both in idle and connected mode. Every CQI reported by the UE correspond to predefined Transport Block Size (TBS) that can be granted on a particular modulation type and coding rates.

Date Rate (bps) = (1-Bler) X TBS (bits) / TTI (secs). (3.17)

Where; Bler = Block Error rate, TBS = Transport Block Size (bits) and TTI = Transmission time Interval.

All types of LTE scheduler are discussed in chapter two of this dissertation. Proportional Fair (PF) scheduler algorithm is default algorithm in this work. The Proportional Fair scheduler provides balance between fairness and the overall system throughput. PF algorithm function as follows: the eNodeB received the feedback of the instantaneous Channel Quality Indicator (CQI) from UE, in terms of a requested data rate $R_{k,n}(t)$, for each user k. Then, it keeps track of the moving average throughput $T_{k,n}(t)$ of each UE k on every Physical Resource Block (PRB) n in a past window of length tc. In time slot t, the Proportional Fair scheduler gives a priority to the UE K^* in the t^{th} time slot and PRB n that satisfy the maximum relative channel quality condition: (Erwu and Kin, 2016).

$$K^* = \arg\text{Max}(\text{n-1}, 2, 3 .., N) \frac{(R_{k,n})^{\alpha}}{(T_{k,n}(t))^{\beta}} \qquad \alpha = \beta = 1 \tag{3.18}$$

Given that $R_{k,n}(t)$ is instantaneous data rate of each K^{th} user in t^{th} Transmission Time interval (TTI) and n^{th} Physical Resource Block (PRB).

The variable α and β value can represent three achievable conditions: If α=1, β=1, the scheduler sets a sense of balance between fairness and throughput in the network system. In this condition, the (3.18) defines the characteristics of Proportional Fair scheduler. Considering a condition where or if α=1, β=0, then, the scheduler algorithm allocates a user with the best channel conditions not minding the user throughputs and performances. This condition could be awesome, if all the users possess the similar or average channel quality condition. The methodology of this condition best describes scheduler of the Maximum rate algorithm. If α=0, β=1, the scheduler reduces to a round-robin scheduling serving all users equally with no regard to users' channel quality or data rate. $R_{k,n}(t)$ can further be described mathematically as the instant service rate on the n^{th} subcarrier at t^{th} TTI and is given as follows (Erwu and Kin, 2016);

$$R_{k,n}(t), = \frac{B}{N}\log_2(1 + SNR) \tag{3.19}$$

Where $R_{k,n}(t)$ is the K^{th} user instant transmission data rate at t^{th} TTI, or time slot (1ms),

B is the total bandwidth provided; N is the number of sub-carriers,

SNR is the signal to noise ratio received on the n^{th} Resource Block (RB) signal of K^{th} user at t^{th} TTI. SNR can be expressed mathematically as follows (Huang et al, 2009);

$$SNR_{k,n}(t) = \frac{S_{k,n} \times H_{k,n}}{N_o \times B/N} \tag{3.20}$$

Where $S_{k,n}$ is allocated transmission power on n^{th} sub-carrier at t^{th} TTI

$H_{k,n}$ is the allocated channel gain on the n^{th} sub-carrier at t^{th} TTI

$\boldsymbol{N}_o$ is the spectral power density of Additive White Gaussian Noise (AWGN)

B is the total bandwidth while N is the number of the sub-carriers ***for K=k*(t)***

From equation 3.20, the moving average throughput $T_{k,n}(t)$ is computed as follows (Huang et al, 2009);

$$\mathrm{T}k,n(t+1) = \begin{cases} \left(1+\frac{1}{tc}\right)\mathrm{T}k,n(t), + \frac{1}{tc}\mathrm{R}k,n(t)\,\boldsymbol{for\ K = k*(t)} \\ \left(1+\frac{1}{tc}\right)\mathrm{T}k,n(t), \qquad \boldsymbol{for\ K \neq k*(t)} \end{cases} \tag{3.21}$$

t*c* is the window size and its parameters controls the network latency, with equation 3.21, the total network fairness to all users and throughput of the network can be adjusted. When parameters t*c* is compromised or adjusted, the network scheduler tend to behave like Maximum Rate algorithm or Round Robin algorithm.

If tc value tends to infinity (tc =∞), the value becomes large and enormous. Here the implemented Proportional Fair algorithm tends to allocate resource exclusively to instantaneous SNR value which is known characteristic of Maximum Rate algorithm which achieves maximum throughput. Alternatively, if tc value tends to unity (tc = 1), in this situation, the implemented PF algorithm exhibits a habit of Round Robin algorithm which achieves fairness to all Users as resource are shared equally and on basis of first come first serve irrespective of channel conditions.

In the peculiarities of SPECTRANET LTD, Abuja where an average of 20% of latched in UEs (Users) consumes about 80% of the radio resource, leaving majority of users which is considered as light user with little resource to share. The developed algorithm was based on differential QoS that will be implemented to improve all users Quality of Experience at every point in time whether an UE belongs to the category classified as heavy, medium and low user of data. The type of devices used, the type of running applications, and number of concurrent application determines categories of users mentioned above, hence, the amount of radio resource requested and granted to the UE. Other considerable factors such as channel condition, proximity to eNodeB and mobility effects which are in turns determinant of UEs data rate (throughput). For the purpose of this work, high data users and low data users were carefully considered. The developed algorithm monitors the behaviour of each UE in a given eNodeB and its data rate. If average data rate of UE goes above 1.8mpbs over a period (15 seconds) is considered high user. However, if UE average data rate runs at 0.8Mbps or below is considered low user as deducted from the empirical data obtained.

All factors affecting performances are handled by the default scheduler based on Proportional Fair in the Base Band Unit (BBU) of each eNodeB. UEs are observed over a period to be running above a given threshold of data rate, are considered high user, and while below defined data rate are classified as low user. If the average number of the high users reaches 20% of the total current number devices latched into the eNodeB, the scheduler sub-divides the radio resource at the ratio of 3:2 (60:40 percent), the earlier apportioned to greater number of devices (low users) while the latter is apportioned to high users, thereby striking balance across board of users. This algorithm improves users Quality of Experience in the network and dynamically readjusts to whole resource poll when the classified number of high users reduces.

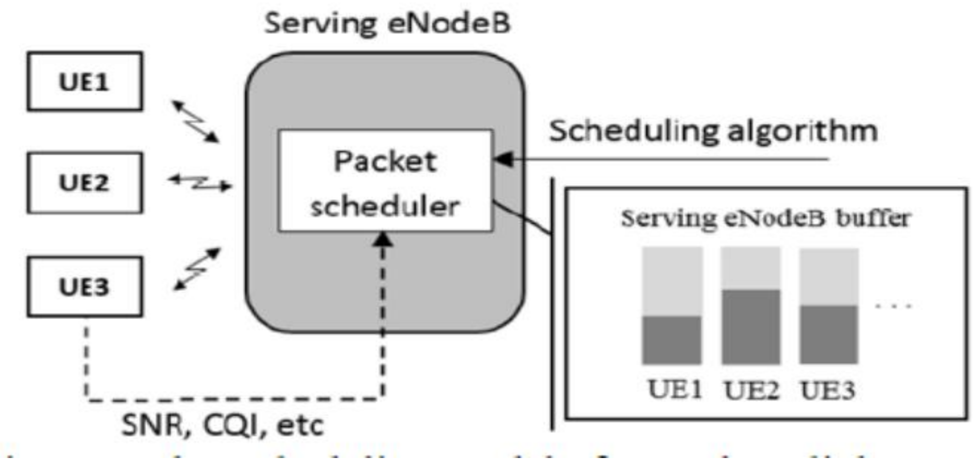

Figure 3.5: Modified Packet Scheduling Process (Larasati *et al.*, 2016)

Consider a single cell system as can be seen in Figure 3.5, where N mobile user represented as user UE_1, UE_2, UE_3 …UE_N are randomly located within the cell served by an eNodeB (scheduler). Each and every UE requests to transmit data to and from the eNodeB to different destination or servers, the rates of transmission are dynamically and randomly varying. Time is divided into small scheduling intervals for each user to transmit known as the time slots. In the default PF process, the next time slot is given to the user considered ready, the scheduler has to be updated by the UE, its CQI and SNR values through the use of pilot signal broadcasted periodically with a very short delay. Always the possible next user to be scheduled is based on weighing scale to compensate between users current rate and fairness, putting up factors to understand the exact need and adequate resource suitable to the UE demand. It compares the ratio of the achievable rate for each user to its average throughput traced by an exponential performance metrics (running average) over a defined period or intervals. The user with the greater preference metric is scheduled next for transmission slot.

$$Yn(t) = \log B \sum_{ki,i(1+k)\ldots}^{Kn} (Tj(t)k \qquad (3.22)$$

B signal bandwidth in (Hz)

Ki, i(1+K) … = Assigned PRB to user i at TTI t

Kn = Maximum assignable PRB

Tj(t) K is average running rate of an UE and described further in equation (3.23)

$$Tj(t)k = \beta * Tj(t-1) + (1 - \beta) X (Rj(k, t)) \tag{3.23}$$

Tj(t)k is defined, sampled four times in a minute, R = bite rate, j = UE, k = given Resource, t = time, β is percentage fraction (0 < β < 1). Therefore, Split Decision is derived as follows:

$$\text{Split decision } = \begin{cases} \text{No } ofusersj(high) \geq 20\% \ (T), + \ \boldsymbol{givenK = 3}: (\boldsymbol{2t}) \\ (Else) \text{ No } ofusers < 20\% \ (T), \quad \boldsymbol{givenK = 1}(\boldsymbol{t}) \end{cases} \tag{3.24}$$

K is the total resource. It is important to notice the total number of active users (T) at each time (t), the average number of active users' (j_{avg}) over a period, the number of high users (j_H) over period. (j_H) < (j_{avg}) < (T)

3.4.4.1 Algorithm Based on Differential Quality of Service (QoS) Development

The algorithm is developed based on differential quality of service (QoS) by incorporating radio resource management (RRM) technique as a sub function to Proportional Fair (PF) scheduling algorithm employed by SPECTRANET LTD, Abuja (SLA). This is targeted to improve cell throughput of LTE network. Leveraging on the concept of the algorithm was shown in Figure 3.6.

This work first examined the performance of the network before implementing RRM technique. The performance improvement is stated based on throughput performance (P), spectral efficiency (ε_s) and the average signal-to-noise ratio (SNR) of the LTE network. The outcome of the developed algorithm will be recommended to SLA in order to improve LTE network performance and other LTE network operators.

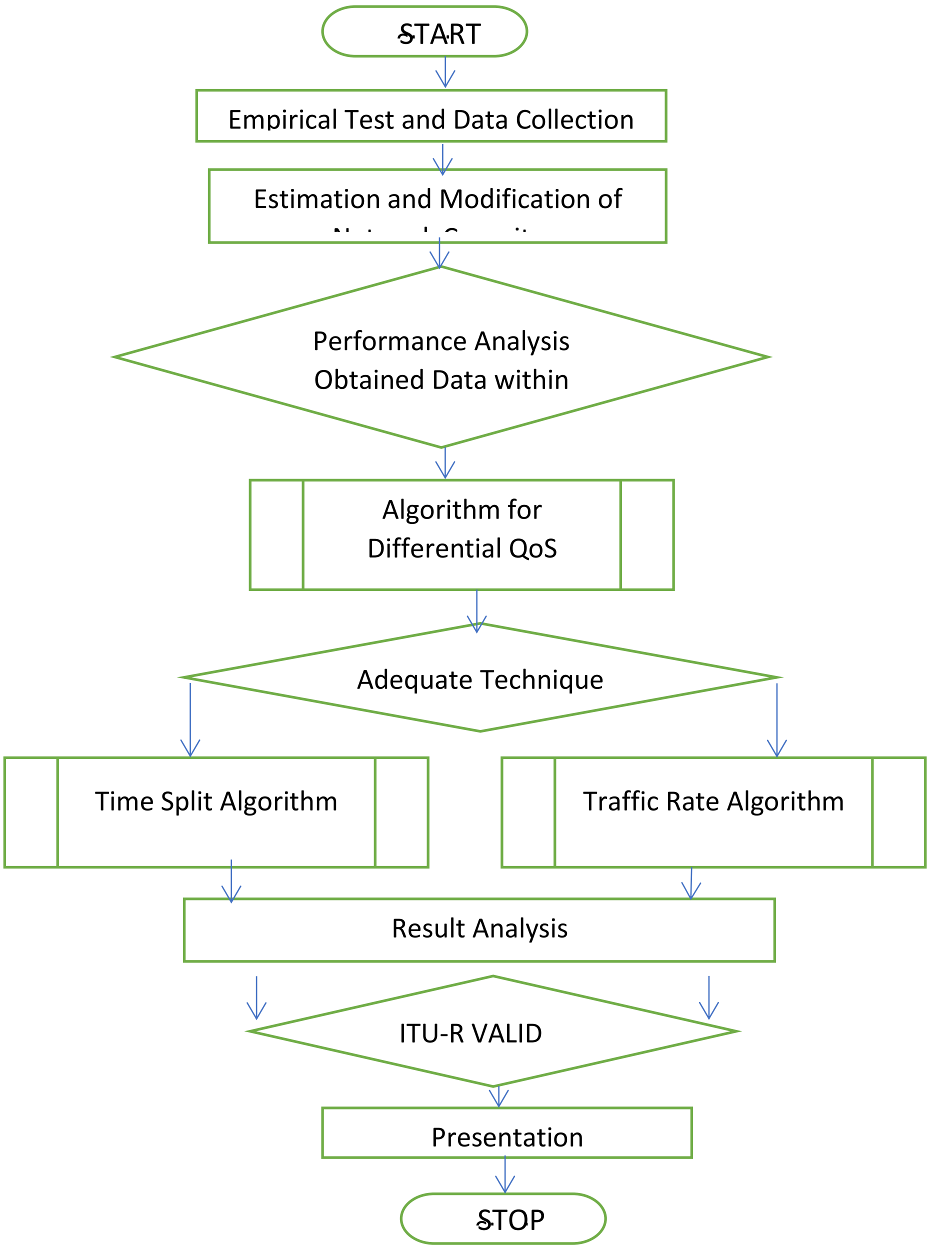

Figure 3.6: Flow-chart Algorithm to Improve cell Throughput of LTE Network

3.4.4.2 Differential Quality of Service (Diff-Serv) Enhancement Algorithm

The enhancement technique is developed based on Time Stamped Algorithm (TSA) (see Figure 3.7) and Traffic volume Algorithm (TVA) (see figure 3.8). The enhancement algorithm is first targeted at generating random users who at various times logs into and out of a base station (eNodeB)

One cell Site (eNodeB): Theoretically, the maximum allowable number of UEs at a time is 299 and minimum of (0) UE at off load.

Each user (UE=user equipment) can be identified with its IP Address, International mobile equipment identity (IMEI), International Mobile Subscriber Identity (IMSI), Media Access address (MAC) Address etc.

These random users generated, shares a given or provisioned bandwidth or Network resource (PRB) at every given time. The users comes in (gets admitted) and goes off the network resource at will spontaneously. The case study network (SLA) operates the following resource and Parameters:

a. Bandwidth= 20MHz, TDD {Time Division Duplex},

b. Frequency = 2.3GHz.

c. Physical resource block {PRB} = 100), DL average utilization = 35%, UL =40%

d. Average throughput (Data rate) peak <= 0.8mbps, off-peak =1.8bps

e. Average number of users/cell = 50

f. Average number of eNodeBs = 145

g. Average number of cells = 403

i. Total user capacity (Active Subscribers) = 15,000

Note that in Practice, different Users at every point in time gets different Quality of experience depending on the following factors:

a. UE’s distance from the cell and more importantly

b. Number of users already on the network (Contention Ratio) and

c. Network Capacity (Bandwidth, center frequency, PRB, MIMO)

d. Application Speed, type and the volume of activities by each user on the network,

e. UE classification,

f. Channel Condition (CQI value, Modulation and coding rate)

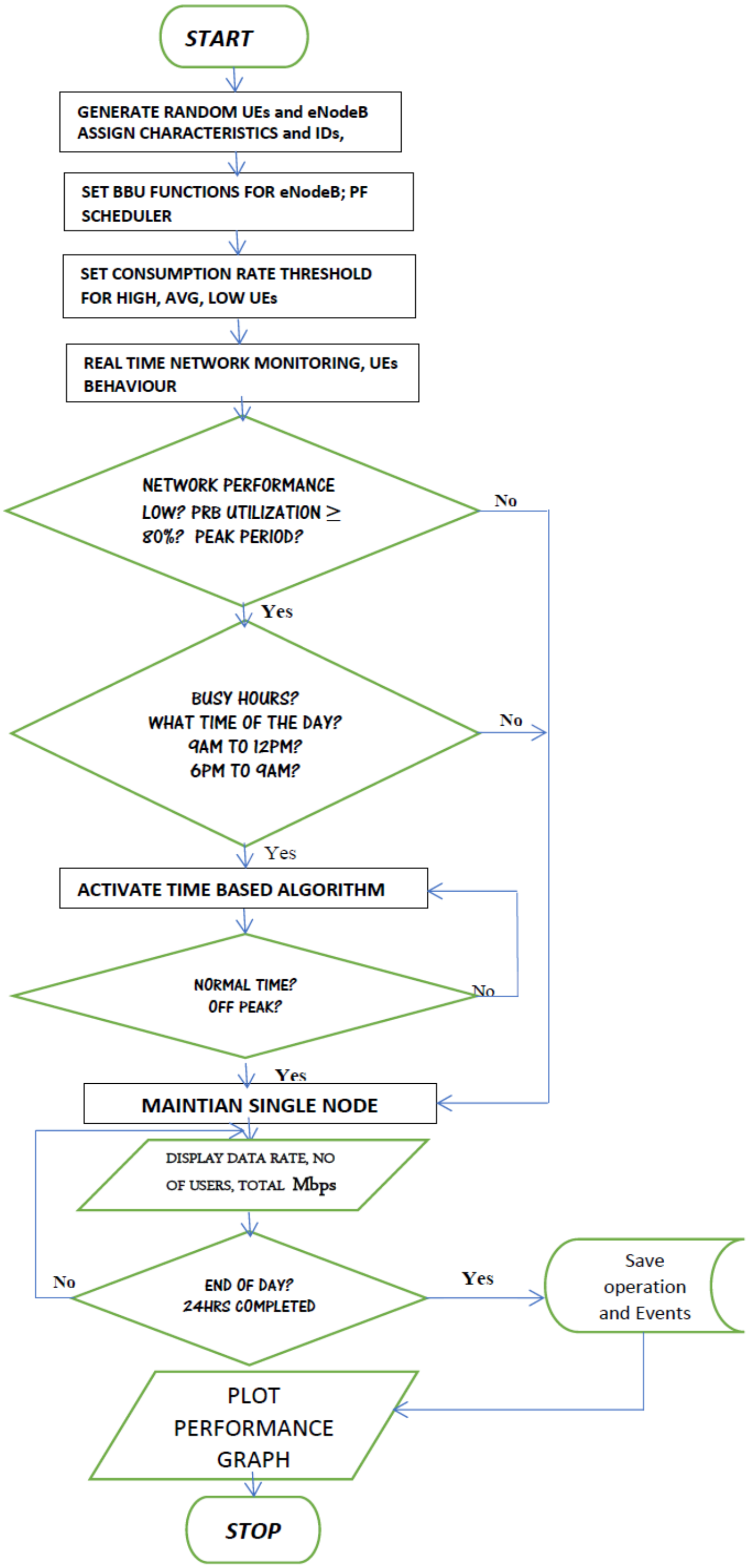

Figure 3.7: Enhancement Algorithm Flow Chart based on Time Stamps (TSA)

There are different kinds of algorithm that can be employed in for the purposes of differentiating Quality of Service in order to improve network performances. Algorithm to identify and separate based on **Data Traffic type** and protocol ports (E.g Web app, video, FTP, UDP, p2p etc). The system studies and learns each data traffic port, separates them to different partitions to cushion the effect of heavy traffic users. This method is considered inefficient because most study into this research showed that most subscriber runs almost same application but at different scale (rate) and time.

This research developed an algorithm capable of Identifying and separating radio resources based on TIME STAMPS. Refer to (Figure 3.7) flow chart algorithm during peak hours. It was established that companies, embassies, private organization, ecommerce owners, learning institute, financial institutes, NGOs, hospitals etc. runs different heavy internet application during peak hours (9AM -12PM). The algorithm studies and learns from statistical records to identify high data rate users through UE's MAC address. For instance during busy hour between (9AM to 12PM) and between (6PM to 9PM), the developed Time stamp algorithm cushions the effect of heavy users on the network by splitting the radio resource at predefined time (Peak Hours) and separates UEs identified as heavy user a portion of the shared resource. However, after the defined time interval, the radio resource becomes common amongst all UEs. Figure 3.8 presents developed flow chart algorithm for differential Quality of Service (DiffServ) based on traffic volume of UEs.

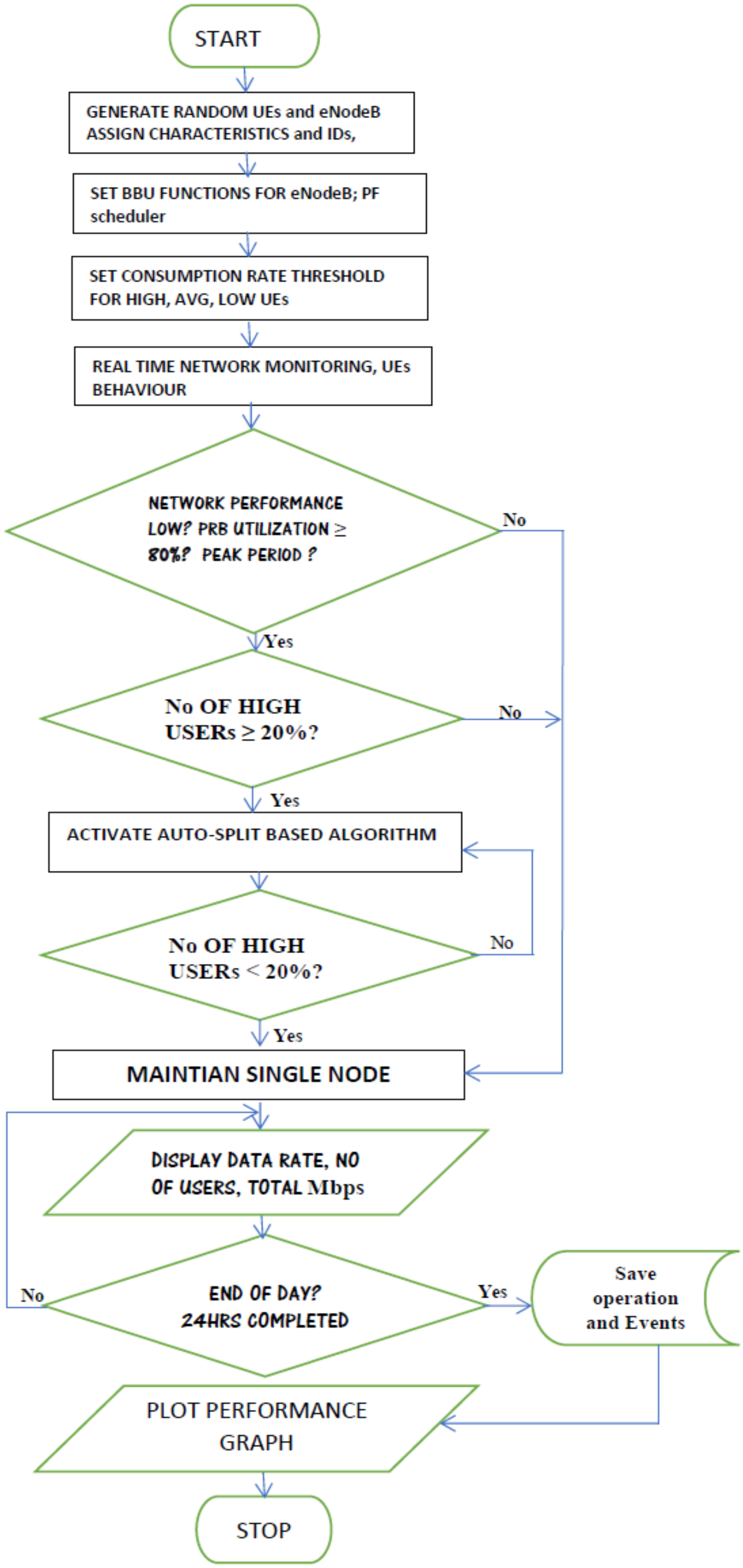

Figure 3.8: Enhancement Algorithm flow chart based on Consumption Rate (TVA)

The enhancement algorithm is enacted if user's Quality of Experience (QoE) drops as result of volume of traffic by users (Congestion) which inversely affects network throughput. The specific task was, at what level is considered the throughput threshold for each UE? Note that 20% or less of subscribers consumes 80% or more of the network resource most of the times. (SPECTRANET, LTD, Abuja and Lagos, 2018) when all other factors that cause poor network experience are in order such faulty equipment, Weak coverage, poor Signal Quality etc.

NEED To Optimize? YES. How to optimize user's Quality of Experience? Apply Differential QoS (DiffServ).

Major tasks lies on how to IDENTIFY and CLASSIFY the users on different platform of same bandwidth? The algorithm was developed to correctly identify and separate from main pool of the bandwidth to newly sub partitioned bandwidth at the ratio of (3: 2) for the best interest of many subscribers. They developed algorithm here is to Identify and separate based on consumption rate of user over predefined time. It enables the system to monitor users at all time, if many users are consuming at high rate and observed to be causing network performance drop, the algorithm prompts for radio resource splitting (as number of UEs in this data rate class gets to 20% of total number users online). Partitioning of the bandwidth resource is at (60-40%) ratio. However, the identified high users (UEs) are transferred to the minor section. Off course, the partition collapses to single poll of bandwidth when the number of heavy users goes below 20% of all users online. Basically, the system continues to add and subtract to from the new partition, provided that the new partition did not exceed the allowable number of users per cell. Algorithm implementation and validation compares with the existing techniques and presents the scheme with best performance .End Programme

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This work incorporates Differential Quality of Service (Diff-Serv) implementation and system integration, analysis of empirical data captured on the network of SPECTRANET, validation of the network results, and discussion of the results. The Differential Quality of Service implementation also involves two enhancement algorithms, thus; Time Stamp Algorithm, (TSA) and Traffic Volume Algorithm (TVA). In this work, different scenarios of 4G LTE network were experimented for better performance using MATLAB tools. The whole processes in this section serves a reference steps to understanding 4G cellular network designs and its performance evaluation. The design and implementation of the cell throughput enhancement algorithm through differential quality of service considering subscribers consumption rate over a time (TVA) and time stamps (TSA) shows Diff-QOS is the best implementable algorithm to improve users' quality of service.

4.1 Evaluation on Empirical Data Obtained

There are about 403 deployed active cells in the network of SPECTRANET LTD, Abuja. Empirical data were obtained through the use of Huawei Imanager 20000 for case daily Key Performance Indicator (KPI) (Refer to Chapter 3.3), Drive test, and MapInfo software, Google Earth Professional, and OpenSignal software were means and tools for data collection and analysis. All actively deployed cells were monitored and studied on daily basis; the daily average performances of each cell for the period under study were computed, and the average for given performance parameter were taken and tabulated against each cell for the given period understudy. (Appendix E). Furthermore, analyses of the avaerga tabulated performances were carried out using Microsoft Excel and presented in graphs (Refer to Figure 4.1 – 4.8). The following events were evaluated from Appendix E average data set:

i. Average Throughput performance per active cell,

ii. Average Throughput Performance against Average number of UEs,

iv. Evaluation of average throughput performance against average number of times DL PRB utilization went above 80%,

v. The Performance effect and relationship between average number of users and PRB utilization.

Consequently, Figures 4.1- 4.8 presents the computed average throughput performance graph for each cell (403 cells) over the five months of study. Due to the large number of cells, the presentations were made in batches of fifty cells per graph for clear pictorial purposes.

Analysis of the average cell throughput performance over the period of study was carried out using the collated (Averaged) data set from daily Downlink throughput (Mbps) of each cell (**Appendix E**).

4.1.1 Average Throughput Performance per Active Cells

The average throughput (Mbps) of each cell performance were computed and analysed

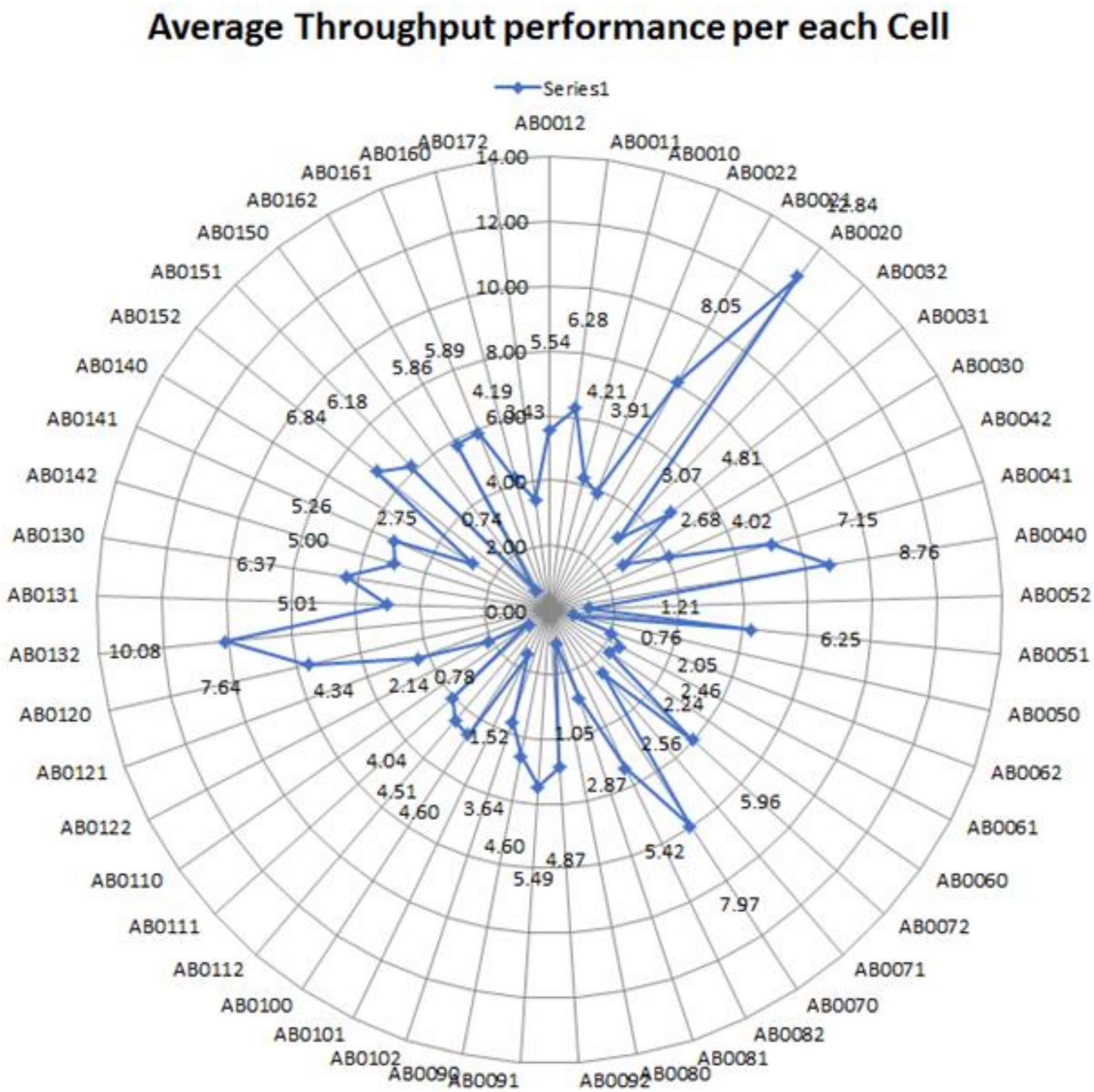

Figure 4.1: Average Throughput (Mbps) Performance per Cell for First-50 Sectors (AB0012 – AB0171)

Figure 4.1 shows an average throughput of actively deployed cell around Abuja over the period of study. The cells were serialized in order of deployment, just like the PCI numbers were given in order of commissioning of sectors. The first 50 sectors of the network showed good number of cells with great throughput over the period; however there are cells that call for attention for their poor throughput performance. Cells with average throughput of less than or equal to 0.8 Mbps are considered to be underperforming while cells with throughput greater than 0.8 Mbps are in the cadre of good performing cells

The underperforming sectors are (Mbps): AB0121 (0.78Mbps), AB0050 (0.76 Mbps), AB0150 (0.74 Mbps)

Sector with good and great performance (Mbps): AB0020 (12.84), AB0132 (10.08), AB0040 (8.70 Mbps), AB0070 (7.97 Mbps), AB0021 (8.05 Mbps)

Percentage of good performing to underperforming: > 80% Great

Causes and Actions for improvement: The possible causes of underperforming cell were as result high number of users and contention ratio, fewer number Monitoring cells to ensure seamless handover to required times, and possible lack of dominant cell in the service areas.

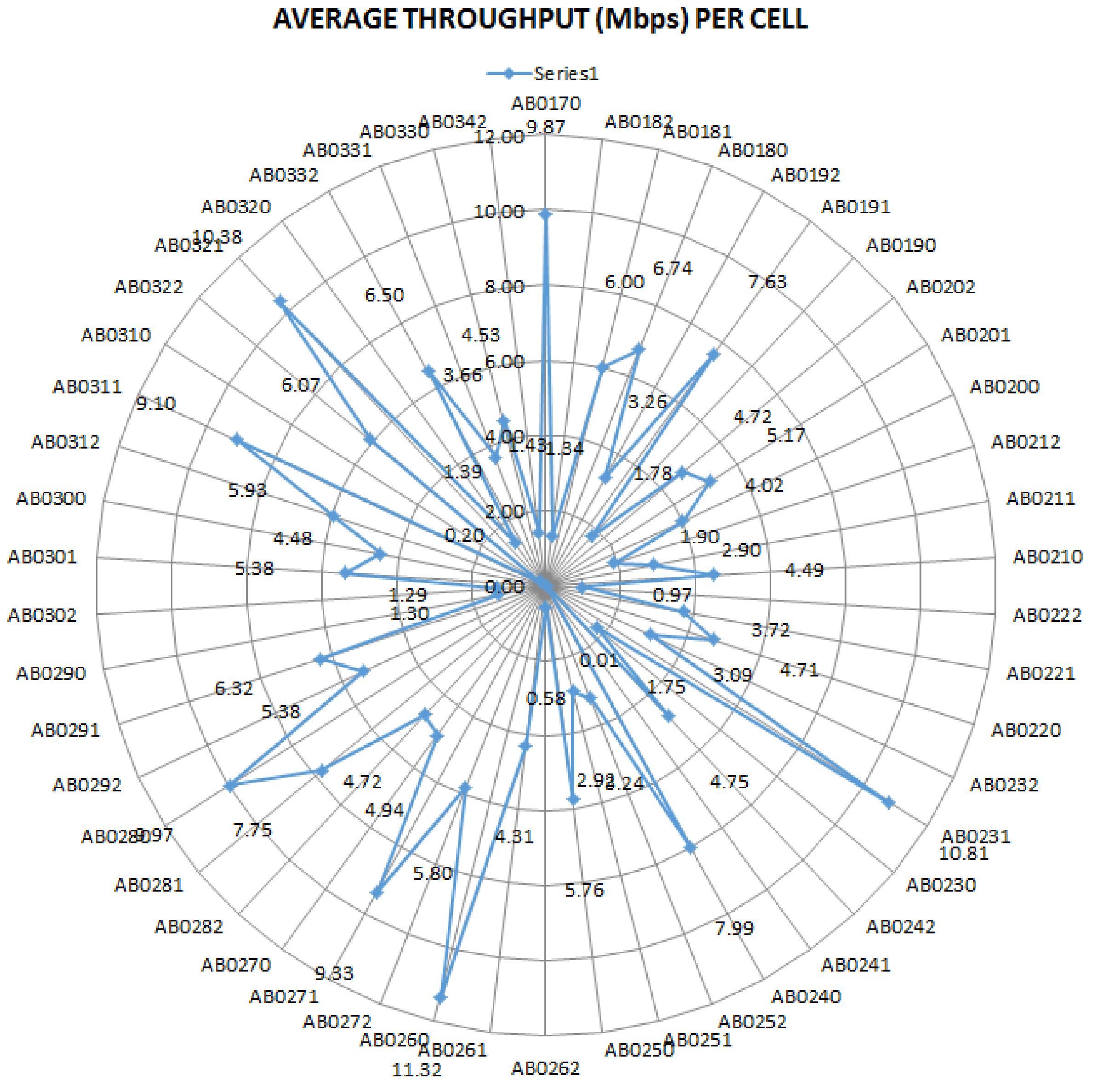

Figure 4.2: Average Throughput (Mbps) Performance per Cell for second-50 Sectors (AB0170 – AB0342)

The underperforming sectors include AB0241 (0.01 Mbps), AB0262 (0.58 Mbps), AB0310 (0.20 Mbps)

Sector with good and great performance (Mbps): AB0311 (9.10 Mbps), AB0260 (11.32 Mbps), AB0231 (10.81 Mbps), AB0321 (10.38 Mbps), AB0170 (9.87 Mbps)

Percentage of good performing to underperforming: > 80% Great

Causes and Actions for improvement: Faulty device, Number of users and contention ratio, Monitoring cells, and handover success rate, lack of dominant cell

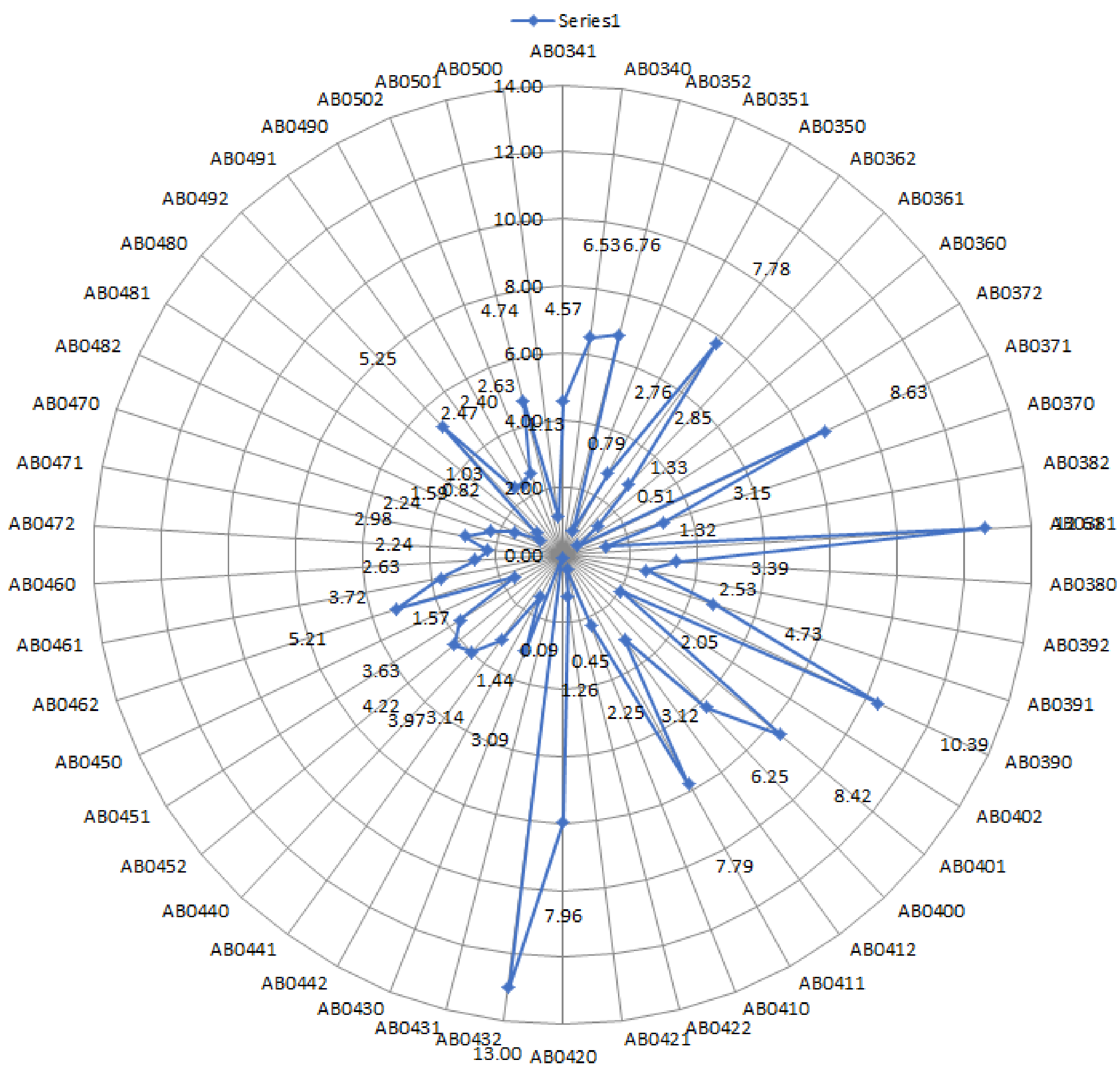

Figure 4.3: Average Throughput (Mbps) Performance per Cell for Third-50 Sectors (AB0341 – AB0500)

The underperforming sectors include AB0372 (0.51 Mbps), AB0351 (0.79 Mbps), AB0422 (0.45 Mbps), AB0431 (0.09 Mbps), AB0481 (0.082 Mbps)

Sector with good and great performance (Mbps): AB0390 (10.39 Mbps), AB0432 (13.00 Mbps), AB0401 (8.42 Mbps), AB0381 (12.61 Mbps), AB0420 (7.96 Mbps)

Percentage of good performing to underperforming: > 80% Great

Causes and Actions for improvement: Number of users and contention ratio, Monitoring cells, faulty network element, lack of dominant cell

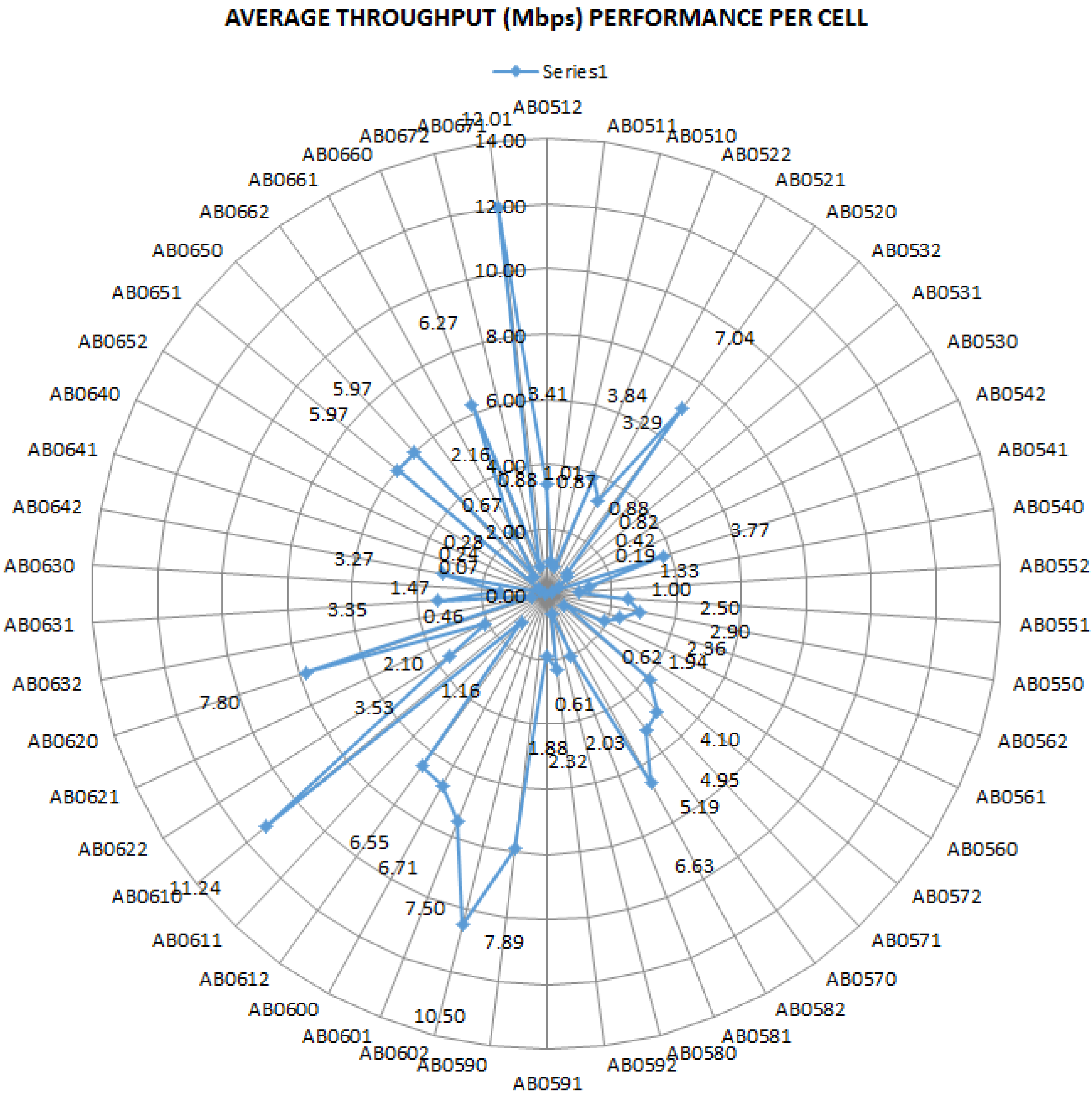

Figure 4.4: Average Throughput (Mbps) Performance per Cell for Fourth-50 Sectors (AB0512 – AB0671)

The underperforming sectors Include: AB0641 (0.07 Mbps), AB0640 (0.24 Mbps), AB0652 (0.67 Mbps), AB0530 (0.42 Mbps), AB0542 (0.19 Mbps)

Sector with good and great performance (Mbps): AB0610 (11.24 Mbps), AB0602 (10.50 Mbps), AB0520 (7.04 Mbps), AB0620 (7.80 Mbps), AB0590 (7.89 Mbps), AB0601 (7.50 Mbps)

Percentage of good performing to underperforming: > 70% (Great)

Causes and Actions for improvement: Number of users and contention ratio, Monitoring cells, high user, lack of dominant cell etc.

