IMPROVING CELL EDGE PERFORMANCE FOR LTE NETWORK USING 0.8 GHz AND 2.6 GHz FREQUENCY BANDS

By

KOFI KWARTENG ABROKWA

(B.Sc. Telecommunication Engineering)

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Declaration

I hereby declare that this submission for the degree of MPhil Telecommunication Engineering is a presentation of my original work and to the best of my knowledge has not been accepted for any other degree or qualification. I confirm that appropriate credit has been given in this thesis where references have been made to the work of others.

Kofi Kwarteng Abrokwa	.....…………………	………………
Student	Signature	Date

Certified by:

Dr. Emmanuel Ampoma Affum	…………………….	………………………
Supervisor	Signature	Date

Certified by:

Dr. James Dzisi Gadze	…………………………..	……………………
Head of Department	Signature	Date

Dedication

I dedicate this work to the Almighty God for the opportunity to enroll in a postgraduate course and the strength he gave me throughout the composition of this thesis.

Acknowledgement

First and foremost, I would like to acknowledge the Almighty God for granting me this awesome privilege to undertake this project and the ability to put this work together.

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Abstract

To provide maximum Physical Downlink Shared Channel (PDSCH) capacity for cell-edge Long Term Evolution (LTE) customers, the received signal strength from the Base Station (BS) to the User Equipment (UE) should be high. However, increasing power levels at the BS to ensure signal availability for users at the cell edge presents Inter-Cell Interference (ICI) in the LTE network, which drastically impacts the Quality of Service (QoS) negatively. As a solution to curb this problem, researchers have adopted several techniques such as Geometric Factor Model (GFM), Heterogeneous Network (HN), and Power Variation System (PVS) to assign a carrier frequency to users based on their respective distance from the base station to boost the signal at the cell edge. However, these methods do not include the current channel conditions present in a multipath fading environment which are the main concern that needs to be taken into consideration. It is therefore imperative to investigate the performance of the LTE network by considering the impairment in the wireless channel to see its corresponding effect on the user performance. The inclusion of these challenges in the wireless channel will give an idea of the performance of the LTE network and the means to improve it for the optimum benefit for the users. This work presents the performance of cell-edge users in the LTE network on 0.8 GHz low band and 2.6 GHz high band, signal propagation experiment in MATLAB\Simulink environment based on Markov model. Carrier aggregation provides a technique for LTE users to access the network using multiple frequency bands, which have varying penetration losses and enlarged bandwidth for the user. The low and high band frequencies used in this work help the user at the cell edge to achieve coverage and throughput at the same time in the LTE network. The simulated signal-to-noise ratio of the two frequencies achieves a better performance metric for customers to experience a good internet service. The average bit error rate (BER) for users using 0.8 GHz was 5.50e-5 while the average bit error rate for users using 2.6 GHz was 1.98e-4. Cell edge users using 0.8 GHz frequency carrier experienced an average of 92% throughput while those on 2.6 GHz experienced an average of 70% throughput. These results provide a realistic and reliable approach to mitigate cell edge challenges for LTE users than those achieved by other methods such as GFM, HN, and PVS used by earlier researchers.

List of Abbreviations

3GPP	Third Generation Partnership Project
ARQ	Automatic Repeat Request
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
BLER	Block Error Ratio
BS	Base Station
CA	Carrier Aggregation
CC	Carrier Component
COMP	Coordinated Multi-Point Joint Processing
CQI	Channel quality indicator
CS	Channel Space
DC	Double Carrier
DCS	Dynamic Cell Selection
DL	Downlink
DPSK	Differential Phase-Shift keying
EPA	Extended Pedestrian A
ETU	Extended Typical Urban
EVA	Extended Vehicular A
FCFS	Fractional Coordinated Fair Scheduling
FDD	Frequency Division Duplexing
FDSS	Frequency diversity and selectivity scheduling

FPC	Fractional Power Control
FSK	Frequency-shift keying
GB	Guard Band
GMBS	Programming-Based General Multi-Band Scheduling
HARQ	Hybrid Automatic Repeat Request
HN	Heterogeneous Network
HSPA	High-Speed Packet Access
IBPC	Interference Based Power Control
iCRRM	Integrated Common Radio Resource Management
IMT	International Mobile Telecommunication
LOS	Line of Sight
LPN	Low Power Nodes
LTE	Long Term Evolution.
MIMO	Multiple Input, Multiple Output
MM-wave MMW	Millimeter-Wave
MTU	Maximum transmission unit
OFDM	Orthogonal Frequency-Division Multiplexing
OQPSK	Offset quadrature phase-shift keying
PCell	Primary Serving Cell
PDU	Packet Unit Data
PRB	Physical Resource Block
PS	Processor Sharing

PSK	Phase-shift keying
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature phase-shift keying
RLS	Received Signal Strength
RSRP	Signal Received Power Level
RSSI	Received Signal Strength Indicator
RZF	Zero-Forcing
SC	Single Carrier
SCell	Secondary Serving Cell
SC-FDMA	Single-Carrier Frequency-Division Multiple Access Scheme
SFBC	Space-Frequency Block Code
SNR	Signal to Noise Ratio
TAU	Test Access Unit
TDD	Time Division Duplex
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
UE	User Equipment
UFQ	Use the First Queue
UL	Uplink
VPL	Vehicular Propagation Losses
WCDMA	Wideband Code Division Multiple Access
WiMAX	Worldwide Interoperability for Microwave Access

Notation and Symbols

$n_1(t)$	Number of single users transmitting on carrier 1
$n_2(t)$	Number of single users transmitting on carrier 2
$mj(t)$	Number of double users transmitting on both carrier 1 and 2
e_1	The unit vector in the cell's area
A_j	Area of the cell
q_j	Probability of user in the area of the cell at a time
R	Total cell radius
$D_{1,J}$	Rate of the function of carrier frequency 1
$D_{2,J}$	Rate of the function of carrier frequency 2
C_1	Peak Data Rate on carrier 1
C_2	Peak Data Rate on carrier 2
J	Number of areas in the cell
σ_0	Amount of data transmitted by the BS
Λ	The total amount of data on both carriers 1 and 2
ρ	Stability condition for the system to
α	Rate of the arrival of users on carrier frequency 1
β	Rate of the arrival of users on carrier frequency 2
$T1$	Infinitesimal time interval
Θ	Traffic intensity
$\dot{C}$	System capacity
γ_J	The average throughput in an area

t’	Time Interval
$\mathbb{R}^{3+}$	3-dimensional vector
$(V_1(t)$	The vector in the Markov process
$ד(n)$	Stationary distribution of the system
$\gamma sc_{.j}$	Throughput for users on a single carrier frequency
$\gamma DC_{.j}$	Throughput for users on a double carrier frequency
$P_{i,k},$	Power transmitted by the BS
$H_{i,ko}$	Random variable in the channel
a	The exponential path loss
N_O	Power spectral density of background noise, c is the carrier frequency
$\emptyset$	Traffic intensity for users on a single carrier
ko	Tier of a band
l	The length from BS to the User equipment
$P_{i,k}$	The transmitted power from the BS
$H_{i,ko}$	Random variable in the channel
$\|\|Y_{ko}\|\|$	The Euclidean norm
a	The exponential path loss
N_O	Power spectral density of background noise, c is the carrier frequency
C_i	Carrier frequency being transmitted
W_0	The wavelength of the carrier frequency

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Chapter 1

1.0 Introduction

1.1 Background

LTE network is among the recent telecommunication technologies that ensure users experience maximum data throughput via wireless means [3]. It is fourth generation (4G) technology deployed to increase the data rate for users compared to those provided by legacy technology in the third-generation network (3G) such as Wideband Code Division Multiple Access (WCDMA) and High-Speed Packet Access (HSPA) [4]. So far LTE has been accepted as high-speed internet access that can provide users with increased accessibility to data services, online video conferencing, online video games, and social media networking platforms [3][3]. LTE provides a maximum downlink (DL) speed of 150 Mbps and an uplink (UL) speed of 20 Mbps. This speed of LTE has achieved a breakthrough in the world of data communication where information can easily be accessed from different places and devices in a matter of seconds [5]. The breakthrough in the LTE network has impacted productivity in academics, the health system, industries, and the world of commerce positively.

The LTE network incorporates a wireless channel as a means of propagating signals from the BS to the users [6]. The introduction of the wireless channel in the LTE system comes along with challenges that impair the signal strength of the receivers. Though LTE promises adequate bandwidth to improve throughput for users, the physical challenges such as reflection, diffraction, and obstruction that exist in a multipath fading environment distort the strength of the carrier frequency thereby reducing the amount of data that the customer receives from the BS as demonstrated in Figure 1.1. These multiple signal distortion in the wireless channel reduces the data rate of LTE users and seriously impairs the frequency carriers used in transmitting data to the users. Cell Edge Users or customers at the tail end of the BS coverage region suffer from signal fading due to these challenges [7].

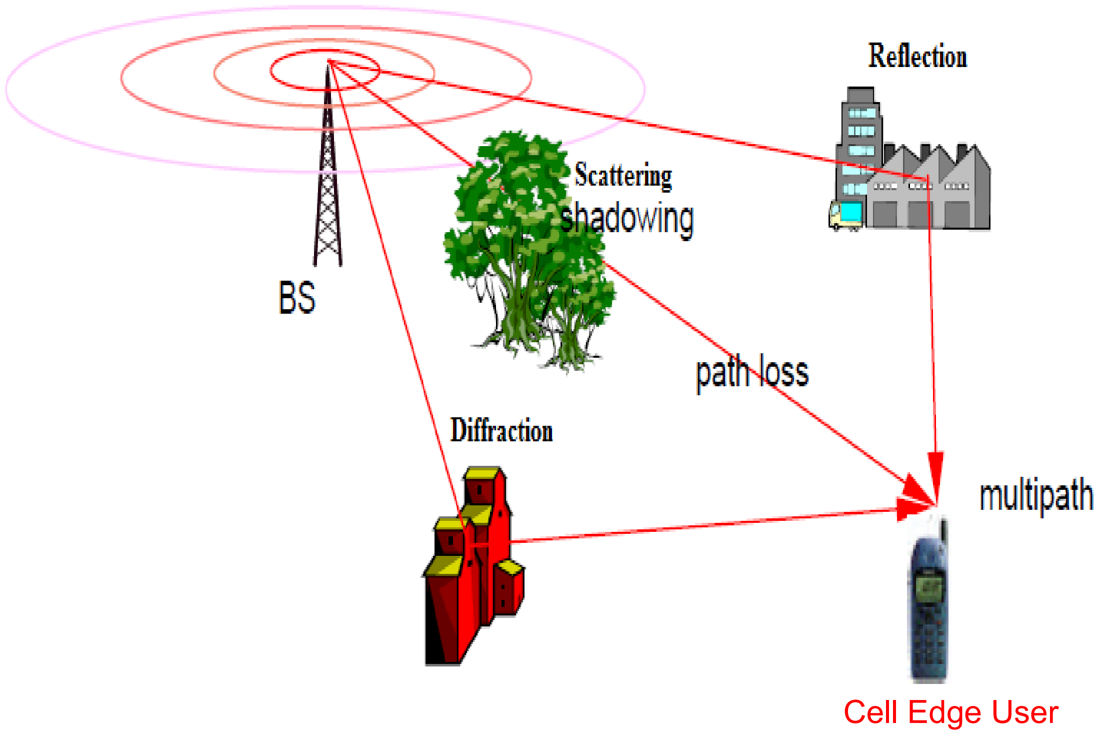

Figure1.1 Challenges Encountered by LTE Users [1].

1.1.1 LTE Carrier Aggregation (CA)

One feature that enables LTE to stand out among the legacy mobile technologies is the ability to provide huge throughput and coverage for the users amid radio challenges by using a technology known as Carrier Aggregation (CA) [8]. CA is a wireless technique that employs multiple frequency carrier components (CC) in transmitting data to users to achieve higher throughput and coverage. Frequency bands used in CA are selected based on their propagating features in a studied radio environment to ensure signals are adequately transmitted to the users with less BER [9]. The robustness of CA provides redundancy in the radio spectrum and ensures that one or all the carrier components transmitted by the BS reaches the receiver. Due to the vastness of the LTE frequency spectrum, CA can be implemented in both low and high-frequency bands [10]. Telecom operators that have a high-frequency band can achieve a high capacity for customers whiles those with low frequency can achieve better coverage for the customers. Operators in possession of both bands stand a chance of providing high capacity and coverage for the users simultaneously [11]. CA uses various LTE bandwidth range from 1.4-20 MHz to increase the data rate significantly for the user. Carrier aggregation (CA) was first introduced in LTE Rel-10 where the BS aggregates several frequency bands to transmit data to the UE [12]. The various carriers being aggregated to achieve throughput and coverage can either be configured as a primary or secondary carrier component. The primary carrier is used to handle mobility, physical control signalling, and also transmitting data to the user. All the other carriers are viewed as secondary carriers with the main functionality of providing higher data rates and coverage [13]. The Rel-10 carrier aggregation supports aggregation up to 5 carriers in both DL and UL in either Frequency Division Duplex (FDD) or Time Division Duplex (TDD) LTE. LTE data rates are enhanced with multiple carrier components to serve customers both far and near the base station. In practice, multi-antenna techniques cannot be used to continuously increase transmission performance, because the constraints on antenna size, complexity, and cost limit the number of antennas that can be installed on BS [14]. To achieve higher performance in the LTE network, the Inter-National Mobile Telecommunication (IMT)-Advanced systems proposed carrier aggregation to combine two or more carrier components for supporting high-data-rate transmission over a wide bandwidth (i.e., up to 100 MHz) for a single UE unit [15]. This technology results in the increased bandwidth of the LTE user as well as providing a redundant radio channel to secure alternate routes for users where the radio environment has wireless impairments [16].