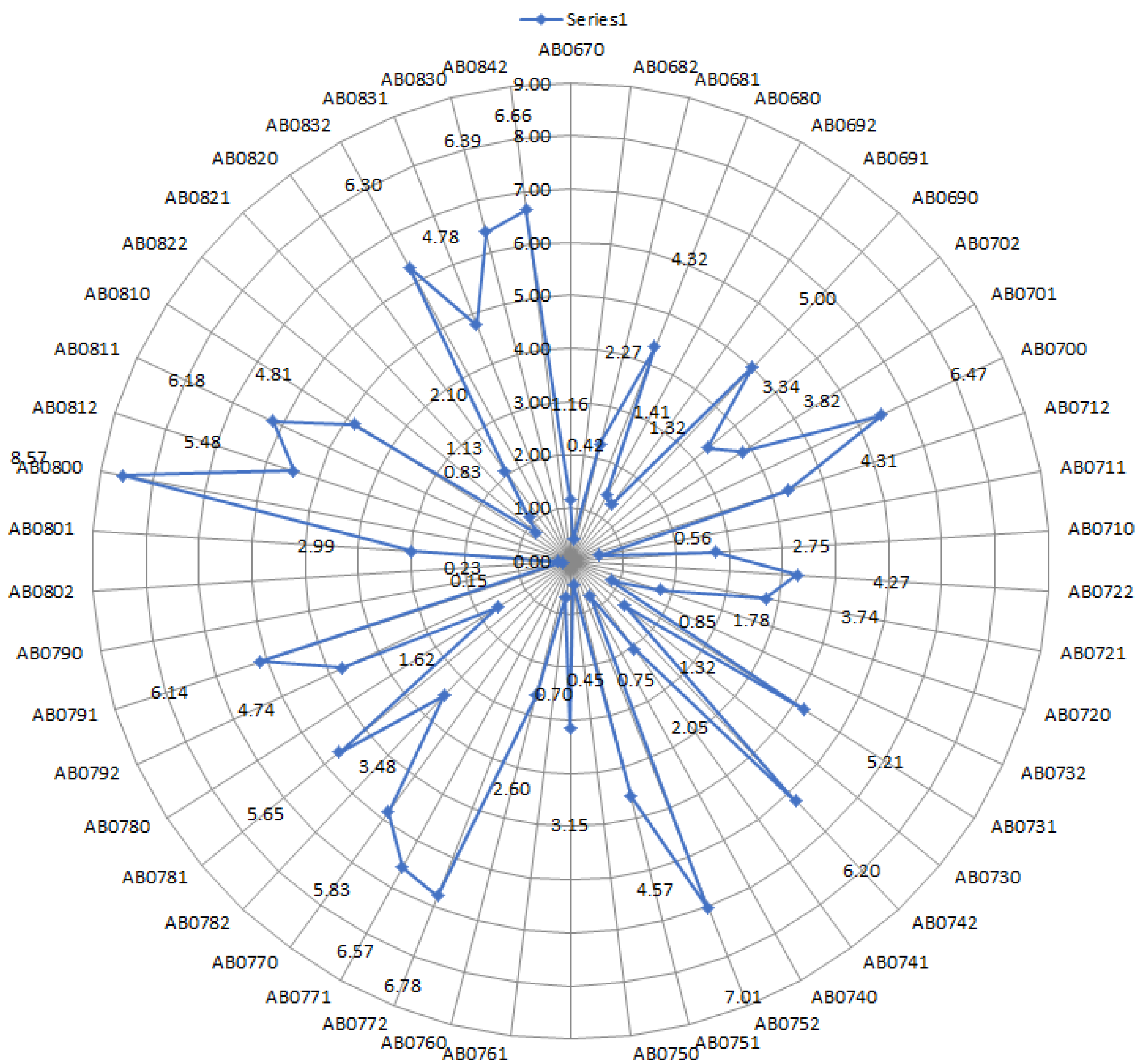

Figure 4.5: Average Throughput (Mbps) Performance per Cell for Fifth-50 Sectors (AB0670 – AB0842)

The underperforming sectors are (Mbps): AB0790 (0.15), AB0802 (0.23), AB0750 (0.45), AB0711 (0.56), AB682 (0.42)

Sector with good and great performance (Mbps): AB0800 (8.57), AB0752 (7.01), AB0772 (6.78), AB0700 (6.47), AB0771 (6.57)

Percentage of good performing to underperforming: > 65% Great

Causes and Actions for improvement: Number of users and contention ratio, Monitoring cells, high users, lack of dominant cell.

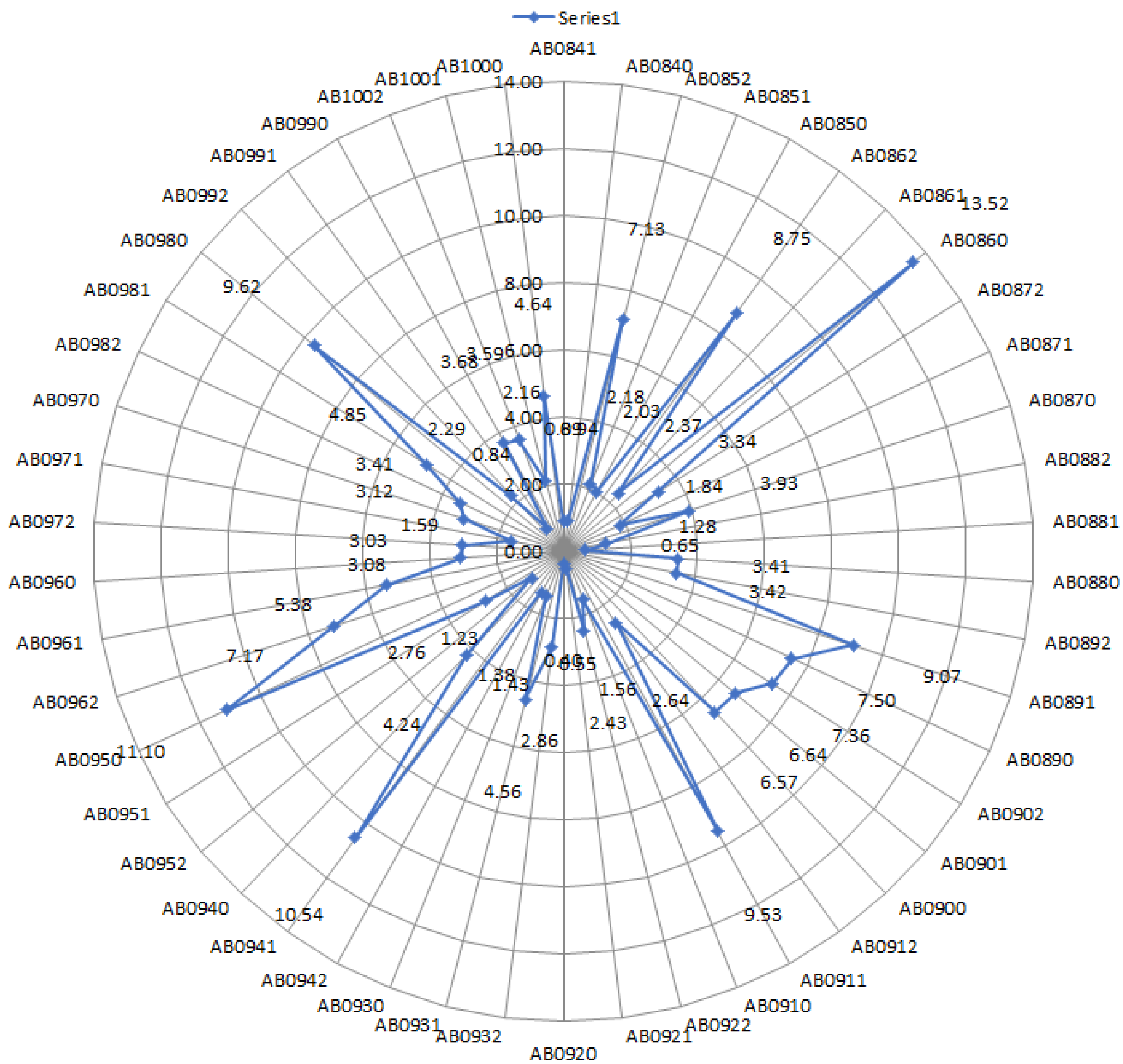

Figure 4.6: Average Throughput (Mbps) Performance per Cell for sixth 50 Sectors (AB0841 – AB1000)

The underperforming sectors are (Mbps): AB0881 (0.65), AB0991 (0.84), AB0921 (0.55), AB0841 (0.8)

Sector with good and great performance (Mbps): AB0950 (11.10), AB0941 (10.54), AB0980 (9.62), AB0911 (9.53), AB0891 (9.07)

Percentage of good performing to underperforming: > 65% Great

Causes and Actions for improvement: Number of users and contention ratio, Monitoring cells, high user, lack of dominant cell

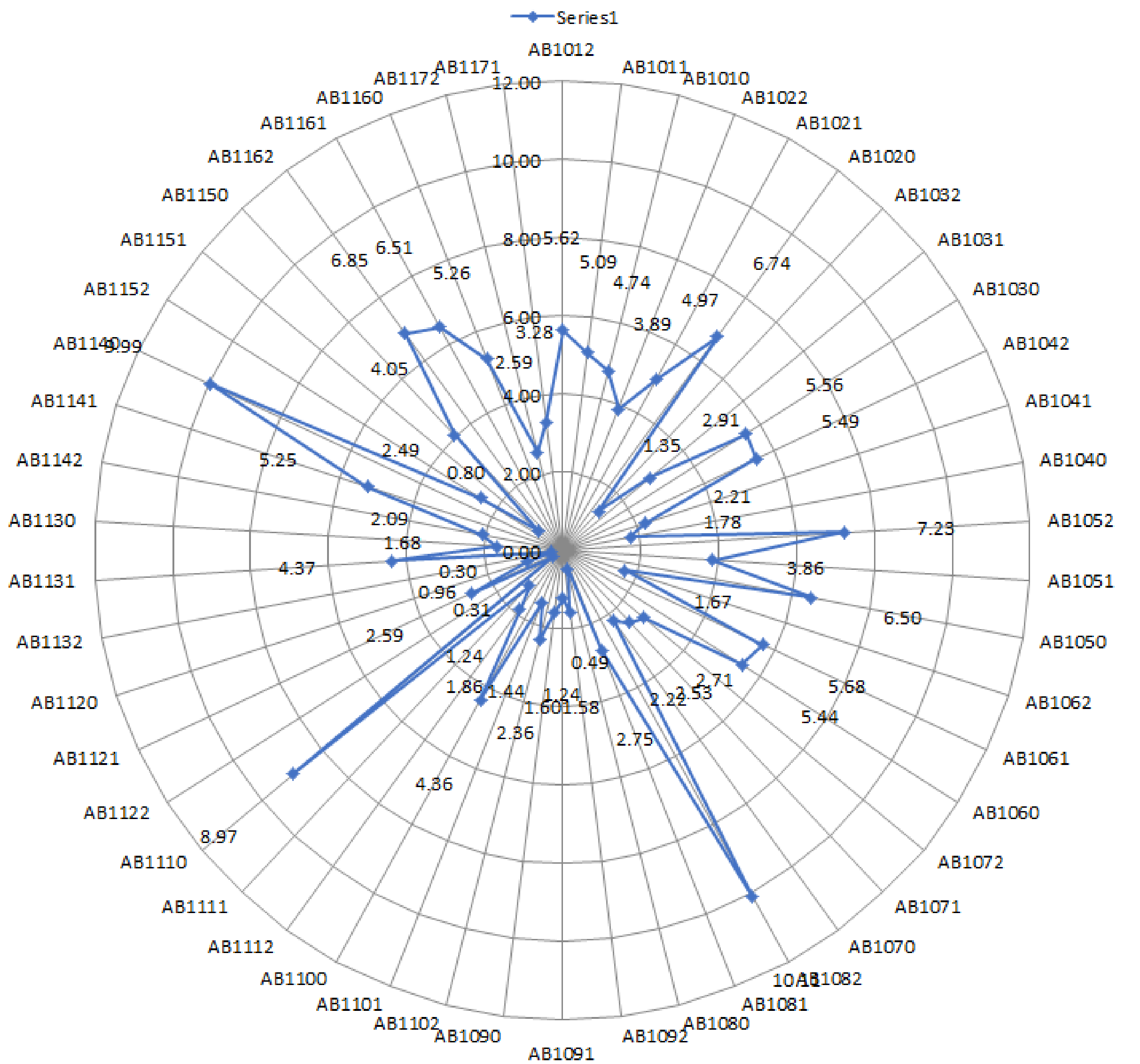

Figure 4.7: Average Throughput (Mbps) Performance per Cell for seventh-50 Sectors (AB1012 – AB1171)

The underperforming sectors are (Mbps): AB1132 (0.30), AB1122 (0.31), AB1080 (0.49), AB1151 (0.8)

Sector with good and great performance (Mbps): AB1140 (9.99), AB1082 (10.11), AB1110 (8.97), AB1052 (7.25), AB1162 (6.85)

Percentage of good performing to underperforming: > 65% Great

Causes and Actions for improvement: Number of users and contention ratio, Monitoring cells, high user, lack of dominant cell

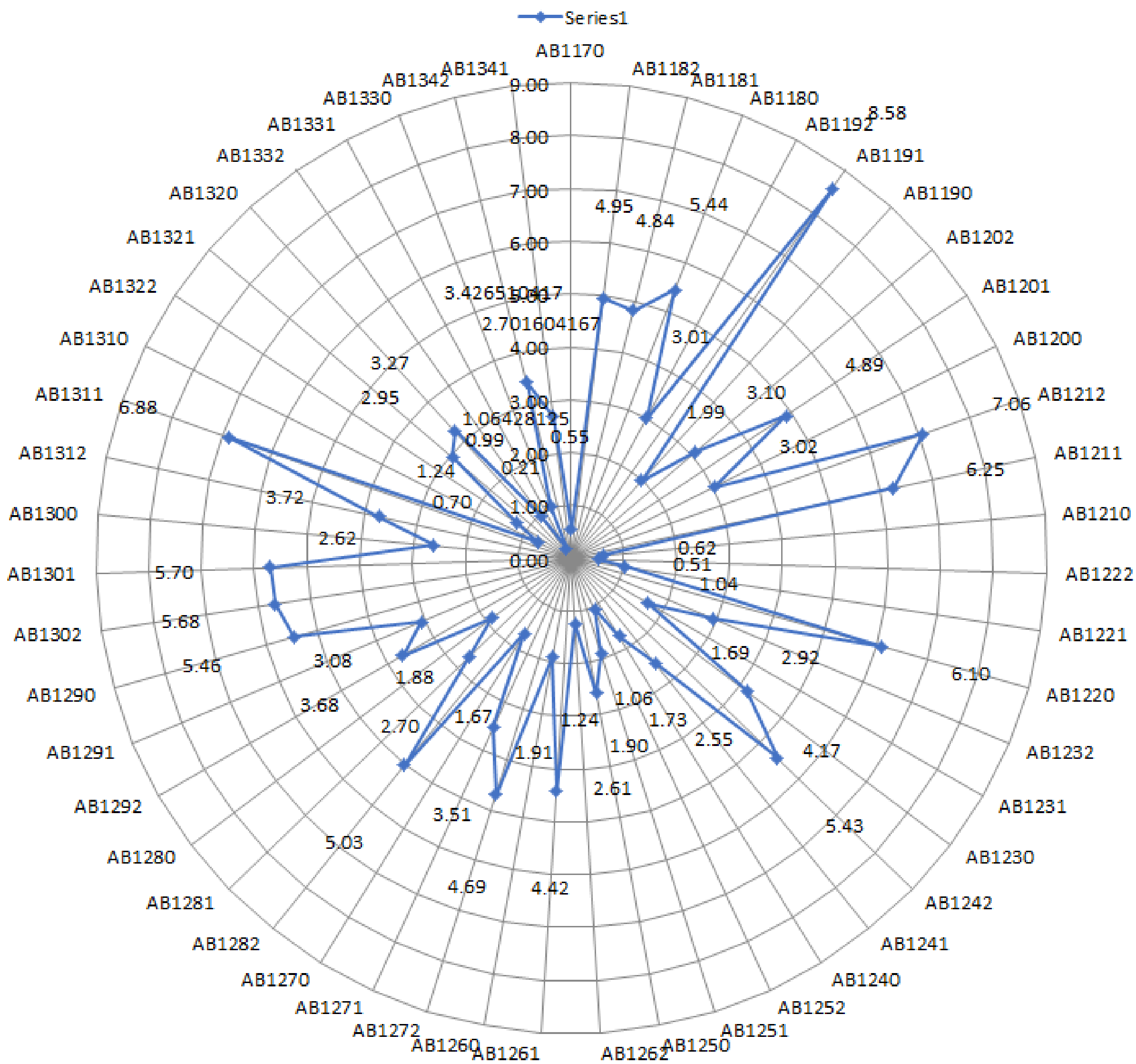

Figure 4.8: Average Throughput (Mbps) Performance per Cell for Eight-50 Sectors (AB1160 – AB1331)

The underperforming sectors are (Mbps): AB1331 (0.21), AB1210 (0.62), AB1310 (0.70), AB1222 (0.51), AB01170 (0.55)

Sector with good and great performance (Mbps): AB1191 (8.58), AB1311 (6.88), AB1211 (6.25), AB1220 (6.10), AB1212 (7.06)

Percentage of good performing to underperforming: > 65% Great

Causes and Actions for improvement: Number of users and contention ratio, Monitoring cells, high user, lack of dominant cell.

4.1.2 Average Throughput Performance against Average Number of UEs

This analysis shows the impact of average number of users on throughput performance; average number of users on each cell is calculated and plotted against average throughput performance

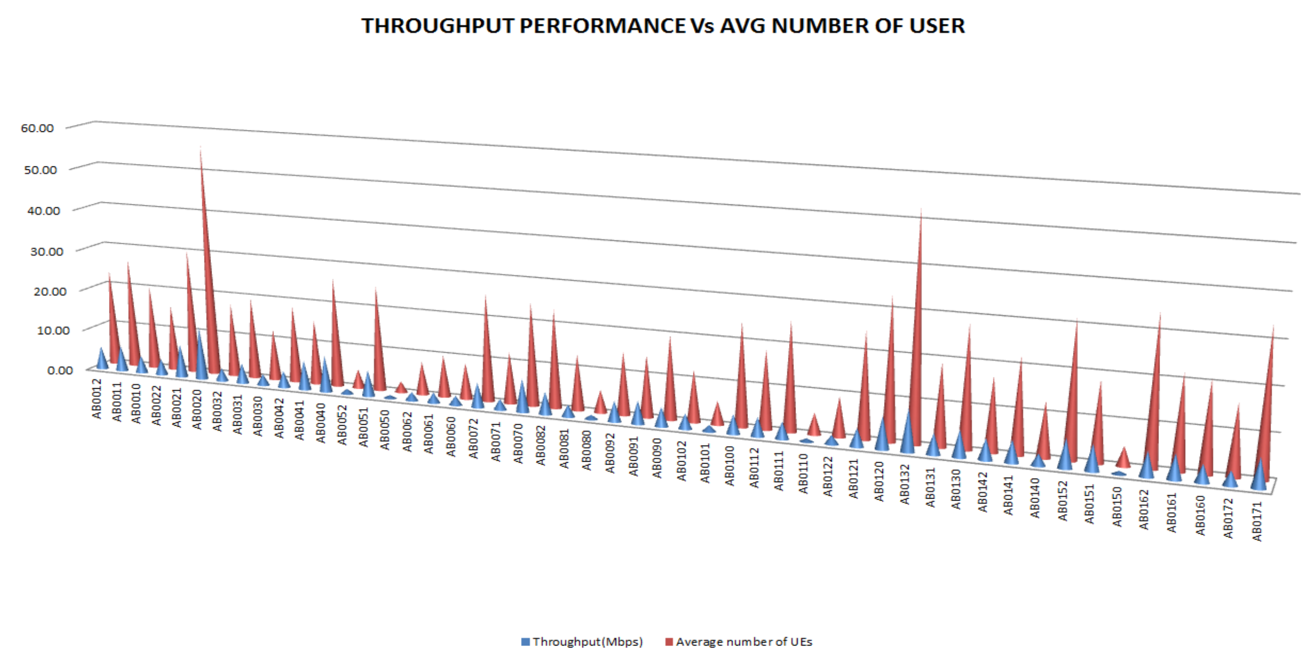

Figure 4.9: Average Throughput (Mbps) Performance against Average Number of UEs 1st 50 sectors (AB0012 –AB0171)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) are underperforming and likely to have many users detach their devices to another eNodeB due to poor Quality of Service, just in the cases of

AB0052, AB0050, AB0080, AB0110, AB0150 etc. They all have users less than 15 and calls for enhancement

Some situation have it that cells with lesser number of UEs (≤15) still offer good throughput (≥ 0.8 Mbps) and quality of service as can be observed for sectors AB0042, AB0041 and AB0142, AB0700 etc.

Some cells have higher UEs (≥ 15) with accepted throughput as can observed for sectors AB0021, AB0020, AB0120, AB0132, AB0162, AB0171 etc. They are stable and performing very well

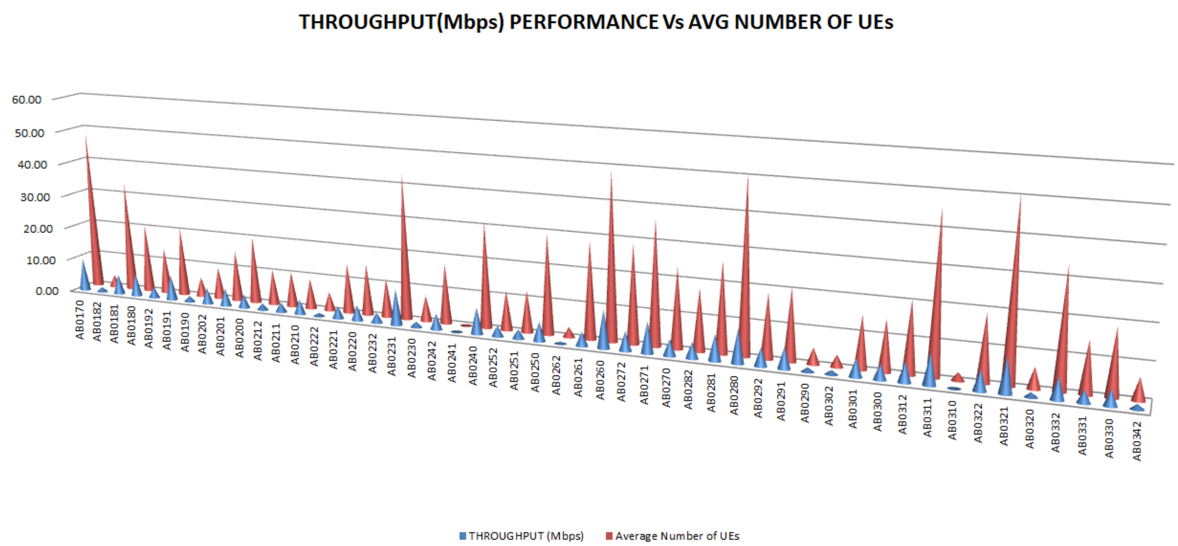

Figure 4.10: Average Throughput (Mbps) Performance Vs Average Number of UEs second-50 Sectors (AB00170 –AB0342)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) calls for enhancement: AB0182, AB0241, AB0262, AB0310, AB0190

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB0220, AB0301, AB0302 and AB0330

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB0170, AB0231, AB0240, AB0260, AB0280, AB0321

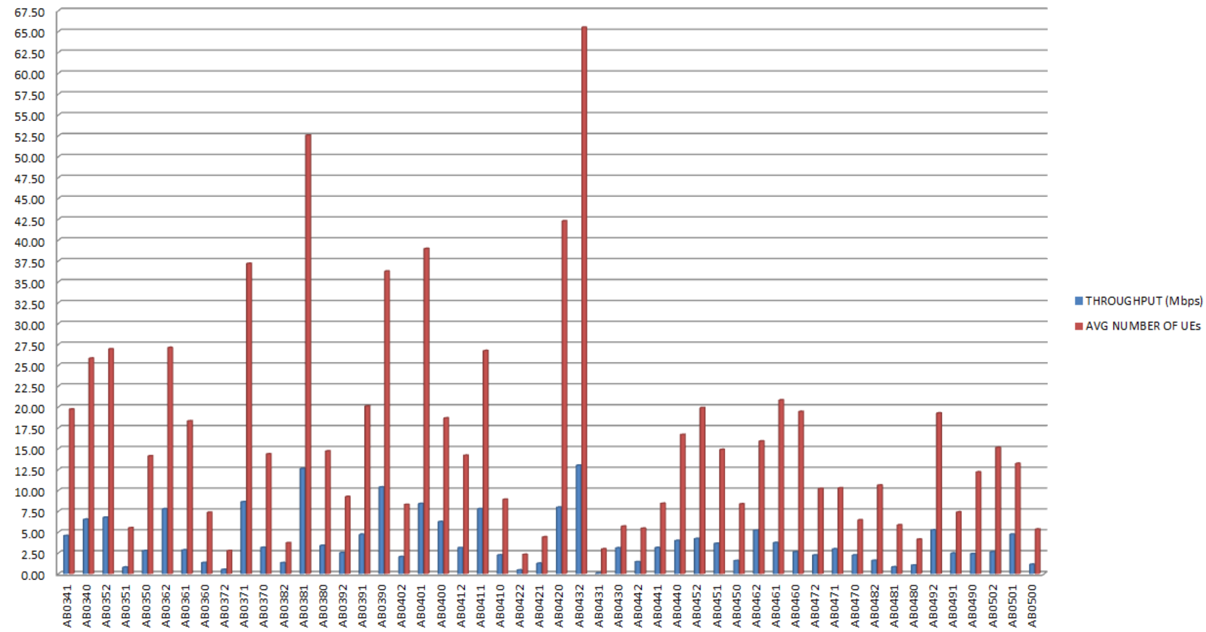

Figure 4.11: Average Throughput (Mbps) Performance Vs Average Number of UEs Third-50 Sectors (AB0341 –AB0500)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) requires performance enhancement:

AB0372, AB0382, AB0422, AB0421, AB0431, AB0480

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB0350, AB0370, AB0380, AB451 etc.

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB0371, AB0381, AB0401, AB0420 and AB0432

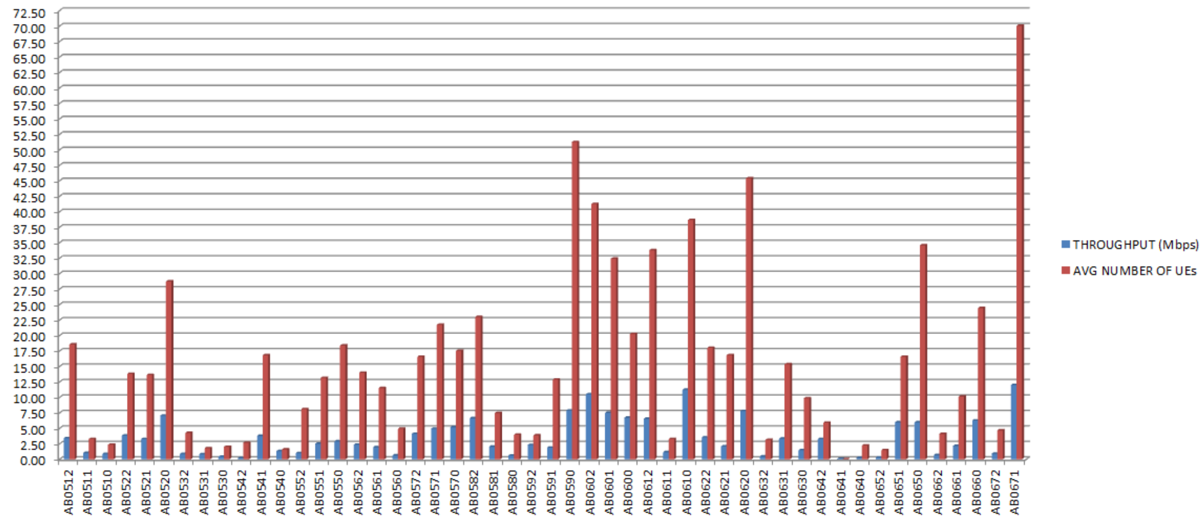

Figure 4.12: Average Throughput (Mbps) Performance Vs Average Number of UEs Fourth-50 Sectors (AB0512 –AB0671)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) requires performance enhancement: AB0511, AB0510, AB031, AB0530, AB0542, AB0641, AB0652 etc.

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB0522, AB0521, AB0551, AB0562 etc.

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB0520, AB0590, AB0602, AB0620 and AB0671

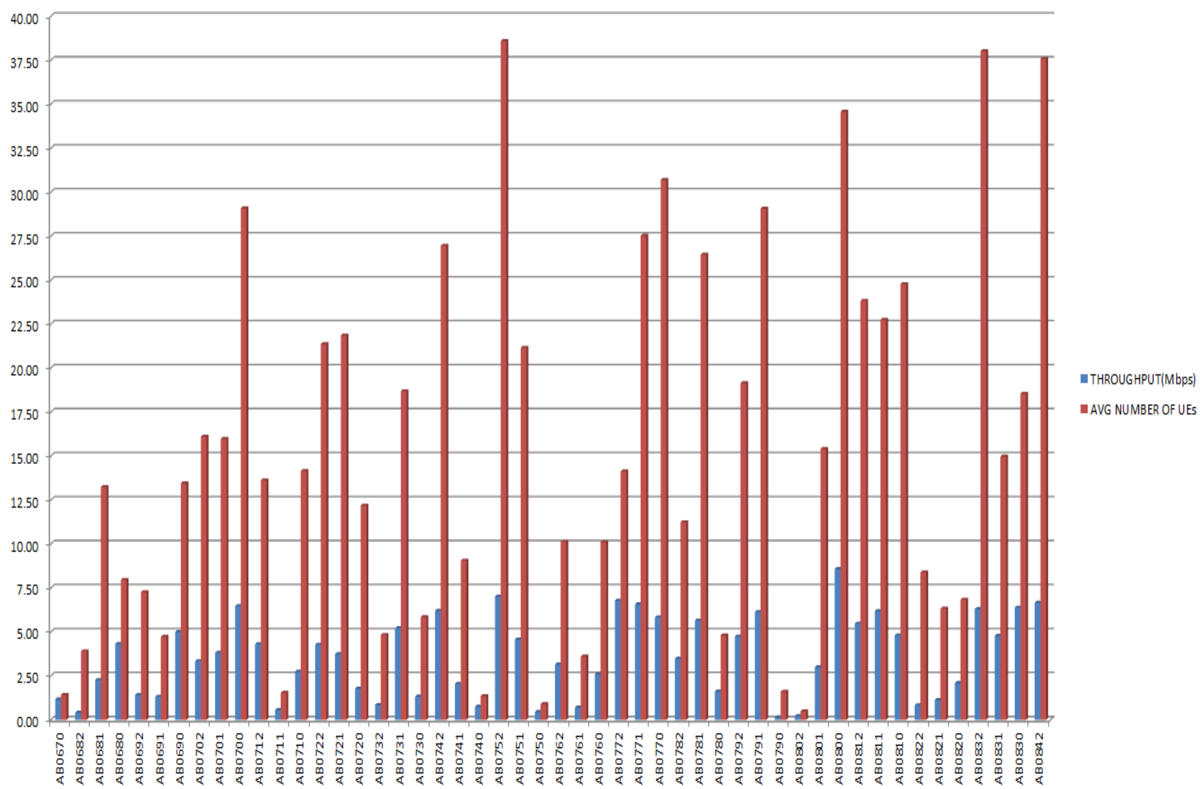

Figure 4.13: Average Throughput (Mbps) Performance Vs Average Number of UEs Fifth-50 Sectors (AB0670 –AB0842)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) requires performance enhancement: AB0670, AB0711, AB0740, AB0750, AB0790, AB0802, etc.

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB0680, AB0690, AB0712, AB0772 etc.

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB0700, AB0752, AB0770, AB0800, AB0832 and AB0842

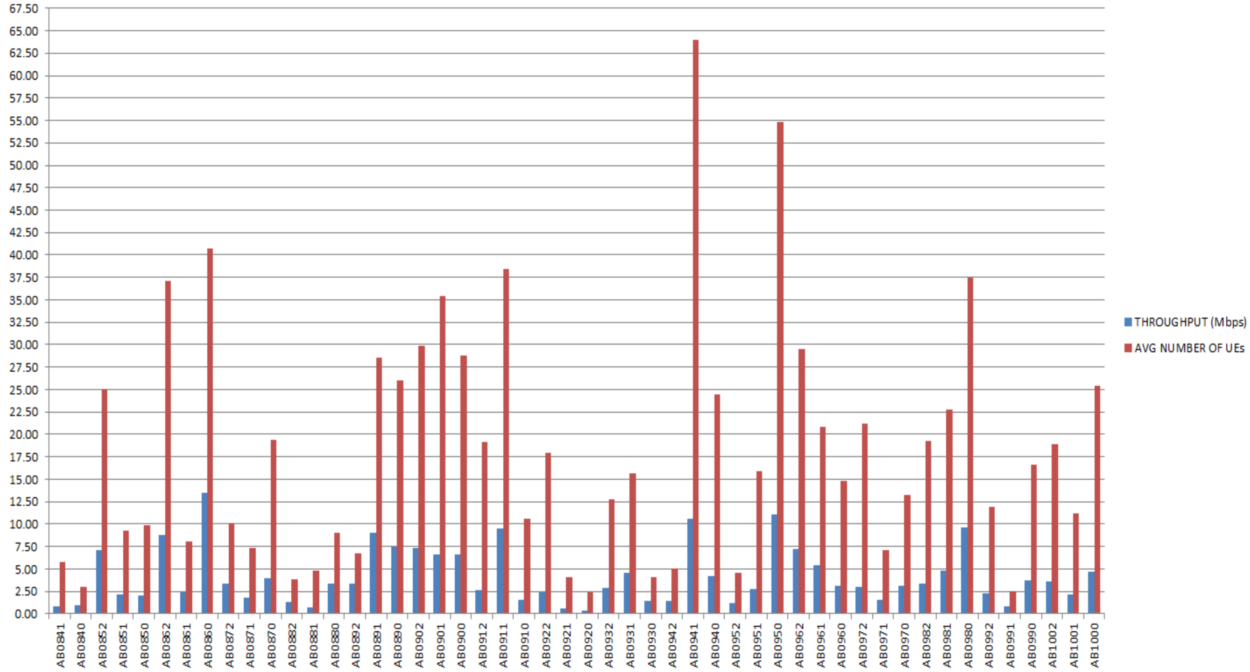

Figure 4.14: Average Throughput (Mbps) Performance Vs Average number of UEs Sixth 50 sector (AB0841 –AB1000)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) requires performance enhancement: AB0840, AB0881, AB0920, AB0921, AB0991 etc.

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB0872, AB0932, AB0960, AB0880 etc.