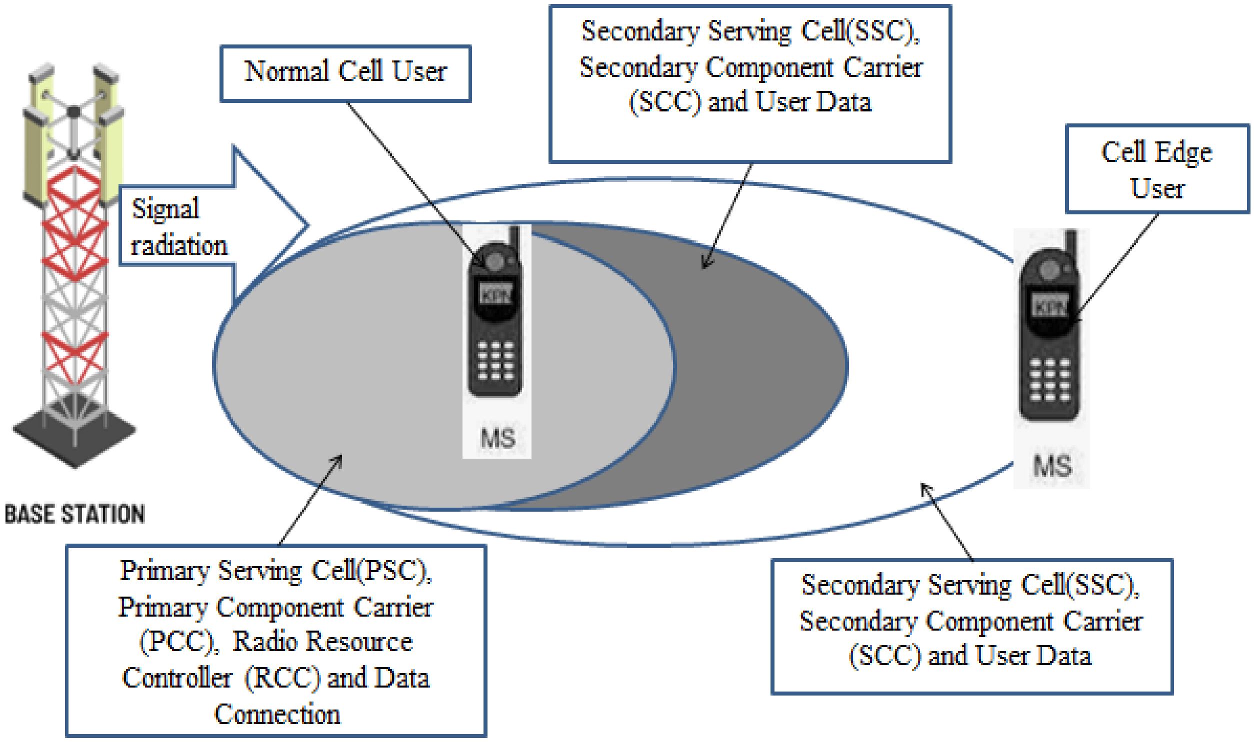

Figure 1.1.1 Carrier Aggregation in LTE Advanced for three (3) Downlink Component Carrier

Implementation of carrier aggregation in LTE has pushed the data rate satisfactorily. Low and high band FDD-LTE is an efficient way of utilizing the frequency spectrum. The low band has an issue with a limited Physical Resource Block (PRB), which introduces congestion and bandwidth limitation on the network. The merit of low frequency is its propagation features [17]. Given the same channel conditions for high band carriers, the low band carrier can travel a farther distance than the high band carrier; users at the cell edge can be served better with the low-frequency band though the throughput might be minimal due to limited bandwidth resources in the low-frequency bands[18]. The high-frequency band has the advantage of increased bandwidth and high Physical Resource Block (PRB) for users [19]. The high band provides a better throughput for users to access the BS than the low-frequency band as demonstrated in Fig 1.1.1. The only disadvantage is the penetration feature; the high-frequency band is easily attenuated by high buildings, mountains, and other obstacles. Carrier aggregation (CA) using different spectrums has been proposed in 3GPP to aggregate multiple component carriers (CCs) from either low or high bands to achieve a higher peak data rate and provide coverage for users. CA can be grouped as Intra-band contiguous and Intra-band non-contiguous, Inter-band contiguous, and Inter-band non-contiguous [20].

1.1.2 Contiguous Intra-Band Carrier Aggregation

It occurs when the CA of the adjacent frequency spectrum is configured in multiples to increase the bandwidth of the BS [21]. The more carriers are aggregated, the more the bandwidth of the BS increases. An example is configuring two carriers in 2.6 GHz in band 7 to increase capacity. The bandwidth of the carrier will be multiple factors of the number of carriers that are aggregated towards the UE. This improves quality of service significantly. Fig 1.1.2 demonstrates examples of contiguous Intra-Band Carrier Aggregation.

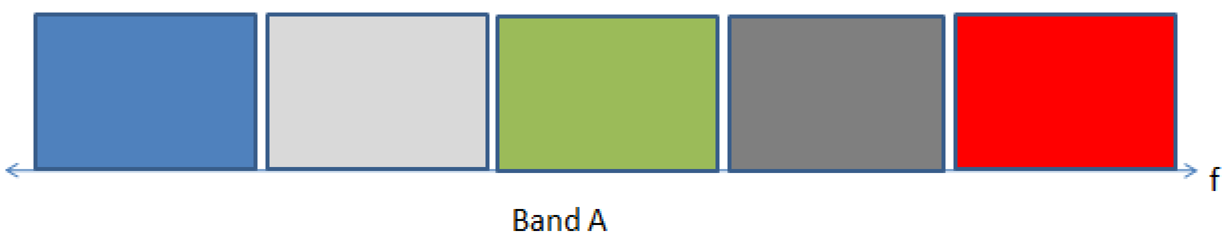

Figure 1.1.2 Examples of Intra-Band Continuous Carrier Aggregation

This technology has been used by authors to improve throughput performance in a congested urban environment. It has been observed that adding up more component carrier have a corresponding increase on the throughput for the users, and thus more carriers provide more bandwidth for users [22]. Consequently, it reduces the congestion in the network and increases

LTE user's quality of service especially in cities with a huge population, and demands for data for mobile applications are high.

1.1.3 Non-Contiguous Intra Band Carrier Aggregation

It is achieved by combining two or more adjacent frequency bands with channel space between the first and the second carrier components. In this carrier aggregation, a gap is reserved from one carrier component to the other. An example is shown in Fig 1.3.

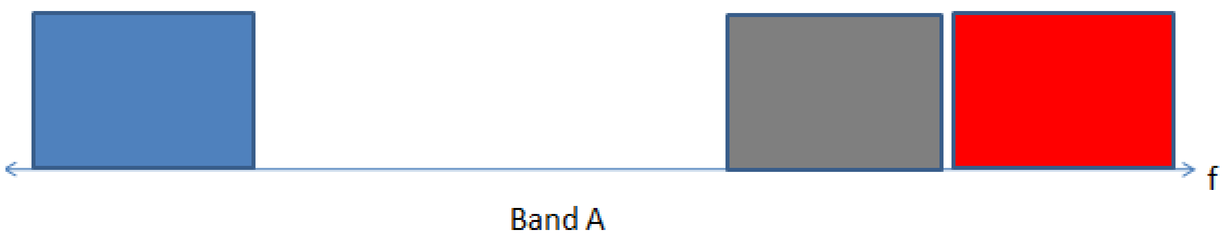

Figure 1.1.3 Examples of Intra-Band Non-continuous Carrier Aggregation

Intra Band non-contiguous carrier aggregation deployed in band 41 (CA_41A_41C) combines contiguous CA (CA_41A) with a non-contiguous element (CA_41C) for a three-carrier DL CA capable of delivering up to 60 MHz DL bandwidth to the UE [23]. In this example, CA_41B was reserved for another purpose. To eliminate interference between the first and the second carriers, a channel space (CS) is normally configured between the two carriers as represented in equation (1.0) as in [24].

$$CS = \left\lfloor \frac{BW_{channel(1)} + BW_{channel(2)} - 0.1|BW_{channel(1)} - BW_{channel(2)}|}{0.6} \right\rfloor 0.3 [MHz] \quad (1.0)$$

Where BW is the bandwidth for the carrier frequency.

In [18] non-contiguous carrier components were implemented to achieve higher throughput and peak data rate for users, it was realized by their MATLAB simulation that the more carrier component introduced at the BS level the more throughput measurement is realized by the LTE user. The configuration of contiguous and non-contiguous intra-band to provide higher bandwidth was achieved in the LTE network deployed in various urban centres and educational environments. Technical challenges of implementing CA in LTE were discussed and possible solution for guard band setting, channel spacing, control signalling, and data allocation was reviewed [25]. Several simulations revealed that Doppler shift frequency has a negligible impact on data transmission and the main factor of interference in adjacent carrier components is frequency aliasing, which lowers the performance of signal and distorts bit error rate.

1.1.4 Inter--Band Carrier Aggregation

$$S_{CA}(t) = S_{tb1}(t)e^{j2\pi f_{c1}t} + S_{tb2}(t)e^{j2\pi f_{c2}t} \tag{1.1}$$

Equation (1.1) as described in [25] aggregate different frequency blocks to transmit data to the user. $S_{tb1}(t)$ and $S_{tb2}(t)$ are time-domain transmitted baseband signal associated with various band to be transmitted, f_{c1} and f_{c2} are carrier frequency from band 1 and band 2, respectively.

Inter-band carrier aggregation provides us with different spectrum frequencies with different coverage distances and throughput. In [25] 0.8 GHz and 2100 MHz was used by the authors to provide capacity and coverage for LTE users as demonstrated in Fig 1.1.4, the authors used the GFM to decide for users, all users who are close to the BS are scheduled on the 2100 MHz while users far away from the BS are scheduled on 0.8 GHz for coverage.

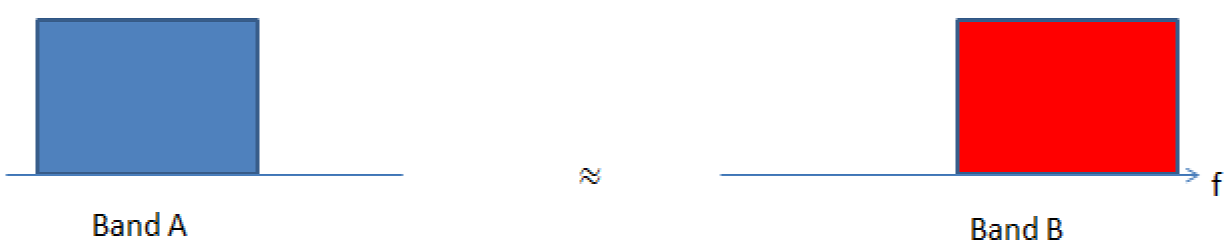

Figure1.1.4 Example of Inter-Band Carrier Aggregation

This is achieved by configuring two frequencies with different capacities of bandwidth to provide throughput and coverage simultaneously [26].

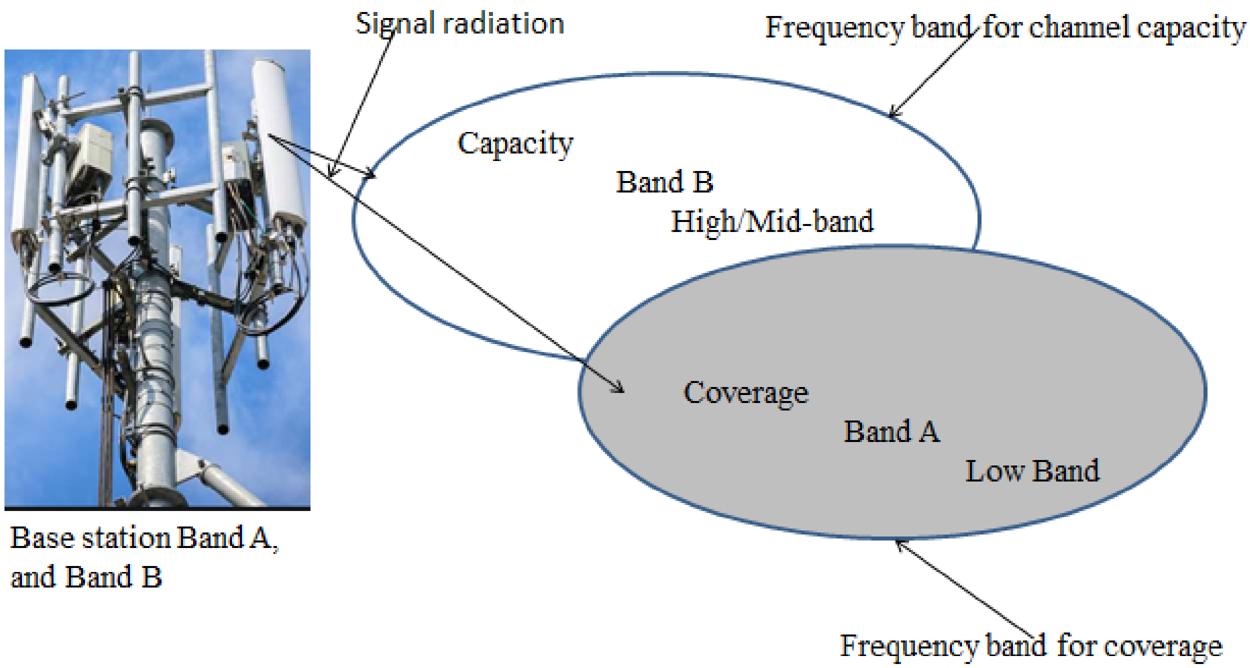

Figure 1.1.4.1 Examples Low and High-Frequency Bands Carrier Aggregation.

1.2 Statement of Problem

Multipath fading in a wireless channel is very high at the cell edge of BS which creates low signal strength for users and affects the throughput of the users. The low signal strength is a result of poor channel quality due to reflection, refraction, and scattering in the radio channel. The multipath fading results in latency, poor QoS and low data rate in LTE services.

So far studies to improve cell edge performance in the LTE network have been limited to GFM, HN, and FPC which do not capture current channel conditions that impair the quality of the transmitted signal. Carrier Aggregation has been used by several authors to increase the data rate of LTE users but has not been used to provide coverage for users at the LTE cell edge to improve performance. Moreover, inadequate studies have been done on carrier aggregation (CA) which factors multipath fading in the LTE radio environment. Again, studies on carrier aggregation to mitigate poor quality of service (QoS) and low data rates for pedestrians, passengers, home and office users at the LTE cell edge have received little attention, which inadvertently creates a problem for these mobile users.

1.3 Aims and Objectives

1.3.1 General Objective

To investigate the performance of LTE user equipment (UE) at the cell edge, using carrier aggregation (CA) based on Markov model.

1.3.2 Specific Objectives

1. To investigate the signal-to-noise ratio (SNR) of 0.8 GHz and 2.6 GHz frequency bands in a non-perfect radio channel environment.
2. To analyze bit error rate (BER) performance of UEs on 0.8 GHz and 2.6 GHz frequency bands in a multipath fading environment using Phase Shift Keying (PSK), Differential Phase Shift Keying (DPSK), Offset Quadrature Phase Shift Keying (OQPSK), Quadrature Amplitude Modulation (QAM), and Frequency Shift Keying (FSK) modulation scheme.
3. To improve the coverage and throughput of 0.8 GHz and 2.6 GHz in multipath fading and non-multi-path fading environments for pedestrian, vehicular, and home users.
4. To examine users' throughput in a non-perfect radio channel using carrier aggregation and compare against theoretical throughput.

1.4 Methodology

MATLAB\Simulink model is used to measure the performance of UE within a wireless channel environment, which receives a signal from the base station (BS). The model estimates the signal-to-noise ratio of LTE users in propagation models such as Extended Pedestrian A (EPA), Extended Vehicular A (EVA), and Extended Typical Urban (ETU) scenarios in multi-path fading environment for 0.8 GHz and 2.6 GHz carrier frequencies. The Simulink also analyzes the probability density function (pdf) and the Bit Error Rate (BER) for the two carriers using DPSK, QAM, OQPSK, FSK, and PSK modulation scheme in Additive White Gaussian Noise (AWGN), Rician fading channel, and Rayleigh fading channel. It then estimates the throughput for the UEs in EPA, EVA, and ETU propagation models.

1.5 Contents and Innovations of the Thesis

This thesis presents a systematic study of carrier aggregation together with channel impairment in the LTE network environment. The work evaluates the performance of 0.8 GHz and 2.6 GHz in multipath fading channels and also presents an analysis of aggregating these two carrier components (frequencies) to provide enhanced throughput and coverage for LTE users.

1.6 Scope of Work

The thesis was done in the domain of wireless communication focusing on the LTE network and the challenges that limit throughput and coverage for users. The work introduces carrier aggregation as one major feature of LTE to address these impairments using band 7 (2.6 GHz) and band 20 (0.8 GHz) frequencies.

1.7 Outline of the Thesis

The thesis is composed of five main chapters and has been organized as follows;

Chapter 2 presents a literature review. Chapter 3 outlines the methodology used in the work. Chapter 4 discusses the performance of UE at 0.8 GHz and 2.6 GHz in AWGN, Rician fading channel, and Rayleigh fading channel. Chapter 5 concludes the work with a recommendation, key findings, and possible future work.

Chapter 2

2.0 Literature Review

2.1 Enhancement of LTE Data Rate Using Carrier Aggregation

This chapter presents the work of several authors on carrier aggregation purposely to achieve the capacity for UEs in the LTE network environment. Their work involves various techniques and models adopted to implement carrier aggregation to enhance data rates for LTE users. Various authors in the literature review considered carrier aggregation without taking into consideration the physical challenges in the wireless channel.

Authors in [25] worked on carrier aggregation to achieve a higher data rate for LTE customers based on the 3GPP standard. Their work was mainly implemented using contiguous and non-contiguous carrier aggregation techniques in the physical layer and medium access channel. Their analysis entailed designing a physical layer of the LTE network using CA. Their analysis includes handover control, guard band setting, and channel space of the two carrier frequencies. Their conclusion proved that adjustment in the doppler shift of the UE in the LTE environment has a tremendous impact on the data rate of the UE and hence the component carriers used in their analysis were time-synchronized to perform a quick handover from one frequency to another in case the UE moves from the coverage of high-frequency band to a low-frequency band to ensure seamless data connectivity.

Bénézit et al in [27] used the Join the Fastest Queue algorithm to schedule UE on a more robust frequency in High-Speed Packet Access (HSPA) environment. Two carrier components were used to achieve load balancing or network redundancy where the UE is served by two different carriers simultaneously to maintain the constant provision of network radio resources to the UE irrespective of the channel conditions. UEs in the HSPA environment were assigned on double carrier (DC) frequency where some were also assigned to single carriers (SC) to investigate their performance difference. The analysis revealed that UEs that were assigned on the double carrier frequencies achieved better performance in terms of throughput than those using the single carriers. Chayon et al in [28] used CA in their work to significantly improve data rate using 3GPP Release 8/9/10 standard specifications. The project aimed to enhance the throughput of LTE customers by aggregating several downlink carriers towards the user. More robust modulation schemes were used to enhance good signal delivery to customers. Their analysis was to compare the result of deploying CA in HSPA and LTE technology. It was realized that the data rate achieved in LTE was higher than that of the HSPA technology (maximum bandwidth is 5 MHz). This was due to more bandwidth availability in the LTE (20 MHz) band spectrum where more carriers with higher bandwidth can be aggregated to serve customers in the LTE network. The aggregation of several carrier components in the LTE spectrum proved to provide better throughput for the user than the HSPA [18].

M. Mohamed in [29] analyzed the performance gains and complexity level that arise from the aggregation of three inter-band carrier components (3CC) compared to the aggregation of two carrier components (2CC) using a Vienna LTE System Level simulator. Their results showed a considerable growth in the average cell throughput of UE when 3CC aggregations are implemented over the 2CC aggregation, at the expense of a reduction in the fairness index of the

LTE resource scheduler. The reduction in the fairness index implies that the scheduler has an increased task in resource allocations due to the added component carrier. Compensating for such a decrease in the fairness index could result in scheduler design complexity and inefficiencies which was the limitation in their paper. Their proposed scheme can be adopted in combining various component carriers, to increase the bandwidth and hence the data rates.

Authors in [30] considered radio resource management problems by zooming into the head of the signal delay or high latency, probability of packet loss, and the delay threshold for different types of data in LTE CA technology. Their analysis revealed that several authors did not consider delay profiles in the CA deployment hence; several constraints of the UE to access high data rate were encountered following the specifications of the LTE-A system. Their work analyzed the improved method to enhance system throughput and simplified the computational complexity of CA both for the downlink and the uplink side of the LTE network. Extensive simulations were carried out with other well-known methods to verify the overall performance of the proposed method. The result obtained indicates that the proposed method outperforms the previous methods in the measurement of average user throughput, average cell throughput, fairness index, and spectral efficiency of LTE cell users.

Rabalo et all in [31]discussed Long Term Evolution-Advanced (LTE-A) integrated Common Radio Resource Management (iCRRM) for inter-band carrier aggregation (CA) between band 7 (2.6 GHz) and band 20 (800 MHz), considering bandwidths of 4 and 10 MHz respectively the two frequency carriers. The iCRRM entity tremendously improved the component carrier (CC) scheduling algorithm and increased the user's quality of service and experience in mobile video and voice traffic. Their analysis entails the overall performance of LTE users in an enhanced multi-band scheduling (EMBS) algorithm using CA which was then compared to the one from a basic multi-band scheduler (BMBS), an integer programming-based general multi-band scheduling (GMBS) without CA. EMBS involves reduced optimization scheduling complexity and allows the allocation of UEs to one or both CCs simultaneously, whereas both BMBS and GMBS only support one CC per UE. Simulations showed that for 5 MHz CCs and cell radius equal to 1,000 m, with EMBS in the 3GPP and ITU-T's 1% packet loss ratio (PLR) threshold is only exceeded above 58 UEs (throughputs of 7.48 and 7.40 Mbps, respectively), while with BMBS only 54 UEs (6.9 Mbps) are supported. This means the EMBS with CA has significant improvement than the BMBS.

Iskandar et al in [32] exploited the advantage of CA and used it in their work to push the data rate of LTE customer satisfaction. Their work was based on testing the performance of multiple frequencies in a test parameter, to consider the block error ratio (BLER) and their corresponding throughput inside a tested area of the LTE network. The tested area was deployed to represent the most common settings in which LTE will be implemented. They configured 40 MHz frequency bandwidth in the simulation to evaluate the performance of the contiguous intra-band and inter-band CA technique. Two carrier components (CCs) were allocated for the primary serving cell (PCell) and secondary serving cell (SCell). The simulation result showed that the downlink BLER tends to increase, as the number of frequency configurations increases. However, for the uplink BLER is zero. Their conclusion revealed that CA deployment with wider PCell bandwidth results in better throughput. In intra-band CA, the throughput of the non-contiguous CA is better than the contiguous CA. Then in the inter-band CA, CC combination with a lower frequency produces higher throughput than CC combination with higher frequency. Their result was a massive way to achieve throughput and coverage for LTE users using low and high band frequency.

Authors in [33] deployed 800 MHz and 2.6 GHz in a Heterogeneous Network (HetNet) environment using a poison point process (PPP) model that incorporates an appropriate notion of load which allows the study of the impact of signal biasing on HetNet performance. It was observed that the gain UE ergodic rate is about 35% to 40% if the small cells adopt optimal biasing factor compared to the case without bias. Their study proved that deploying 800 MHz and 2.6 GHz band in both the macro and micro cells help the HetNet best exploit the CA features which enable the UE to achieve maximum data rate. The biasing factor at both the macro and micro cells maintains average signal strength for improved UE throughput performance. Ntouni et al in [24] did comprehensive work using licensed and unlicensed bands in non-contiguous carrier aggregation to solve the issue of frequency scarcity in the LTE Advanced network. Their work proved that the use of these bands is a sure way of enhancing large mobile broadband bandwidth in the LTE system to mitigate congestion in the radio access network (RAN). Their work evaluated the error performance under different physical layer parameters, the authors concluded that Heterogeneous Band non-contiguous carrier aggregation technology can be efficiently applied to the design of next-generation mobile broadband networks for LTE customers far and near the base station.

In [34] authors deployed femtocells and Macrocells in LTE networks along roadsides to mitigate the mobile penetration losses in vehicles for passengers using LTE devices. Their study emphasis the losses UEs encounters while in buses or public transport. It was realized that there are massive path losses that hinder mobile users to receive the best signal from the BS. Their analysis which was based on MATLAB simulation of two noncontiguous carrier aggregations showed a noticeable improvement of ergodic throughput by 5% in vehicular propagation losses (VPL) of 40 dB while 90% of vehicular UEs spectral efficiency has improved by 1.3 b/cu under a VPL of 25 dB. [22] in [30] discussed ways of improving downlink throughput for LTE customers by using the downlink ring estimation method. User's throughput at various sides of the cell was measured and their reference signal received power level (RSRP) was also measured. The correlation between the downlink throughput and the signal levels was also measured for various carrier components for UEs in different regions of the LTE environment. The analysis revealed that UEs with good signal strength had better RSRP than those with bad signal strength and poor coverage. UEs signal was optimum when it is being served by all the two carrier components available from the base station. The throughput for the UEs was equally high when the UEs very close to the base station are being served by the two carrier component than when the UEs are being served by a single carrier.

In [35] authors did massive work in inter-carrier aggregation in the 700 MHz and 2.4 GHz bands to achieve coverage and throughput for users by using the scheduling algorithm method to transmit radio resources to UEs. The scheduling algorithm used in their work enabled the UE to receive a strong signal from the BS irrespective of the distance from the BS. UEs data rate increased significantly as a result of the combined low and high band carrier frequencies which consequently compensate for path losses in the wireless channel. Greater bandwidth of 20 MHz was achieved using 2.4 GHz for customers while 5 MHz bandwidth was achieved using 700 MHz. The lower frequency helped in mitigating challenges facing cell edge users while the high-frequency band increased the radio resources block for users to achieve peak data rate [19].

Sesia et al in [5] implemented contiguous and non-contiguous carrier aggregation with the objectives of improving the performance of the LTE network. They considered a performance metric such as base station signalling process, base station handovers, physical and medium access control layers challenges, guard band setting, and the means to improve them to achieve maximum user throughput. Their simulations showed that UE's Doppler frequency shift has only a limited impact on the data transmission performance over wide frequency bands in a high-speed mobile environment when the carrier components are time-synchronized. The frequency aliasing will generate much more interference between adjacent carrier components and therefore greatly degrades the bit error rate performance of downlink data transmissions. The only way to solve this challenge is to synchronize both the two carriers being used to eliminate disparity in transmission time between the carrier components. They concluded that synchronization of the two carrier component eliminates high latency in the downlink channel and improve the peak data rate of the UE. Rana et al in [35] discussed ways of increasing the bandwidth of LTE Advanced for users other than that of Worldwide Interoperability for Microwave Access (WiMAX) technology. The authors used both contiguous and non-contiguous carrier aggregation to achieve this target. Their main goal was to increase the data rate significantly for all users irrespective of users' location in an urban environment. Their work discussed the advantage of using several orthogonal frequency-division multiplexing (OFDM) subcarriers which are major features of LTE to increase the throughput of the LTE frequency large to deliver huge data to all consumers on the network. Again the use of the multiple component sub-careers was a good way to increase the bandwidth of LTE from 20 MHz to 100 MHz. The more sub-careers were used in the LTE OFDM symbol the more bandwidth and the throughput increased. The result of their work showed that increasing OFDM sub-carriers at the transmitter side increases the downlink (DL) throughput and hence provides maximum UE's peak data rate [37].

2.2 Carrier Aggregation to Improve Cell Edge Users Performance

Gochev et al in [2] worked massively on Fractional Power Control (FPC) and Interference Based Power Control (IBPC) system in their project to assign physical resource block (PRB) to UEs that has a weak signal or are very far from the BS, the BS using FPC increases in power when it measures low signal strength due to frequency fading, in such instance, the BS can increase corresponding power to provide coverage for cells at the cell edge, in the IBPC when the UEs identifies low gains due to interference from neighbouring BS, it automatically increases its power to receive the signal from the BS. Moreover, when there are multiples of UEs in an LTE environment this yields to interference in the system. The IBPC algorithm enables a particular UE to have access to its resource and limits all other UEs to avoid increasing their power to cause interference in the system. The reduction of interference noise from neighbouring BS improves the signal strength for the UEs to achieve a maximum data rate.

In [38] the authors studied Macro BSs and low power nodes (LPN) in the heterogeneous network and how to prevent interference in LTE network, they introduced an adaptive bias configuration strategy which can set a bias value to mitigate interference in advanced LTE network, the algorithm studies the environmental factors that can assign a load to cell edge users by using the method of bias initialization, system performance feedback and dynamic bias value setting, to improve network performance at the cell edge. They concluded the use of LPN is the modest way of adequately eliminating system interference at the cell edge to ensure maximum signal strength for UEs.

In [39] authors worked on interference cancelling algorithm LTE network to improve the cell-edge performance to increase the data rate of cell edge users, their work identified inter-cell interference, and its adverse effect on UEs at the cell edge, this makes it difficult for UEs to get a lot of signals at a particular time, they introduced reference signal interference canceller (RSIC) at the UE which mute base station that imposes another signal to a neighbouring cell edge BS that the UE is connected to, in this way the UE is connected to only one serving cell with stronger signal for maximum throughput.