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB0862, AB0860, AB0902, AB0911, AB0941 and AB0950

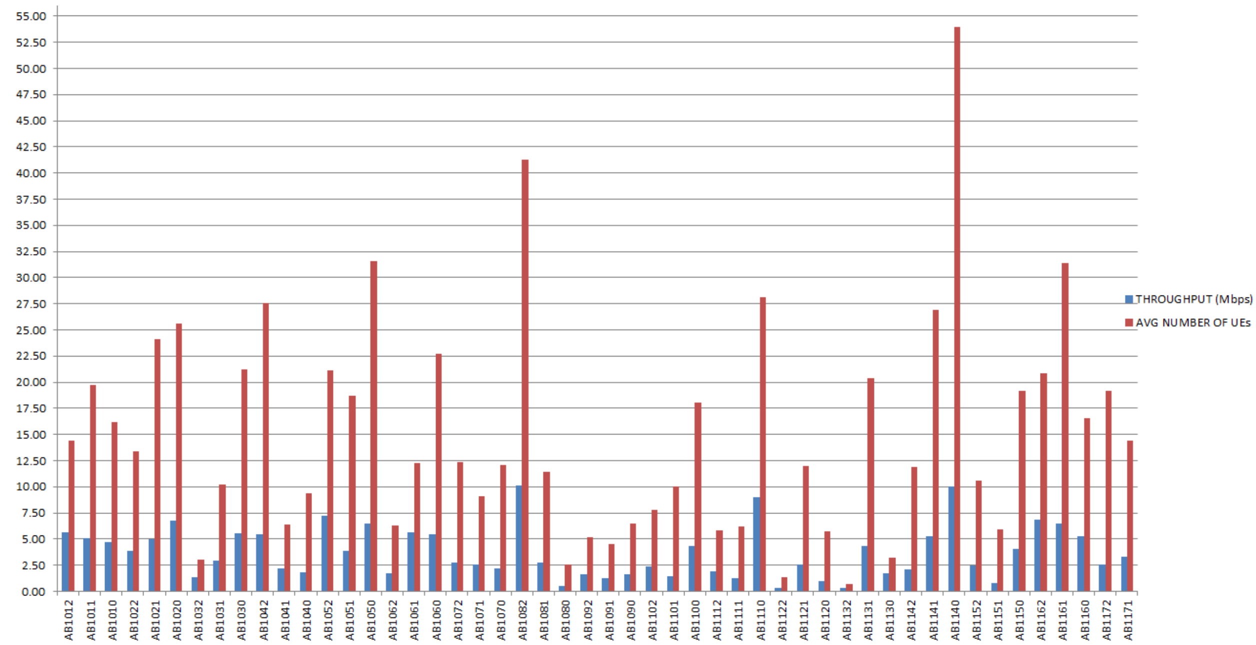

Figure 4.15: Average Throughput (Mbps) Performance Vs Average number of UEs Seventh 50 sector (AB1012 –AB1171)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) requires performance enhancement: AB1080, AB1122, AB1132, AB1151 etc.

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB1012, AB1022, AB1061, AB1031, AB1171 etc.

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB1021, AB1020, AB1042, AB1050, AB1082, AB1110, AB1140 and AB1161

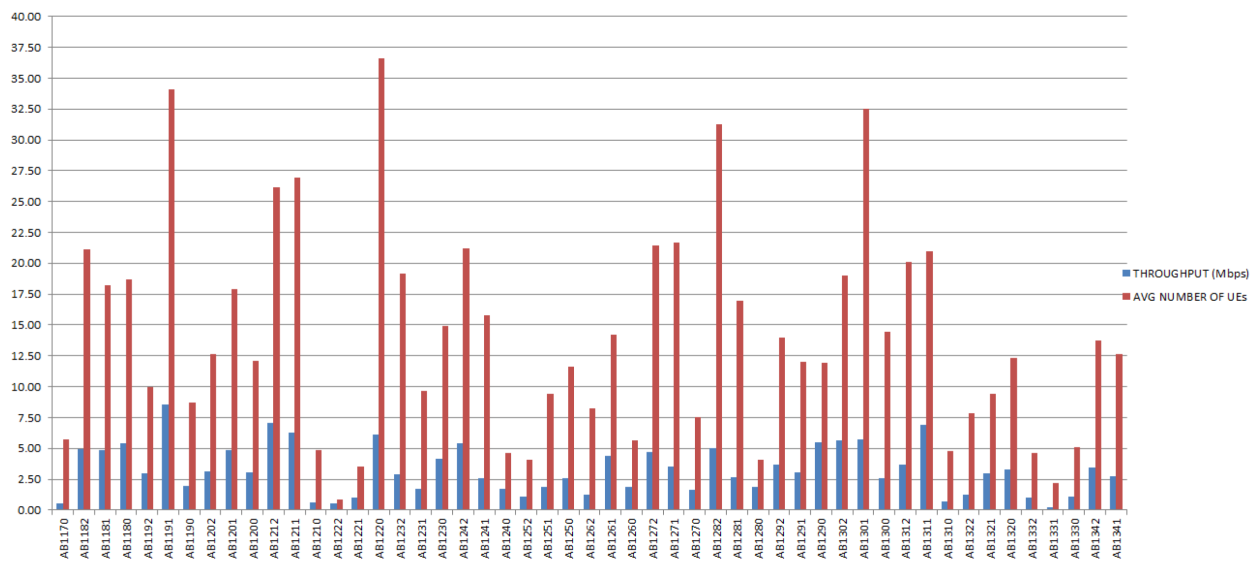

Figure 4.16: Average Throughput (Mbps) Performance Vs Average number of UEs Eight 50 sectors (AB1170 –AB1341)

X-axis represents numeric values with respect to average throughput and number of UEs, Y-axis represents Cell IDs.

Cells with low throughput (≤0.8Mbps) and few users (≤15) requires performance enhancement: AB1170, AB1210, AB1222, AB1310, AB1331 etc.

Cells with lesser number of UEs (≤15) and good throughput (≥ 0.8Mbps) is in stable network condition: AB1230, AB1261, AB1292, AB1342, AB1341 etc.

Cells with higher UEs (≥ 15) with accepted throughput and quality of Service: AB1191, AB1212, AB1220, AB1282, AB1301, AB1311 etc.

4.1.3 Evaluation of Average Throughput Performance against Average Number of Times DL PRB Utilization Went above 80%

This section evaluates the PRB utilization against cell throughput performance, theoretically, the higher the PRB utilization approaches 80% and beyond, congestion in network is likely to trigger and the serving eNodeB will start dropping packets as well as stop admitting new UEs on request for radio bearer. The graphs in figure 17 -24 shows average of the cell throughput performance against PRB utilization.

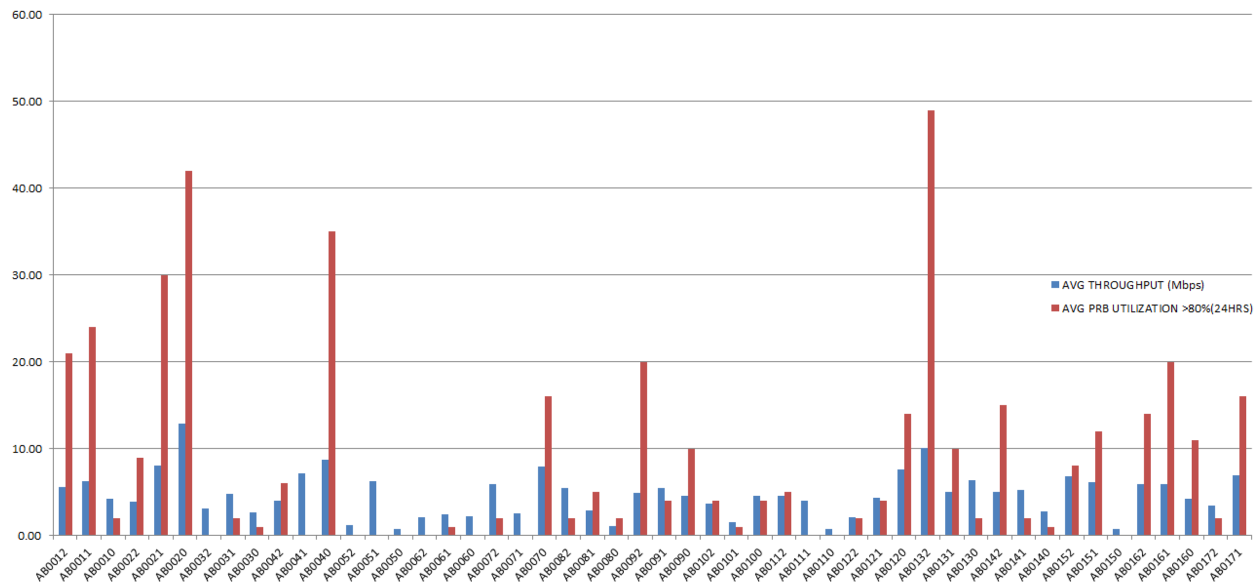

Figure 4.17: Average Cell Throughput Versus Average PRB Utilization above 80% (24hrs) 1st 50 sectors (AB0012 –AB0171)

X-axis represents numeric values with respect to average throughput and number of Average PRB above 80%, Y-axis represents Cell IDs.

Good performing cells will possess average of throughput ≥ 0.8Mbps and Average PRB Utilization of ≥25% such as in the cases of AB0021, AB0020, AB0040, and AB0132

Cells whose PRBs are barely utilized, calls for attention, because, it's either the eNodeB is failing to grant UEs radio bearers on request, or the eNodeB may be covering an area not designated (Island coverage). Wrong configuration or faulty equipment may be diagnosed in such cells. Observe sectors AB0052, AB0050, AB0110, and AB0150

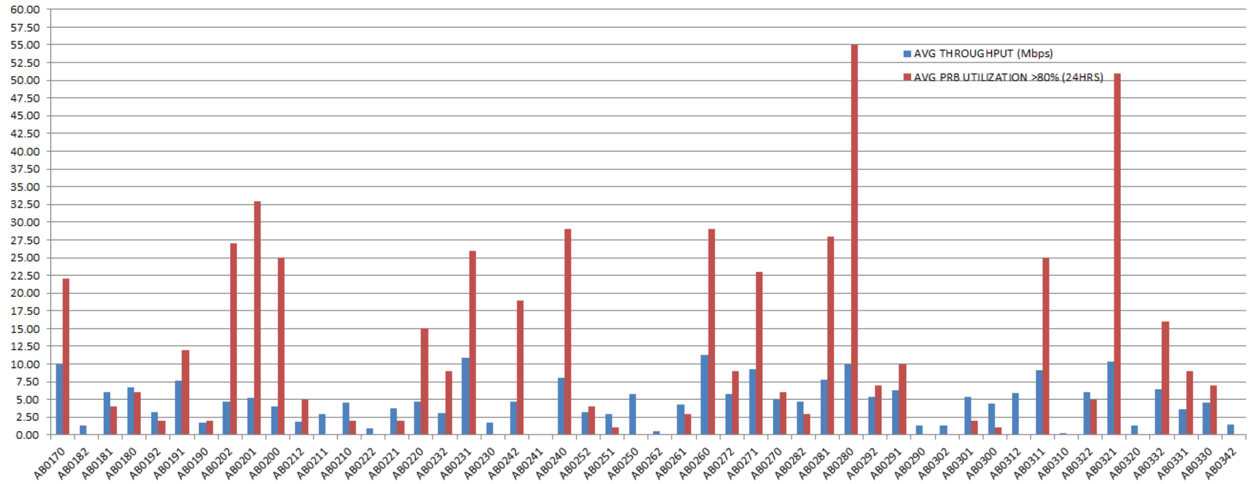

Figure 4.18: Average Cell Throughput versus Average PRB Utilization above 80% (24hrs) 2nd 50 sectors (AB0170 –AB0342)

X-axis represents numeric values with respect to average throughput and number of Average PRB above 80%, Y-axis represents Cell IDs.

Good performing cells will possess average of throughput ≥ 0.8Mbps and Average PRB Utilization of ≥25% such as in the cases of AB0202, AB0201, AB0231, AB0240, AB0260, AB0280, and AB0321.

Cells whose PRBs are barely utilized, calls for attention, because, it's either the eNodeB is failing to grant UEs radio bearers on request, or the eNodeB may be covering an area not designated (Island coverage). Wrong configuration or faulty equipment may be diagnosed in such cells. Observe sectors AB0182, AB0222, AB0241, AB0262 and AB0310

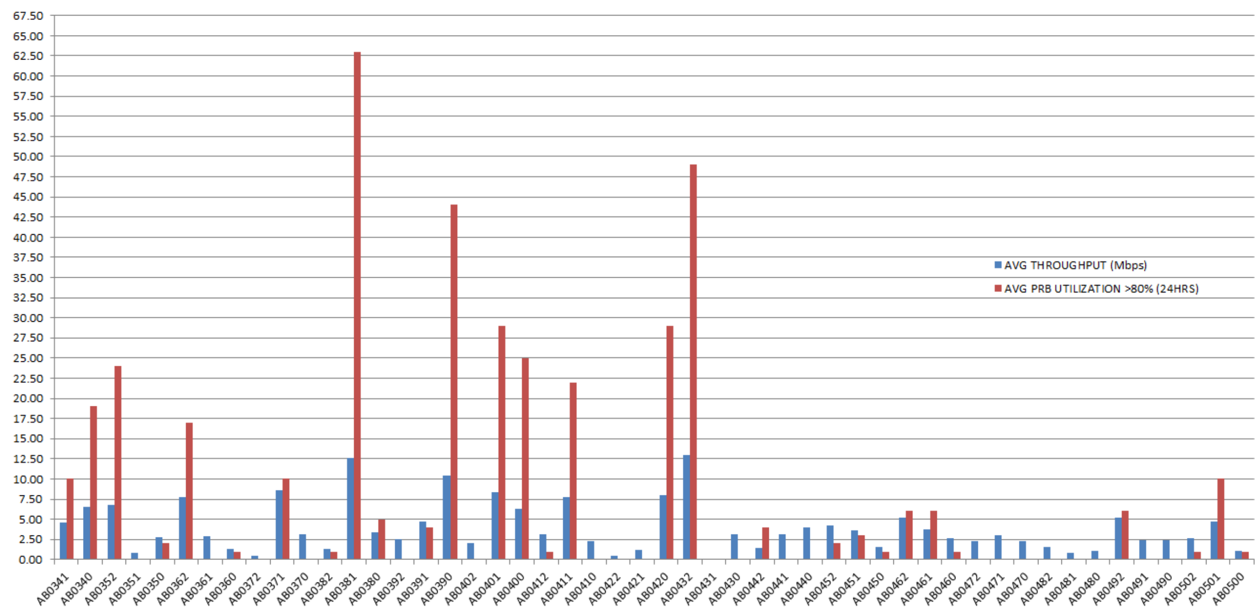

Figure 4.19: Average Cell Throughput Versus Average PRB Utilization above 80% (24hrs) 3rd 50 sectors (AB0341 –AB0500)

X-axis represents numeric values with respect to average throughput and number of Average PRB above 80%, Y-axis represents Cell IDs.

Observe from Figure 4.19, good performing cells will possessed an average throughput ≥ 0.8Mbps and Average PRB Utilization of ≥25% such as in the cases of AB0381, AB0390, AB0401, AB0400, AB0420, and AB0432

Cells whose PRBs are hardly consumed, calls for attention and requires enhancement because, it's either the eNodeB is failing to grant UEs radio bearers on request, or the eNodeB may be covering an area not designated (Island coverage). Wrong configuration or faulty equipment may be diagnosed in such cells. Observe sectors AB0372, AB0422, AB0431, AB0481 and AB0480

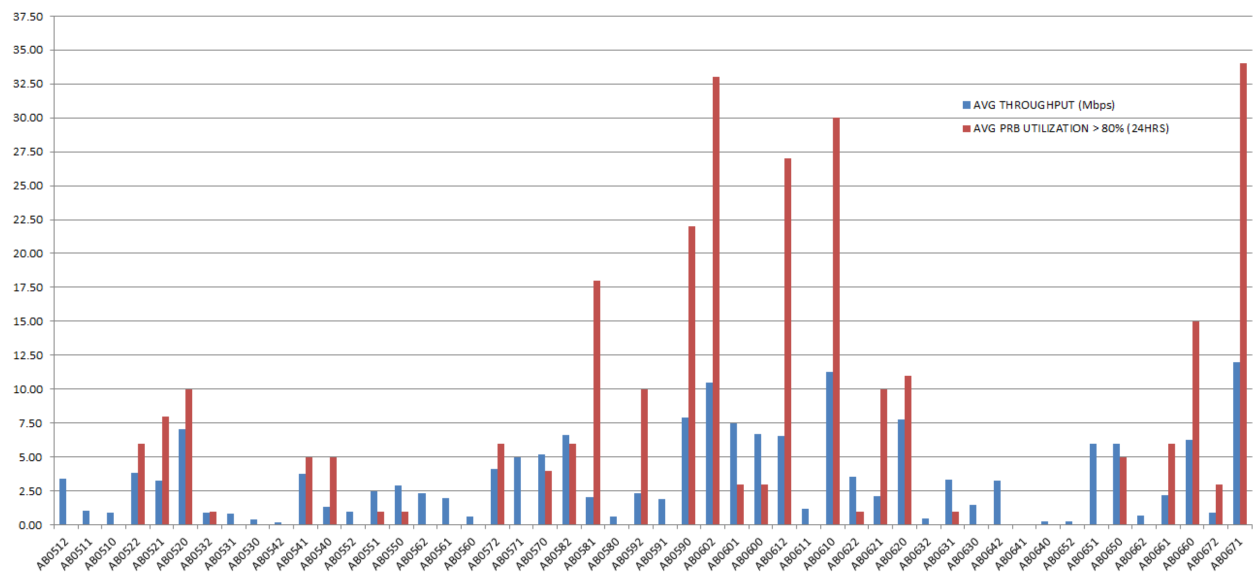

Figure 4.20: Average Cell Throughput Versus Average PRB Utilization above 80% (24hrs) 4th 50 sectors (AB0512 –AB0671)

X-axis represents numeric values with respect to average throughput and number of Average PRB above 80%, Y-axis represents Cell IDs.

Figure 4.20 is observed to have the following good performing cells whose average throughput is ≥ 0.8Mbps and Average PRB Utilization of ≥25% such as in the cases of AB0602, AB0612, AB0610, and AB0671.

Cells whose PRBs are barely consumed, calls for attention, because, it's either the eNodeB is failing to grant UEs radio bearers on request, or the eNodeB may be covering an area not designated (Island coverage). Wrong configuration or faulty equipment may be diagnosed in such cells. Observe sectors AB0530, AB0542, AB0641, AB0642 and AB0652

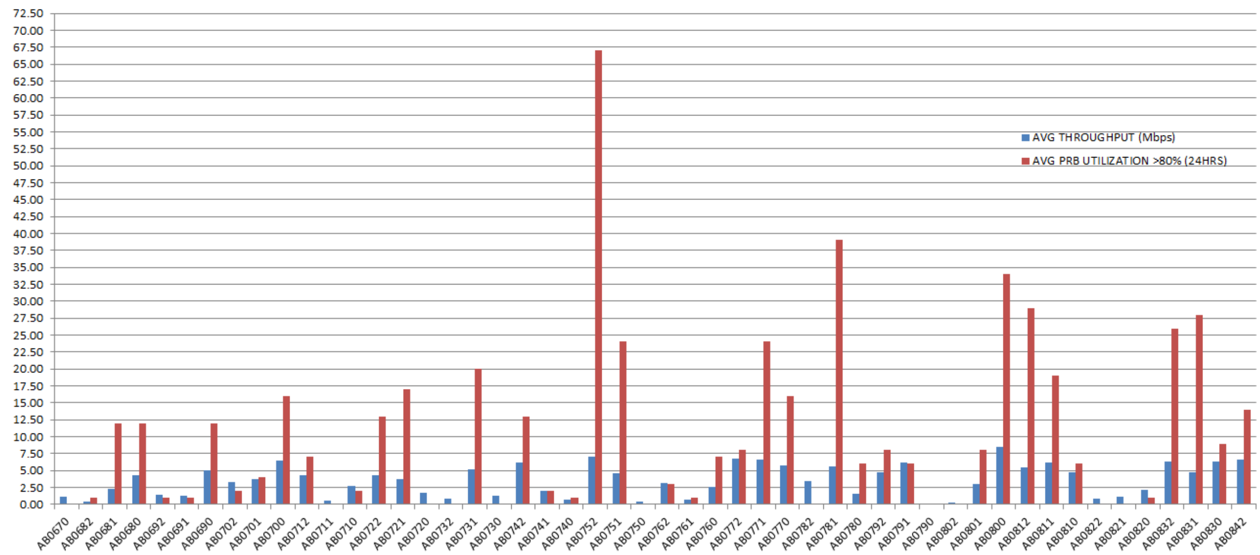

Figure 4.21: Average Cell Throughput Versus Average PRB Utilization above 80% (24hrs) 5th 50 sectors (AB0670 –AB0842)

X-axis represents numeric values with respect to average throughput and number of Average PRB above 80%, Y-axis represents Cell IDs.

Good performing cells will possess average of throughput ≥ 0.8Mbps and Average PRB Utilization of ≥25% such as in the cases of AB0752, AB0781, AB0800, AB0812, AB0832 and AB0831

Cells whose PRBs are barely utilized, calls for attention, because, it's either the eNodeB is failing to grant UEs radio bearers on request, or the eNodeB may be covering an area not designated (Island coverage). Wrong configuration or faulty equipment may be diagnosed in such cells. Observe sectors AB0682, AB0711, AB0732, AB0740, AB0750, AB0790, AB0802 and AB0822

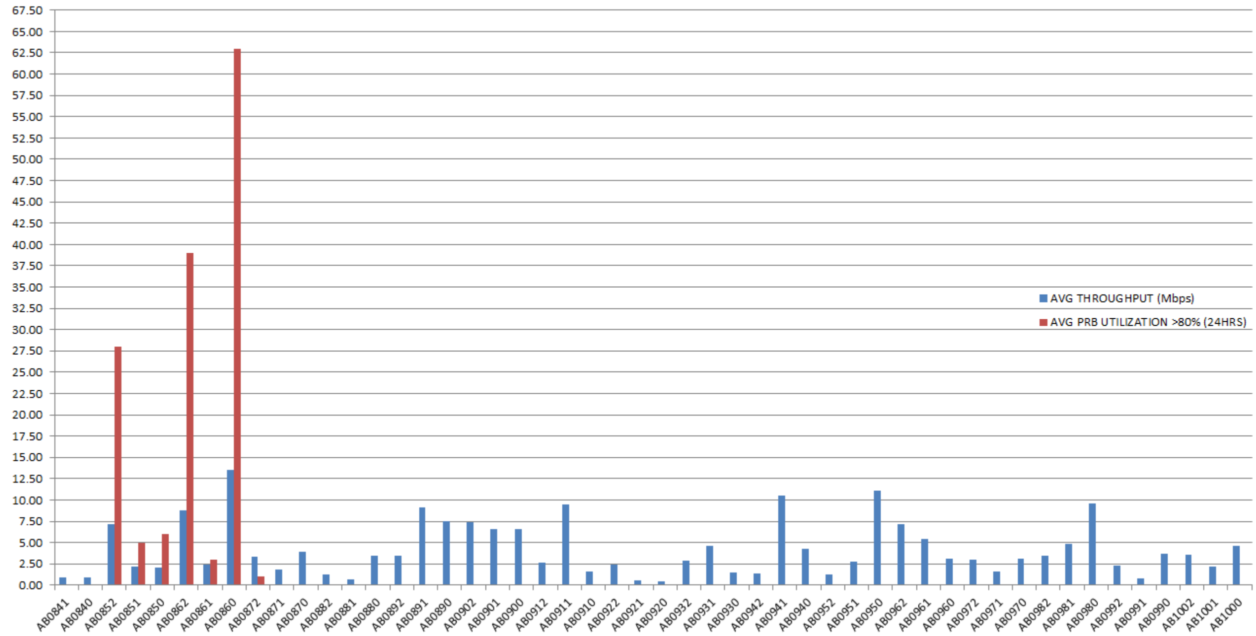

Figure 4.22: Average Cell Throughput Versus Average PRB Utilization above 80% (24hrs) 6th 50 sectors (AB0841 –AB1000)

X-axis represents numeric values with respect to average throughput and number of Average PRB above 80%, Y-axis represents Cell IDs.

Good performing cells will possess average of throughput ≥ 0.8Mbps and Average PRB Utilization of ≥25% such as in the cases of AB0852, AB0862 and AB0860

Figure 4.22 sampled more of newly deployed cells, in the new locations, fewer numbers of users were recorded (refer to Figure 4.14), poor performing cells were observed based on throughput which includes sector AB0881, AB0921, AB0920 and AB0991]

4.1.4 The Effect and Relationship between Average Number of Users and PRB Utilization

This section describes the relationship effect between average numbers of users in a network cell against PRB utilization. The sampled cells in figure 4.23 – 4.28 showed the number of times the cell's PRB utilization went above 80% and its corresponding average number of users. Theoretically the higher the number of UEs that latch into an eNodeB, there is will high utilization of the Physical resource blocks (PRB), observe at most times the number of users tends to be higher or equal to the number of times the PRB utilization went above 80% for each cell. Robust and stable network will show higher number of users with minimal number of times the PRB utilization going above 80%.

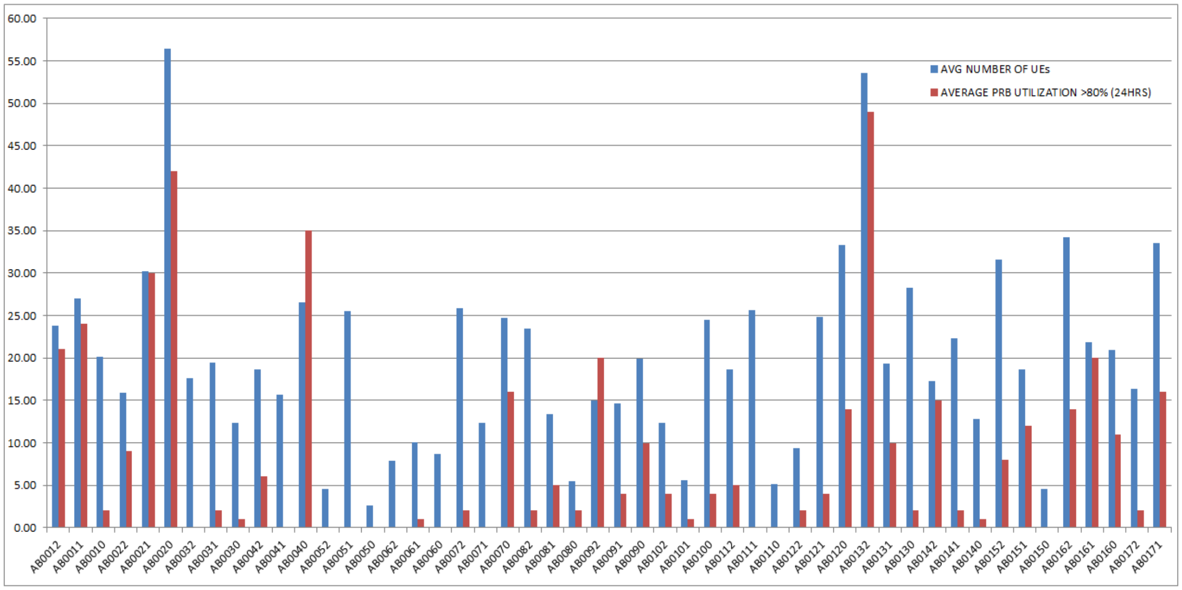

Figure 4.23: Average Number of UEs Vs Average PRB UTILIZATION >80% Count (24Hrs) 1st 50 Sectors (AB0012-AB0171)

The graph figure 4.23 shows the first 50 sectors (AB0012 – AB0171) performance as regards to PRB utilization greater than 80% count (Number of times) and its corresponding average number of users. Cell AB0020 and AB0132 proved to be have most robust service, they both recorded over the period of study an average of 57 users with an average of 42 times hitting the PRB utilization above 80%. They also have shown at the previous analysis to have an average throughput above 10Mbps,

These sectors; AB0032, AB0052, AB0051, AB0062, AB0060, AB0111, AB0110, AB0150 showed to have at an average, very little number of times utilizing their PRB above 80%.

The cells whose average number of times the PRB utilization went above 80% is greater than average number of users are likely to have low average throughput performance just as in the case of AB0140 with an average of 17 times hitting PRB utilization above 80% but have an average number of user set at 12, going back to earlier analysis cell AB0140 recorded an average of 2Mbps (refer to figure 4.1), usually in this case RF engineers will suspect high data rate users causing performance degradation. Finally, cells with very low number of users are always a call for concern, especially if the cells are located in populated area of the town. Over time, such cells will tend to be underperforming as can be observed in the cases of AB0050 and AB0150 with 2.5 and 4.5 average number users respectively, notice also from the earlier analysis (Figure 4.1), their average throughput performance are below 0.7 Mbps

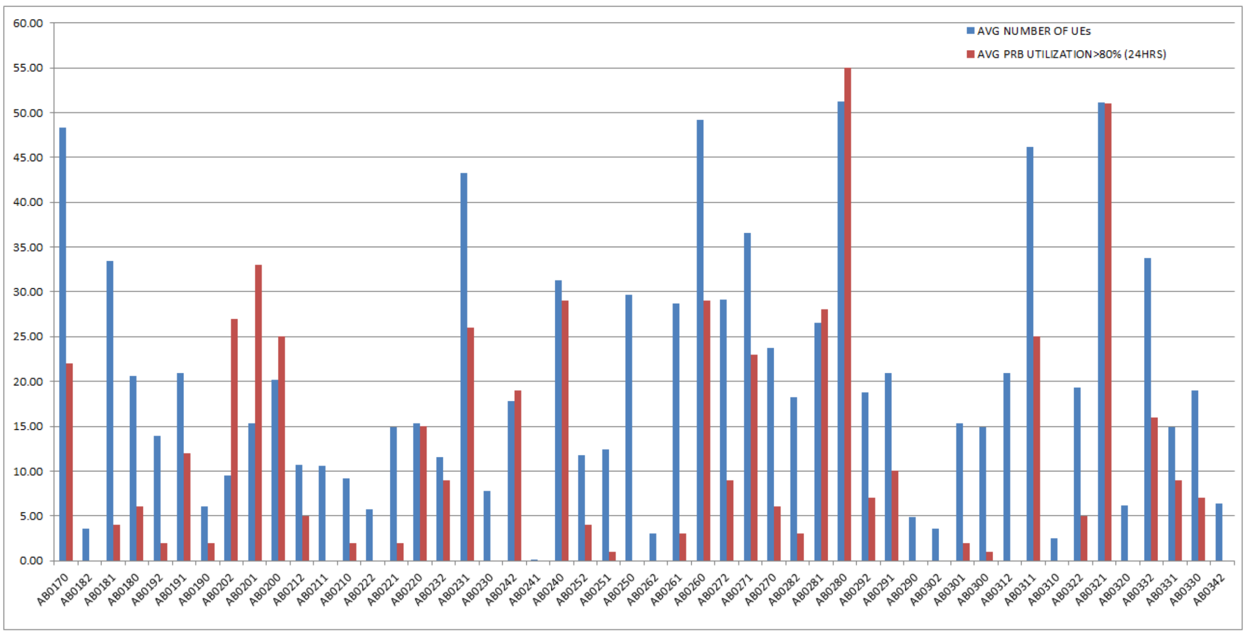

Figure 4.24: Average Number of UEs Vs Average PRB UTILIZATION >80% Count (24Hrs) 2nd 50 Sectors (AB00170-AB0342)

The graph figure 4.24 shows the second 50 sectors (AB00170 – AB0342) performance as regards to PRB utilization greater than 80% count (Number of times) and its corresponding average number of users. Robust Cell performers will tend to have higher number users with acceptable degree of PRB utilization hitting above 80% as well as average throughput performance, just in cases of AB0170, AB0260, and AB0311.

The cells whose average number of times the PRB utilization went above 80% is greater than average number of users is likely to have low average throughput performance, observe sectors AB0202, AB201, AB0200, and AB0280

These sectors; AB0182, AB0230, AB0290, AB0302, AB0310, AB0320, AB0342, showed to have at an average, very little number of times having their PRB utilized above 80%.

Cells with very low number of users are always a call for concern such as in the case of AB0241 where PRB utilization is always low. From earlier analysis (Figure 4.2) on throughput performance, it has an average performance of 100kbps

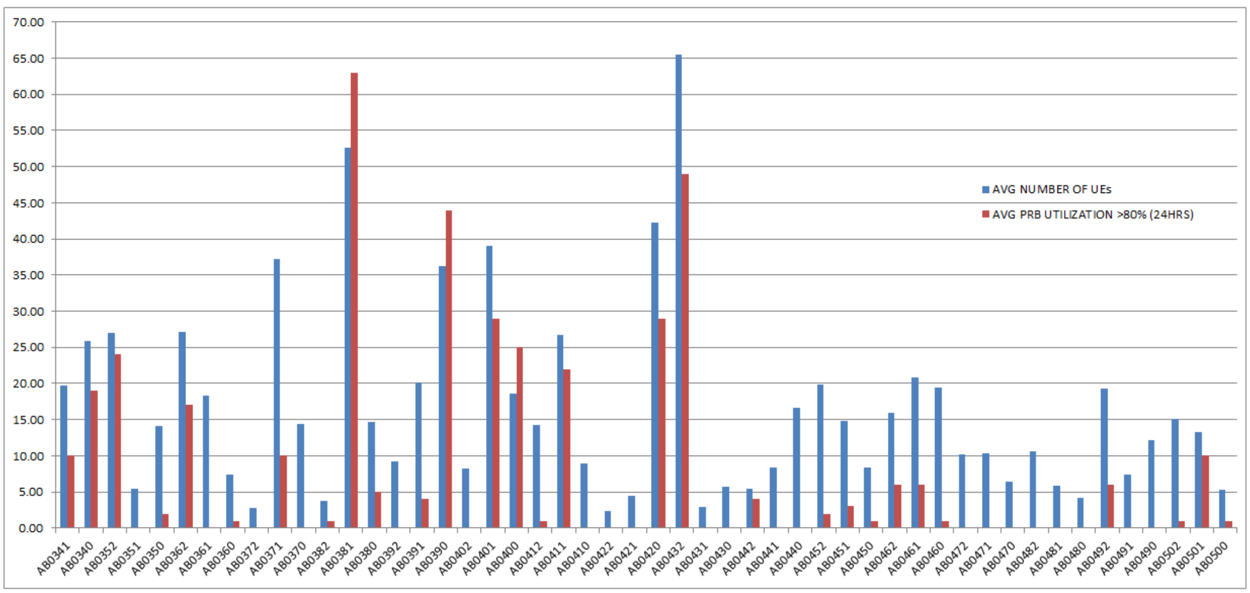

Figure 4.25: Average Number of UEs Vs Average PRB UTILIZATION >80% Count (24Hrs) 3rd 50 Sectors (AB0341-AB0500)

The graph figure 4.25 shows the third 50 sectors (AB0341 – AB0500) performance as regards to PRB utilization greater than 80% count (Number of times) and its corresponding average number of users

Robust Cell performers are AB0371, AB0420, and AB0432

The cells whose average number of times the PRB utilization went above 80% is greater than average number of users is likely to have low average throughput performance just in the case of AB0381 and AB0390

Sectors AB0351, AB061, AB0372, AB0370, AB0392, AB0402, AB0410,AB0440 etc. showed to have at an average, very little number of times having their PRB utilized above 80%.

Cells with very low number of users are always a call for concern and requires further investigation such as in the cases of AB0372, AB0382, AB0422, and AB0431

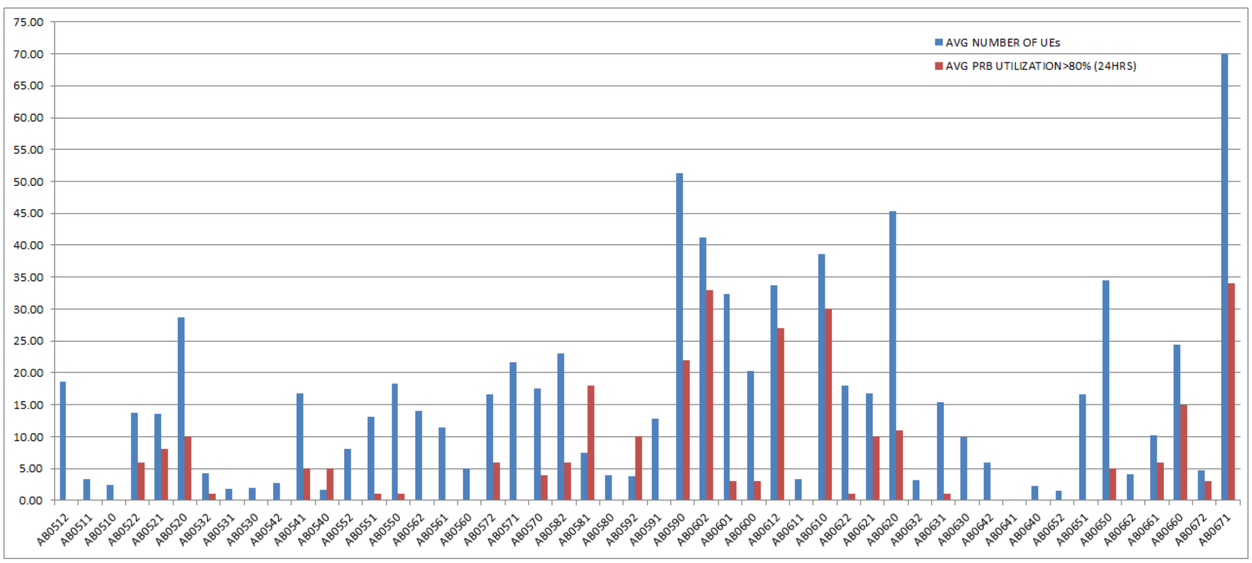

Figure 4.26: Average Number of UEs Vs Average PRB UTILIZATION >80% Count (24Hrs) 4th 50 Sectors (AB0512-AB0671)

The graph figure 4.26 shows the fourth 50 sectors (AB0512 – AB0671) performance as regards to PRB utilization greater than 80% count (Number of times) and its corresponding average number of users.

Reliable Cell performers are AB0590, AB0671, AB0602, AB-610, and AB0620; they have high users and great throughput as can be observed in earlier data analysis (figure 4.4)

Cells with very low number of users as well as low number of PRB utilization are always a sign for concern and requires further investigation such as in the cases of AB0641, AB0640, AB0652, AB0531 and AB0530

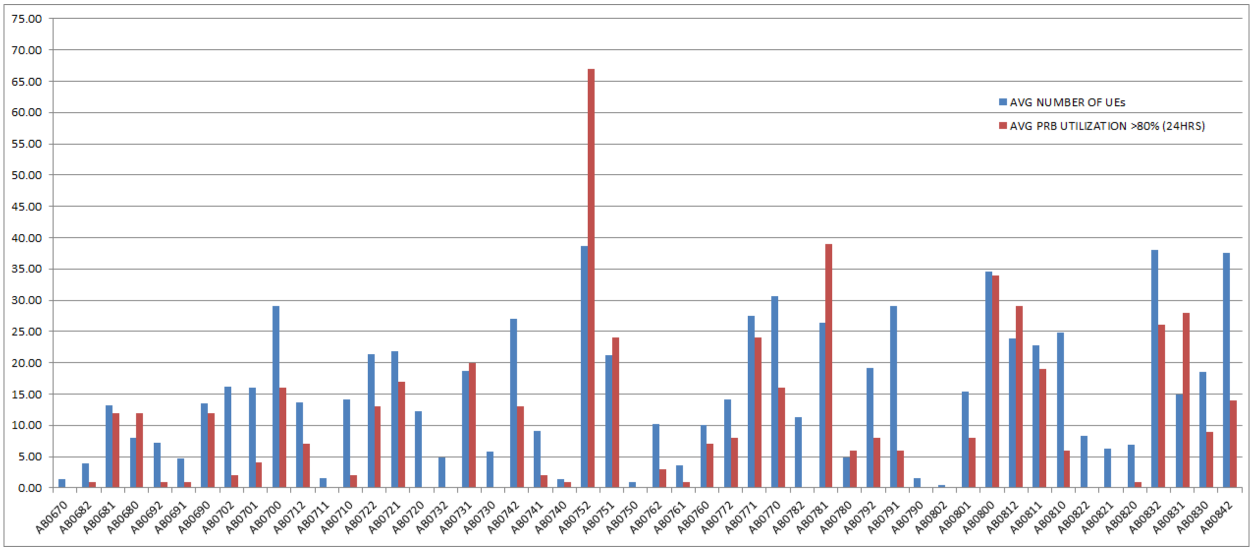

Figure 4.27: Average Number of UEs Vs Average PRB UTILIZATION >80% Count (24Hrs) 5th 50 Sectors (AB0670-AB0842)

The graph figure 4.27 shows the fifth 50 sectors (AB0670 – AB0842) performance as regards to PRB utilization greater than 80% count (Number of times) and its corresponding average number of users.

Healthy Cell performers achieved high data rate, high number of user and fewer PRB utilization above 80%, as observed for sectors AB0700, AB0800, AB0832, AB0482, and AB0810.

Cells with very low number of users as well as low number of PRB utilization are always a sign for concern and requires further investigation such as in the cases of AB0670 AB0711, AB0740, AB0750, AB0790 and AB0802.

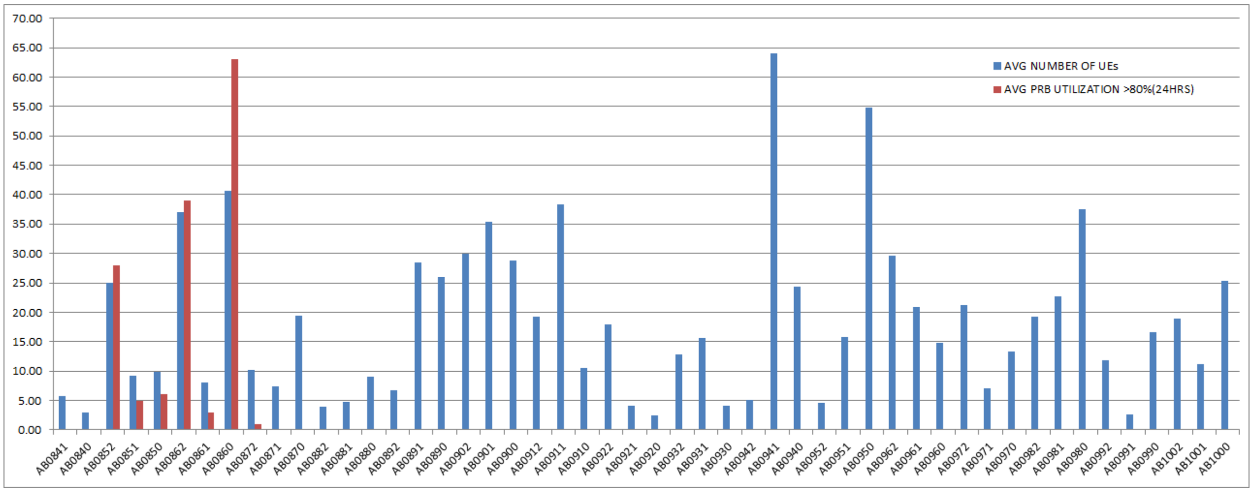

Figure 4.28: Average Number of UEs Vs Average PRB UTILIZATION >80% Count (24Hrs) 6th 50 Sectors (AB0841-AB1000)

The graph figure 4.28 shows the sixth 50 sectors (AB0841 – AB1000) performance as regards to PRB utilization greater than 80% count (Number of times) and its corresponding average number of users

High Quality Cell performers are AB0941, AB0950, AB0980, and AB0911

Cells with very low number of users as well as low number of PRB utilization are always a sign of poor performance and require further investigation such as in the cases of AB0670 AB0711, AB0840, AB0920, and AB0991. It was also observed that cells in newly deployed areas hardly exceed PRB utilization above 80% as can be observe in sectors AB071 through AB0100.

4.1.5 Remote Investigation and Analysis by Google Earth Pro

Google Earth Pro is a computer program that uses satellite imagery to present 3-dimentional view of all coordinates of the earth, it offers telecommunication operators platform to integrate their base station's (eNodeB) coordinates as well as other functional configuration to be able remotely monitor each cell's activity at every given time. This section shows a typical solution applied in ratifying subscriber's compliant of slow browsing in MBORA district, Abuja using Google Earth Pro tool. Other neighbouring subscribers reside in CITEC Estate, PATNASONIC

Estate, EMAB Global Estate etc., as can be seen in the diagnostic map, figure 4.29. The diagnosis, resolution and optimization of the site problem was done on 10th April, 2019, different measures of diagnosis was taken in order to ascertain the root causes, and efficient decision to improve the subscribers' quality of service in the area.

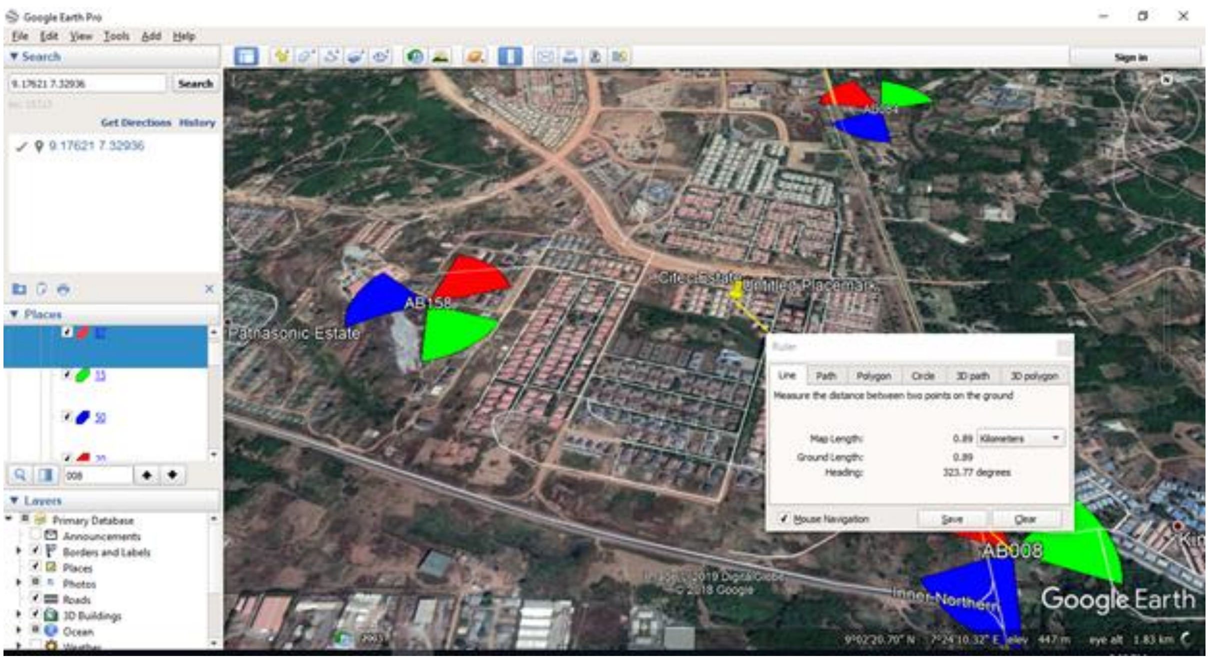

Figure 4.29: Troubleshooting SPECTRANET eNodeB Sectors AB158, AB008 and AB084 Serving MBORA DISTRICT, Abuja

RF engineers can observe the status of hosted cells around Abuja metropolis. The first step towards the troubleshooting was to generate the coordinate of one the subscribers and traced on Google Earth Pro to observe which of the cells in the area that is serving the UE. It was observed that within the coordinate area, most UE latches into an eNodeB AB008 which was discovered to be further away from UEs in the area. Google Earth Pro tool and KPI data are used to do the troubleshooting, if not satisfied with the analysis, RF engineers can further prepare and visit the site to perform either Drive test or use Huawei Hi-Studio application to ascertain the cell throughput problem, RSRP, RSRQ, SINR etc. of the cells in the region. Open Signal software application is an alternative to Huawei Hi-studio. The figure 4.29 shows the

UE's location with poor data performance, the location of the serving cell AB008. The second action taken was to measure the distance between the UE and the serving eNodeB which gives an approximate distance of 900meters with serving angle of 324 degrees while by mere observation from the map, it showed there is a closer eNodeB to UE than AB008. This factor of distance is not enough reason to make a resolution hence, other event parameters have to be checked, evaluated before taking practical actions.

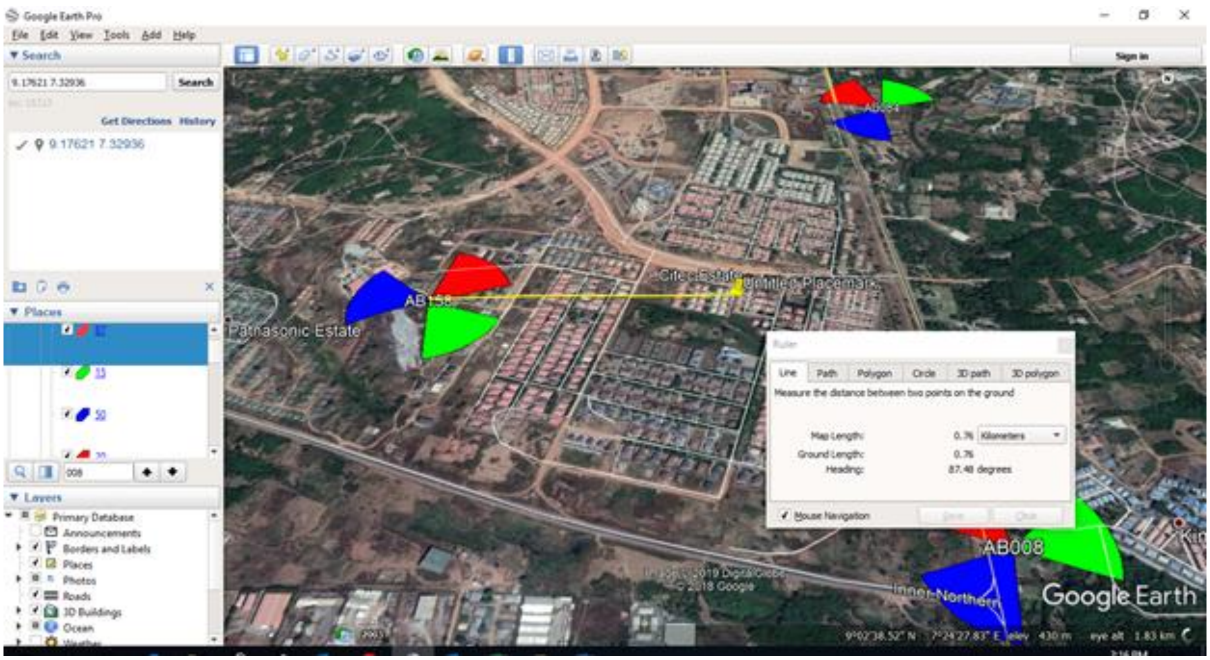

Figure 4.30: Troubleshooting SPECTRANET eNodeB Sectors AB158, AB008 and AB084 Serving MBORA District

The trouble shooting process continued by verifying the exact distance of supposed (eNodeB) cell stationed to serve the troubled area. The Figure shows a metered distance of the UE experiencing poor data services with google Earth Pro. eNodeB AB158 is about 760meters away from the UE with a serving angle of 87.48 degrees. Observe the next eNodeB on the map is AB084, however, is located across the road, so it is left out of this investigation because the UE in question is further away and does not fall under its footprint.

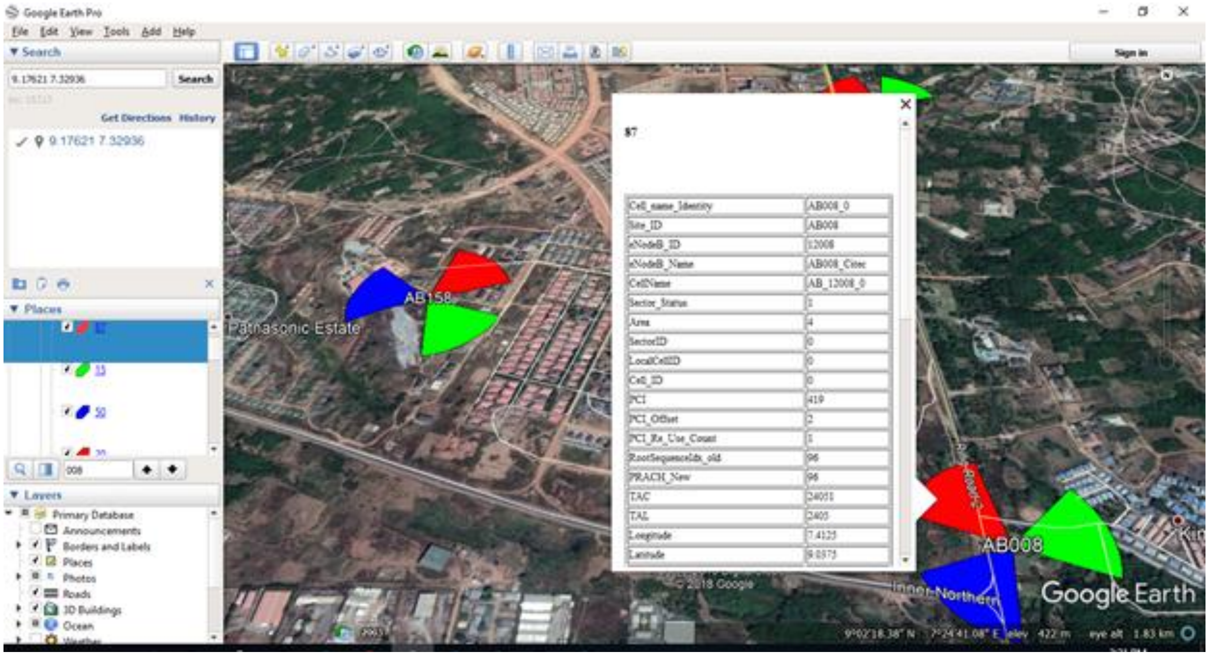

Figure 4.31: Troubleshooting SPECTRANET eNodeB Sectors AB158, AB008 and AB084 Serving MBORA District Abuja

The next line of action was to observe the loads (Average number of Users), congestion status and PRB utilization and PCI offsets of the eNodeBs, thus AB008 and AB158. As can be seen in the Figure 4.31, the average number of user latched into AB008 is 87 UEs while the supposed cell AB158 to be serving the UE under investigation has only 31 UEs latched at an average. Physical Resource Block utilization PRB are okay for both cells, from the KPI data observed in the last 72 hours (three days) showed AB008 surpassed 80% three times while AB158 maintained PRB utilization below 80%. Congestion trigger only occurred thrice on AB008 and none at AB158. PCI offset are both same, hence some level of interference but due to distances apart, the effect may be negligible unless proven otherwise at the end of the investigation.

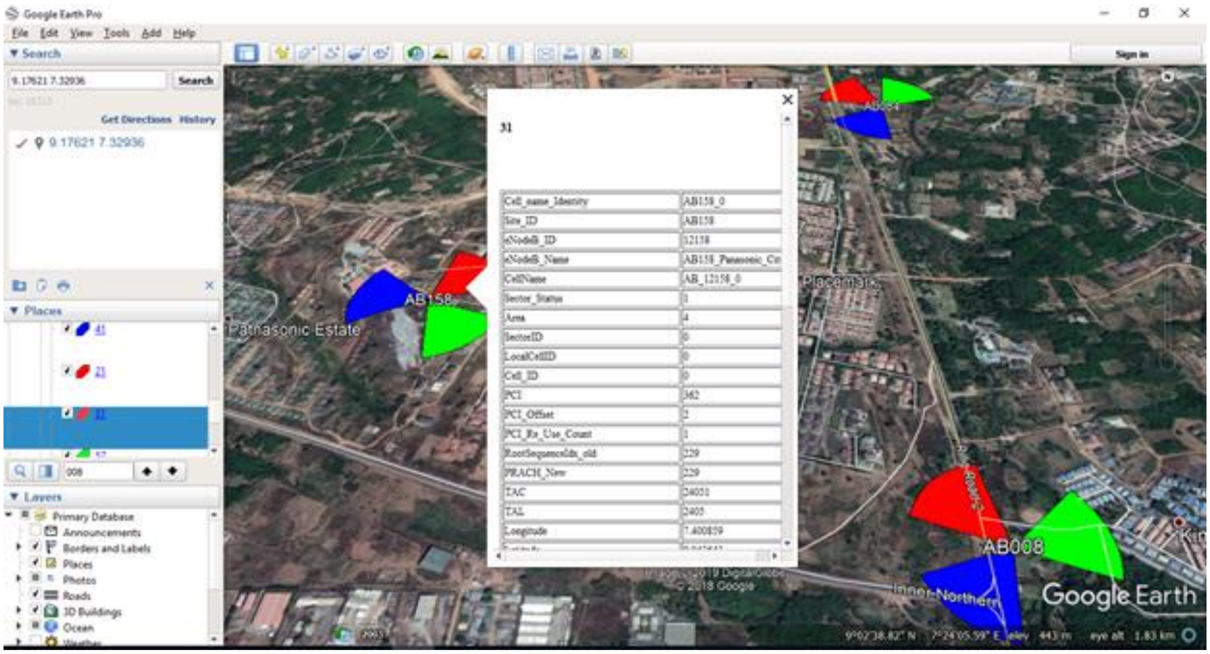

Figure 4.32: Troubleshooting SPECTRANET eNodeB Sectors AB158, AB008 and AB084 serving MBORA District, Abuja

The figure 4.32 confirms the average number of UEs (31) latched on AB158, PCI offset configuration and other parameter status

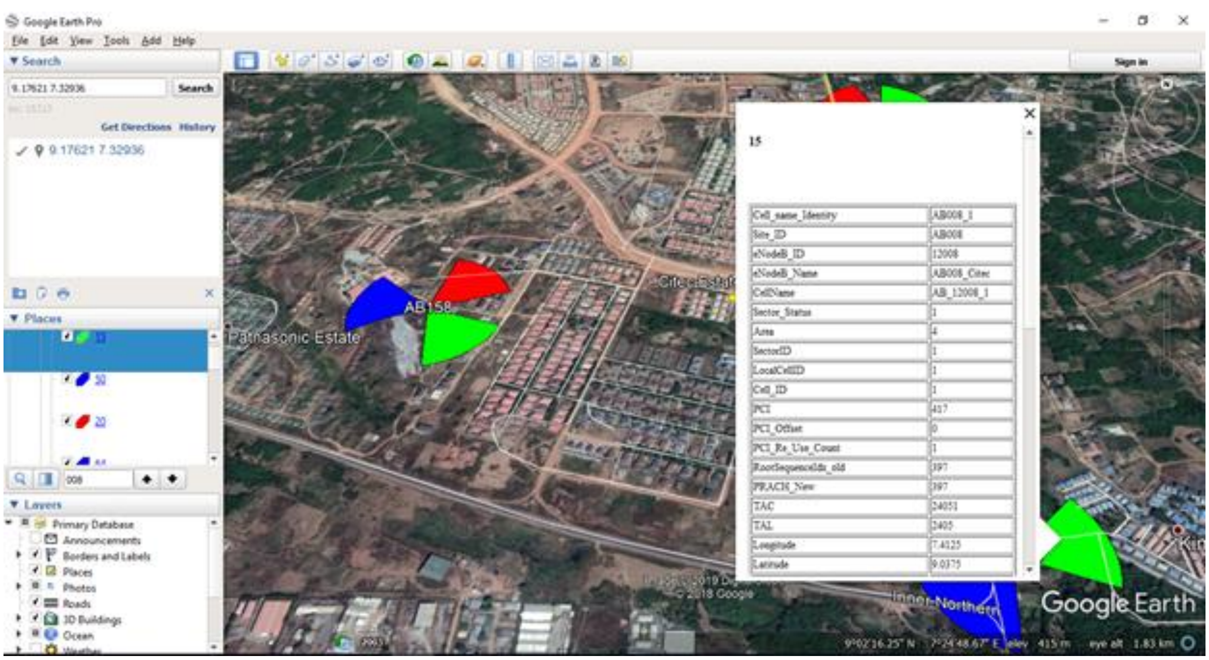

Figure 4.33: Troubleshooting SPECTRANET eNodeB Sectors AB158, AB008 and AB084 Serving MBORA District.

In order to ascertain the co cells of sector AB008, the load and performance of the neighbouring cells of same site was probed. The figure 4.33 confirms the average number of UEs (15) latched on AB008, PCI off of Zero (0) configuration and other parameter status. Everything here looks very fine, good SINR, good RSRP and RSRQ.

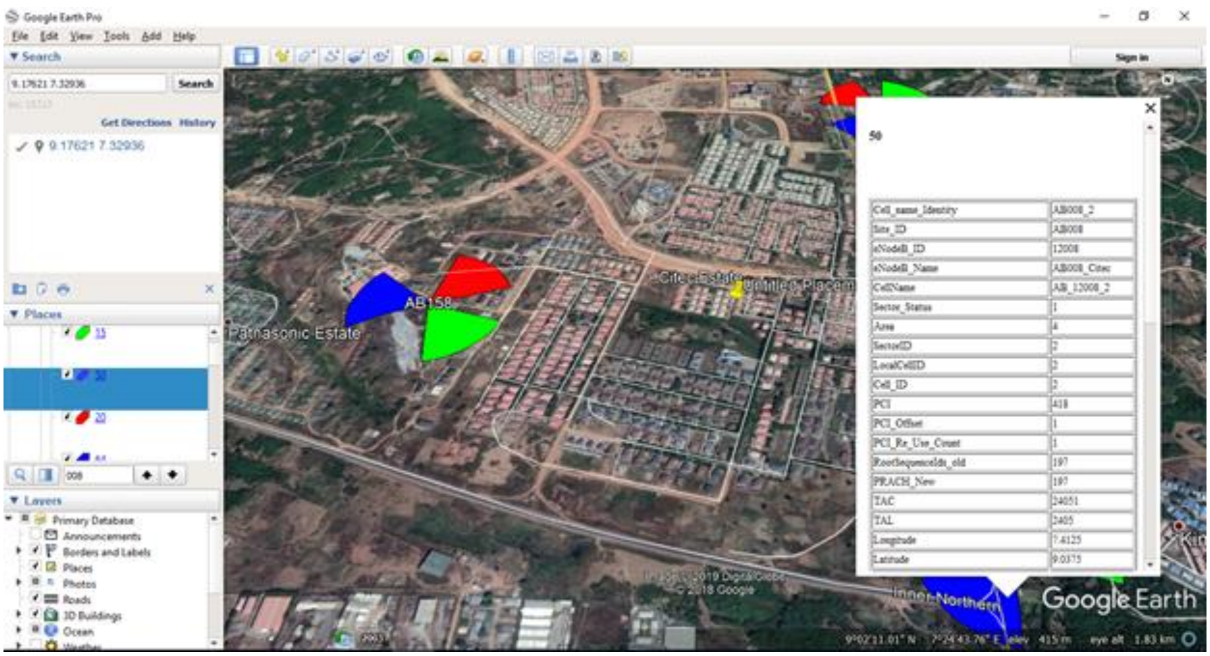

Figure 4.34: Troubleshooting SPECTRANET eNodeB Sites AB158, AB008 and AB084 serving MBORA District

In order to ascertain the co cell of AB008, the load and performance of cell was probed. Figure 4.34 confirms the average number of UEs (50) latched on AB008, PCI off set of one (1) configuration and other parameter status. Good SINR, good RSRP and RSRQ.

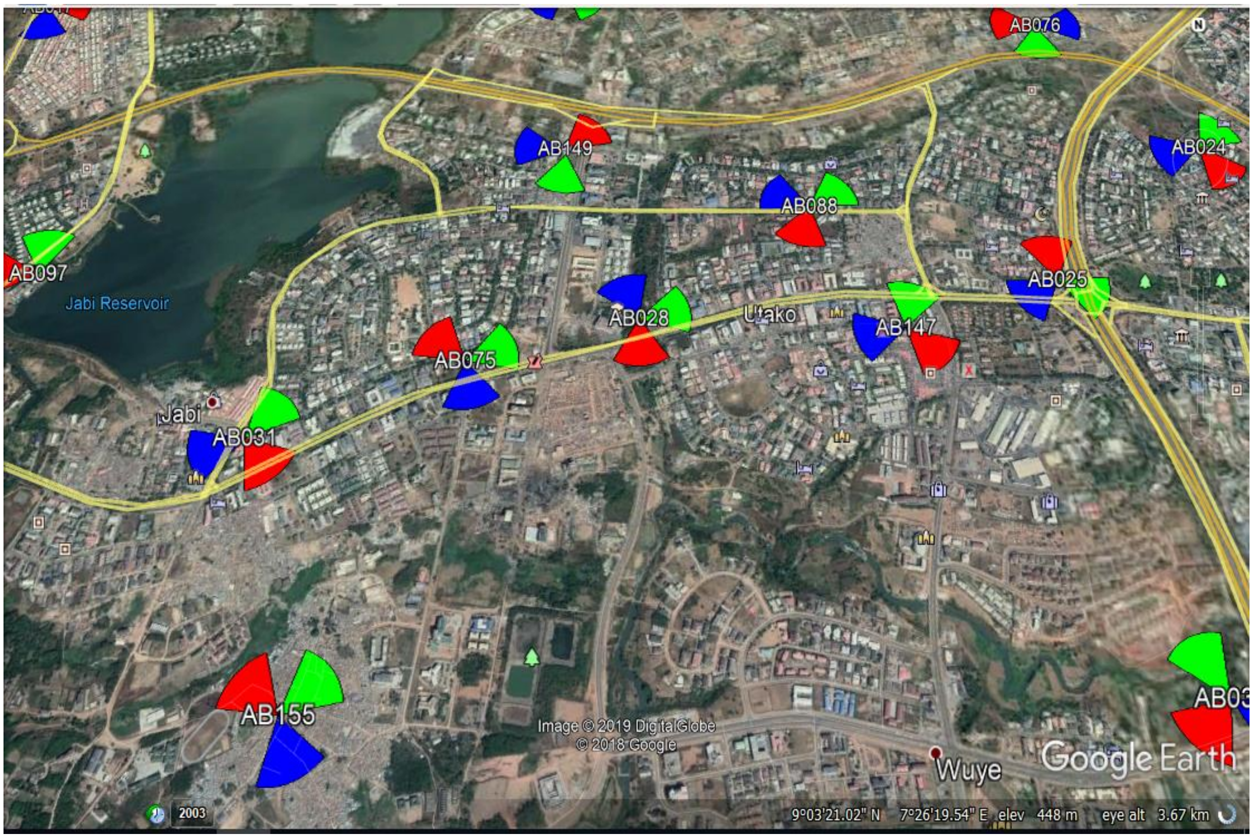

Figure 4.35: Overview of SPECTRANET eNodeB Sites in Abuja Metropolis

Summary and Resolution: The supposed cell to be serving the area with the UE under investigation was observed to be under underutilized while UEs under its designated footprint were experiencing low data throughput. This is because AB158 with PCI offset of two (2) has island coverage and lacks power concentration in the area of designated to serve as a dominant cell. It was down tilted to its designated area of coverage while the AB008_2 was also worked on, M1E2 to reduce its transmit power and improve the SINR within the area. These operations saw the UE under investigation latched back to AB158_2 and the load on AB008_2 balanced and QOS in both areas improved.

4.1.6 Drive Test Investigation and Analysis

Drive test helps identify cell's Physical Cell identifier (PCI) number, performance of RSRP which gives the detail of the total transmit power towards a particular area, RSRQ which gives details of quality of received signal at a every given location, and SINR value which presents ratio of signal strength against noise at every given location

Figure 4.36: Drive Test for Optimization over GWARIMPA eNodeB Sites

Figure 4.36 is a screen grab of events during drive test using TEMS Investigation 15.3.4, the Sites and sectors, PCI, and Signal Quality indication (Red= Poor, Yellow= Good, Green = Excellent). Observe the handover symbols, the monitoring cells etc.

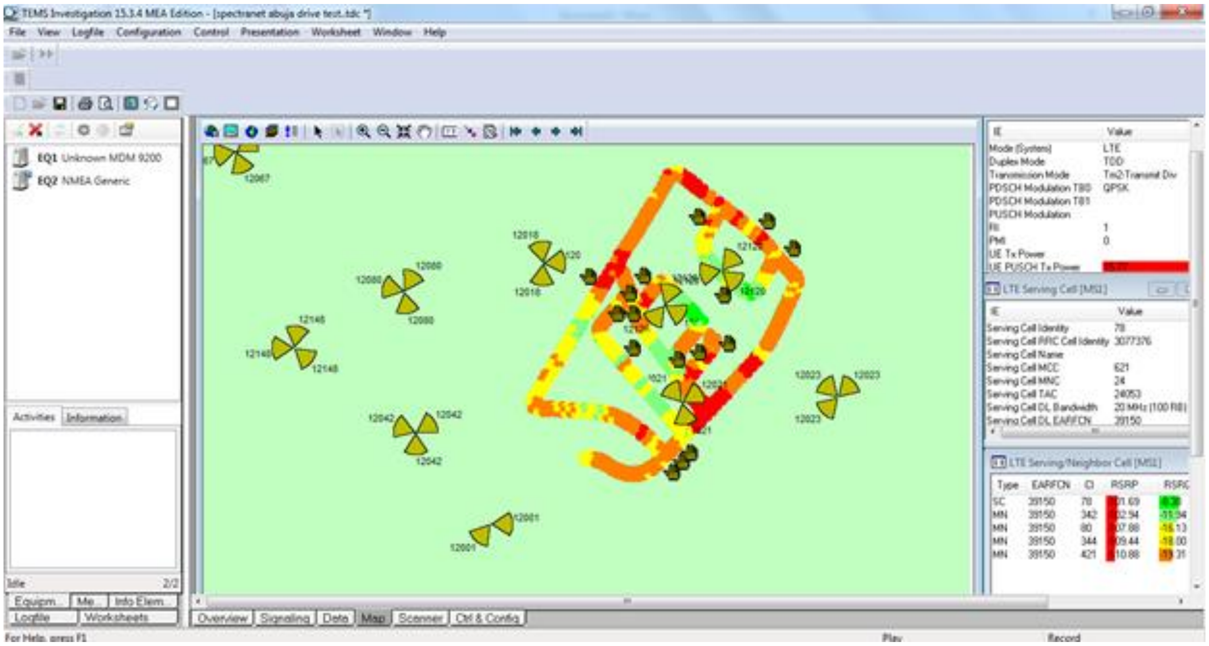

Figure 4.37: Drive Test for Optimization over MAITAMA District eNodeB Sites

Figure 4.37 is a screen grab of events during drive test using TEMS Investigation 15.3.4 at Maitama District Abuja, the Sites and sectors, PCI, Signal Quality indication is identified by colours (Red= Poor, Yellow= Good, Green = Excellent), observe some sites are two sectored sites but Majorly 98% of the sites in Maitama district are three sectored site, also observe the handover symbols, whenever there is frequent and successive handovers within a short distance, it becomes a sign degraded service or wrong configuration, the monitoring cells to each serving are listed on the right hand side of the tab viewing each connectivity and performance of each cell and UE, ever ready to accept UEs with poor RSRP and UEs making request for handover etc. The generated data log is further analysed using MapInfo software

4.1.7 MAP INFO Analysis

MapInfo professional is a software tool used to analyse data log collected during drive test, MapInfo helps to see the eNodeBs on map, as it relates to real life scenario. It shows the exact lobes of each cell in a site, helps to know the tilt angle with respect to azimuth and elevation. In a glance, MapInfo helps to visualize all the sites and observes the areas that needs coverage, interfering cells and shows the number of users in each cell. Drive test helps identify cell's Physical Cell identifier (PCI) number, performance of RSRP which gives the detail of the total transmit power towards a particular area, RSRQ which gives details of quality of received signal at a every given location, and SINR value which presents ratio of signal strength against noise at every given location.

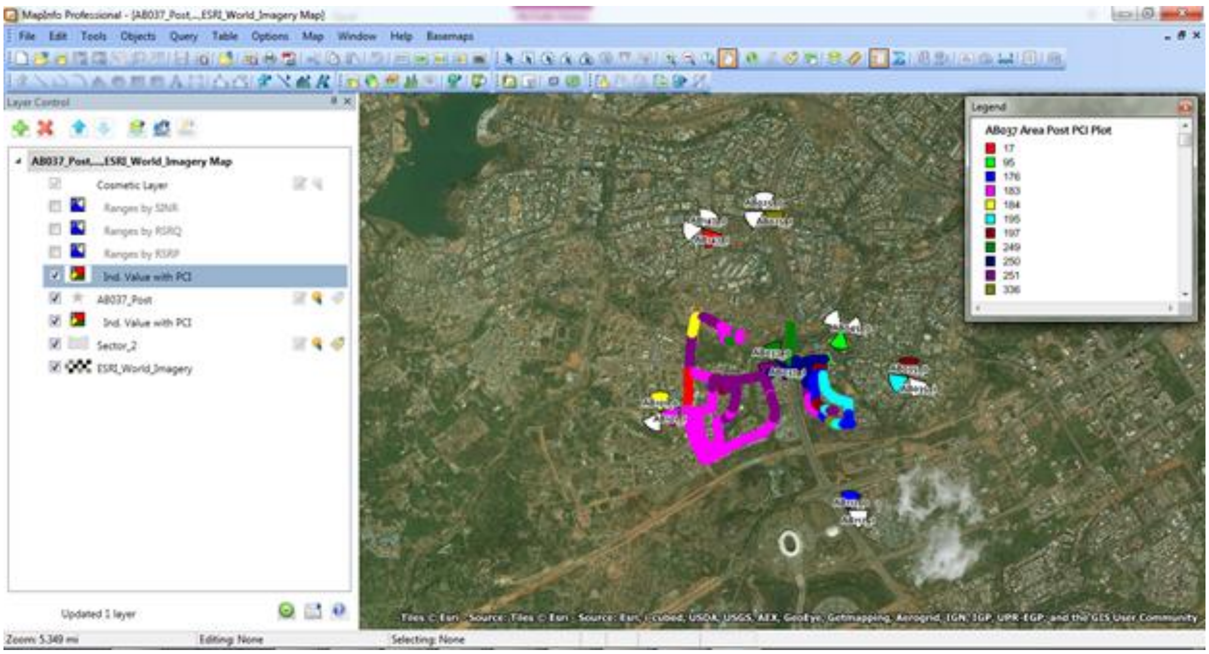

Figure 4.38: PCI Generation (AB037- WUSE Zone 7)

MapInfo Pro.11 gives pictorial view of the raw data collected and shows the exact location of events and aids for effective optimization after employing TEMs Investigation 15.3.4 MEA Edition. Captured and log files are extracted and saved as (.txt) extension file format, and imported to Microsoft excel. First step was re-arrange the excel file, filter and remove initialization stages without data capture and all null cells, leaving cells with most important parameters such as the Latitude and longitude, the Physical Cell Identity (PCI), RSRP, RSRQ and SINR. Import all the data captured through the movement path using each coordinate points into MapInfo and with the help of Environmental System Research Institute (ESRI) world Imagery tool, all the paths passed are now represented as dots in MapInfo GUI, the dots represents over 500, 000 data of different events captured during the drive test. It could be more depending on how long the drive test took and distances covered. Usually, 10 to 25 minutes is okay for defined drive test path of 2 – 5Km. The longer the drive test, the larger the volume of data obtained, hence more difficult to analyze. Although, MapInfo does best to simplify the analysis unlike any other tool; Secondly, check the PCI numbers that were captured during the Drive Test (DT), those captured represents active and serving cells during the DT. Filter the data to obtain only PCI column, from the given example, PCI 261, 340, 267 etc., all participated. Two or more PCIs can belong to one site and they are not serially numbered. It all depends on the network operator and at the time each cell is deployed. They can be in serial if the three cells came up at the same time, then it can be numbered as 240, 241 and 242 can easily be assigned to form a 3- sectored site.

Map the PCI on MapInfo ensuring they corresponds the coordinates. This function falls under the "individual values mapping tool" and the coordinates are obtained from Engineering Planning Tool (EPT) data. Subsequently, match the mapped PCIs with its corresponding cell Name identity such as AB147_0, AB147_1, AB147_2, AB025_0, AB025_1, AB025_2 etc. These cell names IDs appears on the top of each sector. Next thing to do on MapInfo is how to match the Dots created to its serving PCI? First, Assign colour to the all dots served by a particular PCI. For instance, if there are 11 PCIs that served during the drive test, it's important to list all and assign different colours to them and enable all dots to appear with their corresponding PCI colours across the path driven. This gives the representation sense of correlation between the dots and PCI showing the dots location each PCI served. Secondly the sectors all have same colour, next thing to do is to give each cell sector a colour. Already the corresponding PCI and their colours are known, then PCIs and Cell name IDs. Assign same colour given to PCI to its corresponding cell name IDs and enable. The MapInfo will now show each cell name ID with unique colour across the path of drive test. All sectors that appeared in 3-sector sites but did not serve during DT are considered to have one colour (say white) for clarification purpose, while those that participated have their unique colours. Next thing is to map out the other parameters as captured during the DT, thus RSRP, RSRQ, SINR

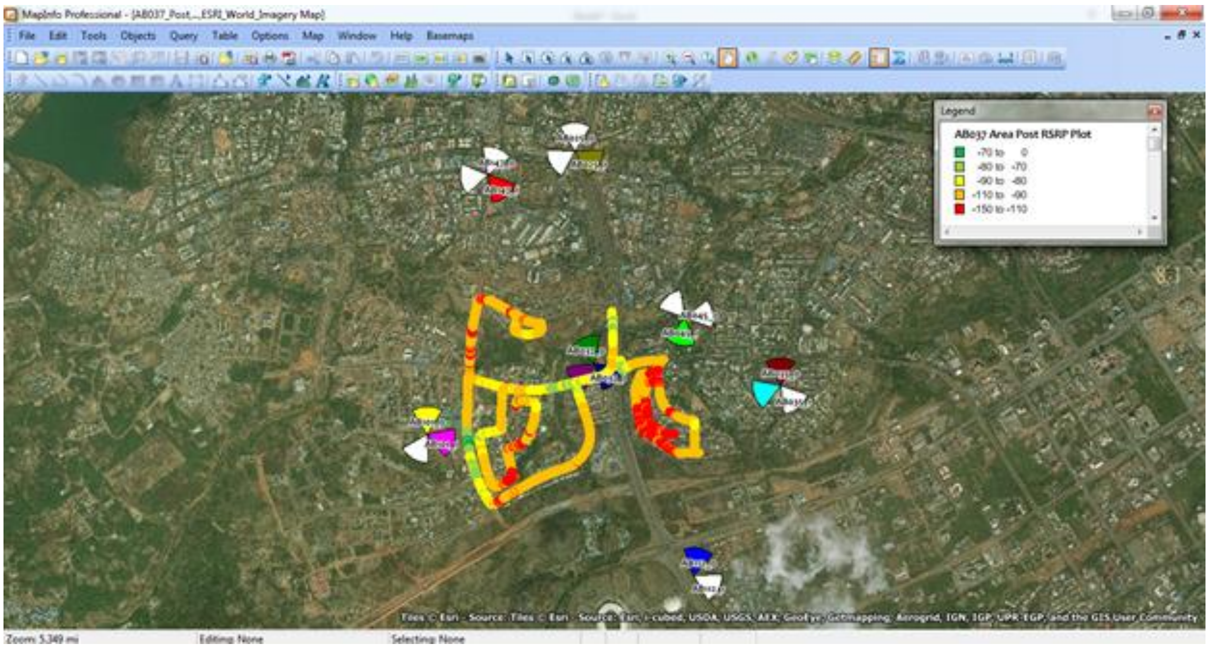

Figure 4.39: RSRP Value Data mapping on MapInfo

RSRP data shows the received power value of each eNodeB transmitting at a particular location and it varies from Zero (Zero) to -150dB. To give sense of judgment and correlation analysis, the values are grouped in ranges, SPECTRANET standard ranges (Figure 4.39) as follows:

-70 to 0dB = Excellent

-80 to -70 dB = Very Good

-90 to -80dB = Good

-110 to -90dB = Bad

-150 to -110dB = Very Bad

These ranges of values are given colours representing paths that have excellent RSRP (deep green), very good (Green), Good RSRP (Yellow), bad RSRP (pale red), and very bad (deep red), after stating and grouping the ranges, colours are assigned to each range then matched with the corresponding captured coordinates and finally plotted to display all paths with definitive colours showing class of performances. Observe the areas with bad and very bad performances, ascertain the cell serving the path, deduct why there are poor performances with respect to RSRP, is it caused by distances between serving eNodeBs with UE?, frequent handovers? Handover failures, number of users, lack of dominant cells? Weak coverages, Cross coverage, PCI offset interference, imbalance between uplink and downlink, fault devices etc.

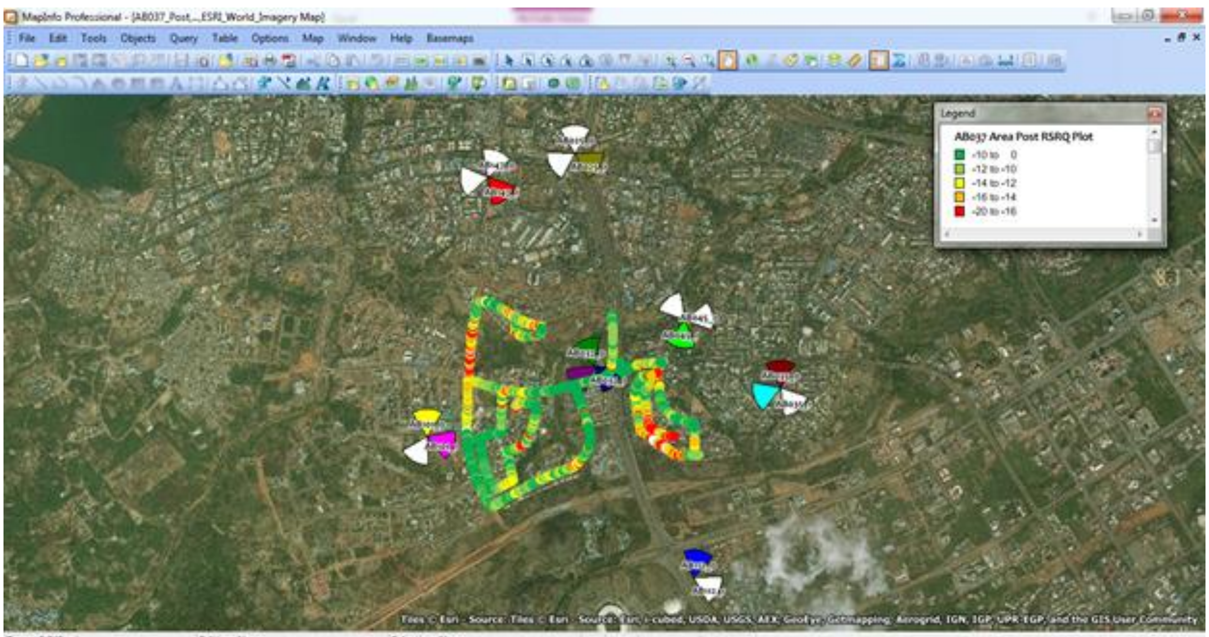

Figure 4.40: RSRQ Value Data Mapping on MapInfo

RSRQ depicts the quality of Radio frequency (RF) received signal, the quality of UE received signal at every point in time. It has values ranging from 0dB to -20dB.