Authors in [37] identified interference in the LTE network that limits the performance of cell-edge users and introduced Coordinated Multi-Point Joint Processing (CoMP JP) and CoMP Dynamic Cell Selection (DCS) to mute BS that has the strongest signal which may yield interference in the radio environment. Conventional DCS schemes can benefit cell edge users by instantaneously selecting the best-served BS for cell-edge users based on limited signalling overhead in the uplink radio interface. DCS with muting scheme further applies to mute to the strongest neighbour cell for decreasing interference to cell edge users. This method allows users at the cell edge to have improved throughput as well as coverage. Authors in [40] used alpha-fair criterion and fractional coordinated fair scheduling (FCFS) scheme for improving the throughput of UEs at the cell edge of LTE network, in a system where there is inter-cell interference where neighbouring cells transmit on the same power, there is the need to introduce FCFS algorithm to schedule resource to UEs at the cell edge on good channel conditions for better channel performance, the use of FCFS helps in the reduction of interference in the LTE network, they also proposed heuristic algorithm which depends on the selection of several customers for resource allocation, this again helps to reduce the effect of interference in the network and enhances cell edge throughput.

Authors in [41] used a fast cell group selection (FCGS) scheme to improve downlink cell edge performance, analyses and simulations were also performed to arrive at the efficient use of FCGS to enhance the throughput of cell edge users. Authors in [37] worked on Dynamic Point Selection (DPS) to increase throughput and coverage for LTE users at the cell edge. In this approach, the radio channel of the UE is studied and the decision is taken at the transmission point on how radio resources would be scheduled for the user to enhance maximum throughput and coverage for the user. Aboul et al in [42] introduced a novel resource allocation algorithm utilizing a frequency reuse scheme where users are scheduled on a carrier with optimum signal level so that interference between adjacent cells and users in the radio channels is minimized. Moreover, to mitigate the LTE network's low latency at the cell edge, the authors developed an algorithm to serve users which were far from the base station with a combinatorial algorithm. Simulation results show that the combinatorial resource allocation algorithm improves both cell edge users' throughput and total average peak data rate per UE, and also achieves improved user's average SNR than the classic reuse scheme. Authors in [38] considered the use of mobile femtocells at the cell edge of LTE users. Their MATLAB investigation showed that the use of mobile femtocells in cars, trains, and at the cell edge has a better performance and quality of service than fixed femtocells. Authors in [43] discussed the need for deploying LTE FDD frequency carrier aggregation technology to curb the scarcity of frequency spectrum and the need to provide sufficient broadband for consumers at the cell edge since different channel obstruction limits the signal strength during propagation. LTE FDD can provide solutions to current wireless network challenges for users to achieve maximum throughput. They discussed that LTE FDD technology has both uplink and downlink channels which reduce latency at the cell edge of the LTE users. Both the user and the base station transmit on different frequencies which consequently improves the user’s performance and eliminates the average user’s latency in the network. Their work was confined to the transformation from TD-SCDMA to FD-LTE, not excluding key innovations to enhance downlink throughput, industry advancement to push users peak data rate satisfactory high, and reduce the complexities in the implementation of FD-LTE, and increase the throughput of cell-edge users. Authors in [44] did massive work on carrier aggregation in TD-LTE technology. They furthered that to curb the disadvantages of users at the cell edge, the throughput of TD-LTE technology should be increased at both the transmitter and the receiver side, and to expand downlink capacity from 100 MHz and peak date rate above 1Gb/s. Their objective was to achieve a downlink capacity of 100 MHz by the implementation of carrier aggregation to provide a maximum internet connection to users continuously at any time or any place. To do this with our limited frequency spectrum, TD-LTE carrier aggregation will be the choice since users transmit and receive data on the same frequency. Data rates are expected to rise to 1Gb/s with the frequency spectrum of 100 MHz by deploying OFDM sub-carrier aggregation. One disadvantage is that the spectrum may not be continuous due to the separated spectrum. Authors in [16] discussed the trend of progress in the various release of LTE and concluded that carrier aggregation can be adopted to increase the throughput and coverage of the user. The former release of LTE supported bandwidth ranging from 1.3, 4, 5, 10, and 20 MHz. In LTE release 10 to 12, we realized that throughput and coverage can be expanded by applying CA technology for both uplink and downlink at the UE and the base station respectively. Five carrier components can be aggregated to provide a downlink data rate of 100 MHz each from different frequency components which is also compatible with release 8/9. In release 8/9 each carrier component has the property of release 8 carrier while release 10 and above allows carrier aggregation which can help us to expand the bandwidth at the base station. Normally different carrier components can be integrated to form carriers for downlink and uplink. Their work was detailed on inter-band CA of the contiguous carrier component and inter-band CA of the non-contiguous component carrier. They exclaimed how the frequency spectrum can be utilized efficiently to mitigate inter-cell interference at the cell edge of LTE users in a heterogeneous network.

Authors in [45] explained the use of CA in the HetNetwork Base station for LTE release 10 and its application of improving network performance for cell-edge users. In CA, uplink or downlink frequencies can use carriers in the contiguous or non-contiguous band to serve the customers. Carrier Aggregation in a previous 3GPP introduced the general technology of configuring Macro and femtocells with a different set of the frequency spectrum. A small cell site was designed at low-cost base stations with the frequency of the same band due to interference, while the Macro-cell site is also configured with another type of frequency to improve cell-edge performance. LTE release 11 supports CA for multiple timing uplink signals for HetNetwork. Huh et al in [46] worked on the downlink LTE carrier aggregation for a chunk of cells with their respective UEs in mind where multiples of antennas have been installed on a base station. Taking any arbitrary number of transceivers in either downlink or uplink mode, it is possible to derive an approximation for a higher data rate, with regularized zero-forcing (RZF) and Eigen-beamforming (BF) network optimization. The difficulty in this approach is when taking approximation for the large farm of BS and UE transceivers, but simulations can produce a precise result for channel estimations. Again, their simulation revealed that the RZF precoding scheme performs similarly to a BF scheme in a wireless network. In [47] the macro base station was configured with high band frequency to serve as the primary cell which will be responsible for radio resource connection (RRC) signalling, and limited data supply while small cells are configured mainly with secondary cells for data transmission in a Heterogeneous network environment to serve users at the cell-edge. CA is very important in deploying the HetNet because users closer to the small site can get higher throughput with no signal fading while the macro cell supply both data and control signals to users. The problem with the coverage is then eradicated by implementing CA technology with two sets of frequency bands for Macro and femtocells. Authors in [46] authors explored the implementation of carrier aggregation in LTE-TDD by improving downlink capacity from the Base station to the mobile station. As against traditional Massive MIMO architecture, their work was to enhance the performance of the LTE-TDD with the introduction of Network-MIMO architecture. From their simulation and numerical result, LTE-TDD technology achieves higher spectral efficiency than Massive MIMO. Their work was considered in a family of BS clusters, thus a service area of the BS was segregated into different blocks, to improve the zero-forcing beamforming (BF) technique for both downlink and uplink signal. This helped to improve interference in the network. Their core objective was to segregate users into equivalence classes and assigning them with different channel time-frequency dimensions to operate separately from each other family in the cluster; this was achieved with the help of a frequency scheduler. Different schemes were then used to modulate data to serve a particular area of the network to improve cell-edge performance.

In [48] the authors dived into the implementation of carrier aggregation and massive multiple inputs multiple-output (MIMO) system in a cellular network to boost up downlink bandwidth for cell-edge users. This technology allows transmission and reception of information by using multiple antennas to increase the spectral bandwidth, in this case, data can be routed according to the number of antennae we have to process downlink and uplink information. Again the multiple antennas were position at an angle where users at the cell edge can receive maximum data from the Base Station. The only disadvantage in their work was the use of varying power systems to transmit data to the different radius of the cell region. They also worked on how to improve spectral efficiency (SE) by using MIMO against cell density operating within higher frequency bands. With variations of factors like distance, transmit power level, frequency reuse factors, and the number of subscribers within a service area of a cell, they achieved a formula for providing spectral efficiency for several UEs within a service area [49].

Hoyman et al in [50] worked on improving cell-edge multi-user performance in 3GPP LTE-Advanced networks by utilizing relaying and base station coordination technologies. Relaying is a technology for enhancing the transmissions between two locations on a radio path and base station coordination is a multi-cell processing technology towards mitigating the inter-cell interference. The authors studied the capacity behaviour of relaying nodes. Two forward strategies, Amplify-and-forward (AF) and Decode-and-forward (DF) were modelled and compared. A new full-duplex (FDX) operation mode of relaying was discussed, as well as a relay network with a multi-antenna receiver. Their results showed that FDX relaying outperforms half-duplex (HDX) relaying, DF relaying has better performance than AF relaying under the condition of an ideal relay link (RL) and a multi-antenna receiver gains more from relaying than a single-antenna receiver. They also applied the pre-coding on the coordinated BS to realize simultaneous multi-user transmissions on the same frequency band. Designs of the pre-coding matrix were then investigated and the results showed that zero-forcing (ZF) pre-coding of base station coordination reaches significant capacity enhancement in the case of a relatively high signal-to-noise ratio (SNR). Finally, they proposed a novel combination transmission scheme that integrates a shared relay node (RN) and coordinated BSs to achieve higher multi-user sum-rate capacity. Their work proved that applying each technology to the combinational scheme separately can be expected in most cases and it turns out to be a good improvement of the cell-edge multi-user performance.

Authors in [51] focused on the relay selection problem to improve cell edge performance, where a user may have in his range several relay nodes to choose from. The conventional selection scheme is based on the channel condition between the relay and the user, such that the user will achieve a high level of throughput from the base station. Alternatively, they proposed in their paper a novel relay selection strategy taking handoff into account over LTE-A multi-hop relay networks. Their goal was to achieve significant performance improvement against legacy centralized resource allocation and handoff algorithms such as disjoint path relay selection. Simulation results showed that the design has the advantage of reducing inter-cell handoff frequency and lowering the handoff failure ratio at the cell edge.

Authors in [52] focused on carrier aggregation of different carrier components to maximize bandwidth for customers, this involves the use of high capacity MIMO of 8 by 8 for downlink and 4 by 4 for uplink to increase throughput for the user, they also considered the use of multiple point transmission at the BS, relay nodes at the cell edge, and autonomous component carrier selection (ACCS) for uncoordinated femtocell deployment to increase throughput and coverage for LTE customers. In [53] authors discussed ways to increasing throughput by introducing mobile or fixed relay into the cellular network. The relay is mounted on vehicles or in a densely populated area to boost up the signal gain for the customers. The relay in the vehicles improves the peak data rate for the passengers while the fixed ones cater to those at the cell edge of the network. They also introduced cell splitting to cater for throughput, which is introducing a new network element in the unreached area to cater for capacity and coverage. Their last resolution was the introduction of sectoring to increase capacity in a densely populated urban environment to eradicate congestion on the network. After this cost analysis was done on several scenarios to select the appropriate tool for capacity improvement in the crowded areas and concluded on the use of cell splitting to increase capacity for users.

Authors in [54] considered increasing capacity for cell centre users and the cell edge users by using dynamic power allocation, in this method, users at the cell centre will have minimum power allocation while those at the cell edge will have increasing power to access the signal from the base station. Their analysis yielded a positive result since users at the cell edge could access the network as well as those nearer to the BS. They also considered increasing the bandwidth for the customers by carrier aggregation to increase throughput for the users. Based on their simulation they concluded that a user 700m from the BS can have an optimum signal from the network.

Authors in [10] authors discussed the use of different scheduling codes to increase capacity in a coarse environment, the schemes used include, round robbin, proportional fair, and proportional demand were used. Proportional fair turns out to increase capacity in a dense urban environment. Iosif et al in [55] set a benchmark for predicting throughput using LTE indicators stated in the third generation partnership project (3GPP), which includes, availability, transmission time interval, and mobility. These counters were measured by the BS and scheduling was done to improve them to increase capacity. The channel quality indicator (CQI) helped to improve the channel quality for maximum transmission of data to the users at the cell edge. Yogapratama et al in [56] analyzed coverage and throughput by using 900 MHz and 10.8 GHz to predict the performance of data throughput in rural communities. Various scenarios of simulations were performed to verify the perfect choice for better capacity performance in rural areas. They concluded that using a bandwidth of 5 MHz in 900 MHz achieves better throughput than the bandwidth of 20 MHz in 10.8 GHz.

Authors in [57] worked on the reduction of inter-cell interference from neighbouring BS to increase total capacity for the customer. This involves designing a good filter antenna for transmission and tilting the antenna to avoid interference of signals, they also worked on adding new cells to match up, with the growing population of people. They worked on improving channel quality by using the instantaneous QoS of the user, if the user's QoS is good, the system uses a scheduling algorithm to allocate a resource to the UE, to increase the data rate for the UE. UEs far away from the BS received signals by using a dynamic power technique to send a signal to the UEs. Authors in [58] investigated the performance of LTE throughput by using the MIMO technique and different modulation schemes. Using multiple antennae significantly improves the capacity for the LTE as well as using a higher modulation scheme also improves the throughput as well.

Authors in [59] discussed scheduling for transmitting a signal to mobile users in a different distant position to improve the downlink throughput, their simulation was based on the frequency diversity and selectivity scheduling (FDSS) which uses channel quality indicator to improve user's throughput, the authors discussed the use of MIMO combined with modulation scheme and space-frequency block code (SFBC) to improve the capacity of LTE downlink capacity for users at the cell edge, it was observed in their simulation that higher modulation scheme increases the capacity of the channel. Simulation analysis was also performed on their work using the Monte Carlo Simulation tool to compare the throughput performances of single input single output (SISO) and multiple-input multiple-output (MIMO). Various ports of the antenna system were configured with different career components to increase the bandwidth of the BS. They concluded that multiple antenna systems can significantly provide LTE network redundancy and improve radio resource availability at the cell edge.

2.3 Carrier Aggregation To Increase Signal Strength for Cell Edge Users

Authors in [60] discussed how to achieve a higher data rate and coverage with carrier aggregation in their work. They proposed that to have a downlink of 1Gb/s in future IMT Advanced mobile CA is very necessary. In [61] authors researched in the deployment of Heterogeneous Networks with the CA feature. The effective way to increase throughput in modern wireless communication is to encourage carrier aggregation in the LTE network. In a Heterogeneous network as in Figure 2.1, CA has to be deployed on the Macro, pico, and femtocells in such a way as to avoid interference in the network. One key element in this technology is to maintain a constant throughput across the network irrespective of the user's position from the base station; this technology has been deployed by many operators across the globe to answer many throughput challenges. Their work highlighted the implementation of the primary career component on the macro cell for signaling and provision of data while configuring secondary cells only on the pico and femtocell for data and coverage for cell-edge users. HetNet can be deployed either on TDD or FDD frequency spectrum; either contiguous intra-band, non-contiguous intra-band, or inter contiguous band can be configured for the HetNet environment. The major challenge in the HetNet is tight coordination between the microcells and the pico or the femtocell as the two frequencies used can bring about interference in the system. There should be better network optimization to prevent signal interference with each other cells.