For evaluation purposes, SPECTRANET groups the values to ascertain level of quality and performance.

-10 to 0dB = Excellent quality (Deep Green)

-12 to -10dB = Very Good quality (Green)

-14dB to -12dB = Good quality (yellow)

-16dB to -14dB = Bad quality (pale Red)

-20dB to -16dB = Very Bad quality (deep red)

Mapping and grouping the ranges, first, colours are assigned each range, then, match with the value ranges to its corresponding coordinates as captured, finally enable plot to display all paths with definitive colours showing class of performances. Observe the areas with good, bad and very bad performances, ascertain the cell serving the path, deduct why there are poor performances with respect to RSRQ, is it caused by distances between serving eNodeBs with UE?, frequent handovers? Handover failures, number of users, lack of dominant cells? Weak coverages, Cross coverage, PCI offset interference, imbalance between uplink and downlink, fault devices etc.

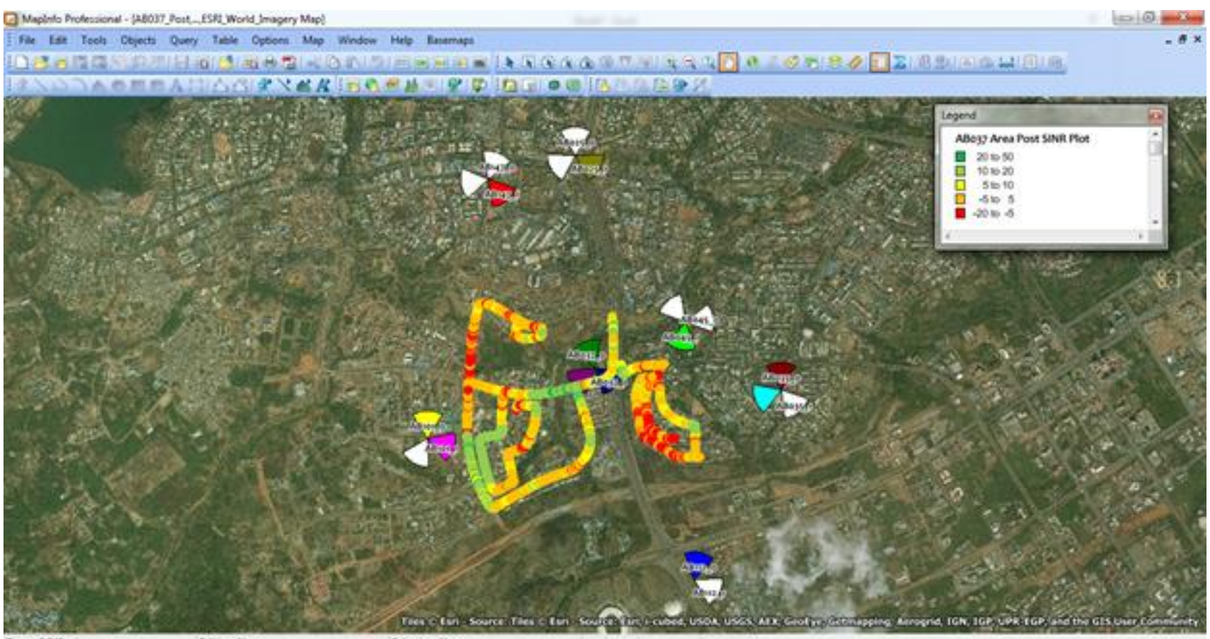

Figure 4.41: SINR Value Data Mapping on MapInfo

Signal to interference Noise ratio depicts the signal strength over noise and interferences at every point in time. It has a range of values from 50dB to -20dB

20 to 50dB = Excellent signal (deep green)

10 to 20dB = Very good signal (green)

5 to 10dB = Good signal (yellow)

-5 to 5dB = Bad signal (pale red)

-20 to -5dB = Very bad Signal (deep red)

First is to Map and group the value ranges, assigning colours to each range, then match them with corresponding coordinates as obtained and enable plot to display all paths with definitive colours showing class of performances. Observe the areas with excellent, bad and very bad performances, ascertain the cell serving the path (spots), deduct why there are poor performances with respect to SINR, is it caused by distances between serving eNodeBs with UE?, frequent handovers? Handover failures, number of users, lack of dominant cells? Weak coverages, Cross coverage, PCI offset interference, imbalance between uplink and downlink, fault devices etc.

4.2 Estimation and Modification of Existing Network Capacity of Network based on Empirical Data Obtained using MATLAB System Tools

The objective is targeted at using the analysed empirical data obtained from SPECTRANET

4.2.1 LTE Waveform Generation

Downlink waveform experiment was first carried out with observation of different RMCs, the waveform differences for different duplex modes. FDD and TDD, the variation in waveforms when OFMDA Channel Noise Generator (OCNG) for 10 sub-frames (10 ms) and 100 sub-frames generation were employed.

R.9 and R.13 was the reference measurement channel for this experiment, its parameters were modified to depict SPECTRANET configuration. Figures 4.43 – 4.48 were the generated waveforms of different parametrization. The MATLAB codes for these experiments is found in Appendix A

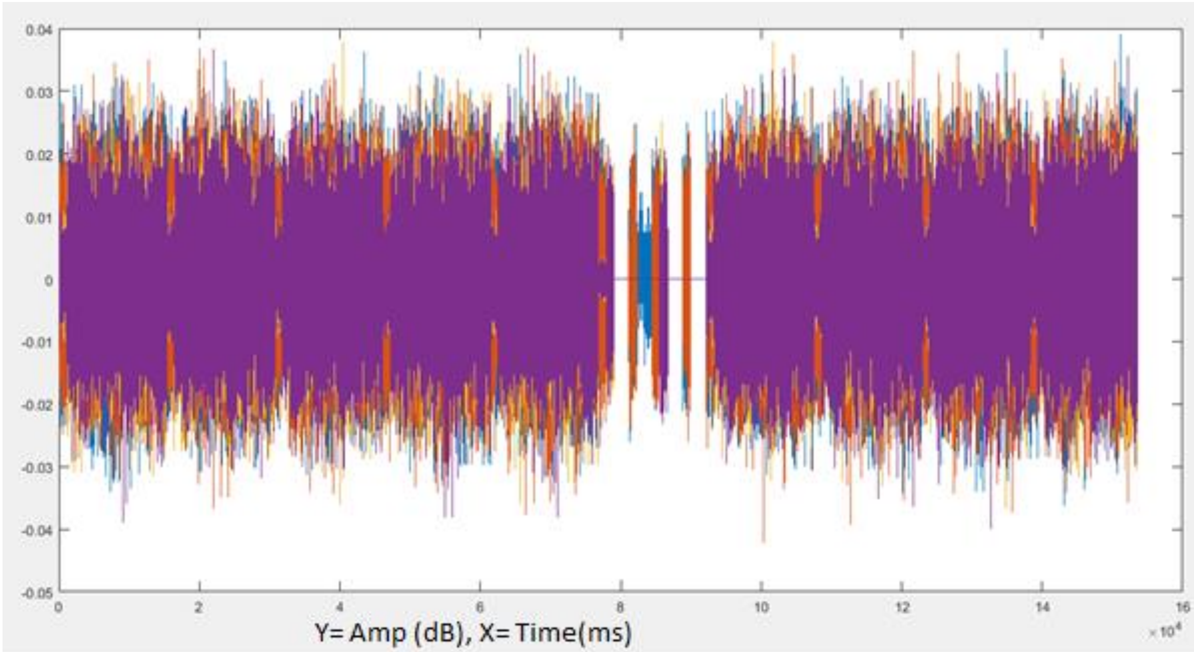

Figure 4.42: RMC.13, 50 PRB, QPSK, 4 Antennas, FDD, 8 HARQ, 10 Sub-Frame, and OCGN (off)

The resulting plot from figure 4.42 presents a standard compliant LTE PDSCH waveform, showing the real part of sub-frames 0 through 9 of the R.13 In-phase/Quadrature (I/Q) waveform, depicting realistic Peak to Average Power ratio (PAPR) and other characteristics of LTE waveforms. One of the major feature of R.13 RMC is transmission scheme which is Spatial multiplexing having 4x4 MIMO system. The waveform generated has four plots per cluster (given in different colours), each corresponding to one of the four transmit antennas model. The sixth sub-frame (sub-frame 5) includes a hole, as specified in 3GPP TS.36 101, which clarifies that the sixth sub-frame for above given configuration should not carry any data or Information bits in the physical downlink shared channel (PDSCH) transmission. The gap in the sixth sub-frame can be observed. The sixth sub-frame with dark blue plot includes no data because the primary and secondary synchronization signals (PSS/SSS) are located in that sub-frame and transmitted from only one antenna.

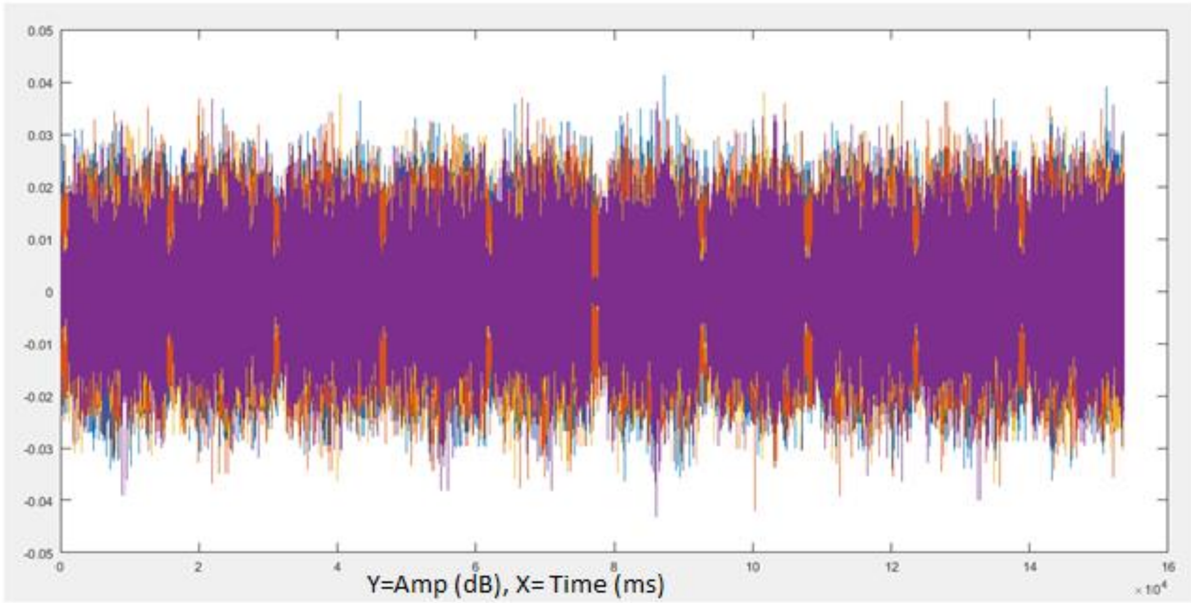

Figure 4.43: RMC.13, 50 PRB, QPSK, 4X4 Antennas, FDD, 8 HARQ, 10 Sub-Frames, OCGN (on)

The Figure 4.43 shows the waveforms of PDSCH signal with introduction of noise, which increased the distortion of the signal, observe the sixth subcarrier now looks as other PDSCH sub-carriers meant for data transmission. Refer to 3GPP TS 36.101, Annex A.3, reference PDSCH transmissions are not scheduled in sub-frame 6 except for the SIB1 associated with PDSCH, enabling the OCNG parameter fills all unused PDSCH resource elements with QPSK modulated random data. Introduction of OFDM noise makes estimation and recovery at receiver more complex, there are numerous measures in 4G LTE to cushion the effect of noise at the receiver, such as Forward Error Correction (FEC), filters, Turbo decoder etc.

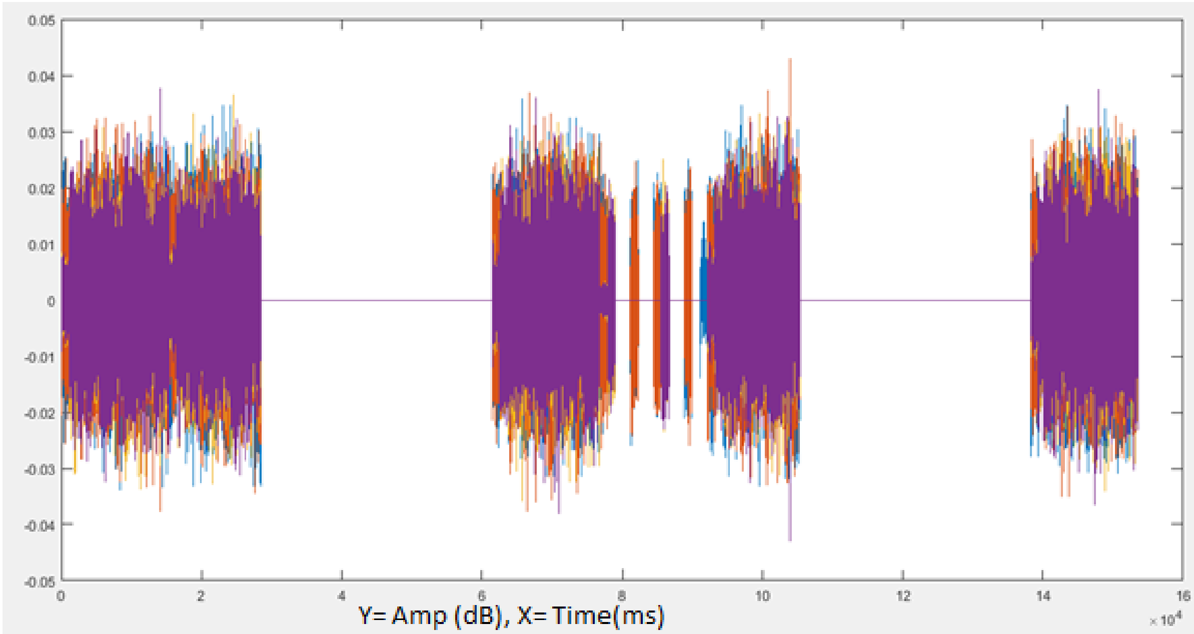

Figure 4.44: RMC.13, 50 PRB, QPSK, 4X4 Antenna, TDD, 7 HARQ, 10 Sub-Frames, OCGN (off)

Figure 4.44 depicts the TDD waveform signal for 10 sub-frames; observe clearly only 5 sub-frames are used for transmission PDSCH against whole 10 sub-frames as can be seen in FDD waveform where the whole of the sub-frames are used for PDSCH data transmission. However if OCNG is enable the sixth subcarrier designated for PSS/SSS is distorted

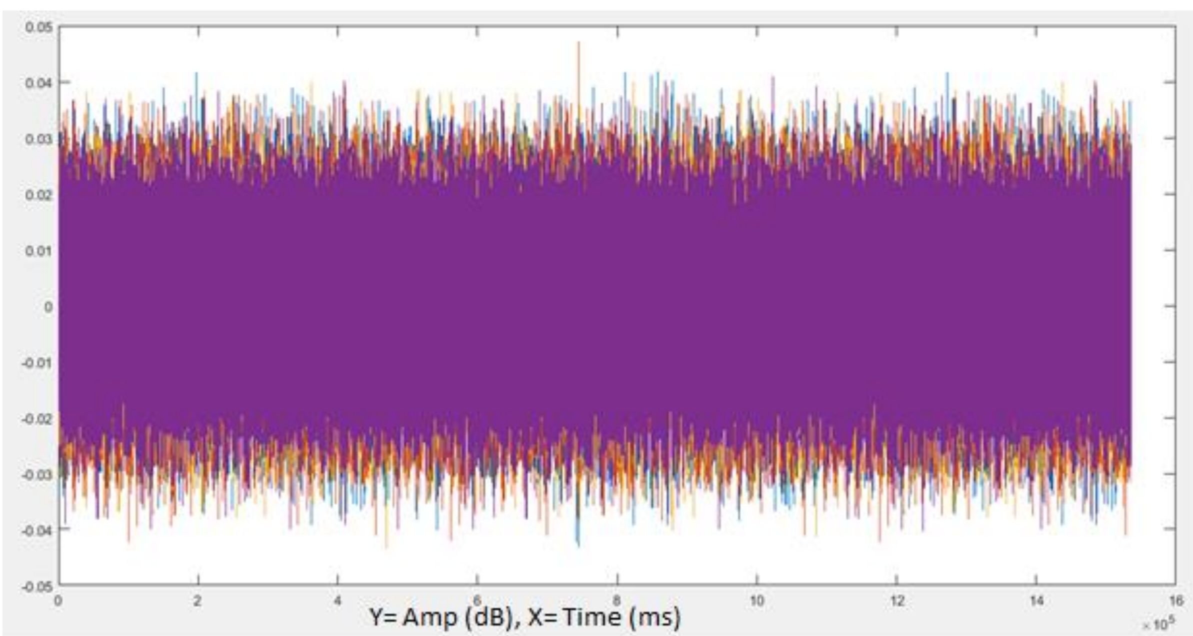

Figure 4.45: RMC.13, 50 PRB, QPSK, 4x4 Antenna, FDD, 8 HARQ, OCGN (on), Sub-frames=100

Figure 4.45 depicts the FDD waveform signal for 100 sub-frames (10 packet frames) generation; observe that the subcarriers are not distinct from each other; it is because of channel imperfection and noise introduction. Secondly, for FDD configuration, the whole spectrum is used for data transmission. However the signal waveforms generated without noise showed each cluster of subcarriers separate from the next cluster. See figure (4.46)

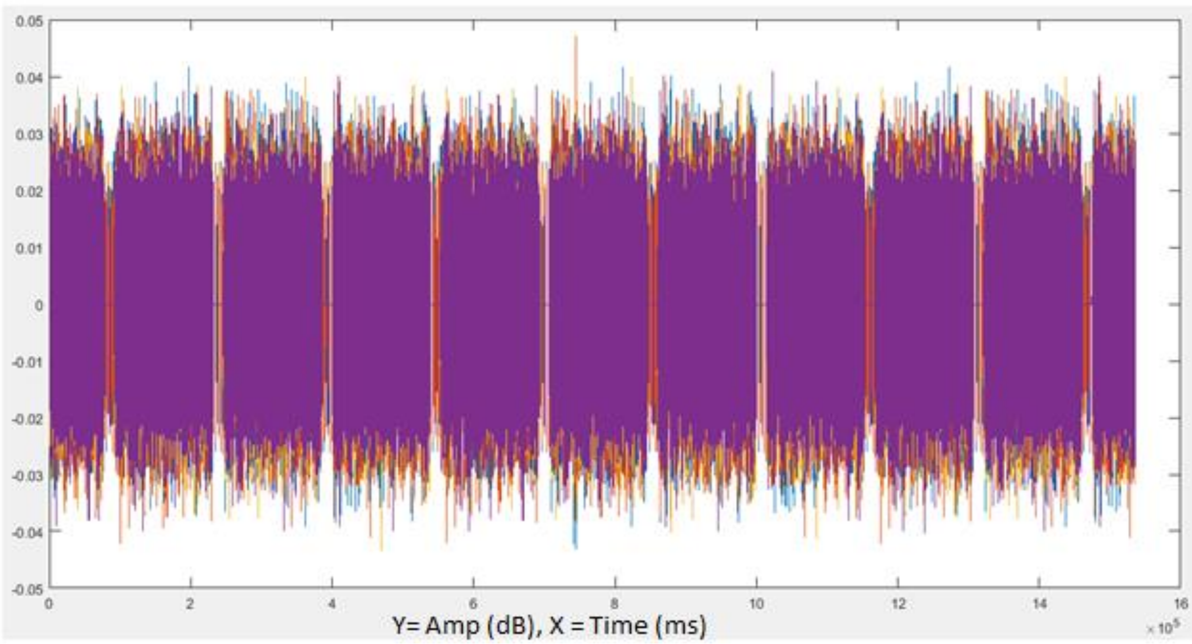

Figure 4.46: RMC.13, 50 PRB, QPSK, 4X4 Antenna, FDD, 8 HARQ, OCGN (off), Sub-frames=100

Figure 4.46 shows the LTE FDD Waveforms of 100 sub-frames without OFDM Channel noise generator. Observe distinct clusters of carriers against the waveform in figure 4.45

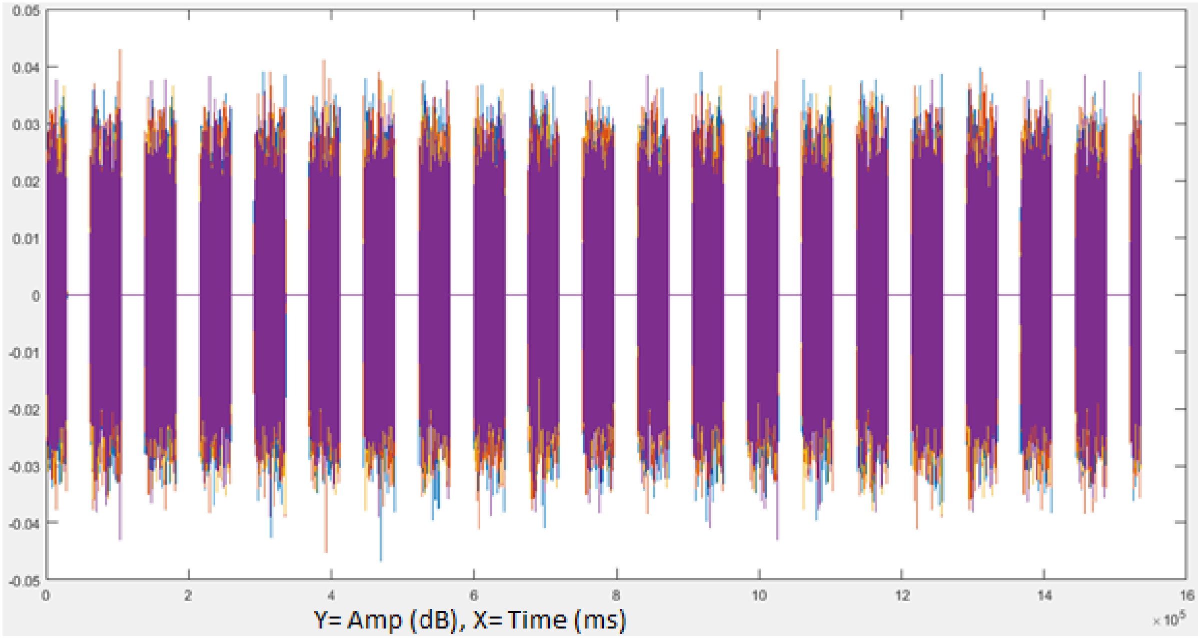

Figure 4.47: RMC.13, 50 PRB, QPSK, 4X4 antenna, TDD, 7 HARQ, OCGN (on), Sub-frames=100

The figure 4.47 shows the generated signal waveform and the effect of higher number of sub-frames (100 sub-frames) for TDD configuration. Half of the spectrum is used for PDSCH data transmission, hence the reasons for well separated cluster of subcarriers.

Observe the separation of carriers in the spectrum as result of Time division Duplex that has shared spectrum for both uplink carriers and downlink carriers while FDD has a paired spectrum, one full spectrum serves downlink carriers and the other serves uplink carriers,

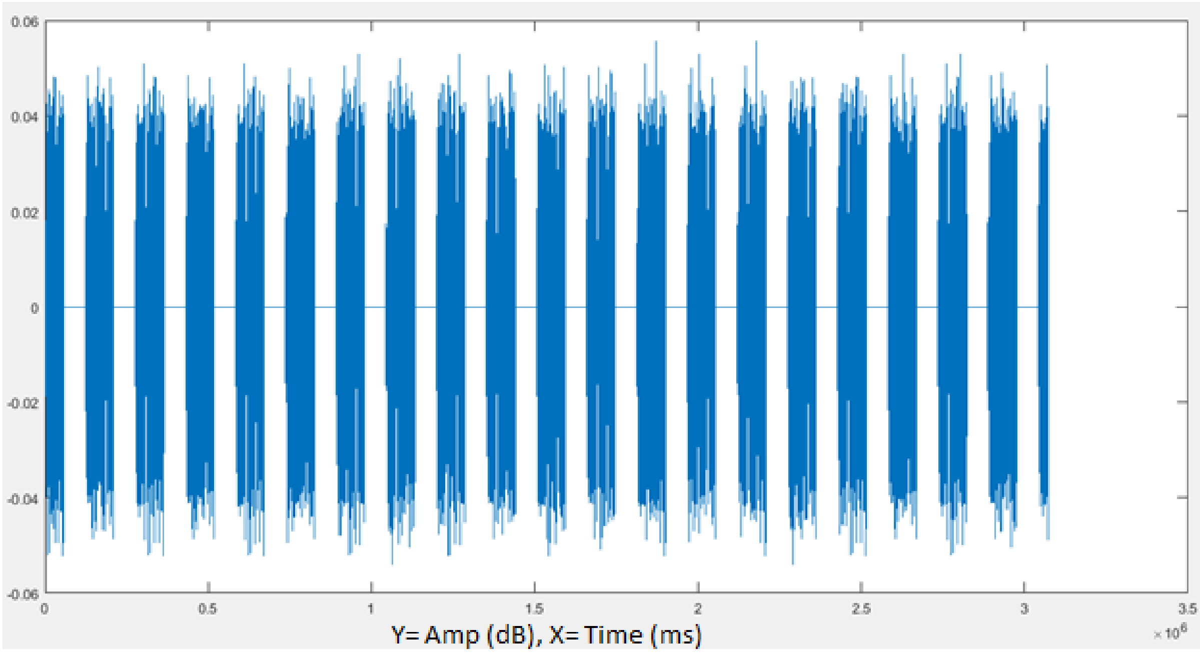

Figure 4.48: RMC.9, 100PRB, 64QAM, 1TX antenna, TDD, 7HARQ, OCGN (ON), 100sub-frames

RMC.9 configuration has one transmit antenna, hence, figure 4.48 shows the effect of signal waveform generated under one transmit antenna. Here there is only one colour representing one antenna signal as against cluster of four signals represented in four different colours emanating from four transmit antennas.

4.2.2 Downlink Waveform Spectrum

The spectrum of individual Reference measurement channel (RMC) waveforms generated can be plotted using a MATLAB function "periodogram" in the command line window. Periodogram is a vital function for examining the amplitude and frequency characteristics of an LTE generated signal. Periodogram is the spectrum of a set of time based signal typically obtained by fast Fourier transform (FFT) of the LTE OFDMA system. Periodogram tends to estimate the spectral density of a signal (also known as Power Spectral density) which characterizes the frequency components of the signal. The estimate of spectral density also detects the periodicity in the data transmitted by observing the peaks with respect to time (ms), It usually shows frequency (MHz) in x-axis, and Power spectral Density (PSD) (dBm/Hz) in y-axis.

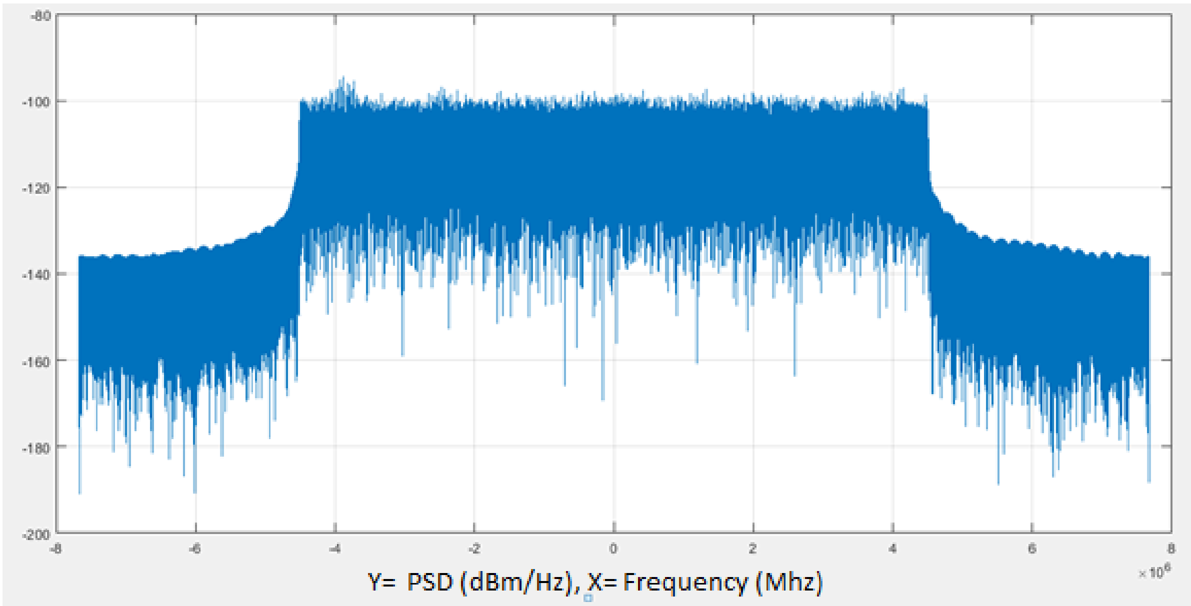

Figure 4.49: RMC.13 SPECTRUM

The spectrum figure shows that the 50 resource blocks allocated for R.13 correspond to 10MHz signal bandwidth as specified in 3GPP TS 36.101

PSD is the power per unit bandwidth, the power spectral density (PSD) of a signal describes the power present in the signal as a function of frequency, per unit frequency. Power spectral density is commonly expressed in watts per hertz (W/Hz) or (dBm/Hz)

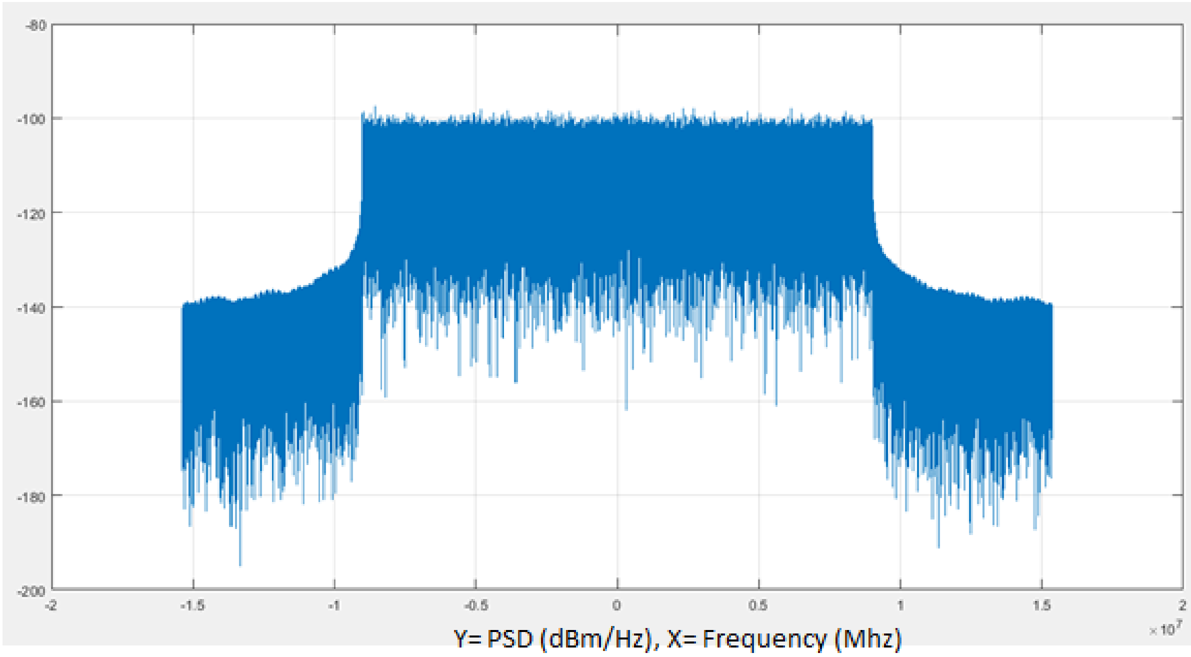

Figure 4.50: RMC.9 SPECTRUM

The above standard-compliant waveform spectrum shows that the 100 resource blocks allocated for R.9 correspond to a 20 MHz signal bandwidth as specified in 3GPP TS 36.101

The carrier frequency in the uplink and downlink is designated by the E-UTRA Absolute Radio Frequency Channel Number (EARFCN) in the range 0 - 65535. The relation between EARFCN and the carrier frequency in MHz for the downlink and Uplink is given in 3GPP table of E-UTRA channel number of 3GPP TS-36.141

The procedures and MATLAB lines codes for generating the spectrums are attached at the appendix A of this work. EUTRA-Test model experiment will helps to observe the LTE Downlink E-test model Waveforms, the Downlink Physical Resource grid and its component arrangement and finally, the SPECTOGRAM for each configured parameter test as experimented in chapter 4.2.3

4.2.3 LTE Downlink Resource Grid and SPECTOGRAM E-TM 3.1

The channel model number and the allocated bandwidth determine the physical channel and signal parameters as specified in 3GPP TS 36.141. The generated waveform using

MATLAB function "timeDomainSig" is a time domain signal after performing OFDM modulation, cyclic prefix insertion and windowing. "txGrid" is a 2-dimensional array representing the resource grid spanning over 10 sub-frames. Reference Measurement Channel (RMCs) and Fixed Reference Channel (FRCs) are useful signals for investigating the frequency components of the waveforms, and the throughput of an LTE system. Corresponding waveforms generated include a single user that typically occupies the whole bandwidth. Nevertheless, testing transmitter performance or eNodeB performance requires more dynamic signals, such as E-TMs, the Evolved Universal Terrestrial Radio Access Test Models. In these special channels, the resource allocation for a user (PDSCH) changes with every sub-frame (1ms), and there can be several users (PDSCHs) transmitting at the same time.

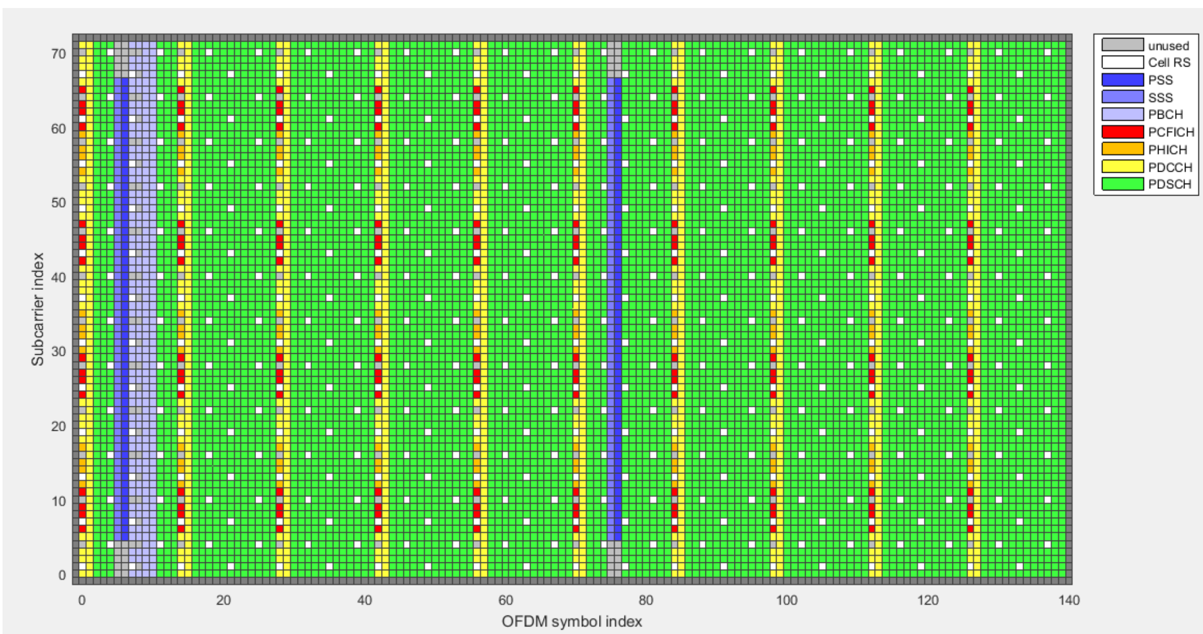

Figure 4.51: Generated Physical Downlink Resource Grid for Test Model E-TM 3.1, (1.4/20MHz)

The following physical channels and signals are generated:

- Reference Signals (Cell RS)
- Primary Synchronization Signal (PSS)
- Secondary Synchronization Signal (SSS)

- Physical Broadcast Channel (PBCH)
- Physical Control Format Indicator Channel (PCFICH)
- Physical Hybrid-ARQ Indicator Channel (PHICH)
- Physical Downlink Control Channel (PDCCH)
- Physical Downlink Shared Channel (PDSCH)

Observe from the resource grid that the resulting number of sub-carriers and OFDM Symbol index is a function of the applied channel bandwidth. 3GPP Technical Specification TS.36, 1.4 Mhz bandwidth has 6 Physical Resource blocks (PRB), and each PRB corresponds to 12 OFDM or 14 OFDM (depending on the applied CP) subcarrier, hence total of 72 sub-carriers. Same is applicable to the resource grid when 5MHz (300 subcarriers), 10 MHz (600 subcarriers) and 20 MHz (1200 subcarriers) bandwidth is experimented.

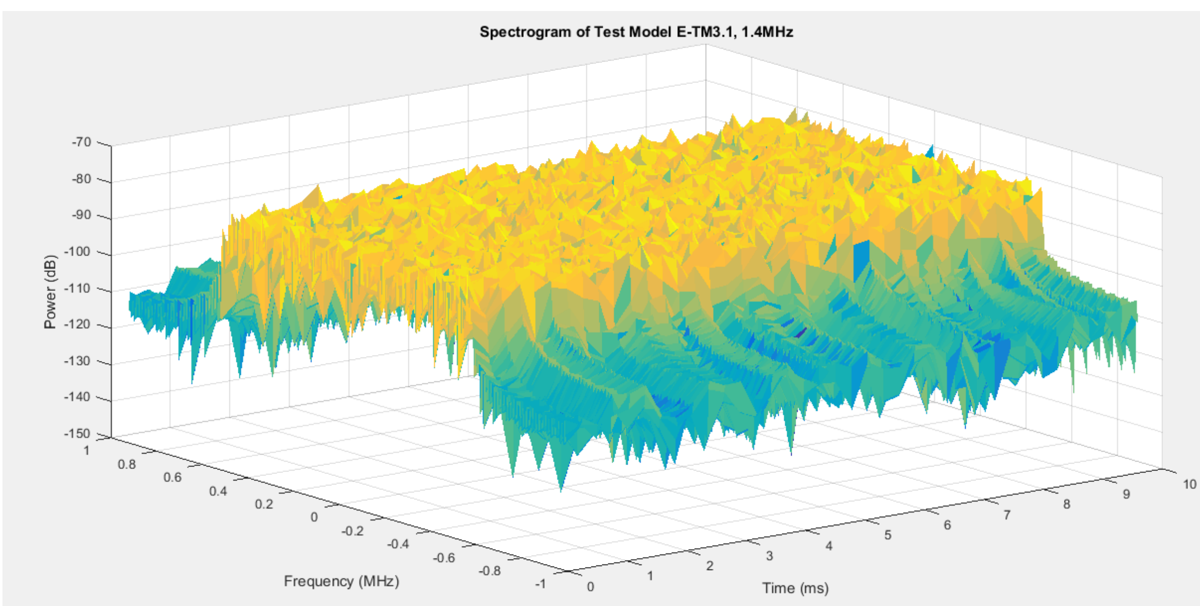

Figure 4.52: Generated Physical Downlink SPECTOGRAM for Test Model E-TM 3.1, 1.4MHz

Spectrogram is plotted from the time domain signal; it rearranges the frequency axis and put zero frequency at the middle characterizing a complex baseband waveform.

Spectrogram is advanced representation of spectrum.

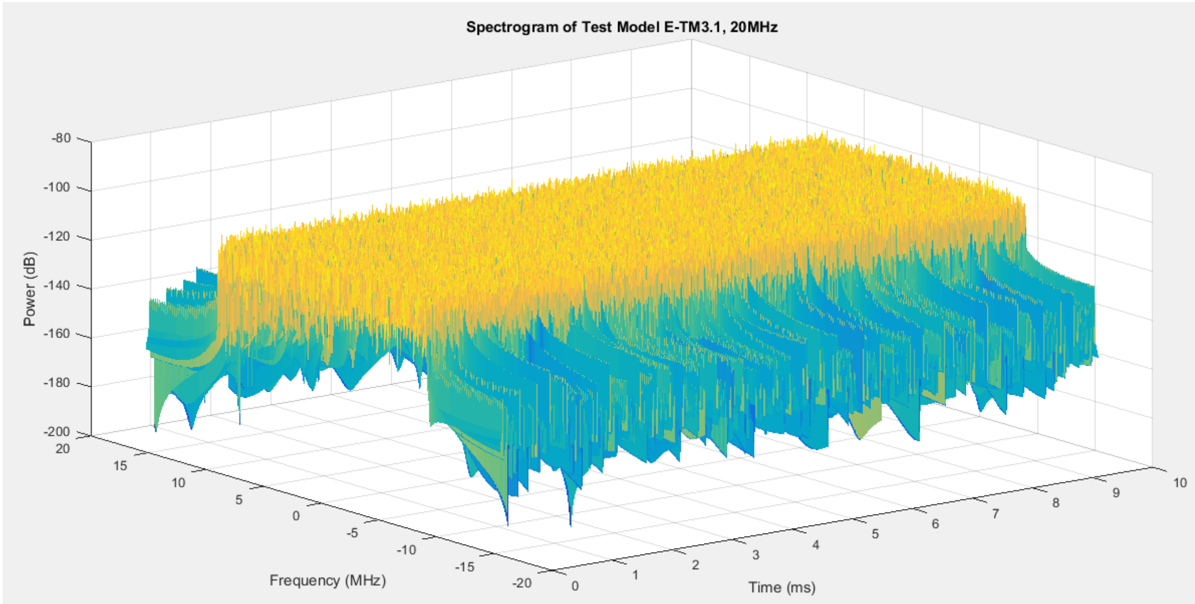

Figure 4.53: Generated Physical Downlink SPECTOGRAM for Test Model E-TM 3.1, 20MHz

Spectrogram can be seen as multiple short periods of spectrum combined together, it is usually obtained by short-time fast Fourier transform

It is three dimensional by nature, which includes time, frequency and magnitude of spectrum; usually time (ms) values plotted on x-axis, frequency (Mhz) values on y-axis, and power (dB) values on Z-axis. Spectrogram makes use of colours to show the magnitude of spectrum

4.2.4 Bit-Error-Rate Testing and Evaluation

Bit error rate, (BER) is a key functional parameter in telecommunication that is used in evaluating systems that transmit digital signal (data) from one transmitting station to one or more receiving stations. BER can be used to assess the performance of radio link as well as Ethernet and fibre optic links for data transmission. The major causes of transmitted data bits to be in error are the channel imperfection, noise, phase jitter, interference etc but mainly noise and changes in propagation path (multipath). These factors causes degradation on the quality of signal demodulated or received.

4.2.5 Relationship between Eb/No and SNR

The energy per bit to noise power spectral density ratio (E_b/N_0) is an important parameter in digital communication. It is a normalized signal-to-noise ratio (SNR) measure, also known as the "SNR per bit". It is especially useful when comparing the bit error rate (BER) performance of different digital modulation schemes without taking bandwidth into account.

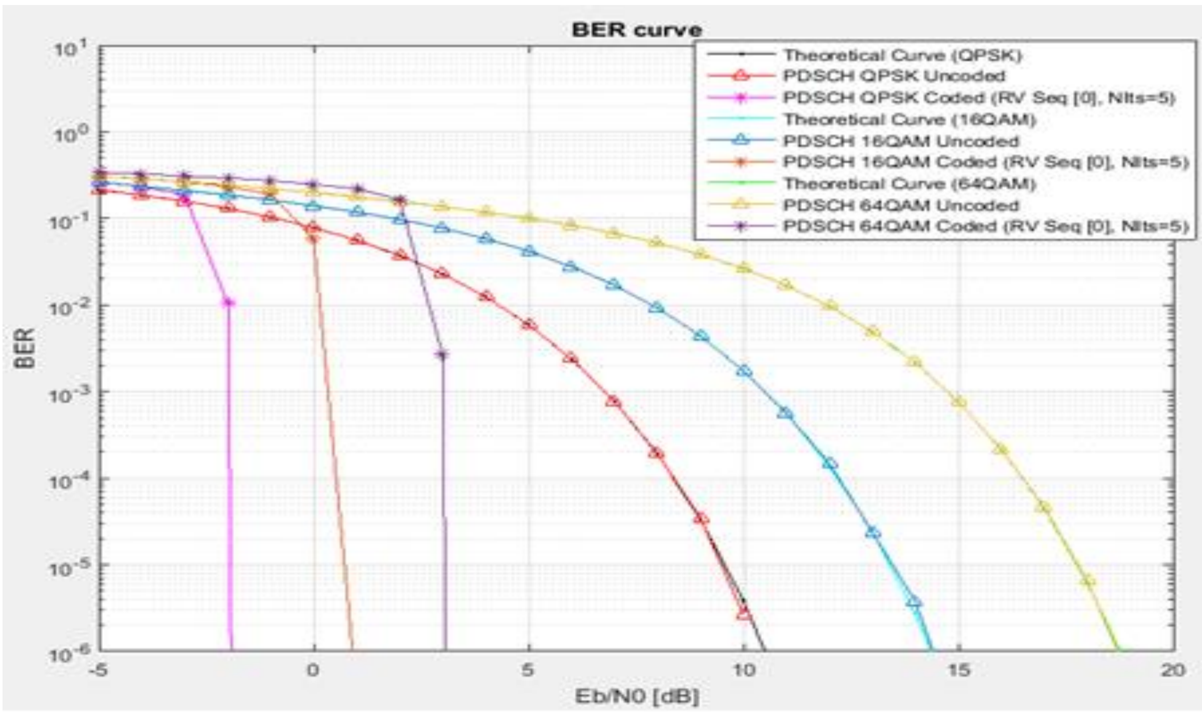

Figure 4.54: BER Performance for QPSK, 16QAM, and 64QAM

The figure 4.54 plot has the following configuration, transport block size (6000), available PDSCH bits (12780), Modulation (QPSK, 16QAM, 64QAM), Eb/No Range (-5: 1:20) , Redundancy version was set to zero [0], turbo decoder iteration set to [5] five

BER increases in Vertical Y-axis, while Eb/No increase horizontally in x-axis. BER remains one of the best metrics to characterize the performance of a digital communication system. When the bit-error-rate BER is high, many received bits will be in error. The worst-case bit-error-rate is 50 percent, at which point, the modem is essentially useless. Most communications systems require bit-error-rates several orders of magnitude lower than this. Even a bit-error-rate of one percent (0.01) is considered quite high, to plot a curve of the bit-error-rate as a function SNR, enough points is needed to cover a wide range of bit-error-rates. At high SNRs, this can become difficult, since the bit-error-rate becomes very low. For example, a bit-error-rate of 10^{-6} means only one bit out of every million bits will be in error. If our test signal only contains 1000 bits, no error is likely to be seen at this Bit-error-rate. For error rate to be statistically significant, each simulation must generate some number of errors. If a simulation generates no errors, it does not mean the bit-error-rate is zero; it only means enough bits were not transmitted. Observe from the plot in figure 4.54, at very low Eb/No, all the modulation order tend to have similar BER performance also close to the theoretical curve and un-coded curve performances. However, with little increase in energy bits, QPSK showed a stronger BER performance as compared to 16QAM and 64QAM. For instance, QPSK has BER of (10^{-2}) at about -3dB Eb/No, while for same BER (10^{-2}) performance, 16QAM and 64QAM requires Eb/No of 2dB and 4dB respectively.

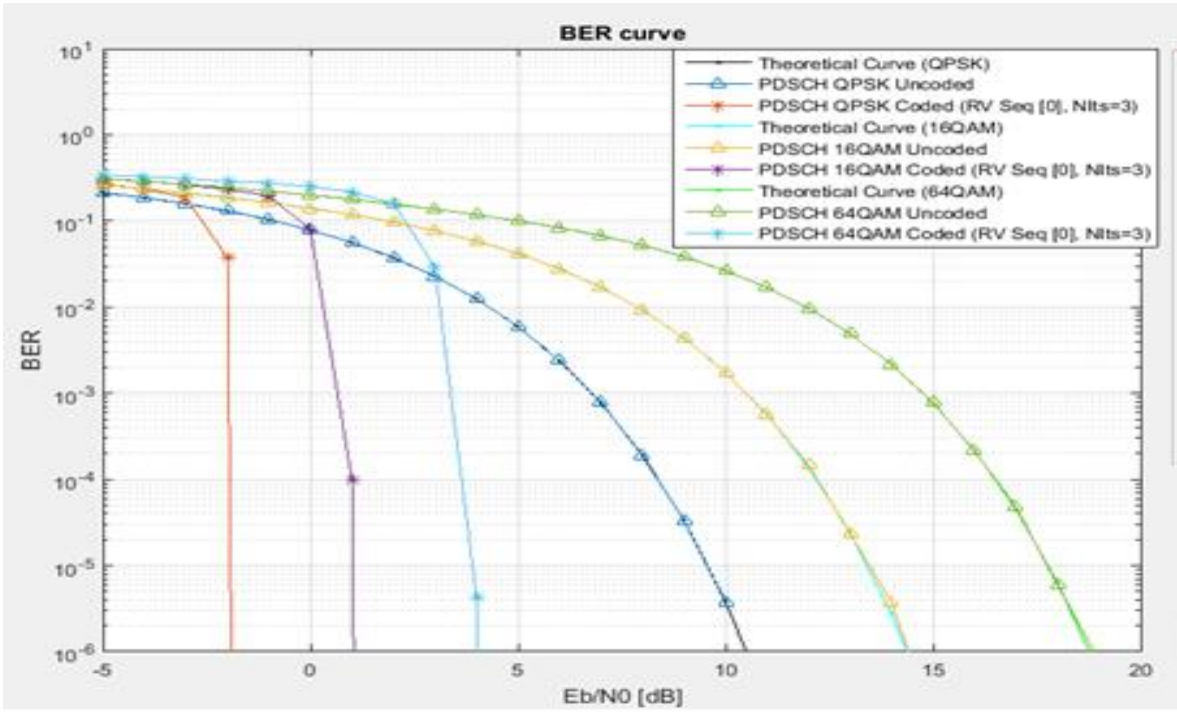

Figure 4.55: BER Performance for QPSK, 16QAM, and 64QAM, Nits (3)

The plot in figure 4.55 has the following configuration, transport block size (6000), available PDSCH bits (12780), Modulation (QPSK, 16QAM, 64QAM), Eb/No Range (-5: 1:20) , Redundancy version was set to zero [0], turbo decoder iteration set to [3].

Observe with the reduction in the number of iteration of the turbo decoder the BER performance for QPSK, 16QAM and 64QAM all degraded requiring more energy per bit

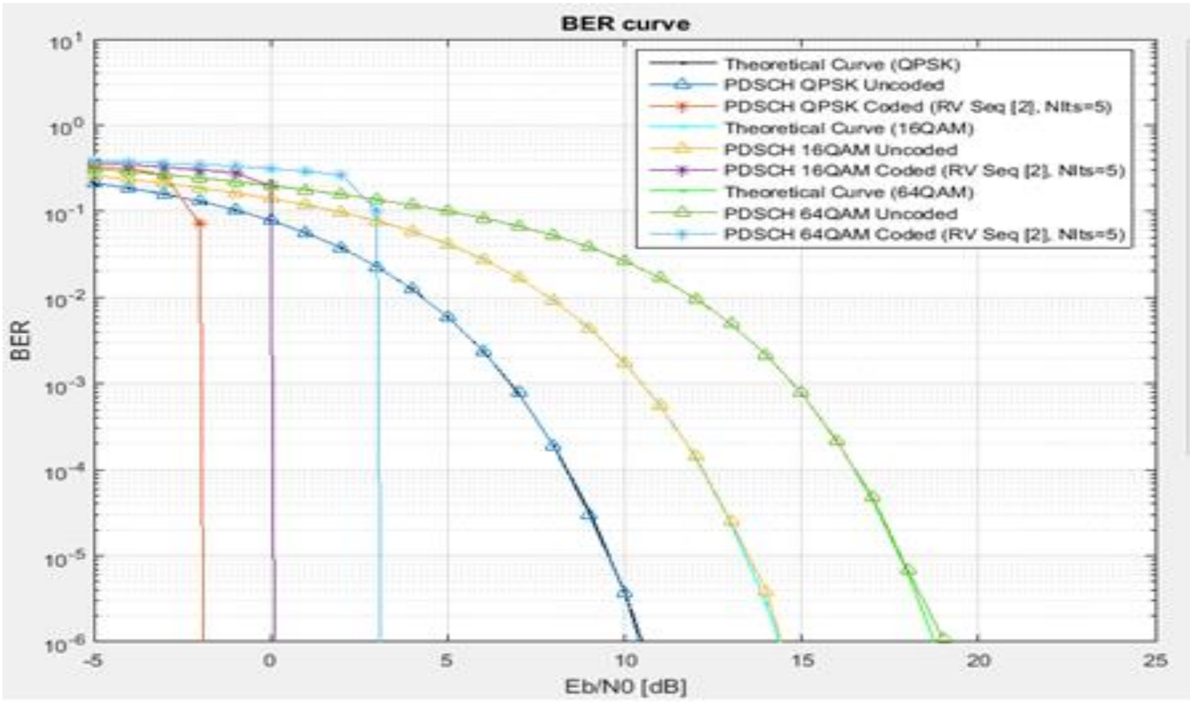

Figure 4.56: BER Performance for QPSK, 16QAM, and 64QAM, RvSeq (2)

Figure 4.56 has the following configuration, transport block size (6000), available PDSCH bits (12780), Modulation (QPSK, 16QAM, 64QAM), Eb/No Range (-5: 1:25) , Redundancy version (2) was set, turbo decoder iteration set to [5].

Observe that with redundancy version of [2], BER performance for the three modulation order got worse and most bits are received in error.

In summary, knowledge of the BER also enables other features of the link such as the power and bandwidth etc. (BER) testing is a powerful methodology for end to end testing of digital transmission systems. A BER test provides measurable and useful information of a network system operational performance. If the BER rises too high then the system performance will noticeably degrade. If it is within limits then the system will operate satisfactorily

4.2.6 LTE PDSCH Throughput Conformance Test

LTE System Toolbox provides a comprehensive set of functions for easy access to standard-compliant PDSCH throughput Conformance test. It could be generated from the interactive application or the equivalent command-line MATLAB code. The experiment demonstrates how to measure the physical downlink shared channel (PDSCH) throughput performance against SNR. It measures the throughput performance of an end-to-end PDSCH simulation in percentage value. The throughput performance is evaluated based on each transmitted frames. The transmitter generates one or two random code-words with information bits, depending on the transmission mode using MATLAB function “lteRMCDLTool”. The generated signal is then passed through a noisy fading channel. The receiver then performs channel estimation, equalization, demodulation, and decoding. The block CRC result at the output of the channel decoder is used to determine the throughput performance of the PDSCH. In this dissertation, the performance of PDSCH of LTE network on different reference channel models RMC R.14 and RMC R.12 were considered, effects were observed for five (5) frames and 20 frames, effects on the performance with respect to change in duplex mode (FDD and TDD) were also evaluated, finally, the performance effect on the different propagation model as specified by 3GPP TS 131.

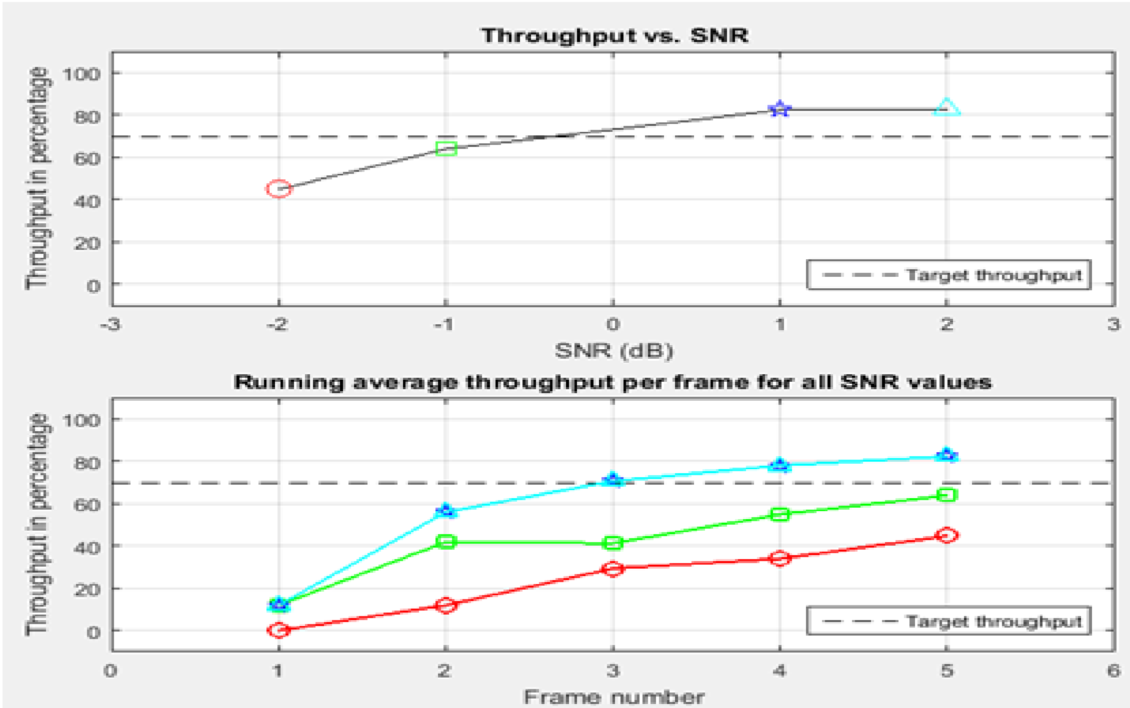

Figure 4.57: Throughput Vs SNR CURVE For RMC.12, FDD, 6PRBs, 2x2 MIMO, QPSK, EPA (5 Frames)

The following parameters were coded to generate the performance graph; Reference Channel [R:12], Duplex Mode: FDD, Transmission Scheme: TX diversity (4x4), PDSCH Rho(dB): -3, Propagation Model: EPA, Doppler (5Hz), Antenna Correlation : Medium, Number Of Receive Antennas: 2, SNR Range (dB): [-2.0 -1.0 1.0 2.0], Simulation Length (Frames): 5, Number of HARQ Processes: 8, Perfect Channel Estimator : Enabled, PMI mode: Wideband

PDSCH Rho (dB) is defined as the PDSCH resource element power allocation in dB

Decreasing the SNR will decrease the throughput of the system because more sub-frames will be lost

Result for -2 dB SNR; Throughput: 42.31%

Result for -1 dB SNR; Throughput: 64.29%

Result for 1 dB SNR; Throughput: 83.09%

Result for 2 dB SNR; Throughput: 83.24%

The second graph sections of figure 4.58 – 4.60 depicts the throughput performance of each frame against their corresponding SNR values

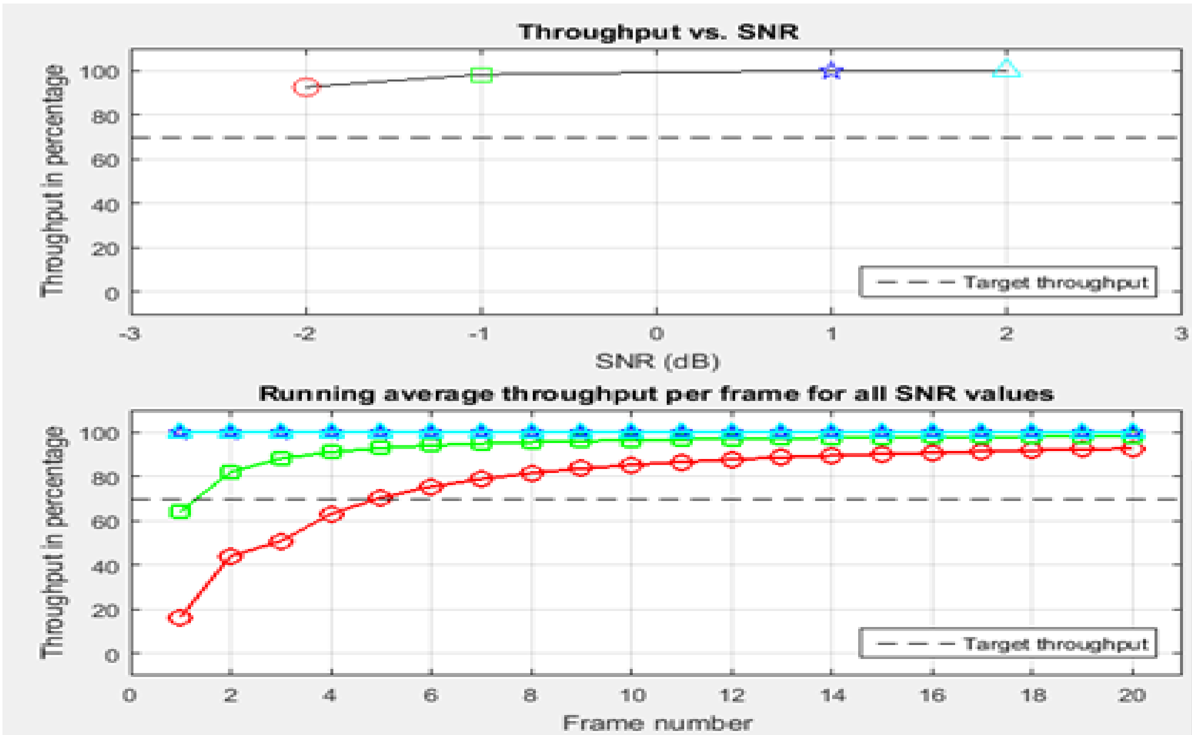

Figure 4.58: Throughput Vs SNR CURVE For R.12, FDD, 6PRBs, 4x4 MIMO, QPSK, EPA, 20 Frames

The following parameters were coded to generate the performance graph; Reference Channel [R:12], Duplex Mode: FDD, Transmission Scheme: TX diversity, PDSCH Rho(dB): -3, Propagation Model: EPA, Doppler (5Hz), Antenna Correlation : Medium, Number Of Receive Antennas: 4, SNR Range (dB): [-2.0 -1.0 1.0 2.0], Simulation Length (Frames): 20, Number of HARQ Processes: 8, Perfect Channel Estimator : Enabled, PMI mode: Wideband

Observe clearly the improvement in SNR performance when 4X4 MIMO (23%) is employed against 2X2 MIMO system. Below are the generated results.

Result for -2 dB SNR; Throughput: 92.61%

Result for -1 dB SNR; Throughput: 98.21%

Result for 1 dB SNR; Throughput: 100.00%

Result for 2 dB SNR; Throughput: 100.00%

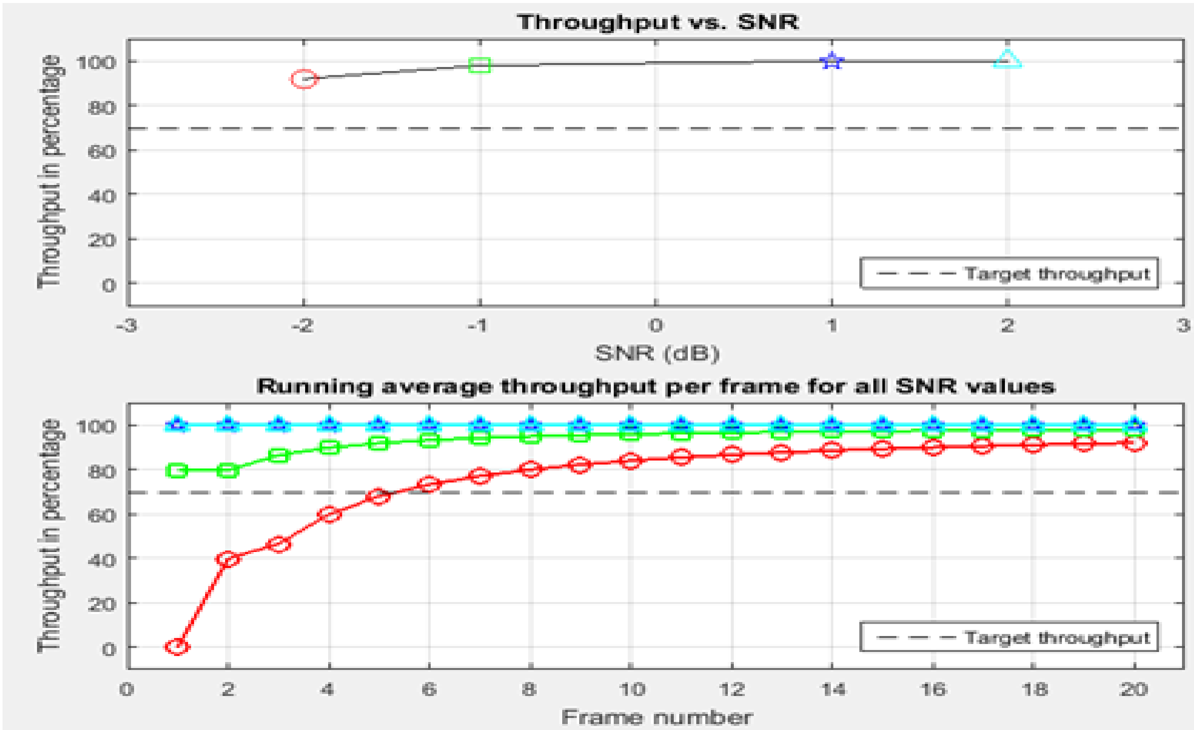

Figure 4.59: Throughput Vs SNR CURVE For R.12, TDD, 6PRBs, 4x4 MIMO, QPSK, EPA (20 Frames), Channel Estimator (On)

The following parameters were coded to generate the performance graph; Reference Channel [R:12], Duplex Mode: TDD, Transmission Scheme: TX diversity, PDSCH Rho(dB): -3, Propagation Model: EPA, Doppler (5Hz), Antenna Correlation : Medium, Number Of Receive Antennas: 4, SNR Range (dB): [-2.0 -1.0 1.0 2.0], Simulation Length (Frames): 20, Number of HARQ Processes: 7 (Highest for FDD, 7 highest for TDD), Perfect Channel Estimator : Enabled, PMI mode: Wideband.

The above plot has the following performance result;

Result for -2 dB SNR; Throughput: 91.99%

Result for -1 dB SNR; Throughput: 97.97%

Result for 1 dB SNR; Throughput: 100.00%

Result for 2 dB SNR; Throughput: 100.00%

In order to observe the difference in duplex modes, FDD and TDD, the parameter configuration is altered and set to TDD duplex mode and the following SNR performance is achieved. Similar performance is achieved, FDD achieved better throughput performance of about 1.2% at both lower SNR, thus, -2dB and -1dB but same performance achieved at higher SNR values. FDD achieved 93.09% and 98.21% throughput performance at SNR of -2dB and -1dB respectively while TDD achieve 91.99% and 97.97% throughput performance at SNR of -2dB and -1dB respectively.

4.2.7 Evaluation of LTE Propagation Models

Observe the PDSCH conformance Measurement test of throughput against SNR performance in different LTE propagation model; there are basically four propagation channel specified in 3GPP TS. 36.

The Extended pedestrian Model (EPA): The model considers UEs at a low speed at 3Km/Hr and 5Hz Doppler Effect

The Extended Vehicular-A Model (EVA): The model considers UEs at a speed of 30Km/Hr and 75Hz Doppler effect

The Extended Typical Urban Model (ETU): The model considers UEs at a speed greater than or equal to 20Km/Hr and 300Hz Doppler Effect

The High Speed Train Model (HST): The model considers UEs at a low speed at 50Km/Hr and 750Hz Doppler Effect.

In wireless communication, there are two kinds of fading, fading as result of Time Dispersion and Frequency dispersion. Time dispersion is caused by multipath time delay spread leading to flat fading and frequency selective fading while Frequency Dispersion fading is caused by Doppler Effect or Doppler spread leading to slow fading or fast fading.

Doppler Effect is witnessed whenever a receiver or transmitter is in motion; the frequency is being shifted, and the change in frequency is described as follows;

$$\Delta f = (V/\lambda) \cos \theta \quad (4.1)$$

Where; Δf is change in frequency, V is the velocity (rate of change in speed), λ is wavelength (function of frequency and speed of light)

The experiment for the purpose of this dissertation, only three of the propagation models (EPA, VA, and ETU) was investigated with respect to the standards of SPECTRANET, Abuja

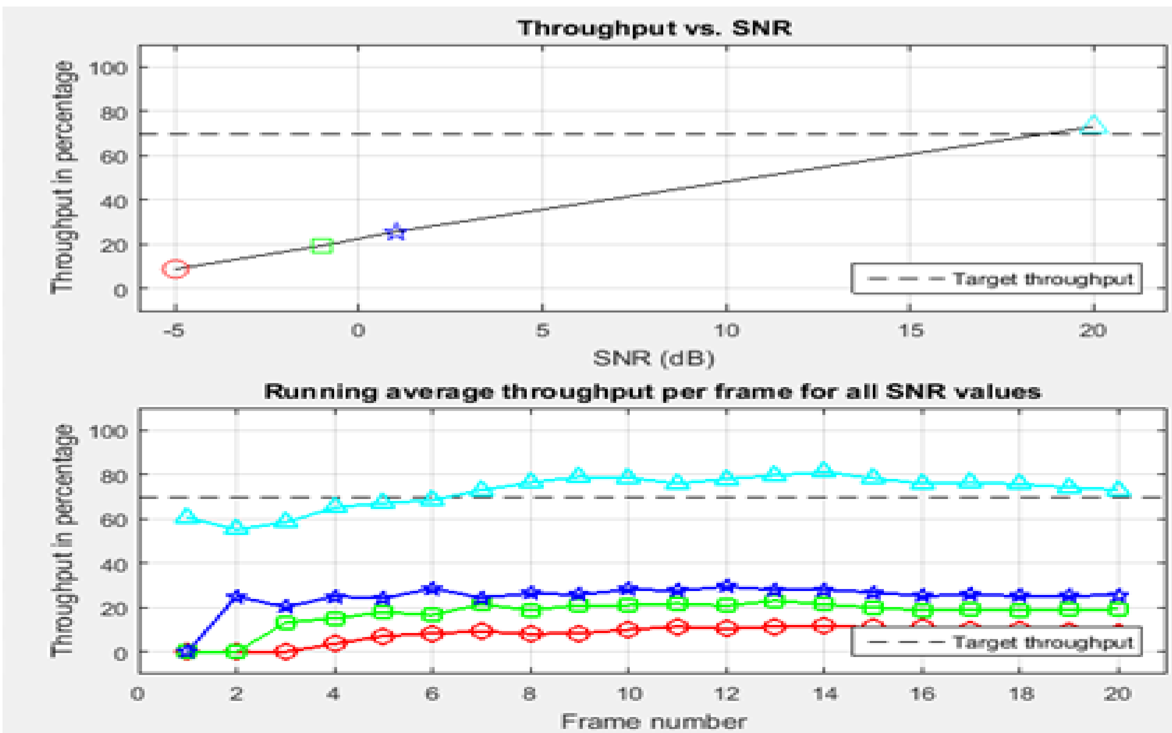

Figure 4.60: Throughput Vs SNR CURVE for R.14, TDD, 50PRBs, 4x4 MIMO, 16QAM, EPA, (20 Frames), Channel Estimator (On)

Result for -5 dB SNR; Throughput: 8.75%

Result for -1 dB SNR; Throughput: 19.28%

Result for 1 dB SNR; Throughput: 25.68%

Result for 20 dB SNR; Throughput: 73.03%

Observe that the configuration above has larger bits of data as result of R.14 model with 50 PRBs, and recall for the simulation 20 frames were generated and demodulated giving rise to throughput degradation. Each radio frame contains 10 sub-frames and one sub-frame comprises of two time slots or resource element which has 72 or 84 sub-carriers depending the cyclic prefix used. Hence hundreds of thousands of information bits are seen in 20 radio frames.

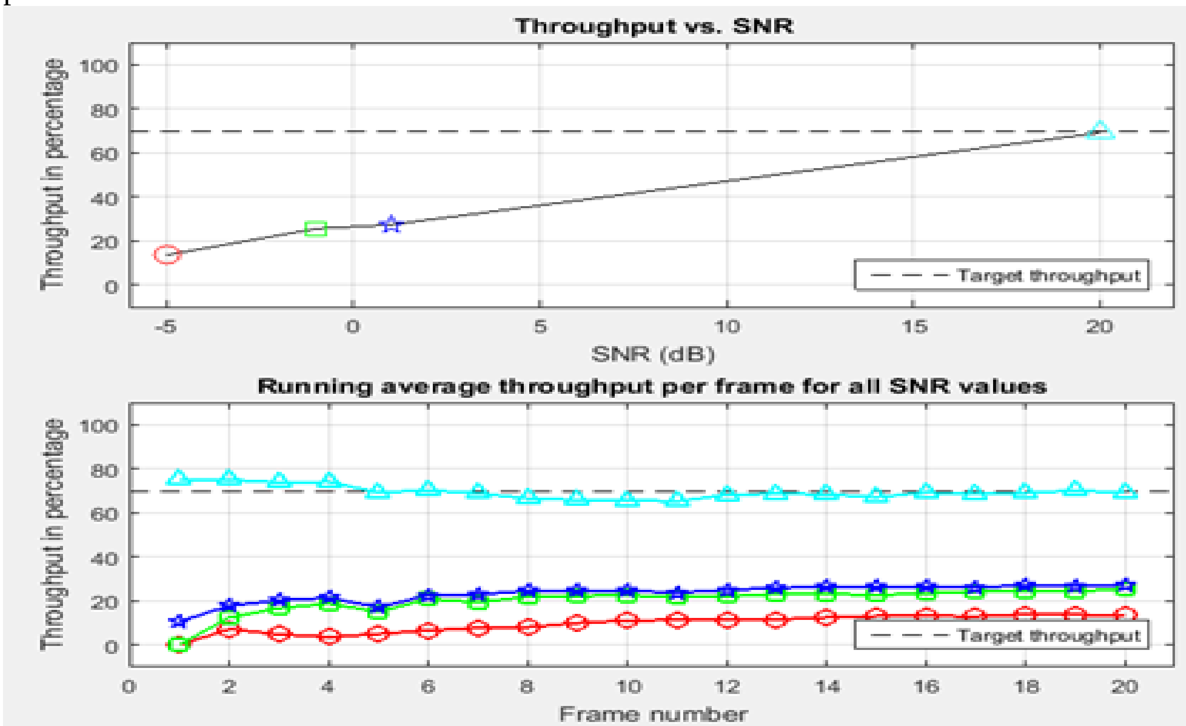

Figure 4.61: Throughput Vs SNR CURVE for R.14, TDD, 50PRBs, 4x4 MIMO, 16QAM, EVA, (20 Frames), Channel Estimator (On)

Result for -5 dB SNR; Throughput: 13.56%

Result for -1 dB SNR; Throughput: 25.53%

Result for 1 dB SNR; Throughput: 27.31%

Result for 20 dB SNR; Throughput: 69.09%

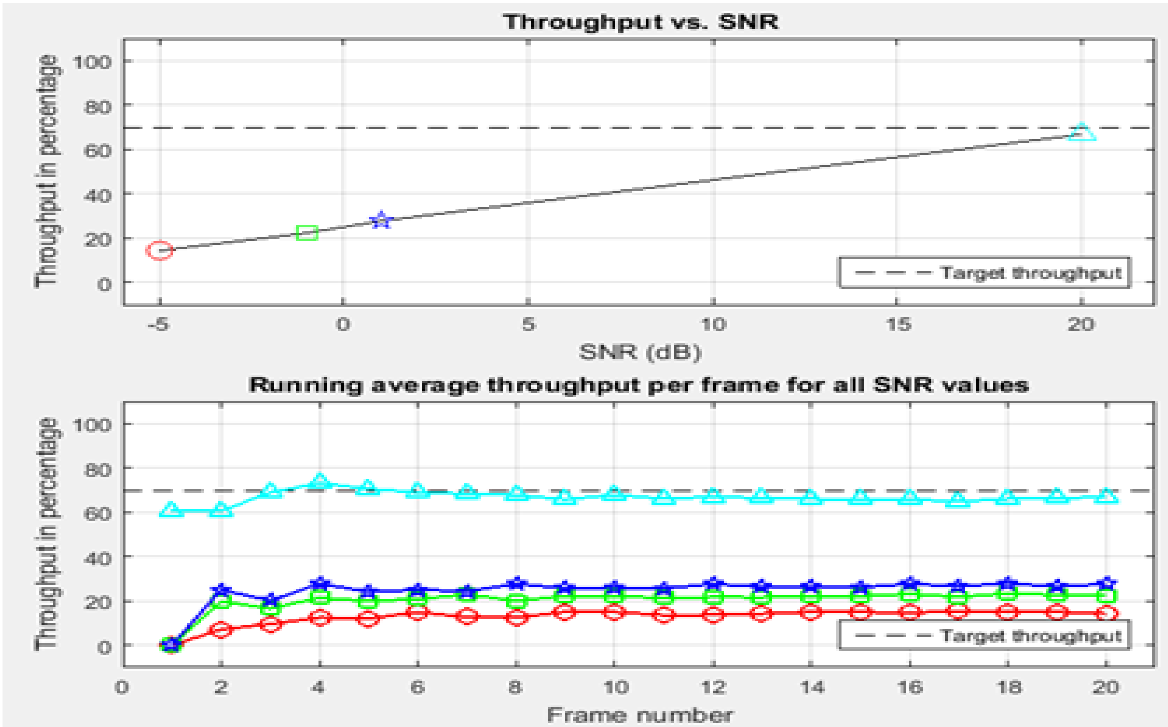

Figure 4.62: Throughput Vs SNR CURVE for R.14, TDD, 50PRBs, 4x4 MIMO, 16QAM, ETU, (20 Frames), Channel Estimator (On)

Result for -5 dB SNR; Throughput: 14.28%

Result for -1 dB SNR; Throughput: 22.31%

Result for 1 dB SNR; Throughput: 27.65%

Result for 20 dB SNR; Throughput: 66.74%

In summary, throughput performance of the three propagation model (EPA, EVA, ETU) also known as delay profile were carried out, the resulting performance as shown in the Figures: 4.60 – 4.62. EPA(5Hz) model offered best throughput performance against high SNR values but has the lowest performance against low SNR values of -5dB, the performance of EPA(300Hz) is better than ETU(700Hz) with respect to stronger SNR value (20dB) while ETU offered best performance with respect to lower SNR (-2dB).