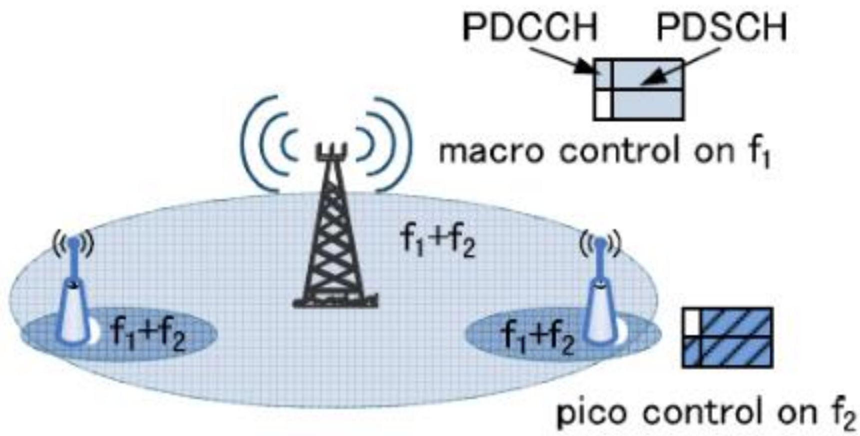

Figure 2.1 Deployment LTE-A HetNet using CA in CO- Channel Deployment Scenario [19].

Eladham et al in [62] achieved carrier aggregation by a combination of several spectra and transmitting them simultaneously, they specified the various bands that can be aggregated in intra-band contiguous, intra-band non-contiguous, and inter-band for LTE release 12 CA. They concluded in their simulation that as more carrier components are aggregated the more UEs data rate and coverage are improved. The high bands used in their work improved data rate significantly whereas the low band improved coverage for users far from the base station.

Authors in [63] analyzed the performance of the LTE-Advance Release 12 physical downlink channel, with the technology of CA in the inter-band non-contiguous. Their work described the underlying system model and the corresponding simulation setup for CA. Various scenarios of carrier aggregation were considered to see which category is relevant to be applied to customers in a certain environment to improve LTE performance. Their analysis revealed the Heterogeneous Band noncontiguous CA technology can be deployed in the next-generation mobile broadband networks as a means to mitigate multipath fading challenges that impair signal strength in the LTE network.

Authors in [29] did a comprehensive work by combining low bands (CA 1,5) with a bandwidth of 20 MHz and high bands (CA 3, 7) with the bandwidth of 40 MHz in HetNet, it was observed that the low-frequency band has the least BER which provides better throughput to users at the cell edge. Authors in [64] worked on GFM, where the authors assign the carrier components to UEs based on their respective distance from the BS. Their analysis was tailored to propagation losses where the low-frequency band is assigned to UEs at the cell edge to improve coverage for UEs close to the BS to have access to all the carrier components available. Their result presents G-factor distribution at different frequency carriers with a macro scenario from a real measured sub-urban environment. It is shown that the 800 MHz frequency carrier exhibits better G-factor distribution than the 2.6 GHz frequency carrier, especially at the cell edge (approximately 4 dB difference in G-factor at 5-percentile CDF curve). The G-factor model demonstrated in their work performed better than UEs on the least load. UEs on the G-Factor model's position are accessed thoroughly by the BS before radio resource scheduling is done whiles UEs on least load randomly receive a signal from the BS without any consideration on their respective distance to the BS. The major challenge with GFM is the lack of a thorough assessment of multipath fading challenges in the wireless channel. The model does not factor in current channel conditions but only distances of UEs from the BS.

2.4 Motivation for This Thesis

Authors in [25, 57-60] among others in the literature review, discussed ways of improving LTE cell edge performance by implementing technology such as Geometry Factor Model, Fractional Power Control, and Heterogeneous network to provide users at the cell edge with good signal power. They went ahead with various mathematical models that can sufficiently ensure good signal strength when users are far from the Base Station. However, these models and analyses performed by the earlier researchers did not factor in multi-path fading in the LTE radio channel. This work considers the main delay profiles in the LTE network which limit signal strength for the pedestrian, motorist, and office/home users and adopt carrier aggregation (low and high-frequency band) to solve the problem using the MATLAB/Simulink model. The low band (0.8 GHz) used provides the user with good coverage whereas the high band used provides the user with increased throughput. The 2.6 GHz used in this work has high penetration losses but is very rich in radio resources that provide maximum data rate for the customer whiles the 0.8 GHz has better penetration losses and good coverage.

Chapter 3

3.0 Methodology

3.1 MATLAB Simulink Model

Chapter three employs MATLAB Simulink Model to analyze the cell edge performance of LTE users on 0.8 GHz (low frequency) and 2.6 GHz (high frequency). The model is built on Markov's model where several UE enters the region of coverage of the BS in an area A_j with cell radius, R. Let the probability q_j be UE that is admitted into the BS at any time within the cell region be expressed as in [27].

$$q_j = \frac{A_j}{\pi (R)^2} \tag{3.0}$$

The throughput of the users are analyzed based on their radius (r_0 and r_1, $\mathrm{R} = \mathrm{r}_0 + \mathrm{r}_{1,}$) to the BS where ($\mathrm{r}_0$ and r_1) are radius at the foot of the BS and the at cell edge respectively.

3.2 System Model

In this thesis, UEs enter the area A_j of a base station using two carrier frequencies 0.8 GHz and 2.6 GHz controlled by the Markov process that distributes the radio resource to the UEs. The BS has a radius of R and can serve a region of Area, the users can be served by 0.8 GHz and 2.6 GHz depending on the distance of the user from the BS or the radio resource available to the BS at that time. Figure 3.1 illustrate the model where all users in the LTE system are scheduled on radio resource on either carrier (carrier 1 or 2) according to their rate of arrival and the radio resource available, users can be scheduled on a single carrier (SC) or double carrier (DC) simultaneously [48].

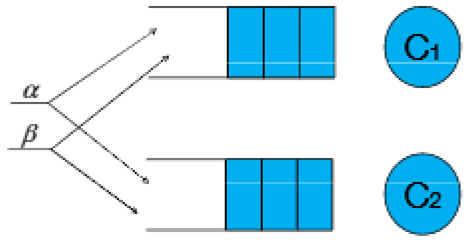

Figure 3.1 Queuing models for UEs accessing radio resources on Single Carrier (SC) and Double Carrier (DC) frequencies[27].

Let

$$n(t) = \left(n_{1,1}(t), n_{2,1}(t), m_1(t); ....; n_{1,j}(t), n_{2,j}(t), m_j(t)\right) \tag{3.1}$$

$n_{1,j}(t)$ is the number of SC UEs in the area A_j currently transmitting on Carrier 1.

$n_{2,j}(t)$ is the number of SC UEs in the area A_j currently transmitting on Carrier 2.

$m_j(t)$ is the number of DC UEs in the area A_j currently transmitting on Carriers 1 and 2.

Let the rate of functions $D_{1,J}$ and $D_{2,J}$ of carriers 1 and 2 be defined as follows [74];

$$\begin{cases} D_{1,J}\,(n(t) = \dfrac{c_{1,j}}{n_1(t) + m(t)}, \\ D_{2,J}\,(n(t) = \dfrac{c_{2,j}}{n_2(t) + m(t)} \end{cases} \tag{3.2}$$

$$n_1(t) = \sum\nolimits_{j=1}^{J} n_{1,j}(t) \tag{3.3}$$

$$n_2(t) = \sum\nolimits_{j=1}^{J} n_{2,j}(t) \tag{3.4}$$

$$m(t) = \sum\nolimits_{j=1}^{J} mj(t) \tag{3.5}$$

$\mathbf{c_{1,j}}$ is the maximum user throughput on carrier 1 and $\mathbf{c_{2,j}}$ is the maximum user throughput on carrier 2. $D_{1,J}$ is the amount of data a user is receiving from the base station on the first carrier frequency and $D_{2,J}$ is the amount of data the user is receiving from the base station on the second carrier frequency.

3.2.1 Carrier Aggregation (CA) Policy for Single Carrier (SC) Users

When UE on SC gets into the BS area in an area A_j at time t, the UE is admitted on Carrier 1 or Carrier 2 according to the SC scheduling policy and the radio resource available to the base station. Let t+ denote any instant, close enough to time t so that no other event occurs in the system during the interval [t; t+]; the system state at time t+ is then updated as follows [48].

$$\text{I1 if } \frac{c_{1,j}}{n_1(t)+m(t)+1} > \frac{c_{2,j}}{n_2(t)+m(t)+1} \tag{3.6}$$

Carrier 1 admit UEs and $n(t_+) = n(t) + e_{1,j;}$

$$\text{I2 if } \frac{c_{2,j}}{n_2(t)+m(t)+1} > \frac{c_{1,j}}{n_2(t)+m(t)+1}, \tag{3.7}$$

Carrier 2 admit UEs and $n(t_+) = n(t) + e_{2,j;}$

$$\text{I3 if } \frac{c_{1,j}}{n_1(t)+m(t)+1} = \frac{c_{2,j}}{n_2(t)+m(t)+1}, \tag{3.8}$$

Carrier 1 or Carrier 2 admit UEs with probability ½. For $1 \le j \le J$, Let $e_{1,} j, e_{2,} j$, and $e_{3,} j$ denote the unit vectors such that $e_{k,j}$ has the $\left(3_j + k - 1\right) - th$ element equal 1.

3.2.2 Carrier Aggregation (CA) Policy for Double Carrier (DC) Users

UEs on DC are scheduled on BS radio resources using Equation (3.6). For BS coverage area and for the time iA_j, and for the time interval $[t, t^{'})$ where the system $n(.)$ remains constant, Carrier 1 and Carrier 2 transfer data σ_1 and σ_2 respectively such that [48];

$$\begin{cases} \sigma_1 = D_{1,j}(n(t))(t^{'} - t), \\ \sigma_2 = D_{2,j}(n(t))(t^{'} - t) \end{cases} \tag{3.9}$$

$$t^{'} - t = \frac{\sigma_1}{D_{1j}(n(t))} = \frac{\sigma_1}{D_{2j}(n(t))} = \frac{\sigma_1 + \sigma_2}{E_j(n(t))} \tag{3.10}$$

Equation (3.9) illustrates that the system transmits signals to the UE at the same time on the two carriers with a transfer rate of;

$$E_j(n(t)) = D_{1,j}(n(t)) + D_{2,j}(n(t)) \tag{3.11}$$

UEs under the coverage of BS which are receiving a signal from the two carriers achieve maximum data rate and have an advantage in terms of QoS over UEs at the tail end of the BS coverage.

3.2.3 Markov Process for SC and DC Users flow.

Let say that SC and DC UEs enter the system according to Poisson processes with respective arrival rates α and β. The amount of data of any (SC or DC) UE is exponentially distributed with mean σ. Let denote $\Lambda = \alpha + \beta$ as the sum of arrival rate in the BS. We again propose that the traffic is equally spread over the BS such that in area A_j SC and DC UEs arrive with intensities $\alpha_j = \alpha q_j$ and $\beta_j = \beta q_j$. Let vector $n(t)$, $t \geq 0$ define a Markov process that can move in an infinitesimal time interval from state n to a specific time [65]:

T1) $n + e_{1j}$ with transition rate $\alpha_j 1\alpha + \frac{\alpha_j}{\alpha^2} 1i3$

T2) $n + e_{2j}$ with transition rate $\alpha_j 1\alpha + \frac{\alpha_j}{\alpha^2} 1i3$

T3) $n + e_{3j}$ with transition rate β_j

T4) $n - e_{1j}$ with a transition rate $n_{1j} D_{1j}(n) / \sigma$ with departure rate proportional to the number n_{1j} of users in A_j

T5) $n - e_{2j}$ with transition rate $n_{1j} D_{1j}(n) / \sigma$ with departure rate proportional to the number n_{2j} users in A_j

T6) $n - e_{3j}$ with transition rate $n_{1j} D_{1j}(n) / \sigma$ with departure rate proportional to the number n_{3j} users in A_j.

The above expression of the Markov process enables the system to query each UE performance at a given time and also enables the system to reschedule the UE to a more robust carrier if the current state of the UE is using low performing carrier frequency.

3.2.4 System Stability

We now address system stability. Let start by considering the case in which radio conditions are uniform over the entire cell so that $J = 1$and the capacity of each carrier is simply $C_{1,1} = C_1$ and $C_{2,1} = C_2$

Defining the system load ρ (with the single area) by [66];

$$\rho = \left(\frac{(\alpha + \beta)\sigma}{C_1 + C_2}\right) \tag{3.12}$$

the stability condition $\rho > 1$

Given the assumptions of exponential flow size and Poisson arrivals, the system state described by a vector $(V_1(t), V_2(t), W(t))$ defines a Markov process in Ṛ$^+$using the transition rates expressed as $J = 1$the evolution of the system can then be described by the equation(3.13) as follows [63].

$$\begin{cases} \frac{dV_1}{dt} = \alpha 1_{i1\sigma} + \frac{\alpha}{2} 1_{i13\sigma} - \frac{C_{1n1}}{n_1 + m^{'}} \\ \frac{dV_2}{d_t} = \alpha 1_{i2\sigma} + \frac{\alpha}{2} 1_{i13\sigma} - \frac{C_{2n2}}{n_1 + m}, \\ \frac{dW}{d_t} = \beta_\sigma - \left(\frac{C_1}{n_1 + m} + \frac{C_2}{n_2 + m} \right), \end{cases} \tag{3.13}$$

Where V_1, V_2 represents the data rates (Mbps) on SC and W represent data rates (Mbps) on DC in queues. Adding equations (3.13) side by side, we obtain

$$\frac{dV}{dt}\left(V_1 + V_2 + W\right) = \left(\alpha + \beta\right)\sigma - C_1 + C_2 \tag{3.14}$$

which < 0 as long as $\rho < 1$. This ensures that the total volume of data $\left(V_1 + V_2 + W\right)$ is a decreasing function of time and that the system empties in a finite time. Inequality $\rho < 1$ is therefore also a sufficient condition for stability. Let us now analyze the system stability in a more general case for $J > 1$ in a different area in the cell, each with its radio conditions such that [48].

$$\frac{1}{\dot{C}} = \sum_{j=1}^{J} \frac{qj}{C_{1,J} + C_{2,J}} \tag{3.15}$$

An appreciable condition for stability of BS in an area is that the total traffic intensity $\left(\alpha + \beta\right)\sigma$ must be less than the total BS capacity ($C_1 + C_2$), that is, $\rho < 1$ with load ρ defined in (3.14). To prove $\rho < 1$ is also sufficient stability condition as [27];

$$\rho = \frac{\left(\alpha + \beta\right)\sigma}{C_1 + C_2}, \tag{3.16}$$

the stability condition $\rho < 1$.