4.3 Development and Implementation of Differential Quality of Service (Diff-Serv) Algorithm

The enhancement algorithm is first targeted at generating random users, whose UEs at various times logs in and out of a base eNodeB. The individual users, when logged on, are assigned with an IP address and their MAC addresses are noted. Spontaneously they exhibit different network characteristics with respect to data rate due to online activities, applications, Channel Quality indicator (CQI) and other factors. One cell Site (eNodeB) has a maximum of 299 allowable numbers of UEs at a time theoretically. Minimum at a time (0) off load, from the data obtained, SPECTRANET does an average of 50 users per cell. Each user (UE=user equipment) can be identified by its IP Address, International mobile equipment identity (IMEI), International Mobile subscriber identity (IMSI) or Media Access Control (MAC) Address. But for the purpose of this work, MAC and IP addresses were used. Although IP addresses are dynamic and could change over time and as UE moves away from the serving eNodeB. Random users generated shares a provisioned bandwidth (PRB) at every given time. The users comes in (Latches in or gets admitted) and goes off the network resource spontaneously and off-course has various degree of activities. The case study network (SLA) operates the following resource and Parameters as listed in chapter three of this work (Table 3.1). The developed algorithms has two approaches to enhancing the cell throughput, the Time stamp Algorithm (TSA) and Traffic volume Algorithm (TVA), refer to the flow chart diagram (figure 3.7) and (figure3.8) respectively. The algorithms were developed with the help Microsoft Visual Studio, Enterprise edition 2015, which has the functions for 4g LTE nodes (eNodeB) and all the scheduling algorithms described by 3GPP. The Integrated Development Environment (IDE) gives the platform to manage much number of users (UEs). The developed enhancement algorithm for this research is named XNET server manager, running both TSA and TVA algorithm as well as the normal algorithm for SPECTRANET configuration. The manager monitors all assigned UEs, keeps record of the data usage and counts the total number of admitted UEs (known as ONLINE USERS), Total number of UEs running above 0.8 Mbps, thus high data rate users (High User), Total number of users running below or equal to 0.8Mbps, thus low data rate users (Low User), as well as time of the day. XNET manager displays the throughput performance of the normal network mode running on proportional fair scheduling, the throughput performance of time based splitting network mode and the throughput performance of consumption rate based splitting network mode. XNET server manager is also programmed to calculate and display in each network mode the total data consumed data per second, the average High user data rate, and the average low user data rate. Splitting of radio resource based on time stamps (TSA) occurs twice within 24hrs for total of 6 hours while the first time split occurs between the hours of 9AM through 12PM, and the second time split occurs between hours of 6pm and 9pm. At every point in time, XNET Manager displays how each network mode algorithm handles network resource for better quality of service to users. Normal network mode is always in single node, while the Time based split algorithm (TSA) can be in single node or split node depending on time of the day, likewise the consumption rate based network mode (TVA) can be in single or split node depending on the number of high data rate users

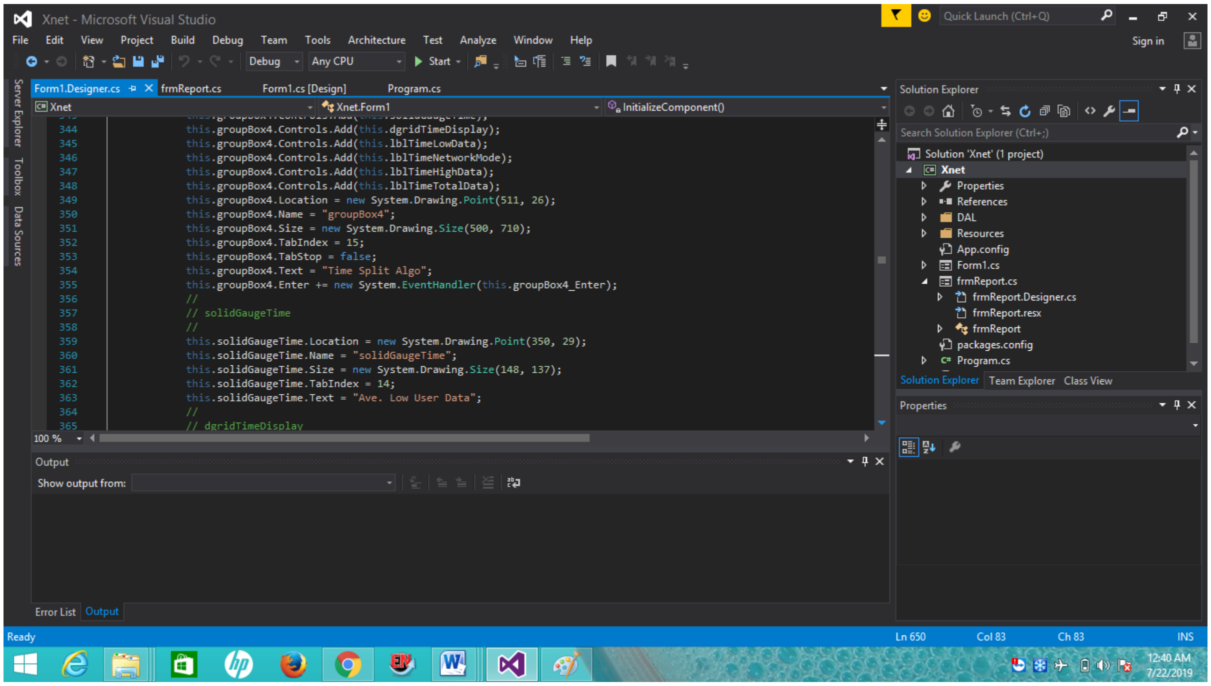

Figure 4.63: Microsoft Visual Studio GUI for XNET Server Manager

Microsoft Visual Studio IDE, Enterprise edition, 2015 was used to develop XNET sever manager, different forms were created for different network mode algorithm, also a database for events and records. Finally form for graphically representation was developed

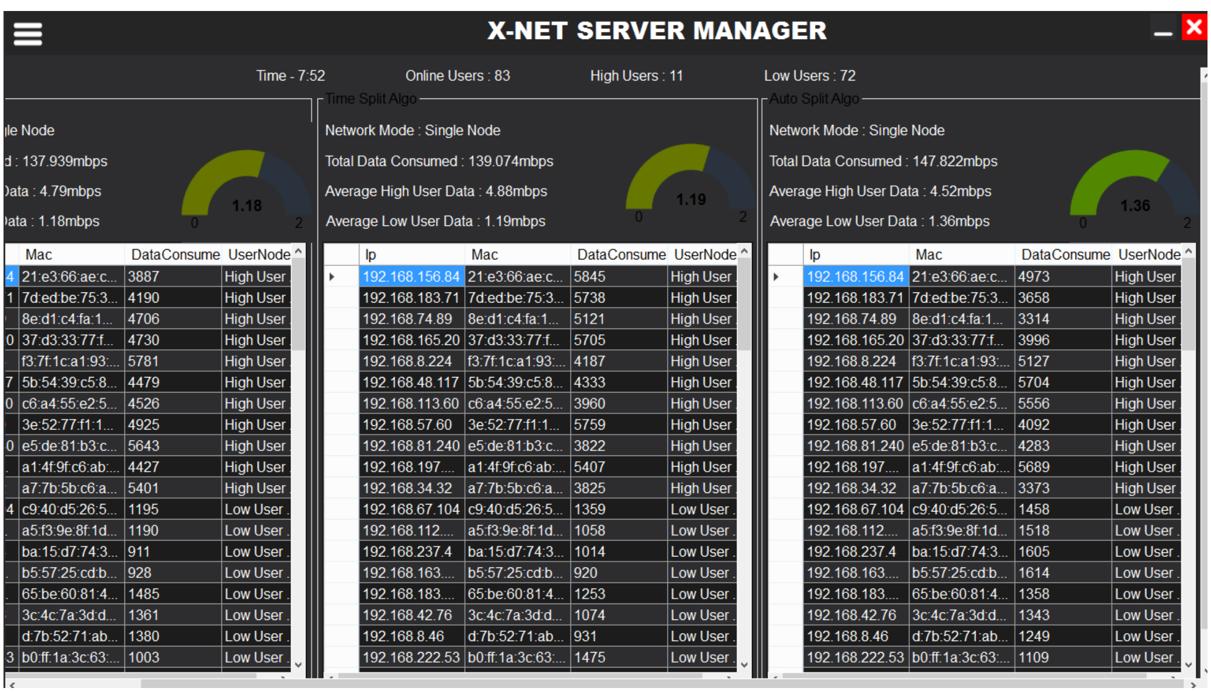

Figure 4.64: Network performance all good for the three network modes

The performance of each UE changes every 1ms, but there is a probability of an UE running at large application to remain on high data rate over a time, the algorithm based on consumption rate (TVA) continuously monitors the UE over 15 seconds to confirm and classify the particular UE as high user. However, once the count register observes the total number of classified high data user gets to 20% of the total number of users online, the radio resource is split at a ratio of 3:2 to compensate many other users on low data rate. The time based system (TSA) splits resources during peak hours (9AM: 12PM, 6PM: 9AM). The Figure 4.64 depicts very good network and channel condition and performance for each network mode is satisfactory hence good quality of service, no complains, no grumbles, throughput performance are in green. The record of network event occurred during off peak hours as can been seen on display (7:52AM), online users= 83, 11 high user and 72 low users. Normal mode was at an average throughput of 1.18 Mbps, while the time stamps network mode (TSA) recorded an average throughput of 1.19Mbps and finally, the Auto-split network based on consumption rate (TVA) recorded 1.36Mbps (Single Node)

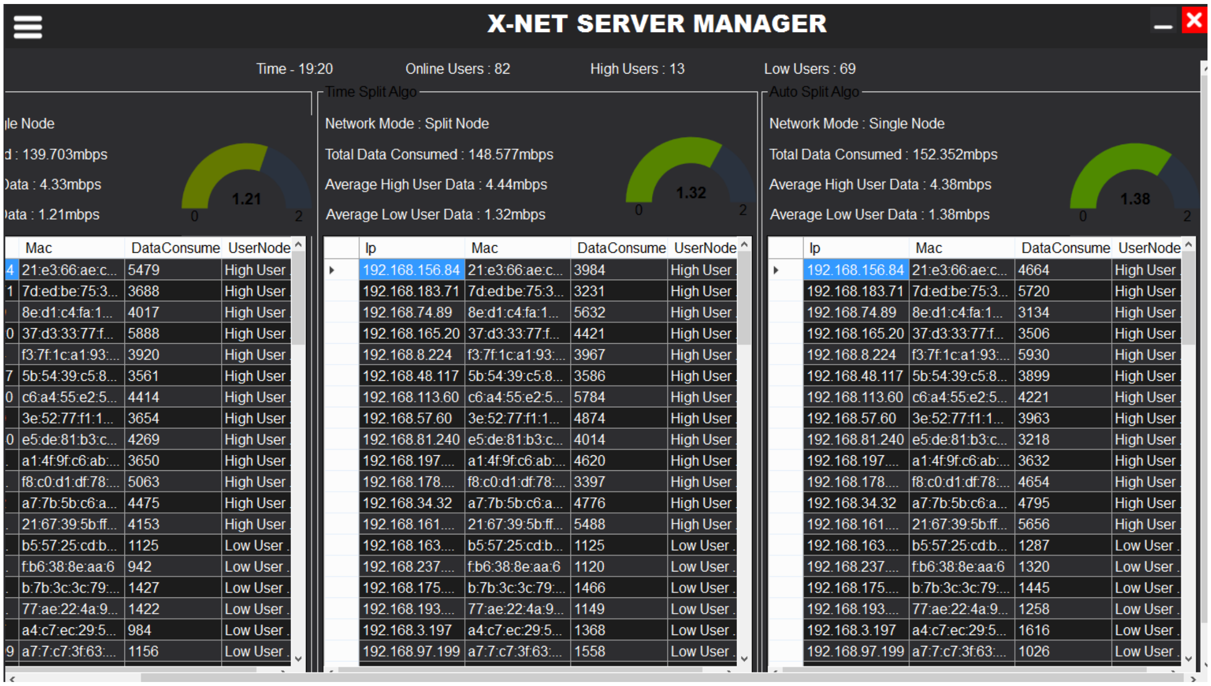

Figure 4.65: Network Performance for the three Network Modes, Time Stamp (TSA) Activated

The Figure 4.65 depicts very good network and channel condition and performance for each network mode is satisfactory hence high quality users experience, no complains, throughput performance are in green. The record of network event occurred during peak hours as can been seen on display 19:20 (7:20PM), online users= 83, 13 high user and 69 low users. Normal mode was at an average throughput of 1.21 Mbps, while the time stamps network mode (TSA) recorded an average throughput of 1.32Mbps (Activated Split Node because of time of the day) and finally, the Auto-split network based on consumption rate (TVA) recorded 1.38Mbps (Single Node).

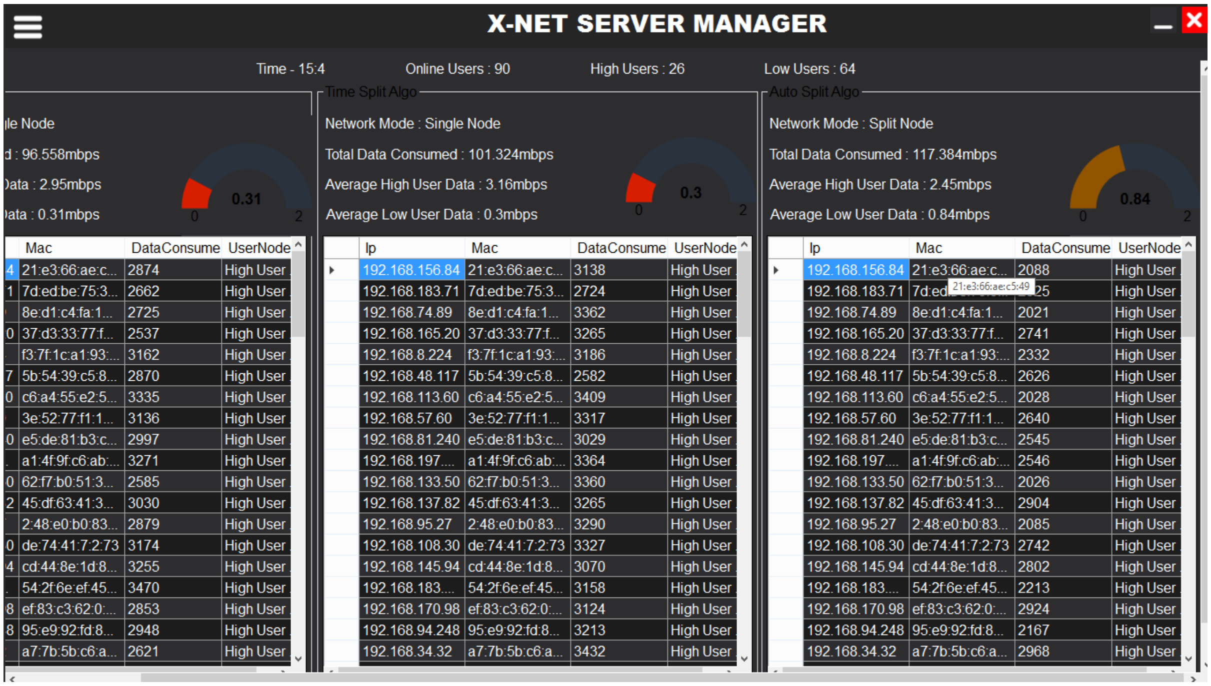

Figure 4.66: Network Performance, AUTO-SPLIT (TVA) Activated

Similarly, poor network and channel condition occurs, where number of users on high data rate (26) is above 20% of total number of users online (90), Differential Quality of Service algorithm based consumption rate (TVA) is activated and resource splits to predefined ratio, and resultant effect was seen to give an average throughput of 0.84 Mbps while the network (TSA) mode that splits based on time got low performance, because it was not yet time of the day in which its algorithm splits the resource, hence a throughput performance of 0.31Mbps, same as normal mode network (0.31 Mbps). This represents real situation for SPECTRANET cells when they are underperforming, but with the implementation of performance enhancement algorithm (TVA or TSA), the network remains stable. Observe situation in figure 4.66, there were high number of users (High users) in the cell, auto-split algorithm (TVA) kept the resource in fair sharing formula and everyone within servicing cell feels good.

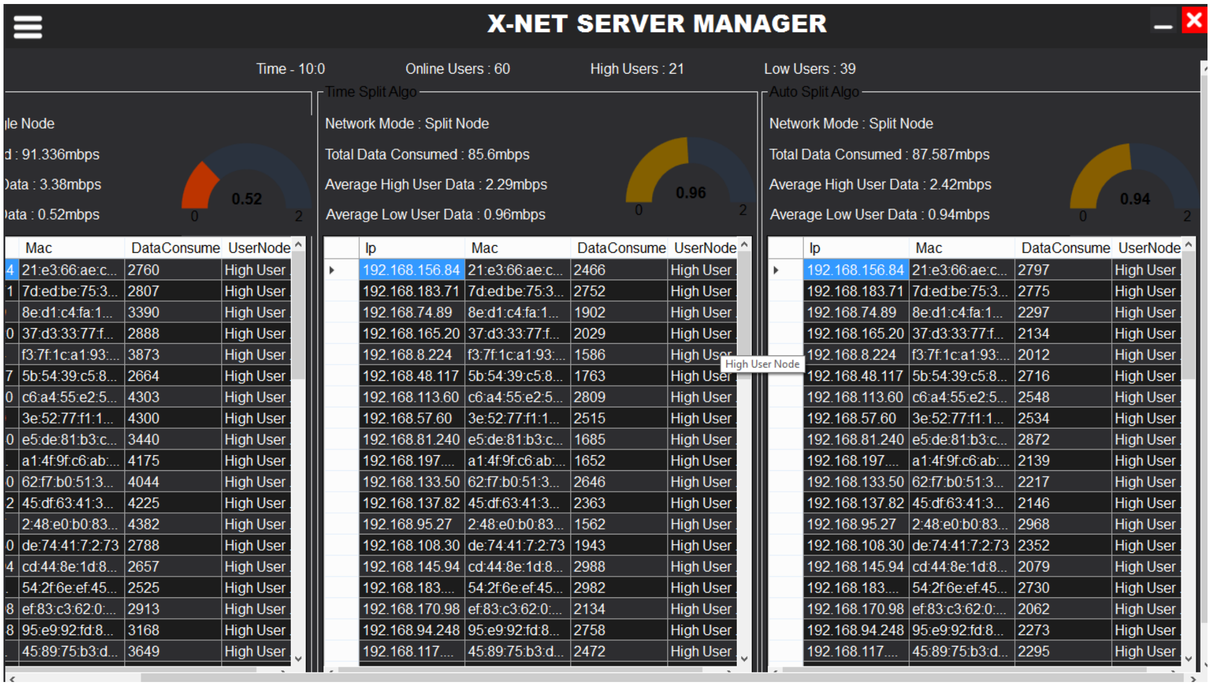

Figure 4.67: Network Performance, Both Time Stamp (TSA) and AUTO-SPLIT (TVA) Activated

The Figure 4.67 depicts a condition for the both algorithms to be activated, from the time of the day displayed, it was during peak hour (10AM), and the cell node was observed to have more than 20% of the user running high data rate, hence, Auto-Split algorithm activated. The normal network mode average throughput was 0.52 Mbps while with activation of time Stamp and Auto –Split algorithm, both gave throughput performance of 0.96Mbps and 0.94Mbps respectively

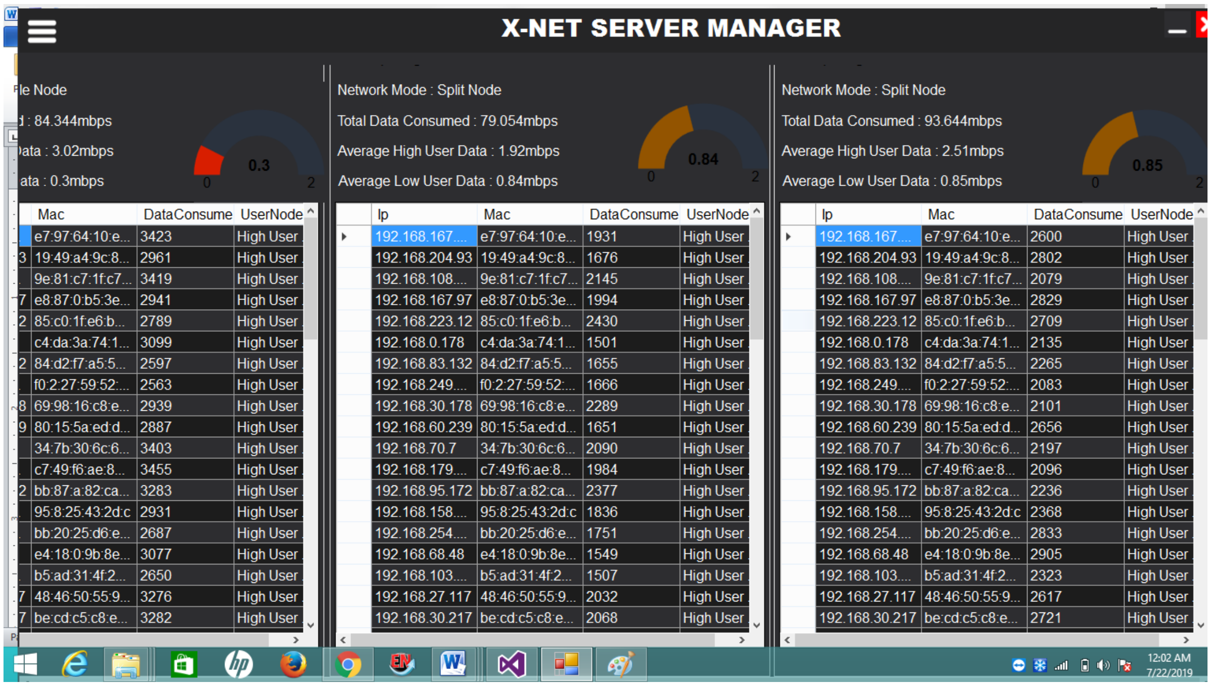

Figure 4.68: Network Modes Performance TSA and TVA Activated

The figure 4.68 showed high data rate users, but at this time, both network enhancement algorithms were activated, the conditions for both algorithms to activate split node were met, it was time of the day predefined as peak period, time based algorithm gave similar throughput performance of 0.84Mbps, while the algorithm based on consumption rate (TVA) is 0.85Mbps, this is another proof that shows that enhancement algorithm (TSA and TVA) actually provides better quality of service than the normal network node which was able to garn 0.3 Mbps for same network conditions.

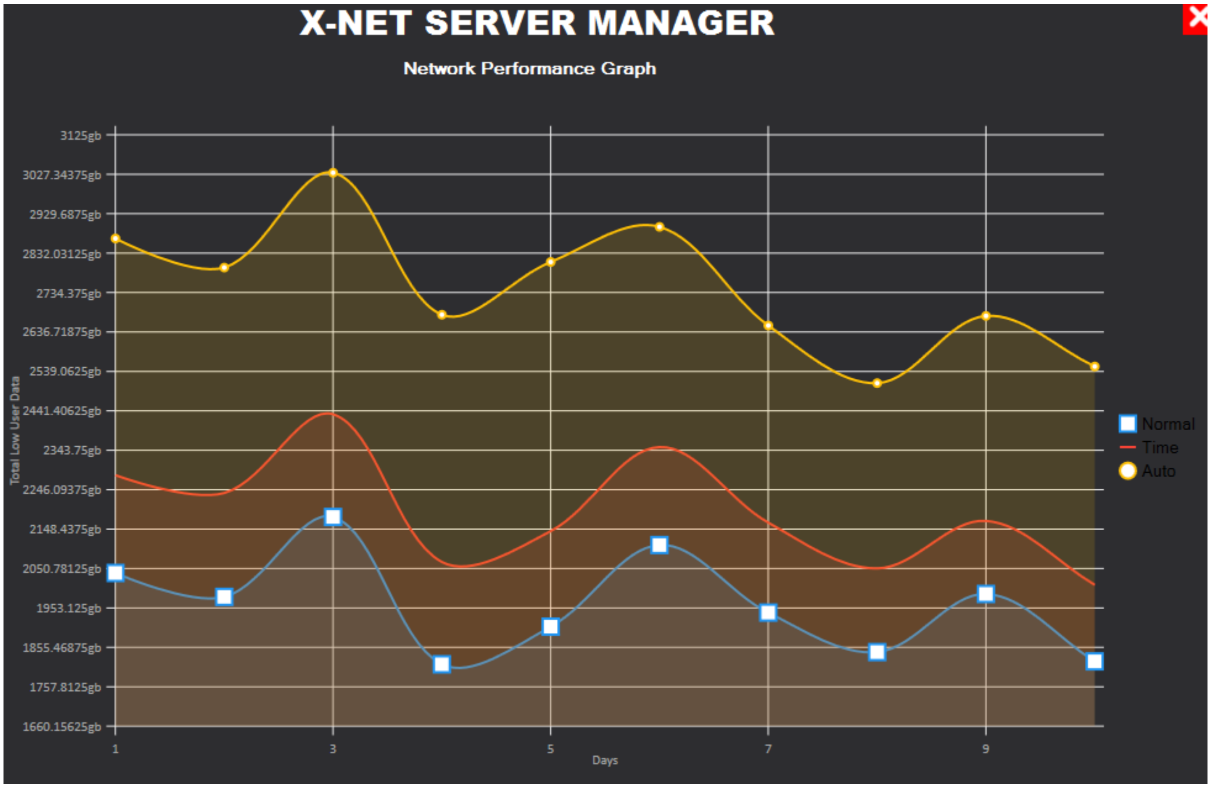

Figure 4.69: Normal, TSA, and TVA Network modes Performance Graph for 10 days Record X-NET Server Manager

Total number of data consumed per second, per minute or per day is a function of cell throughput performance. Figure 4.69 is a plot of performance in terms of total number of data consumed per day in Giga-Byte (GB) for each network mode spanning over 10 days record, at end of every 24 hours, X-Net Server Manager saves the events of the day to database. From the Figure 4.69 experiments, the third day showed to be the best cell performance day for the three network modes, users with TVA integrated mode had the highest number of data consumed (3,027 GB) followed by the TSA integrated mode with total of 2,441(GB) while Normal network mode gave up total of 2,183 GB of data. However, the worst day performances were observed also, TVA worst day performance was observed on the 8th day with total of 2,500 GB, TSA worst day performance was on the 10th day with record of 2,023 GB while the Normal network mode worst day performance was on the 4th day with total of 1,813 GB consumed. TVA integrated system proved to offer better cell throughput in terms of data capacity (Best day) against the Normal network mode by 38.6%, TVA mode also performed better than TSA by 24%. Table 4.1 further detailed the percentage changes in performance

Table 4.1 Average Data Capacity Performances and Percentage Changes in Normal, TSA, and TVA Network Modes for 10 days

S/N	**Network Modes**	**Best Day Avg Data**	**Worst Day Avg Data**	**Best Day: TSA better than Normal Mode (% change)**	**Best Day: TVA better than Normal Mode (% change)**	**Best Day: TVA better than TSA Mode (% change)**
1	**Normal**	2183 GB	1813 GB	11.80%	38.60%	24.00%
2	**TSA**	2441GB	2023 GB	Worst Day: TSA better than Normal Mode (% change)	Worst Day: TVA better than Normal Mode (% change)	Worst Day: TVA better than TSA Mode (% change)
3	**TVA**	3027 GB	2500 GB	11.60%	37.80%	23.00%

In summary, from figure 4.64 – 4.69, the differentiated Quality of Service approach was implemented, tested and analysed amongst normal network mode for SPECTRANET poor performing cell parameters, the performance of three network modes were instantaneously measured at different conditions and values are recorded in table 4.2. The measurement witnessed three instances per channel condition

Table 4.2: Instantaneous Measurement for Throughput Performances of the network modes

S/N	**NETWORK MODE**	**NORMAL (MBPS)**			**TSA(MBPS)**			**TVA(MBPS)**		
	Instant measurement(IM)	1st IM	2nd IM	3rd IM	1st IM	2nd IM	3rd IM	1st IM	2nd IM	3rd IM
1	PEAK PERIOD	0.83	0.86	1.21	1.04	1.05	1.36	1.07	1.05	1.37
2	High User ≥20%	0.56	0.31	0.36	0.58	0.30	0.31	0.93	0.84	0.85
3	Good Channel condition	1.18	1.24	1.21	1.19	1.25	1.36	1.36	1.36	1.37
4	PEAK Period and High users ≥20%	0.52	0.3	0.55	0.96	0.84	0.95	0.94	0.85	0.94
5	Good Channel Condition but Peak Period	1.18	1.21	0.86	1.30	1.32	1.05	1.24	1.38	1.05

Table 4.2 specified five channel condition for measurement instances, which recorded three instances for each condition, first, Peak period was a channel condition where by instant measurement were taken to observe the performance of TSA algorithm against the TVA and normal network modes. Secondly, the High user ≥ 20 condition was a channel condition where instant measurements were taken to observe the performance effect of only TVA mode against TSA and Normal network modes.

Thirdly, Good condition was an excellent channel condition and instant measurements were taken to observe cell throughput performance for each network mode.

Fourthly, PEAK and High user ≥20 was a condition resulting to TSA algorithm being activated as well as the TVA algorithm. Instant measurements were taken to observe the cell performances of each network mode.

Finally, Good condition and Peak period: condition for excellent channel condition but in peak period of the day leading to activation of TSA. The measurements were taken to observe the cell throughput performances for TSA against TVA and normal network modes.

Observations: TSA, TVA and Normal network mode have similar cell throughput performance when network condition is good, this is because there is no condition to activate either of the Diff-Serv algorithms, refer to third condition of Table 4.2. TSA algorithm is only activated during peak period defined for 9am through 12pm and 6pm to 9pm daily, if TVA is activated during off peak, TSA mode tend to have similar cell throughput performance as Normal mode. The performance enhancement of TSA mode is significantly noticed; when the peak period occurs at the same time the number of high users is ≥20% of total online users, in other words, TSA mode performance is better for conditions that activates TVA. Refer to condition four (4) of Table 4.2. TSA can be activated at time network conditions are good and stable, refer to 5^{th} condition of Table 4.2; the TSA average performance increment against Normal mode is 12.9%, this is small compared to TSA enhancement for condition four (4) of Table 4.2, which pulled percentage increment of 139% against normal network mode, nonetheless, similar margin of performance was achieved by TVA for same conditions.

TVA proved to be more efficient enhancement algorithm in handling the poor performing cells of SPECTRANET LTD, Abuja which has been observed to be as result of numerous activities perpetrated by higher data rate users. From Table 4.2, observe that TVA is only activated when appropriate, thus when the network performance condition is undesirable, however TSA can be activated even at the time of quality service delivery. Observe the second condition of table 4.2; TVA network mode with average cell throughput of (0.81Mbps) doubled the average throughput performance of TSA (0.41Mbps) as well as Normal mode (0.40 Mbps). While for the first condition of Table 4.2 where TSA is activated during peak period and gained average throughput of 1.15 Mbps, unfortunately, at those instance network throughput for TVA and normal modes achieved similar performances of 1.16 Mbps, and 0.966Mbps respectively, this shows that most times to observe the effect of TSA algorithm, conditions for TVA has to be met.

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

This dissertation presented a technique for cell throughput enhancement of 4G LTE network using SPECTRANET LTD, Abuja as a case study. The work successfully studied the architecture and performance of SPECTRANET network for a period of Seven months, starting from November, 2018 through February 2019 and from April to June 2019 in order to cover both extreme weather conditions of Abuja. The result obtained was used to characterise SPECTRANET network and predicted the network element behaviours as well as developed an implementable differential Quality of Service (Diff-Serv QOS) algorithms to enhance cell throughput, empirical method was employed for data measurement and collection through the use of different measurement tool kits such as Huawei Imanager 2000, drive test kits, Huawei I-Studio, Google earth Pro and Open signal software.

The work effectively carried out performance evaluation on the empirical data obtained, the average throughput (Mbps) performance per active cells over the period of study were correctly analysed and root causes of poor performing cells were identified, the work also evaluated the effects of cell throughput performance against average number of users. However, the research made use Google Earth Pro for remote RF investigation on troubled cells, while Drive test technique, Open-signal and I-studio software were deployed for on-filed RF investigation and further analysis on generated data log were performed using MAP INFO software. The dissertation modelled an efficient method of estimating and modifying existing network capacity based on empirical data using MATLAB System Tools.

Finally, based on differential Quality of Service (Diff-Serv), the work developed two performance enhancement algorithms for cell throughput of 4G LTE network with respect to the peculiarities of the network under study, Traffic volume algorithm (TVA) and Time stamp algorithm (TSA) were developed, both algorithm were validated and tested with the aid of Microsoft Visual Studio IDE, 2015. It showed the effectiveness of the proposed enhancement algorithm in terms of data throughput and network capacity, at average network conditions TSA and TVA recorded an average throughput performance of 2.34Mbpsand 2.89Mbps respectively against existing network performance on 1.91Mbps.

5.2 Conclusion

Reliability of 4G LTE network relies on the ability of the operators to maintain high level of availability, connectivity and Quality of service. The increasing demand for mobile broadband services with high data rate, speed and quality of service has been the motivation behind 4G LTE network deployment in Nigeria, however the most critical function of Evolved Universal Terrestrial Radio Area Network (E-UTRAN) is the scheduling algorithm implemented in the eNodeB, this function is decisive for the subscribers Quality of Service (QOS) and Quality of Experience (QOE), therefore enhancing its operations is of high importance to network operators, however this work studied the peculiarities of SPECTRANET network, and observed that small percentage (less than 20%) of subscribers consumes about 80% of the radio resources per troubled sectors. The work developed cell throughput enhancement algorithm based on differential quality of service (Diff-Serv) employing Time Stamps Algorithm (TSA) and Traffic Volume Algorithm (TVA). The proposed algorithms demonstrated cell throughput enhancement by 11.6% and 38.7% respectively over the existing network performance whose average cell throughput performance is 1.9 Mbps, however at severe network conditions, the TSA and TVA achieved an average cell throughput of 0.91Mbps against 0.41 Mbps of existing network average performance. Nonetheless, the average number of users per active cell increased from 50 to 60 User Equipment per Cell. The model promises SPECTRANET network, cost effectiveness, optimal spectrum utilization, and improved service quality and above all faster return on investment (ROI) as subscribers will prescribe to their service.

5.3 Recommendation

1. Reliability of 4G LTE network relies on the ability of the operators to maintain high level of availability, connectivity and Quality of service, advanced methods of detecting and remotely resolving underperforming cells problems are recommended.
2. It is highly recommended for SPECTRANET LTD, Abuja to incorporate TSA and TVA algorithms especially to underperforming cell sites predominantly occupied by offices and residential with data rate users.

5.4 Contributions to Knowledge

The major contributions of this dissertation are: made in this work

1. Definitive approach to acquiring Key Performance Indicators (KPI) data for 4G LTE was developed
2. Effective methods of analysing KPI and empirical data of 4G LTE network was technically advanced
3. Simulative methods of estimating network capacity of deployed 4G network was developed
4. Time Stamp Algorithm (TSA) was developed as cell throughput enhancement technique

for SPECTRANET network which demonstrated 11.6% improvement over the existing network performance

5. Traffic volume Algorithm (TVA) was developed as cell throughput enhancement technique for SPECTRANET network which demonstrated 37.8% improvement over the existing network performance

6. The resulting algorithms are adaptable and can be easily fine-tuned and be applied to other 4G LTE network operators, as well as operational sectors where time and human resource are to be maximized. For instance, in the banking sector, TSA and TVA can applied for effective management of staff by automatically differentiating operation based on time stamps, volume of customer and type of service required by customers, also in Transportation system, automatic road traffic management based of time of the day and volume of traffic, differentiating paths for rapid response agencies and commuters.

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Appendix A: Publications from the Research Work

1. **SIMULATIVE METHODS OF ESTIMATING AND MODIFYING DEPLOYED 4G LTE NETWORK CAPACITY IN TERMS OF THROUGHPUT PERFORMANCE. Ogbuokebe .S.K, Idigo V.E, Alumona T.L, and Okeke R.O (Published in Journal of Engineering and Applied Sciences (JEAS), 2019)**

2. **FOURTH GENERATION LONG TERM EVOLUTION (4G LTE) KEY PERFORMANCE INDICATOR ANALYSIS AND PERFORMANCE EVALUATION OF SPECTRANET.**
   Ogbuokebe S.K, Idigo V.E., Umar A. S., Alumona T.L
   (Published in International Journal for Electronic and Telecommunication System Research, 2019)

Appendix B: 3GPP Technical Specification Excerpts

Appendix C: Matlab Codes

Matlab Codes for Generating various PDSCH Spectrum

```
rmc = lteRMCDL('R.9');

Data = randi([0 1], 1, sum(rmc.PDSCH.TrBlkSizes));

[waveform, txgrid, RMCcfgOut] = lteRMCDLTool(rmc, Data);

plot(real(waveform));

figure

Fs = RMCcfgOut.SamplingRate;

[y,f] = periodogram(waveform(:,1),[],[],Fs,'centered');

plot(f,10*log10(y)); grid on
```

Matlab Coding for E-TEMs:

```
tm = '1.1';
bw = '20MHz';
[timeDomainSig, txGrid, txInfo] = lteTestModelTool(tm,bw);
hPlotDLResourceGrid(txInfo,txGrid);
```

CODING for Resource Grid Generation, E-TEMs conformance test, Spectrogram

```
tm = '1.1';
bw = '1.4MHz';
[timeDomainSig, txGrid, txInfo] = lteTestModelTool(tm,bw);
hPlotDLResourceGrid(txInfo,txGrid);

% to compute spectogram
[y,f,t,p] = spectrogram(timeDomainSig, 512, 0, 512, txInfo.SamplingRate);
f = (f-txInfo.SamplingRate/2)/1e6;
p = fftshift(10*log10(abs(p)));

% to plot the spectogram
figure;
surf(t*1000,f,p,'EdgeColor','none');
xlabel('Time (ms)');
ylabel('Frequency (MHz)');
tm = '3.1';
bw = '20MHz';
[timeDomainSig, txGrid, txInfo] = lteTestModelTool(tm,bw);
hPlotDLResourceGrid(txInfo,txGrid);

% to compute spectogram
[y,f,t,p] = spectrogram(timeDomainSig, 512, 0, 512, txInfo.SamplingRate);
f = (f-txInfo.SamplingRate/2)/1e6;
p = fftshift(10*log10(abs(p)));
%dbstop
```

Matlab codes % to plot the spectogram

```
figure;
surf(t*1000,f,p,'EdgeColor','none');
xlabel('Time (ms)');
ylabel('Frequency (MHz)');
zlabel('Power (dB)');
title('Spectrogram of Test Model E-TM3.1, 20MHz');
```

Matlab CODING for ACLR /COMMENTS:

```
% Generate the downlink configuration structure for RMC R.6
cfg = lteRMCDL('R.6');

% Generate the waveform which is a T-by-P matrix where T is the number of
% time-domain samples and P is the number of receive antennas
[waveform, ~, info] = lteRMCDLTool(cfg, [1; 0; 0; 1]);

% Write the sampling rate and chip rate to the configuration structure to
% allow the calculation of ACLR parameters
cfg.SamplingRate = info.SamplingRate;
cfg.UTRAChipRate = 3.84;              % UTRA chip rate in MCPS


% Calculate ACLR measurement parameters
[aclr, nRC, R_C, BWUTRA] = hACLRParameters(cfg);


% Apply required oversampling
resampled = resample(waveform,aclr.OSR,1);

% Calculate E-UTRA ACLR
aclr = hACLRMeasurementEUTRA(aclr, resampled);

% Calculate UTRA ACLR
aclr = hACLRMeasurementUTRA(aclr, resampled, nRC, R_C, BWUTRA);


% <matlab:edit('hACLRResults.m') hACLRResults.m> displays the ACLR and
% plots the adjacent channel powers.


hACLRResults(aclr);


displayEndOfDemoMessage(mfilename)
```

Appendix D: XNET Server Manager Codes

```
namespaceXnet
{
partialclassForm1
    {
///<summary>
///Required designer variable.
///</summary>
privateSystem.ComponentModel.IContainer components = null;

///<summary>
/// Clean up any resources being used.
///</summary>
///<param name="disposing">true if managed resources should be disposed; otherwise,
false.</param>
protectedoverridevoid Dispose(bool disposing)
        {
if (disposing && (components != null))
            {
components.Dispose();
            }
base.Dispose(disposing);
        }

#region Windows Form Designer generated code

///<summary>
///Required method for Designer support - do not modify
/// the contents of this method with the code editor.
///</summary>
privatevoidInitializeComponent()
        {
this.components = newSystem.ComponentModel.Container();
System.Windows.Forms.DataGridViewCellStyle dataGridViewCellStyle1 =
newSystem.Windows.Forms.DataGridViewCellStyle();
System.Windows.Forms.DataGridViewCellStyle dataGridViewCellStyle2 =
newSystem.Windows.Forms.DataGridViewCellStyle();
```

```
System.Windows.Forms.DataGridViewCellStyle dataGridViewCellStyle3 =
newSystem.Windows.Forms.DataGridViewCellStyle();
System.Windows.Forms.DataGridViewCellStyle dataGridViewCellStyle4 =
newSystem.Windows.Forms.DataGridViewCellStyle();
System.Windows.Forms.DataGridViewCellStyle dataGridViewCellStyle5 =
newSystem.Windows.Forms.DataGridViewCellStyle();
System.Windows.Forms.DataGridViewCellStyle dataGridViewCellStyle6 =
newSystem.Windows.Forms.DataGridViewCellStyle();
this.label1 = newSystem.Windows.Forms.Label();
this.panSide = newSystem.Windows.Forms.Panel();
this.btnReport = newSystem.Windows.Forms.Button();
this.groupBox2 = newSystem.Windows.Forms.GroupBox();
this.label6 = newSystem.Windows.Forms.Label();
this.label5 = newSystem.Windows.Forms.Label();
this.label4 = newSystem.Windows.Forms.Label();
this.label3 = newSystem.Windows.Forms.Label();
this.label2 = newSystem.Windows.Forms.Label();
this.dgridAutoDisplay = newSystem.Windows.Forms.DataGridView();
this.timTimer = newSystem.Windows.Forms.Timer(this.components);
this.lblTime = newSystem.Windows.Forms.Label();
this.timLogInOut = newSystem.Windows.Forms.Timer(this.components);
this.lblOnlineUsers = newSystem.Windows.Forms.Label();
this.lblHighUser = newSystem.Windows.Forms.Label();
this.lblLowUser = newSystem.Windows.Forms.Label();
this.lblAutoNetworkMode = newSystem.Windows.Forms.Label();
this.lblAutoTotalData = newSystem.Windows.Forms.Label();
this.lblAutoHighData = newSystem.Windows.Forms.Label();
this.lblAutoLowData = newSystem.Windows.Forms.Label();
this.groupBox3 = newSystem.Windows.Forms.GroupBox();
this.solidGaugeAuto = newLiveCharts.WinForms.SolidGauge();
this.groupBox4 = newSystem.Windows.Forms.GroupBox();
this.solidGaugeTime = newLiveCharts.WinForms.SolidGauge();
this.dgridTimeDisplay = newSystem.Windows.Forms.DataGridView();
this.lblTimeLowData = newSystem.Windows.Forms.Label();
this.lblTimeNetworkMode = newSystem.Windows.Forms.Label();
this.lblTimeHighData = newSystem.Windows.Forms.Label();
this.lblTimeTotalData = newSystem.Windows.Forms.Label();
this.groupBox5 = newSystem.Windows.Forms.GroupBox();
this.solidGaugeNormal = newLiveCharts.WinForms.SolidGauge();
```

```
this.dgridNormDisplay = newSystem.Windows.Forms.DataGridView();
this.lblNormLowData = newSystem.Windows.Forms.Label();
this.lblNormNetworkMode = newSystem.Windows.Forms.Label();
this.lblNormHighData = newSystem.Windows.Forms.Label();
this.lblNormTotalData = newSystem.Windows.Forms.Label();
this.bwAuto = newSystem.ComponentModel.BackgroundWorker();
this.bwTime = newSystem.ComponentModel.BackgroundWorker();
this.bwNormal = newSystem.ComponentModel.BackgroundWorker();
this.bwSaveDaily = newSystem.ComponentModel.BackgroundWorker();
this.picMenu = newSystem.Windows.Forms.PictureBox();
this.picMinimise = newSystem.Windows.Forms.PictureBox();
this.picClose = newSystem.Windows.Forms.PictureBox();
this.panel1 = newSystem.Windows.Forms.Panel();
this.panel2 = newSystem.Windows.Forms.Panel();
this.dataGridViewTextBoxColumn5 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataGridViewTextBoxColumn6 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataGridViewTextBoxColumn7 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataGridViewTextBoxColumn8 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.displayUserBindingSource = newSystem.Windows.Forms.BindingSource(this.components);
this.dataGridViewTextBoxColumn1 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataGridViewTextBoxColumn2 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataGridViewTextBoxColumn3 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataGridViewTextBoxColumn4 = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.ipDataGridViewTextBoxColumn = newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.macDataGridViewTextBoxColumn =
newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.dataConsumedDataGridViewTextBoxColumn =
newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.userNodeTypeDataGridViewTextBoxColumn =
newSystem.Windows.Forms.DataGridViewTextBoxColumn();
this.panSide.SuspendLayout();
this.groupBox2.SuspendLayout();

((System.ComponentModel.ISupportInitialize)(this.dgridAutoDisplay)).BeginInit();
this.groupBox3.SuspendLayout();
this.groupBox4.SuspendLayout();

((System.ComponentModel.ISupportInitialize)(this.dgridTimeDisplay)).BeginInit();
this.groupBox5.SuspendLayout();
```

```
((System.ComponentModel.ISupportInitialize)(this.dgridNormDisplay)).BeginInit();
            ((System.ComponentModel.ISupportInitialize)(this.picMenu)).BeginInit();
            ((System.ComponentModel.ISupportInitialize)(this.picMinimise)).BeginInit();
            ((System.ComponentModel.ISupportInitialize)(this.picClose)).BeginInit();
this.panel1.SuspendLayout();
this.panel2.SuspendLayout();

((System.ComponentModel.ISupportInitialize)(this.displayUserBindingSource)).BeginInit()
;
this.SuspendLayout();
//
// label1
//
this.label1.AutoSize = true;
this.label1.Font = newSystem.Drawing.Font("Arial Black", 20F,
System.Drawing.FontStyle.Bold, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
this.label1.Location = newSystem.Drawing.Point(540, 2);
this.label1.Name = "label1";
this.label1.Size = newSystem.Drawing.Size(499, 48);
this.label1.TabIndex = 0;
this.label1.Text = "X-NET SERVER MANAGER";
//
// panSide
//
this.panSide.BackColor = System.Drawing.Color.FromArgb(((int)(((byte)(37)))),
((int)(((byte)(37)))), ((int)(((byte)(38)))));
this.panSide.Controls.Add(this.btnReport);
this.panSide.Controls.Add(this.groupBox2);
this.panSide.Location = newSystem.Drawing.Point(5, 56);
this.panSide.Name = "panSide";
this.panSide.Size = newSystem.Drawing.Size(294, 752);
this.panSide.TabIndex = 1;
this.panSide.Visible = false;
//
// btnReport
//
this.btnReport.FlatStyle = System.Windows.Forms.FlatStyle.Flat;
```

```
this.btnReport.Font = newSystem.Drawing.Font("Arial", 12F,
System.Drawing.FontStyle.Bold, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
this.btnReport.Location = newSystem.Drawing.Point(2, 266);
this.btnReport.Name = "btnReport";
this.btnReport.Size = newSystem.Drawing.Size(289, 57);
this.btnReport.TabIndex = 4;
this.btnReport.Text = "REPORTS";
this.btnReport.UseVisualStyleBackColor = true;
this.btnReport.Click += newSystem.EventHandler(this.btnReport_Click);
//
// groupBox2
//
this.groupBox2.Controls.Add(this.label6);
this.groupBox2.Controls.Add(this.label5);
this.groupBox2.Controls.Add(this.label4);
this.groupBox2.Controls.Add(this.label3);
this.groupBox2.Controls.Add(this.label2);
this.groupBox2.Location = newSystem.Drawing.Point(3, 29);
this.groupBox2.Name = "groupBox2";
this.groupBox2.Size = newSystem.Drawing.Size(288, 228);
this.groupBox2.TabIndex = 3;
this.groupBox2.TabStop = false;
this.groupBox2.Text = "Node Details";
//
// label6
//
this.label6.AutoSize = true;
this.label6.Location = newSystem.Drawing.Point(9, 192);
this.label6.Name = "label6";
this.label6.Size = newSystem.Drawing.Size(198, 23);
this.label6.TabIndex = 17;
this.label6.Text = "Cell Name : AB001_1";
//
// label5
//
this.label5.AutoSize = true;
this.label5.Location = newSystem.Drawing.Point(9, 156);
this.label5.Name = "label5";
this.label5.Size = newSystem.Drawing.Size(95, 23);
```

```
this.label5.TabIndex = 16;
this.label5.Text = "Cell Id : 1";
//
// label4
//
this.label4.AutoSize = true;
this.label4.Location = newSystem.Drawing.Point(9, 110);
this.label4.Name = "label4";
this.label4.Size = newSystem.Drawing.Size(198, 23);
this.label4.TabIndex = 15;
this.label4.Text = "Cell Name : AB001_0";
//
// label3
//
this.label3.AutoSize = true;
this.label3.Location = newSystem.Drawing.Point(9, 77);
this.label3.Name = "label3";
this.label3.Size = newSystem.Drawing.Size(95, 23);
this.label3.TabIndex = 14;
this.label3.Text = "Cell Id : 0";
//
// label2
//
this.label2.AutoSize = true;
this.label2.Location = newSystem.Drawing.Point(9, 39);
this.label2.Name = "label2";
this.label2.Size = newSystem.Drawing.Size(178, 23);
this.label2.TabIndex = 13;
this.label2.Text = "EnodeBId : AB001";
//
// dgridAutoDisplay
//
this.dgridAutoDisplay.AllowUserToAddRows = false;
this.dgridAutoDisplay.AllowUserToDeleteRows = false;
this.dgridAutoDisplay.AllowUserToOrderColumns = true;
            dataGridViewCellStyle1.BackColor =
System.Drawing.Color.FromArgb(((int)(((byte)(28)))), ((int)(((byte)(28)))),
((int)(((byte)(28)))));
this.dgridAutoDisplay.AlternatingRowsDefaultCellStyle = dataGridViewCellStyle1;
```

```
this.dgridAutoDisplay.AutoGenerateColumns = false;
this.dgridAutoDisplay.BackgroundColor =
System.Drawing.Color.FromArgb(((int)(((byte)(28)))), ((int)(((byte)(28)))),
((int)(((byte)(28)))));
this.dgridAutoDisplay.ColumnHeadersHeightSizeMode =
System.Windows.Forms.DataGridViewColumnHeadersHeightSizeMode.AutoSize;
this.dgridAutoDisplay.Columns.AddRange(newSystem.Windows.Forms.DataGridViewColumn[] {
this.ipDataGridViewTextBoxColumn,
this.macDataGridViewTextBoxColumn,
this.dataConsumedDataGridViewTextBoxColumn,
this.userNodeTypeDataGridViewTextBoxColumn});
this.dgridAutoDisplay.DataSource = this.displayUserBindingSource;
            dataGridViewCellStyle2.Alignment =
System.Windows.Forms.DataGridViewContentAlignment.MiddleLeft;
            dataGridViewCellStyle2.BackColor =
System.Drawing.Color.FromArgb(((int)(((byte)(45)))), ((int)(((byte)(45)))),
((int)(((byte)(48)))));
            dataGridViewCellStyle2.Font = newSystem.Drawing.Font("Arial", 12F,
System.Drawing.FontStyle.Regular, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
            dataGridViewCellStyle2.ForeColor = System.Drawing.Color.White;
            dataGridViewCellStyle2.SelectionBackColor =
System.Drawing.SystemColors.Highlight;
            dataGridViewCellStyle2.SelectionForeColor =
System.Drawing.SystemColors.HighlightText;
            dataGridViewCellStyle2.WrapMode =
System.Windows.Forms.DataGridViewTriState.False;
this.dgridAutoDisplay.DefaultCellStyle = dataGridViewCellStyle2;
this.dgridAutoDisplay.Location = newSystem.Drawing.Point(6, 172);
this.dgridAutoDisplay.Name = "dgridAutoDisplay";
this.dgridAutoDisplay.ReadOnly = true;
this.dgridAutoDisplay.RowTemplate.Height = 24;
this.dgridAutoDisplay.Size = newSystem.Drawing.Size(488, 506);
this.dgridAutoDisplay.TabIndex = 3;
//
// timTimer
//
this.timTimer.Interval = 500;
this.timTimer.Tick += newSystem.EventHandler(this.timTimer_Tick);
//
```

```
// lblTime
//
this.lblTime.AutoSize = true;
this.lblTime.Location = newSystem.Drawing.Point(439, 0);
this.lblTime.Name = "lblTime";
this.lblTime.Size = newSystem.Drawing.Size(121, 23);
this.lblTime.TabIndex = 4;
this.lblTime.Text = "Time - 00:00";
//
// timLogInOut
//
this.timLogInOut.Interval = 2000;
this.timLogInOut.Tick += newSystem.EventHandler(this.timLogInOut_Tick);
//
// lblOnlineUsers
//
this.lblOnlineUsers.AutoSize = true;
this.lblOnlineUsers.Location = newSystem.Drawing.Point(608, 0);
this.lblOnlineUsers.Name = "lblOnlineUsers";
this.lblOnlineUsers.Size = newSystem.Drawing.Size(140, 23);
this.lblOnlineUsers.TabIndex = 7;
this.lblOnlineUsers.Text = "Online Users : ";
//
// lblHighUser
//
this.lblHighUser.AutoSize = true;
this.lblHighUser.Location = newSystem.Drawing.Point(818, 0);
this.lblHighUser.Name = "lblHighUser";
this.lblHighUser.Size = newSystem.Drawing.Size(123, 23);
this.lblHighUser.TabIndex = 8;
this.lblHighUser.Text = "High Users : ";
//
// lblLowUser
//
this.lblLowUser.AutoSize = true;
this.lblLowUser.Location = newSystem.Drawing.Point(1015, 0);
this.lblLowUser.Name = "lblLowUser";
this.lblLowUser.Size = newSystem.Drawing.Size(122, 23);
this.lblLowUser.TabIndex = 9;
```

```
this.lblLowUser.Text = "Low Users : ";
//
// lblAutoNetworkMode
//
this.lblAutoNetworkMode.AutoSize = true;
this.lblAutoNetworkMode.Location = newSystem.Drawing.Point(6, 36);
this.lblAutoNetworkMode.Name = "lblAutoNetworkMode";
this.lblAutoNetworkMode.Size = newSystem.Drawing.Size(157, 23);
this.lblAutoNetworkMode.TabIndex = 10;
this.lblAutoNetworkMode.Text = "Network Mode : ";
//
// lblAutoTotalData
//
this.lblAutoTotalData.AutoSize = true;
this.lblAutoTotalData.Location = newSystem.Drawing.Point(6, 71);
this.lblAutoTotalData.Name = "lblAutoTotalData";
this.lblAutoTotalData.Size = newSystem.Drawing.Size(217, 23);
this.lblAutoTotalData.TabIndex = 11;
this.lblAutoTotalData.Text = "Total Data Consumed : ";
//
// lblAutoHighData
//
this.lblAutoHighData.AutoSize = true;
this.lblAutoHighData.Location = newSystem.Drawing.Point(6, 105);
this.lblAutoHighData.Name = "lblAutoHighData";
this.lblAutoHighData.Size = newSystem.Drawing.Size(240, 23);
this.lblAutoHighData.TabIndex = 12;
this.lblAutoHighData.Text = "Average High User Data : ";
//
// lblAutoLowData
//
this.lblAutoLowData.AutoSize = true;
this.lblAutoLowData.Location = newSystem.Drawing.Point(7, 139);
this.lblAutoLowData.Name = "lblAutoLowData";
this.lblAutoLowData.Size = newSystem.Drawing.Size(239, 23);
this.lblAutoLowData.TabIndex = 13;
this.lblAutoLowData.Text = "Average Low User Data : ";
//
// groupBox3
```

```
//
this.groupBox3.Controls.Add(this.solidGaugeAuto);
this.groupBox3.Controls.Add(this.dgridAutoDisplay);
this.groupBox3.Controls.Add(this.lblAutoLowData);
this.groupBox3.Controls.Add(this.lblAutoNetworkMode);
this.groupBox3.Controls.Add(this.lblAutoHighData);
this.groupBox3.Controls.Add(this.lblAutoTotalData);
this.groupBox3.Location = newSystem.Drawing.Point(1015, 26);
this.groupBox3.Name = "groupBox3";
this.groupBox3.Size = newSystem.Drawing.Size(500, 710);
this.groupBox3.TabIndex = 14;
this.groupBox3.TabStop = false;
this.groupBox3.Text = "Auto Split Algo";
this.groupBox3.Enter += newSystem.EventHandler(this.groupBox3_Enter);
//
// solidGaugeAuto
//
this.solidGaugeAuto.Location = newSystem.Drawing.Point(350, 36);
this.solidGaugeAuto.Name = "solidGaugeAuto";
this.solidGaugeAuto.Size = newSystem.Drawing.Size(148, 137);
this.solidGaugeAuto.TabIndex = 0;
this.solidGaugeAuto.Text = "Ave. Low User Data";
//
// groupBox4
//
this.groupBox4.Controls.Add(this.solidGaugeTime);
this.groupBox4.Controls.Add(this.dgridTimeDisplay);
this.groupBox4.Controls.Add(this.lblTimeLowData);
this.groupBox4.Controls.Add(this.lblTimeNetworkMode);
this.groupBox4.Controls.Add(this.lblTimeHighData);
this.groupBox4.Controls.Add(this.lblTimeTotalData);
this.groupBox4.Location = newSystem.Drawing.Point(511, 26);
this.groupBox4.Name = "groupBox4";
this.groupBox4.Size = newSystem.Drawing.Size(500, 710);
this.groupBox4.TabIndex = 15;
this.groupBox4.TabStop = false;
this.groupBox4.Text = "Time Split Algo";
this.groupBox4.Enter += newSystem.EventHandler(this.groupBox4_Enter);
//
```

```
// solidGaugeTime
//
this.solidGaugeTime.Location = newSystem.Drawing.Point(350, 29);
this.solidGaugeTime.Name = "solidGaugeTime";
this.solidGaugeTime.Size = newSystem.Drawing.Size(148, 137);
this.solidGaugeTime.TabIndex = 14;
this.solidGaugeTime.Text = "Ave. Low User Data";
//
// dgridTimeDisplay
//
this.dgridTimeDisplay.AllowUserToAddRows = false;
this.dgridTimeDisplay.AllowUserToDeleteRows = false;
this.dgridTimeDisplay.AllowUserToOrderColumns = true;
            dataGridViewCellStyle3.BackColor =
System.Drawing.Color.FromArgb(((int)(((byte)(28)))), ((int)(((byte)(28)))),
((int)(((byte)(28)))));
this.dgridTimeDisplay.AlternatingRowsDefaultCellStyle = dataGridViewCellStyle3;
this.dgridTimeDisplay.AutoGenerateColumns = false;
this.dgridTimeDisplay.BackgroundColor =
System.Drawing.Color.FromArgb(((int)(((byte)(28)))), ((int)(((byte)(28)))),
((int)(((byte)(28)))));
this.dgridTimeDisplay.ColumnHeadersHeightSizeMode =
System.Windows.Forms.DataGridViewColumnHeadersHeightSizeMode.AutoSize;
this.dgridTimeDisplay.Columns.AddRange(newSystem.Windows.Forms.DataGridViewColumn[] {
this.dataGridViewTextBoxColumn1,
this.dataGridViewTextBoxColumn2,
this.dataGridViewTextBoxColumn3,
this.dataGridViewTextBoxColumn4});
this.dgridTimeDisplay.DataSource = this.displayUserBindingSource;
            dataGridViewCellStyle4.Alignment =
System.Windows.Forms.DataGridViewContentAlignment.MiddleLeft;
            dataGridViewCellStyle4.BackColor =
System.Drawing.Color.FromArgb(((int)(((byte)(45)))), ((int)(((byte)(45)))),
((int)(((byte)(48)))));
            dataGridViewCellStyle4.Font = newSystem.Drawing.Font("Arial", 12F,
System.Drawing.FontStyle.Regular, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
            dataGridViewCellStyle4.ForeColor = System.Drawing.Color.White;
            dataGridViewCellStyle4.SelectionBackColor =
System.Drawing.SystemColors.Highlight;
```

```
            dataGridViewCellStyle4.SelectionForeColor =
System.Drawing.SystemColors.HighlightText;
            dataGridViewCellStyle4.WrapMode =
System.Windows.Forms.DataGridViewTriState.False;
this.dgridTimeDisplay.DefaultCellStyle = dataGridViewCellStyle4;
this.dgridTimeDisplay.Location = newSystem.Drawing.Point(6, 172);
this.dgridTimeDisplay.Name = "dgridTimeDisplay";
this.dgridTimeDisplay.ReadOnly = true;
this.dgridTimeDisplay.RowTemplate.Height = 24;
this.dgridTimeDisplay.Size = newSystem.Drawing.Size(488, 506);
this.dgridTimeDisplay.TabIndex = 3;
//
// lblTimeLowData
//
this.lblTimeLowData.AutoSize = true;
this.lblTimeLowData.Location = newSystem.Drawing.Point(7, 139);
this.lblTimeLowData.Name = "lblTimeLowData";
this.lblTimeLowData.Size = newSystem.Drawing.Size(239, 23);
this.lblTimeLowData.TabIndex = 13;
this.lblTimeLowData.Text = "Average Low User Data : ";
//
// lblTimeNetworkMode
//
this.lblTimeNetworkMode.AutoSize = true;
this.lblTimeNetworkMode.Location = newSystem.Drawing.Point(6, 36);
this.lblTimeNetworkMode.Name = "lblTimeNetworkMode";
this.lblTimeNetworkMode.Size = newSystem.Drawing.Size(157, 23);
this.lblTimeNetworkMode.TabIndex = 10;
this.lblTimeNetworkMode.Text = "Network Mode : ";
//
// lblTimeHighData
//
this.lblTimeHighData.AutoSize = true;
this.lblTimeHighData.Location = newSystem.Drawing.Point(6, 105);
this.lblTimeHighData.Name = "lblTimeHighData";
this.lblTimeHighData.Size = newSystem.Drawing.Size(240, 23);
this.lblTimeHighData.TabIndex = 12;
this.lblTimeHighData.Text = "Average High User Data : ";
//
```

```
// lblTimeTotalData
//
this.lblTimeTotalData.AutoSize = true;
this.lblTimeTotalData.Location = newSystem.Drawing.Point(6, 71);
this.lblTimeTotalData.Name = "lblTimeTotalData";
this.lblTimeTotalData.Size = newSystem.Drawing.Size(217, 23);
this.lblTimeTotalData.TabIndex = 11;
this.lblTimeTotalData.Text = "Total Data Consumed : ";
//
// groupBox5
//
this.groupBox5.Controls.Add(this.solidGaugeNormal);
this.groupBox5.Controls.Add(this.dgridNormDisplay);
this.groupBox5.Controls.Add(this.lblNormLowData);
this.groupBox5.Controls.Add(this.lblNormNetworkMode);
this.groupBox5.Controls.Add(this.lblNormHighData);
this.groupBox5.Controls.Add(this.lblNormTotalData);
this.groupBox5.Location = newSystem.Drawing.Point(5, 26);
this.groupBox5.Name = "groupBox5";
this.groupBox5.Size = newSystem.Drawing.Size(500, 710);
this.groupBox5.TabIndex = 16;
this.groupBox5.TabStop = false;
this.groupBox5.Text = "Normal Algo";
//
// solidGaugeNormal
//
this.solidGaugeNormal.Location = newSystem.Drawing.Point(352, 36);
this.solidGaugeNormal.Name = "solidGaugeNormal";
this.solidGaugeNormal.Size = newSystem.Drawing.Size(148, 137);
this.solidGaugeNormal.TabIndex = 14;
this.solidGaugeNormal.Text = "Ave. Low User Data";
//
// dgridNormDisplay
//
this.dgridNormDisplay.AllowUserToAddRows = false;
this.dgridNormDisplay.AllowUserToDeleteRows = false;
this.dgridNormDisplay.AllowUserToOrderColumns = true;
```

```
            dataGridViewCellStyle5.BackColor =
System.Drawing.Color.FromArgb(((int)(((byte)(28)))), ((int)(((byte)(28)))),
((int)(((byte)(28)))));
this.dgridNormDisplay.AlternatingRowsDefaultCellStyle = dataGridViewCellStyle5;
this.dgridNormDisplay.AutoGenerateColumns = false;
this.dgridNormDisplay.BackgroundColor =
System.Drawing.Color.FromArgb(((int)(((byte)(28)))), ((int)(((byte)(28)))),
((int)(((byte)(28)))));
this.dgridNormDisplay.ColumnHeadersHeightSizeMode =
System.Windows.Forms.DataGridViewColumnHeadersHeightSizeMode.AutoSize;
this.dgridNormDisplay.Columns.AddRange(newSystem.Windows.Forms.DataGridViewColumn[] {
this.dataGridViewTextBoxColumn5,
this.dataGridViewTextBoxColumn6,
this.dataGridViewTextBoxColumn7,
this.dataGridViewTextBoxColumn8});
this.dgridNormDisplay.DataSource = this.displayUserBindingSource;
            dataGridViewCellStyle6.Alignment =
System.Windows.Forms.DataGridViewContentAlignment.MiddleLeft;
            dataGridViewCellStyle6.BackColor =
System.Drawing.Color.FromArgb(((int)(((byte)(45)))), ((int)(((byte)(45)))),
((int)(((byte)(48)))));
            dataGridViewCellStyle6.Font = newSystem.Drawing.Font("Arial", 12F,
System.Drawing.FontStyle.Regular, System.Drawing.GraphicsUnit.Point, ((byte)(0)));
            dataGridViewCellStyle6.ForeColor = System.Drawing.Color.White;
            dataGridViewCellStyle6.SelectionBackColor =
System.Drawing.SystemColors.Highlight;
            dataGridViewCellStyle6.SelectionForeColor =
System.Drawing.SystemColors.HighlightText;
            dataGridViewCellStyle6.WrapMode =
System.Windows.Forms.DataGridViewTriState.False;
this.dgridNormDisplay.DefaultCellStyle = dataGridViewCellStyle6;
this.dgridNormDisplay.Location = newSystem.Drawing.Point(6, 172);
this.dgridNormDisplay.Name = "dgridNormDisplay";
this.dgridNormDisplay.ReadOnly = true;
this.dgridNormDisplay.RowTemplate.Height = 24;
this.dgridNormDisplay.Size = newSystem.Drawing.Size(488, 506);
this.dgridNormDisplay.TabIndex = 3;
//
// lblNormLowData
```

```
//
this.lblNormLowData.AutoSize = true;
this.lblNormLowData.Location = newSystem.Drawing.Point(7, 139);
this.lblNormLowData.Name = "lblNormLowData";
this.lblNormLowData.Size = newSystem.Drawing.Size(239, 23);
this.lblNormLowData.TabIndex = 13;
this.lblNormLowData.Text = "Average Low User Data : ";
//
// lblNormNetworkMode
//
this.lblNormNetworkMode.AutoSize = true;
this.lblNormNetworkMode.Location = newSystem.Drawing.Point(6, 36);
this.lblNormNetworkMode.Name = "lblNormNetworkMode";
this.lblNormNetworkMode.Size = newSystem.Drawing.Size(157, 23);
this.lblNormNetworkMode.TabIndex = 10;
this.lblNormNetworkMode.Text = "Network Mode : ";
//
// lblNormHighData
//
this.lblNormHighData.AutoSize = true;
this.lblNormHighData.Location = newSystem.Drawing.Point(6, 105);
this.lblNormHighData.Name = "lblNormHighData";
this.lblNormHighData.Size = newSystem.Drawing.Size(240, 23);
this.lblNormHighData.TabIndex = 12;
this.lblNormHighData.Text = "Average High User Data : ";
//
// lblNormTotalData
//
this.lblNormTotalData.AutoSize = true;
this.lblNormTotalData.Location = newSystem.Drawing.Point(6, 71);
this.lblNormTotalData.Name = "lblNormTotalData";
this.lblNormTotalData.Size = newSystem.Drawing.Size(217, 23);
this.lblNormTotalData.TabIndex = 11;
this.lblNormTotalData.Text = "Total Data Consumed : ";
//
// bwAuto
//
this.bwAuto.DoWork += newSystem.ComponentModel.DoWorkEventHandler(this.bwAuto_DoWork);
```

```
this.bwAuto.RunWorkerCompleted +=
newSystem.ComponentModel.RunWorkerCompletedEventHandler(this.bwAuto_RunWorkerCompleted)
;
//
// bwTime
//
this.bwTime.DoWork += newSystem.ComponentModel.DoWorkEventHandler(this.bwTime_DoWork);
this.bwTime.RunWorkerCompleted +=
newSystem.ComponentModel.RunWorkerCompletedEventHandler(this.bwTime_RunWorkerCompleted)
;
//
// bwNormal
//
this.bwNormal.DoWork +=
newSystem.ComponentModel.DoWorkEventHandler(this.bwNormal_DoWork);
this.bwNormal.RunWorkerCompleted +=
newSystem.ComponentModel.RunWorkerCompletedEventHandler(this.bwNormal_RunWorkerComplete
d);
//
// bwSaveDaily
//
this.bwSaveDaily.DoWork +=
newSystem.ComponentModel.DoWorkEventHandler(this.bwSaveDaily_DoWork);
//
// picMenu
//
this.picMenu.Image = global::Xnet.Properties.Resources.menu;
this.picMenu.Location = newSystem.Drawing.Point(1, 2);
this.picMenu.Name = "picMenu";
this.picMenu.Size = newSystem.Drawing.Size(50, 50);
this.picMenu.SizeMode = System.Windows.Forms.PictureBoxSizeMode.StretchImage;
this.picMenu.TabIndex = 6;
this.picMenu.TabStop = false;
this.picMenu.Click += newSystem.EventHandler(this.picMenu_Click);
//
// picMinimise
//
```

```
this.picMinimise.Anchor =
((System.Windows.Forms.AnchorStyles)((System.Windows.Forms.AnchorStyles.Top |
System.Windows.Forms.AnchorStyles.Right)));
this.picMinimise.BackColor = System.Drawing.Color.FromArgb(((int)(((byte)(45)))),
((int)(((byte)(45)))), ((int)(((byte)(48)))));
this.picMinimise.Image = global::Xnet.Properties.Resources.minimise;
this.picMinimise.Location = newSystem.Drawing.Point(1469, 3);
this.picMinimise.Name = "picMinimise";
this.picMinimise.Size = newSystem.Drawing.Size(30, 30);
this.picMinimise.SizeMode = System.Windows.Forms.PictureBoxSizeMode.StretchImage;
this.picMinimise.TabIndex = 5;
this.picMinimise.TabStop = false;
this.picMinimise.Click += newSystem.EventHandler(this.picMinimise_Click);
this.picMinimise.MouseLeave += newSystem.EventHandler(this.picMinimise_MouseLeave);
this.picMinimise.MouseHover += newSystem.EventHandler(this.picMinimise_MouseHover);
//
// picClose
//
this.picClose.Anchor =
((System.Windows.Forms.AnchorStyles)((System.Windows.Forms.AnchorStyles.Top |
System.Windows.Forms.AnchorStyles.Right)));
this.picClose.BackColor = System.Drawing.Color.Red;
this.picClose.Image = global::Xnet.Properties.Resources.close;
this.picClose.Location = newSystem.Drawing.Point(1505, 3);
this.picClose.Name = "picClose";
this.picClose.Size = newSystem.Drawing.Size(30, 30);
this.picClose.SizeMode = System.Windows.Forms.PictureBoxSizeMode.StretchImage;
this.picClose.TabIndex = 2;
this.picClose.TabStop = false;
this.picClose.Click += newSystem.EventHandler(this.picClose_Click);
this.picClose.MouseLeave += newSystem.EventHandler(this.picClose_MouseLeave);
this.picClose.MouseHover += newSystem.EventHandler(this.picClose_MouseHover);
//
// panel1
//
this.panel1.Anchor =
((System.Windows.Forms.AnchorStyles)(((System.Windows.Forms.AnchorStyles.Top |
System.Windows.Forms.AnchorStyles.Left)
            | System.Windows.Forms.AnchorStyles.Right)));
```

```
this.panel1.BackColor = System.Drawing.Color.FromArgb(((int)(((byte)(37)))),
((int)(((byte)(37)))), ((int)(((byte)(38)))));
this.panel1.Controls.Add(this.label1);
this.panel1.Controls.Add(this.picMenu);
this.panel1.Controls.Add(this.picClose);
this.panel1.Controls.Add(this.picMinimise);
this.panel1.Location = newSystem.Drawing.Point(2, 0);
this.panel1.Name = "panel1";
this.panel1.Size = newSystem.Drawing.Size(1543, 50);
this.panel1.TabIndex = 17;
this.panel1.MouseDown +=
newSystem.Windows.Forms.MouseEventHandler(this.panel1_MouseDown);
this.panel1.MouseMove +=
newSystem.Windows.Forms.MouseEventHandler(this.panel1_MouseMove);
this.panel1.MouseUp += newSystem.Windows.Forms.MouseEventHandler(this.panel1_MouseUp);
//
// panel2
//
this.panel2.Anchor =
((System.Windows.Forms.AnchorStyles)((((System.Windows.Forms.AnchorStyles.Top |
System.Windows.Forms.AnchorStyles.Bottom)
            | System.Windows.Forms.AnchorStyles.Left)
            | System.Windows.Forms.AnchorStyles.Right)));
this.panel2.AutoScroll = true;
this.panel2.Controls.Add(this.lblTime);
this.panel2.Controls.Add(this.groupBox5);
this.panel2.Controls.Add(this.lblOnlineUsers);
this.panel2.Controls.Add(this.groupBox4);
this.panel2.Controls.Add(this.lblHighUser);
this.panel2.Controls.Add(this.groupBox3);
this.panel2.Controls.Add(this.lblLowUser);
this.panel2.Location = newSystem.Drawing.Point(2, 64);
this.panel2.Name = "panel2";
this.panel2.Size = newSystem.Drawing.Size(1543, 744);
this.panel2.TabIndex = 18;
//
// dataGridViewTextBoxColumn5
//
this.dataGridViewTextBoxColumn5.DataPropertyName = "Ip";
```

```
this.dataGridViewTextBoxColumn5.HeaderText = "Ip";
this.dataGridViewTextBoxColumn5.Name = "dataGridViewTextBoxColumn5";
this.dataGridViewTextBoxColumn5.ReadOnly = true;
this.dataGridViewTextBoxColumn5.Width = 120;
//
// dataGridViewTextBoxColumn6
//
this.dataGridViewTextBoxColumn6.DataPropertyName = "Mac";
this.dataGridViewTextBoxColumn6.HeaderText = "Mac";
this.dataGridViewTextBoxColumn6.Name = "dataGridViewTextBoxColumn6";
this.dataGridViewTextBoxColumn6.ReadOnly = true;
this.dataGridViewTextBoxColumn6.Width = 120;
//
// dataGridViewTextBoxColumn7
//
this.dataGridViewTextBoxColumn7.DataPropertyName = "DataConsumed";
this.dataGridViewTextBoxColumn7.HeaderText = "DataConsumed(kbps)";
this.dataGridViewTextBoxColumn7.Name = "dataGridViewTextBoxColumn7";
this.dataGridViewTextBoxColumn7.ReadOnly = true;
this.dataGridViewTextBoxColumn7.Width = 110;
//
// dataGridViewTextBoxColumn8
//
this.dataGridViewTextBoxColumn8.DataPropertyName = "UserNodeType";
this.dataGridViewTextBoxColumn8.HeaderText = "UserNodeType";
this.dataGridViewTextBoxColumn8.Name = "dataGridViewTextBoxColumn8";
this.dataGridViewTextBoxColumn8.ReadOnly = true;
//
// displayUserBindingSource
//
this.displayUserBindingSource.DataSource = typeof(Xnet.DAL.DisplayUser);
//
// dataGridViewTextBoxColumn1
//
this.dataGridViewTextBoxColumn1.DataPropertyName = "Ip";
this.dataGridViewTextBoxColumn1.HeaderText = "Ip";
this.dataGridViewTextBoxColumn1.Name = "dataGridViewTextBoxColumn1";
this.dataGridViewTextBoxColumn1.ReadOnly = true;
this.dataGridViewTextBoxColumn1.Width = 120;
```

```
//
// dataGridViewTextBoxColumn2
//
this.dataGridViewTextBoxColumn2.DataPropertyName = "Mac";
this.dataGridViewTextBoxColumn2.HeaderText = "Mac";
this.dataGridViewTextBoxColumn2.Name = "dataGridViewTextBoxColumn2";
this.dataGridViewTextBoxColumn2.ReadOnly = true;
this.dataGridViewTextBoxColumn2.Width = 120;
//
// dataGridViewTextBoxColumn3
//
this.dataGridViewTextBoxColumn3.DataPropertyName = "DataConsumed";
this.dataGridViewTextBoxColumn3.HeaderText = "DataConsumed(kbps)";
this.dataGridViewTextBoxColumn3.Name = "dataGridViewTextBoxColumn3";
this.dataGridViewTextBoxColumn3.ReadOnly = true;
this.dataGridViewTextBoxColumn3.Width = 110;
//
// dataGridViewTextBoxColumn4
//
this.dataGridViewTextBoxColumn4.DataPropertyName = "UserNodeType";
this.dataGridViewTextBoxColumn4.HeaderText = "UserNodeType";
this.dataGridViewTextBoxColumn4.Name = "dataGridViewTextBoxColumn4";
this.dataGridViewTextBoxColumn4.ReadOnly = true;
//
// ipDataGridViewTextBoxColumn
//
this.ipDataGridViewTextBoxColumn.DataPropertyName = "Ip";
this.ipDataGridViewTextBoxColumn.HeaderText = "Ip";
this.ipDataGridViewTextBoxColumn.Name = "ipDataGridViewTextBoxColumn";
this.ipDataGridViewTextBoxColumn.ReadOnly = true;
this.ipDataGridViewTextBoxColumn.Width = 120;
//
// macDataGridViewTextBoxColumn
//
this.macDataGridViewTextBoxColumn.DataPropertyName = "Mac";
this.macDataGridViewTextBoxColumn.HeaderText = "Mac";
this.macDataGridViewTextBoxColumn.Name = "macDataGridViewTextBoxColumn";
this.macDataGridViewTextBoxColumn.ReadOnly = true;
this.macDataGridViewTextBoxColumn.Width = 120;
```

```
//
// dataConsumedDataGridViewTextBoxColumn
//
this.dataConsumedDataGridViewTextBoxColumn.DataPropertyName = "DataConsumed";
this.dataConsumedDataGridViewTextBoxColumn.HeaderText = "DataConsumed(kbps)";
this.dataConsumedDataGridViewTextBoxColumn.Name =
"dataConsumedDataGridViewTextBoxColumn";
this.dataConsumedDataGridViewTextBoxColumn.ReadOnly = true;
this.dataConsumedDataGridViewTextBoxColumn.Width = 110;
//
// userNodeTypeDataGridViewTextBoxColumn
//
this.userNodeTypeDataGridViewTextBoxColumn.DataPropertyName = "UserNodeType";
this.userNodeTypeDataGridViewTextBoxColumn.HeaderText = "UserNodeType";
this.userNodeTypeDataGridViewTextBoxColumn.Name =
"userNodeTypeDataGridViewTextBoxColumn";
this.userNodeTypeDataGridViewTextBoxColumn.ReadOnly = true;
//
// Form1
//
this.AutoScaleMode = System.Windows.Forms.AutoScaleMode.None;
this.BackColor = System.Drawing.Color.FromArgb(((int)(((byte)(45)))),
((int)(((byte)(45)))), ((int)(((byte)(48)))));
this.ClientSize = newSystem.Drawing.Size(1548, 814);
this.Controls.Add(this.panSide);
this.Controls.Add(this.panel1);
this.Controls.Add(this.panel2);
this.Font = newSystem.Drawing.Font("Arial", 12F, System.Drawing.FontStyle.Regular,
System.Drawing.GraphicsUnit.Point, ((byte)(0)));
this.ForeColor = System.Drawing.Color.White;
this.FormBorderStyle = System.Windows.Forms.FormBorderStyle.None;
this.Name = "Form1";
this.StartPosition = System.Windows.Forms.FormStartPosition.CenterScreen;
this.Load += newSystem.EventHandler(this.Form1_Load);
this.panSide.ResumeLayout(false);
this.groupBox2.ResumeLayout(false);
this.groupBox2.PerformLayout();

((System.ComponentModel.ISupportInitialize)(this.dgridAutoDisplay)).EndInit();
```

```
this.groupBox3.ResumeLayout(false);
this.groupBox3.PerformLayout();
this.groupBox4.ResumeLayout(false);
this.groupBox4.PerformLayout();

((System.ComponentModel.ISupportInitialize)(this.dgridTimeDisplay)).EndInit();
this.groupBox5.ResumeLayout(false);
this.groupBox5.PerformLayout();

((System.ComponentModel.ISupportInitialize)(this.dgridNormDisplay)).EndInit();
            ((System.ComponentModel.ISupportInitialize)(this.picMenu)).EndInit();
            ((System.ComponentModel.ISupportInitialize)(this.picMinimise)).EndInit();
            ((System.ComponentModel.ISupportInitialize)(this.picClose)).EndInit();
this.panel1.ResumeLayout(false);
this.panel1.PerformLayout();
this.panel2.ResumeLayout(false);
this.panel2.PerformLayout();

((System.ComponentModel.ISupportInitialize)(this.displayUserBindingSource)).EndInit();
this.ResumeLayout(false);

        }

#endregion

privateSystem.Windows.Forms.Label label1;
privateSystem.Windows.Forms.PanelpanSide;
privateSystem.Windows.Forms.PictureBoxpicClose;
privateSystem.Windows.Forms.DataGridViewdgridAutoDisplay;
privateSystem.Windows.Forms.TimertimTimer;
privateSystem.Windows.Forms.LabellblTime;
privateSystem.Windows.Forms.PictureBoxpicMinimise;
privateSystem.Windows.Forms.TimertimLogInOut;
privateSystem.Windows.Forms.PictureBoxpicMenu;
privateSystem.Windows.Forms.LabellblOnlineUsers;
privateSystem.Windows.Forms.LabellblHighUser;
privateSystem.Windows.Forms.LabellblLowUser;
privateSystem.Windows.Forms.LabellblAutoNetworkMode;
privateSystem.Windows.Forms.LabellblAutoTotalData;
```

```
privateSystem.Windows.Forms.LabellblAutoHighData;
privateSystem.Windows.Forms.LabellblAutoLowData;
privateSystem.Windows.Forms.GroupBox groupBox2;
privateSystem.Windows.Forms.BindingSourcedisplayUserBindingSource;
privateSystem.Windows.Forms.Label label6;
privateSystem.Windows.Forms.Label label5;
privateSystem.Windows.Forms.Label label4;
privateSystem.Windows.Forms.Label label3;
privateSystem.Windows.Forms.Label label2;
privateSystem.Windows.Forms.GroupBox groupBox3;
privateSystem.Windows.Forms.GroupBox groupBox4;
privateSystem.Windows.Forms.DataGridViewdgridTimeDisplay;
privateSystem.Windows.Forms.LabellblTimeLowData;
privateSystem.Windows.Forms.LabellblTimeNetworkMode;
privateSystem.Windows.Forms.LabellblTimeHighData;
privateSystem.Windows.Forms.LabellblTimeTotalData;
privateSystem.Windows.Forms.GroupBox groupBox5;
privateSystem.Windows.Forms.DataGridViewdgridNormDisplay;
privateSystem.Windows.Forms.LabellblNormLowData;
privateSystem.Windows.Forms.LabellblNormNetworkMode;
privateSystem.Windows.Forms.LabellblNormHighData;
privateSystem.Windows.Forms.LabellblNormTotalData;
privateSystem.Windows.Forms.DataGridViewTextBoxColumnipDataGridViewTextBoxColumn;
privateSystem.Windows.Forms.DataGridViewTextBoxColumnmacDataGridViewTextBoxColumn;
privateSystem.Windows.Forms.DataGridViewTextBoxColumndataConsumedDataGridViewTextBoxCol
umn;
privateSystem.Windows.Forms.DataGridViewTextBoxColumnuserNodeTypeDataGridViewTextBoxCol
umn;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn1;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn2;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn3;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn4;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn5;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn6;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn7;
privateSystem.Windows.Forms.DataGridViewTextBoxColumn dataGridViewTextBoxColumn8;
privateSystem.ComponentModel.BackgroundWorkerbwAuto;
privateSystem.ComponentModel.BackgroundWorkerbwTime;
privateSystem.ComponentModel.BackgroundWorkerbwNormal;
```

```
privateLiveCharts.WinForms.SolidGaugesolidGaugeAuto;
privateLiveCharts.WinForms.SolidGaugesolidGaugeTime;
privateLiveCharts.WinForms.SolidGaugesolidGaugeNormal;
privateSystem.ComponentModel.BackgroundWorkerbwSaveDaily;
privateSystem.Windows.Forms.ButtonbtnReport;
privateSystem.Windows.Forms.Panel panel1;
privateSystem.Windows.Forms.Panel panel2;
    }
}
```

Appendix E: Collated Average KPI Data