Equation 3.12 is relevant in the application of achieving a more robust network by using two carriers.

3.2.5 System Capacity

The total channel capacity $C_{1,j} + C_{2,j}$ denoted as $(\dot{C})$ or maximum average throughput in the area A_j is weighted by probabilities in the range of $1 \le j \le J$. Let the system load be expressed as [27];

$$\rho = \frac{(\alpha + \beta)\sigma}{\dot{C}} \tag{3.17}$$

This is a necessary stability condition $\rho < 1$. Also, let ρ_j be the load in the area A_j the traffic intensity offered by users is A_j divided by the total capacity $(\dot{C})$ in A_j is such that

$$\rho_j = \frac{(\alpha_j + \beta_j)\sigma}{C_{1,j} + C_{2,j}} \tag{3.18}$$

According to (3.14), a necessary stability condition for multiple carrier frequencies is needed to provide radio resources to the users, again the total offered load on both carriers 1 and 2 must be less than 1, that is [64];

$$\sum_{j=1}^{J} \rho_j < 1 \qquad 3.19)$$

For Bernoulli scheduling policy users in the area A_j are scheduled on carrier 1 with probability $\frac{C_{1,j}}{(C_{1,j} + C_{2,j})}$ and carrier 2 with probability $\frac{C_{2,j}}{(C_{1,j} + C_{2,j})}$. For $\sum_{j=1}^{J} \rho_{1,j} < 1$ where $\rho_{1,j}$ is the load on the carrier 1 induced by users from the area A_j that is,

$$\rho_{1,j} = \left[(\alpha_j + \beta_j) \frac{C_{1,j}}{C_{1,j} + C_{2,j}} \right] X \frac{\sigma}{C_{1,j}} = \rho j \tag{3.20}$$

ρ_j given in (3.19). Analyzing the stability of BS coverage area for a given policy on throughput the above discussion shows that the throughput $\left(\gamma^B\right)$ for Bernoulli policy is always positive in the capacity region defined by $\rho < 1$. In terms of throughput when $\gamma \geq \gamma^B > 0$ the CA based on Markov model designed for single and double carrier users performs better than the Bernoulli as long as $\rho < 1$.

3.3 Channel Models for Frequency Carriers

Wireless channel is characterized by diffraction, reflection, ionization, etc. of the signal in a multipath fading environment, as a result of this, the signal undergoes series of distortion before arriving at the UE. For communication to be very successful the transmitted signal should be error-free or close to error-free [67]. There are three categories of channels that this thesis considered: Additive White Gaussian Noise Channel (AWGN), Rician, and Rayleigh fading Channels.

3.3.1 Rayleigh Fading Channel

Rayleigh Fading channel occurs when there is no line of sight between the transmitter and the receiver (UE), there is a high loss of packet in this noise channel since the transmitted signal diverges through different paths before arriving at their destination. In [68] if the signal is considered as a Gaussian distribution process concerning the individual components and the signal has zero mean value and the phase lies between 0 to 2π radian. Then the pdf can be given as [69];

$$P_R\left(R\right) = \frac{R}{e^2} e - \frac{R^2}{2\delta^2}, 0 \leq R \leq \alpha \tag{3.21}$$

Where R is the distance between the transmitter and the receiver and δ is the load density of the signal from the transmitter to the receiver.

3.3.2 Rician Fading Channel

This type of fading environment ensures the maximum amount of data to be transmitted to the UE in a fading environment with the UE having a perfect line of sight (LOS) with the transmitter, though there is signal deterioration yet the degree of error is lesser than that of Rayleigh fading Channel. The probability density function of the Rician channel as in [69] can be expressed as;

$$P_R(R) = \frac{R}{e^2} e - \frac{R^2 + A^2}{2\delta^2} \left(\frac{RA}{\delta^2} \right), 0 \le R \le a \qquad (3.22)$$

Where R is the radius of the UE from the transmitter and A is the amplitude of the signal in the radio channel.

3.3.3 Additive White Gaussian Noise (AWGN) Channel

In AWGN the received signal of UE from a transmitter does not undergo thorough deterioration as compared to the Rayleigh noise and the Rician fading channel. The received signal for AWGN can be modelled as [24];

$$H_j(t) = A_j(\Theta) + N_j(\mathrm{t}) \qquad (3.23)$$

Where $A_j(\Theta)$ is the array manifold vector and $N_j(\mathrm{t})$ is the AWGN with zero mean and two-sided power spectra density given by No/2.

3.4 SNR Values In Multi-Path Fading Channel

Measurement of SNR values with regards to the 0.8 GHz and 2.6 GHz, for different radio channel conditions; based on the equation (3.23) various measurements of SNR values were measured for the two frequencies. The distance between the UE and BS is continuously varied and the corresponding SNR values are measured as [70];

$$\mathrm{SNR}_{ik} = \frac{x_{i,k} P_{i,k} H_{i,ko} \left\| Y_{ko} \right\|^{-ai}}{\sum_{l \grave{o} K} \sum_{Y \in \varnothing i,l \setminus Yko} 1 P_{i,l} H_{i,Y} \left\| Y \right\|^{-ai+wi,k}} \tag{3.24}$$

$P_{i,k}$ is the transmitted power from the BS, $H_{i,k0}$ is a random variable in the channel, $\|Y_{k0}\|$ Euclidean norm is the distance between the BS and UE, a is the exponential path loss [71];

$$W = \frac{bN_0}{C_i} \tag{3.25}$$

N_0 is power spectral density of background noise, c is the carrier frequency, C_i is the carrier frequency. For simplicity $P_{i,k}$, $||Y_{ko}||$, a values were chosen as a constant of 1.

3.5 Generation of Channel Parameters on 0.8 GHz and 2.6 GHz Carriers.

The channel parameter is generated using MATLAB or Simulink described in LTE 3GPP TS36.101 Technical specification illustrated in Figure 3.2. The Simulink is built on Markov model principles which examine three delay profiles of UEs such as Extended Pedestrian (EPA) UE, Extended Vehicular (EVA) UE, and Extended Urban (ETU) UE in LTE radio environment. The Simulink is fed with SNR calculated from the two carrier frequencies 0.8 GHz and 2.GHz to transmit data to the UEs over a multipath fading and non-multi-path fading wireless environment. Hybrid Automatic Repeat Request (HARQ) is used as an error correction scheme to ensure data is well transmitted to the UE. The UE receptivity depends on the current channel conditions which determine the amount of SNR received by the UE. If the BER of the signal is low, the model schedule the UE on both carrier components to achieve peak data rate, whereas if the BER measured by the UE is high the model schedule the UE on the carrier component that has a low path loss feature to provide coverage for the UE.

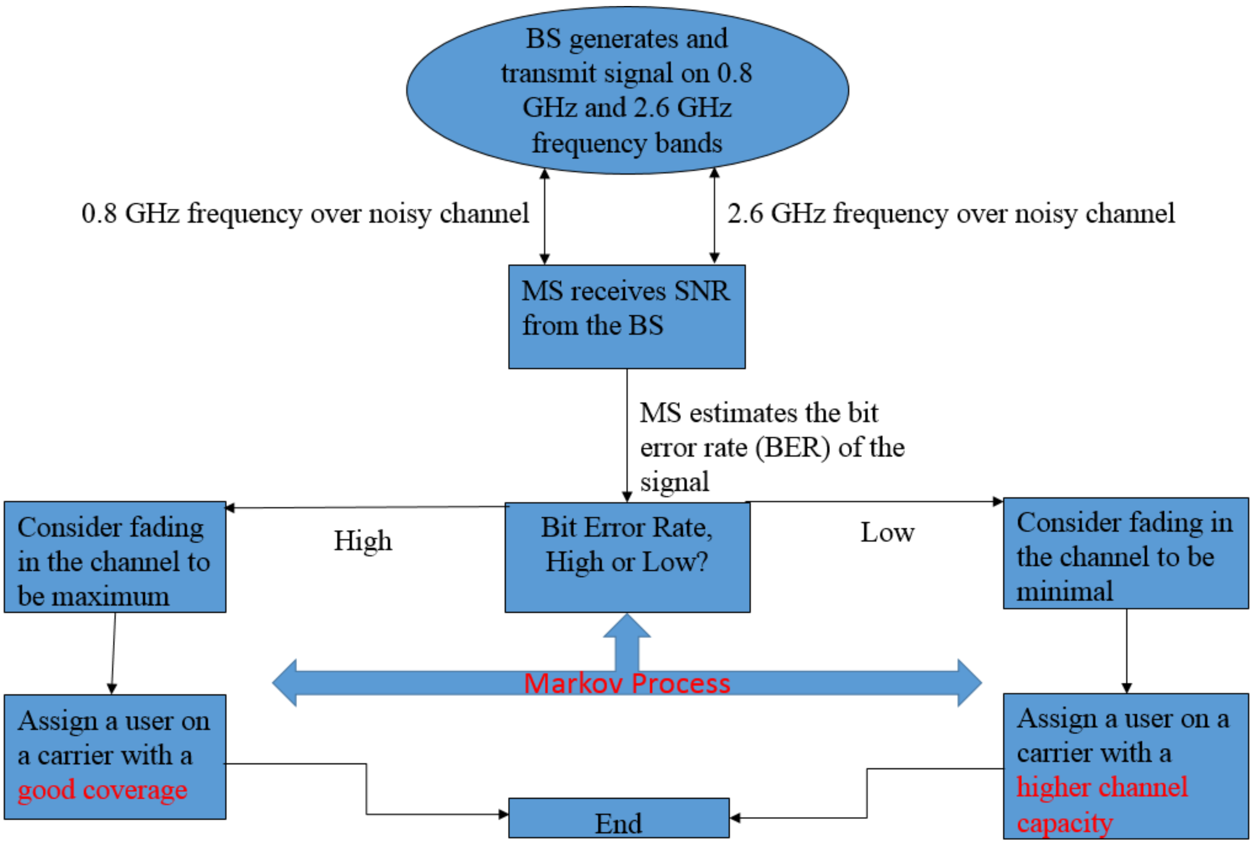

Figure 3.2 Physical Downlink Shared Channel (PDSC) demodulation performance Test as specified in TS36.101 MATLAB/Simulink Model

In this way, UEs at the cell edge have access to resources in the LTE network with the most appropriate carrier component in the two frequencies being aggregated.

3.5.1 Generation of User Parameters

The following procedures were followed to achieve performance metrics such as SNR, pdf, BER, and throughput measurement of LTE users along the roadside (pedestrian), in vehicles, and also users in a building.

1. The SNR of users on the 0.8 GHz and 2.6 GHz frequency bands in a non-perfect radio channel were determined. For users transmitting on any of the frequencies from the BS in a wireless channel, the SNR is given by the equation (3.26) as in [72]

$$\text{SNR} = 10 \log10 \text{ (Signal Power / Noise Power) dB} \quad (3.26)$$

2. The probability density function (pdf) of users transmitting on 0.8 GHz and 2.6 GHz frequency bands in AWGN, Rician, and Rayleigh fading channels were determined.

   The probability density function of the signal in Additive White Gaussian Noise is represented as in equation (3.23).

Table 3.3.1 Parameters for Generating Throughput for 0.8 GHz and 2.6 GHz

Parameters	**Settings**
Component Carriers	0.8 GHz and 2.6 GHz,
Bandwidth	10Mps
Physical resource blocks	50PRBs
Duplex Mode	FDD
Propagation loss	10dB
Doppler shift	50Hz, 300Hz, 750Hz
Propagation Model	EVA, EPA, ETU
UE Arrival	Poisson time arrival
Transmission scheme	Diversity

UE Receiver	2 MIMO
System Model	Markov Model

3. The BER of users transmitting on 0.8 GHz and 2.6 GHz frequency bands were determined, using a selected modulation scheme such as PSK, DPSK, OQPSK, QAM, and FSK to enhance users' performance.
4. The throughputs of users transmitting on 0.8 GHz and 2.6 GHz in a multipath fading environment were determined.
5. The throughput of users transmitting on 0.8 GHz and 2.6 GHz frequency bands in non-multipath fading environments were determined and the results were compared to that of the multi-path fading environment using equation (3.27) as in [72]

$$\mathrm{C} = E\left[R_C log_2\left(1 + \frac{E_S}{N_t R_c N_o}\|H\|^2{}_F\right)\right](bps/Hz) \qquad (3.27)$$

R_c is the code rate of the space-time block coding (STBC) defined as Es /T, where Es is the energy signal transmitted from the BS, and T is the number of time slots to transmit one block code and

$$|H|^2{}_F = \sum_{i=l}^{N}\sum_{J=1}^{M}\|h_{iJ}\|^2 \qquad (3.28)$$

$|H|$ is the squared Frobenius norm of the channel matrix H, hij is the channel gain from the ith transmit antenna to the jth receive antenna [49].

3.6 Throughput Analysis of User Equipment (UE) on 0.8 GHz and 2.6 GHz

The capacity analysis was done for various UE walking along the roadside (pedestrian), in urban or in building enclosure, and also UE in a moving vehicle, in each scenario the throughput was observed to be different in performance. This may account for different propagation paths that the frequency goes through before reaching the user. Signal to noise ratio was evaluated for 0.8 GHz and 2.6 GHz in a varying distance of UE from the BS using the MATLAB algorithm. MATLAB/Simulink (LTE Throughput signal generator) is then used to estimates the capacity for each of the frequencies based on the distance of the UE from the BS. The Simulink accepts the values of SNR which then generates the corresponding throughput for each SNR value. The simulation was performed for UEs in different delay profiles such as pedestrians, users in the vehicle, and also users in a building or urban environment. The throughput results for UEs in each delay profiles were measured and plotted using MATLAB Algorithm.

Chapter 4

4.0 Results And Discussion

This chapter presents the results of MATLAB simulations on the signal-to-noise ratio (SNR), Bit Error Rate (BER), and throughput experienced by users in the LTE network. It presents the experimental numerical and graphical result obtained from MATLAB\Simulink on 0.8 GHz and 2.6 GHz frequency bands and the performance difference of each frequency.

4.1 Bit Error Rate (BER) For 0.8 GHz and 2.6 GHz Carrier Frequencies

The signals from the base station were modulated by PSK, DPSK, OQPSK, QAM, and FSK schemes as it was propagated from the base station to the user on the 0.8 GHz and 2.6 GHz carrier frequencies in a fading wireless channel. BER and throughput simulations were performed for the 0.8 GHz band and 2.6 GHz band using the above modulation schemes to enhance the performance of the data delivery to user equipment at the cell edge. Simulations for each scenario were configured as inter-band carrier aggregation to show the distinctiveness of each band in a multipath fading environment, each frequency demonstrates the properties of penetration losses, bit error rate, and throughput amidst a multipath fading environment. Both low and high order modulation schemes were used to transmit signals in AWGN, Rayleigh fading, and Rician fading channels to see which modulation is best suited for peculiar settings. A graph of BER is then plotted against E_b/N_o to represent how much signals are distorted as it travels from the base station to the user equipment. The more errors detected by the user the less intelligible the data becomes to the user which results in delay and low data rates. Figure (4.1-4.8) illustrates the performance of 0.8 GHz and 2.6 GHz inter-carrier aggregation for bit error rate and throughput using MATLAB/Simulink.

4.1.1 BER Analysis For 0.8 GHz Carrier Using PSK And DPSK Modulation

Simulations were performed for 0.8 GHz using PSK low order modulation scheme and DPSK high modulation scheme. It was observed that 0.8 GHz has a low BER with the PSK modulation scheme whereas 0.8 GHz has a high BER with the DPSK modulation scheme. The DPSK modulation schemes have more energy in the AWGN than the PSK as seen the graph Fig 4.1, which is due to less error in the AWGN channel than the other fading channels. The PSK has lower BER as compared to the DPSK which can be used to improve the coverage of users at the cell edge.

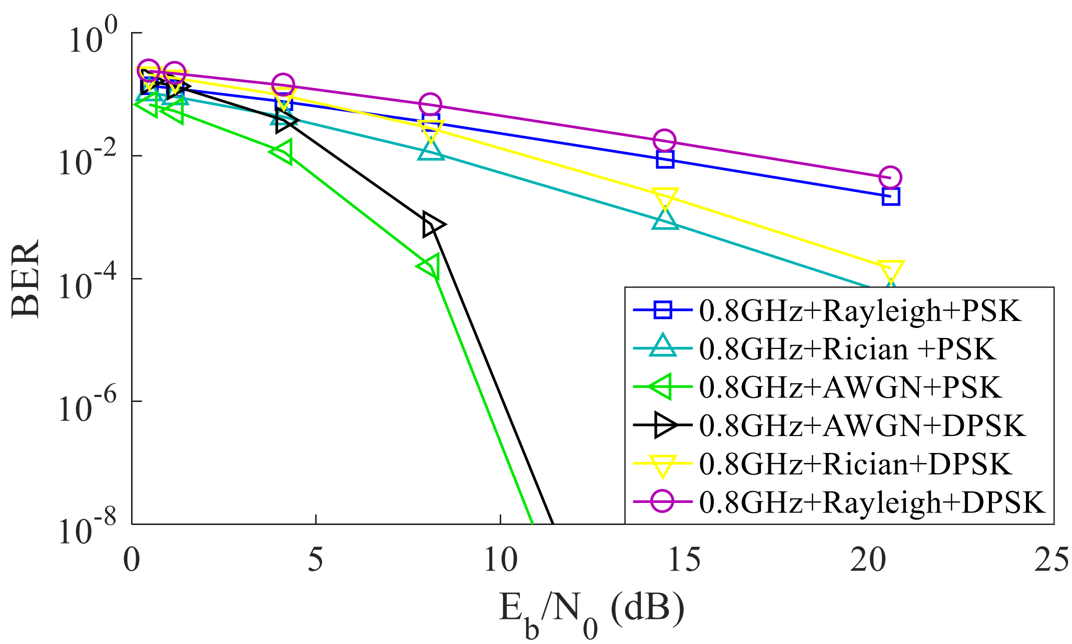

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Figure 4.1 Varying PSK(low order) and DPSK(high order) Modulation Scheme for 0.8 GHz frequency.

4.1.2 BER Analysis For 2.6 GHz Carrier Using PSK And DPSK Modulation

Simulations were performed for 2.6 GHz using PSK low order modulation scheme and DPSK high modulation scheme. It was found out that the 2.6 GHz has a lower BER with the PSK modulation scheme whereas 2.6 GHz has a high BER with the DPSK modulation scheme as seen Fig 4.2.

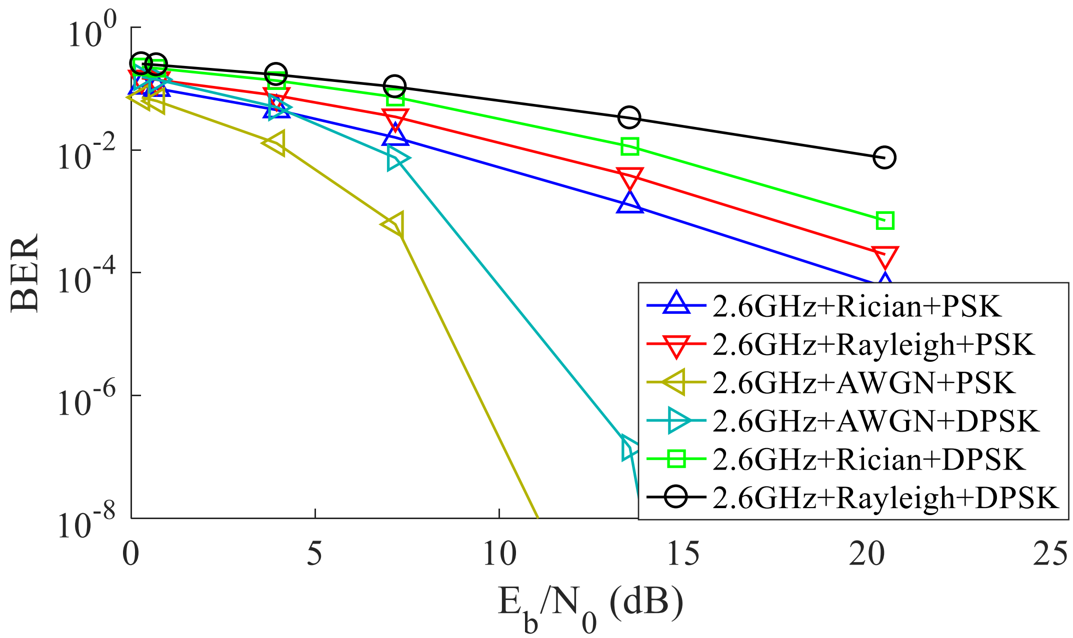

Figure 4.2 Varying PSK and DPSK Modulation Scheme for 2.6 GHz frequency.

4.1.3 BER Analysis of 0.8 GHz and 2.6 GHz Carriers Using PSK Modulation

Fig 4.3 illustrate the BER performance of 0.8 GHz and 2.6 GHz in AWGN, Rician and Rayleigh fading channels. SNR values received by users had an amount of error rate as the signal traversed in the three channels. In the simulation users' performance in AWGN recorded low and high BER values of 2.75e-52 and 0.0676 on 0.8 GHz respectively. Users' BER performance on 2.6 GHz for low and high values were 7.11e-51 and 0.0717 respectively. BER low and high values recorded on the Rician fading channel were 5.50e-5 and 0.1048 on 0.8 GHz respectively and 1.98e-4, 0.1476 on the 2.6 GHz respectively. BER low and high values for Rayleigh channel for PSK were found as 0.0021 and 0.1369 on the 0.8 GHz respectively and BER low and high values for 2.6 GHz were 0.0022 and 0.1405 respectively. The BER readings were very low for AWGN, high for the Rician fading channel, and very high for the Rayleigh fading Channel

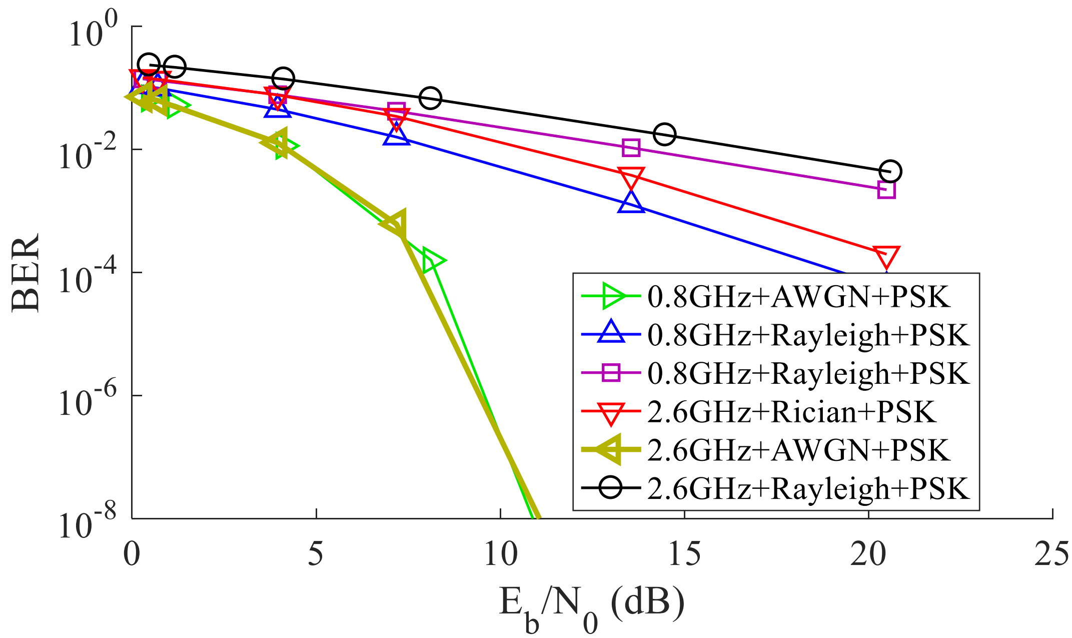

Figure 4.3 Varying PSK Modulation Scheme for 0.8 GHz and 2.6 GHz frequency.

4.1.4 BER Analysis of 0.8 GHz and 2.6 GHz Carriers Using FSK Modulation

Fig 4.5 shows a graphical result of the FSK modulation scheme used in the transmission of signal in Rayleigh, Rician fading channel, and AWGN. The measurement done in AWGN recorded BER low and high values of 2.95e-52 and 0.0679 on 0.8 GHz respectively, and BER of low and high values of 7.51e-51 and 0.0757 on 2.6 GHz frequency respectively. BER low and high values recorded on the Rician fading channel were 5.56e-5 and 0.1548 on 0.8 GHz respectively. BER low and high values for the Rayleigh channel for PSK were found as 0.0025 and 0.1479 on the 0.8 GHz respectively and BER low and high values for 2.6 GHz were 0.0122 and 0.2405 respectively. The BER readings were very low for AWGN, high for the Rician fading channel, and very high for the Rayleigh fading Channel

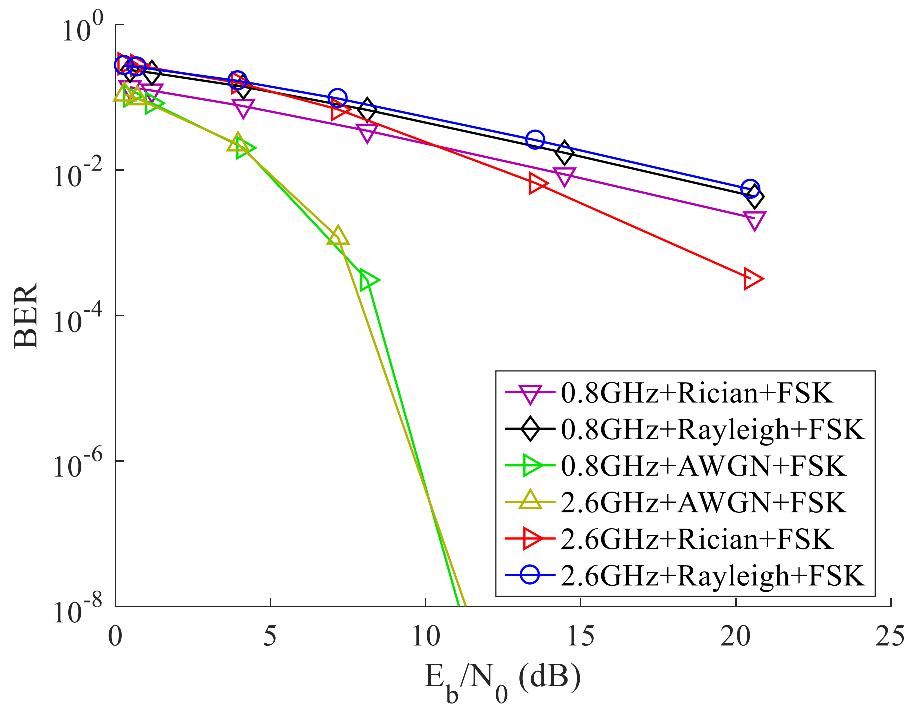

Figure 4.4 Varying FSK Modulation Scheme for 0.8 GHz and 2.6 GHz.

4.1.5 BER Analysis of 0.8 GHz and 2.6 GHz Carriers Using DPSK Modulation

Fig 4.5 shows a clear difference between the performance of the PSK and the DPSK is the variation of energy of the signal. It is realized that the DPSK has more energy but high BER. Both on the 0.8 GHz and the 2.6 GHz the PSK performs with less bit error rate against the signal to noise ratio while the DPSK has a more bit error rate against the signal to noise ratio. In the AWGN noise, there is a distinct difference in the bit error rate for DPSK more than that of the performance of PSK bit error rate in the AWGN channel. There is also a marginal difference in PSK and DPSK performance in the Rayleigh fading channel and Rician fading channel. AWGN recorded BER low and high values of 5.25e-51 and 0.1639 on 0.8 GHz respectively, and BER of low and high values of 1.34e-30 and 0.1538 on 2.6 GHz frequency respectively.

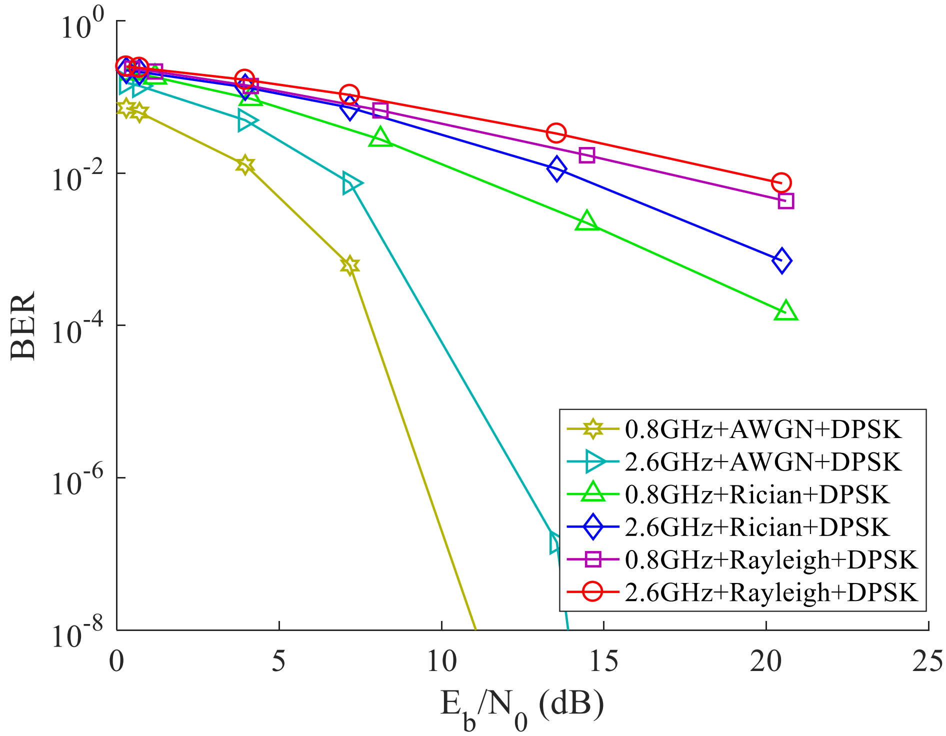

Figure 4.5 Varying DPSK Modulation Scheme for 0.8 GHz and 2.6 GHz and 2.6 GHz frequency.

BER measurement for low and high values recorded on Rician fading Channel were 1.45e-4 and 0.2061 on 0.8 GHz respectively and 5.82e-5 and 0.1086 on the 2.6 GHz respectively, also the BER measurement for low and high values for Rayleigh fading channel for PSK was found as 0.0043 and 0.2364 on the 0.8 GHz respectively and BER low and high values for 2.6 GHz were 0.0073 and 0.2515 respectively. The BER readings were very low for AWGN, high for the Rician fading channel, and very high for the Rayleigh fading Channel.

4.1.6 BER Analysis of 0.8 GHz and 2.6 GHz Carriers Using OQPSK Modulation

Fig 4.6 illustrated BER measurement was done for OQPSK higher modulation schemes,

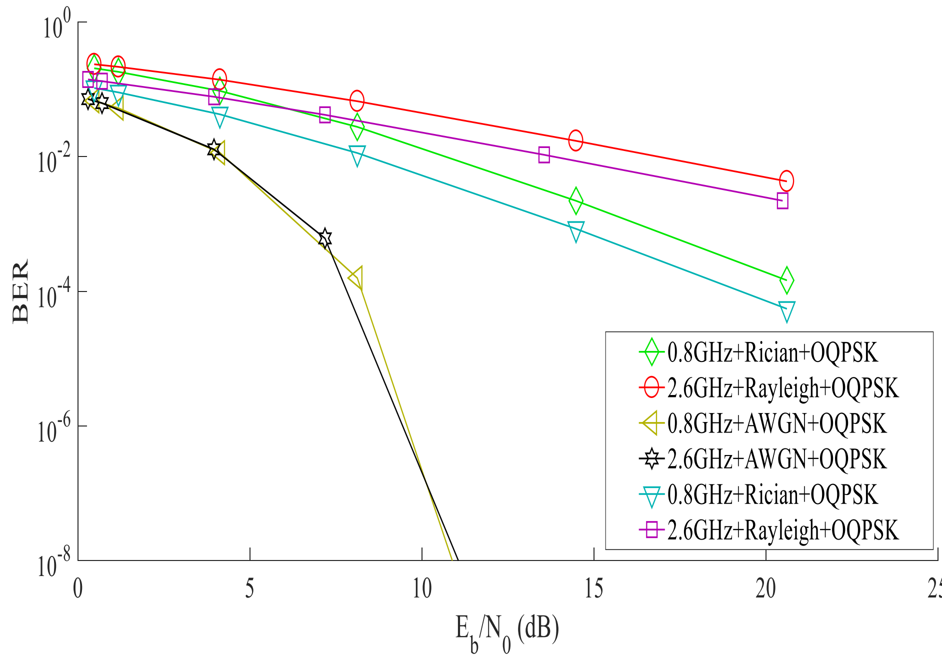

Figure 4.6 Varying OQPSK Modulation Scheme for 0.8 GHz and 2.6 GHz.

AWGN recorded BER low and high values of 2.75e-52 and 0.0676 on 0.8 GHz respectively, and BER of low and high values of 7.11e-51 and 0.0717 on 2.6 GHz frequency respectively. BER low and high values recorded on Rician fading channel were 5.50e-5 and 0.1048 on 0.8 GHz respectively and 1.98e-4, 0.1476 on the 2.6 GHz respectively, also the BER low and high values for Rayleigh Channel for OQPSK were found as 0.0021, 0.1369 on the 0.8 GHz respectively and BER low and high values for 2.6 GHz were 0.0022 and 0.1405 respectively. The BER readings were very low for AWGN, high for the Rician fading channel, and very high in Rayleigh fading channel.

4.1.7 BER Analysis 0.8 GHz and 2.6 GHz Carriers Using QAM Modulation

QAM modulation scheme was used in the transmission of signal in Rayleigh, Rician fading channel, and Additive White Gaussian Noise Channel (AWGN) as seen Fig 4.7.

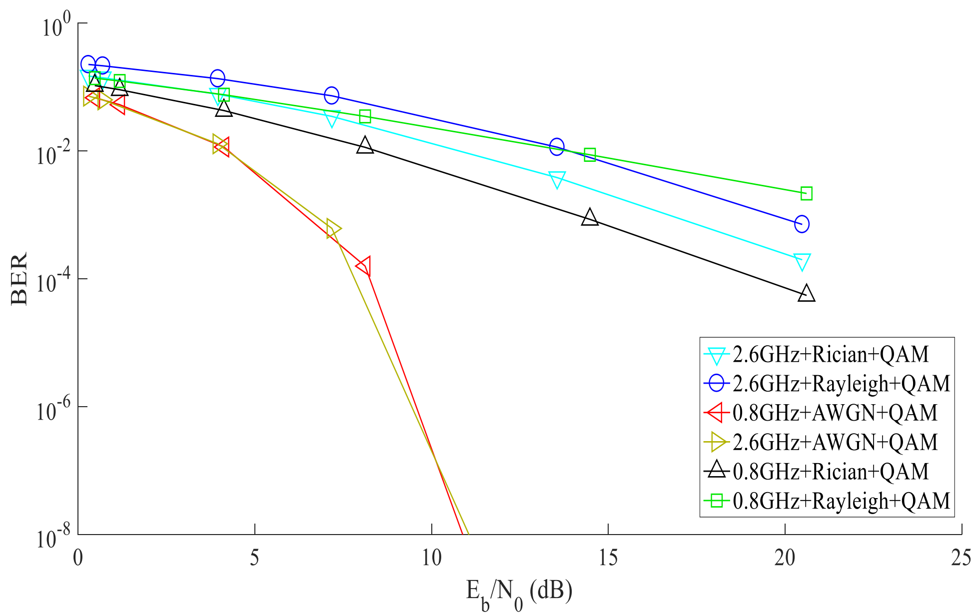

Figure 4.7 Varying QAM Modulation Scheme for 0.8 GHz and 2.6 GHz frequencies

The measurement done in AWGN recorded low and high BER values of 2.75e-52 and 0.0676 on 0.8 GHz respectively. BER of low and high values of 7.11e-51 and 0.0717 on 2.6 GHz frequency respectively. BER low and high values recorded on the Rician fading channel were 5.50E-5, 0.1048 on 0.8 GHz respectively, and 1.98e-4, 0.1476 on the 2.6 GHz respectively, also the BER low and high values for Rayleigh fading channel for QAM were found as 0.0021 and 0.1369 on the 0.8 GHz respectively and BER low and high values for 2.6 GHz were 0.0022 and 0.1405 respectively. The BER readings were very low for AWGN, high for the Rician fading channel, and very high in Rayleigh fading Channel.

4.2 Performance of 2.6 GHz and 0.8 GHz Carrier Frequencies.

Figures 4.8 and 4.9 demonstrate the performance difference of 2.6 GHz and 0.8 GHz as it is transmitted in a multipath fading channel to the user.

4.2.1 Performance of 2.6 GHz in Fading Channel

The Figure 4.8 graph shows the variation in performance of signal in AWGN, Rician, and Rayleigh fading channels. It is observed that AWGN has less error rate than the Rician and the Rayleigh while the Rician also performs better than the Rayleigh noise channel. In the Rician noise channel, we observe the gradual deterioration of bit error whereas the Rayleigh performs poorer. Since UE arrival rates are rampant in such a fading environment a more robust carrier frequency should be used to solve this issue. As observed from the graph signal transmitted in the

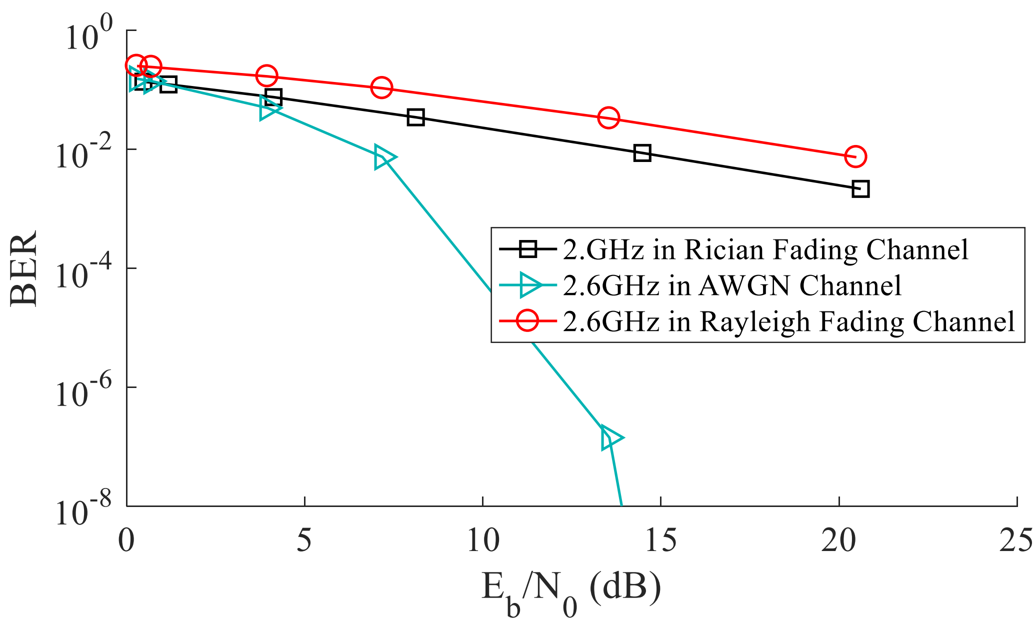

Figure 4.8 Performance of 2.6 GHz frequency in AWGN, Rician and Rayleigh Noise Channel

Rician and Rayleigh fading channels will have more bit errors and noise than the signal transmitted in the AWGN channel.

4.2.2 Performance of 0.8 GHz in Fading Channel

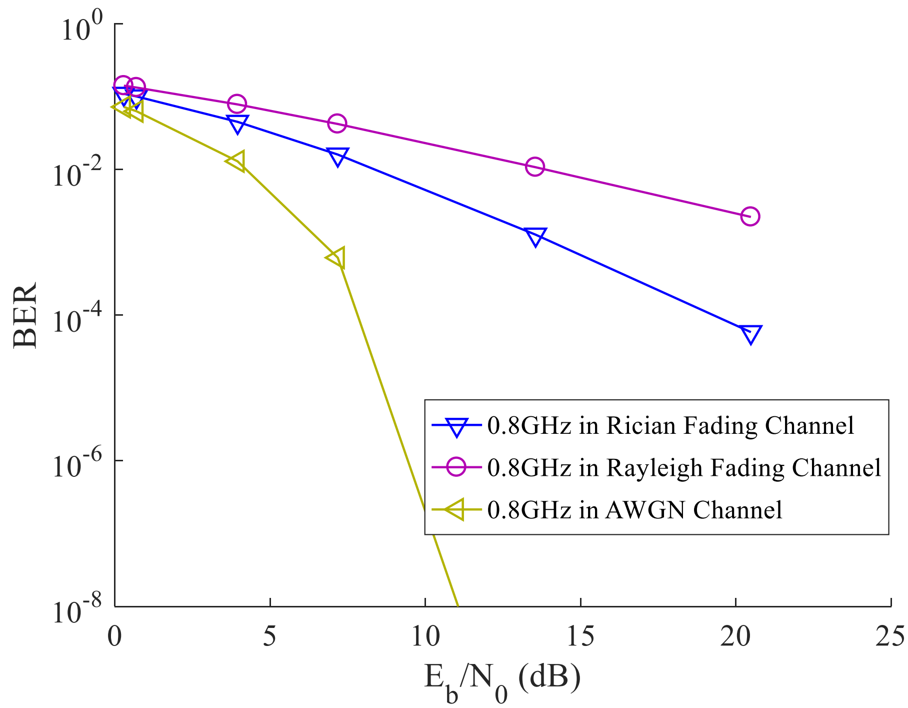

Figure 4.9 Performance of 0.8 GHz frequency in AWGN, Rician, and Rayleigh Noise Channel.

In the 0.8 GHz analysis, the BER in AWGN is better than that of the Rician and the Rayleigh performs worse. It is observed that UEs in the AWGN will have less fading with the stronger and robust signal, while UEs in the Rician and the Rayleigh Channel will suffer much delay, low data rate, and errors in their signal transmission and receptivity. The Rayleigh fading channel especially has the worse performance. It is observed from the diagram that there are more bit errors in the Rayleigh noise channel followed by Rician and then AWGN in 0.8 GHz. However, 0.8 GHz achieves better performance in the Rician fading channel than 2.6 GHz in the Rician fading channel.

4.3.1 Comparison of Average BER with prior works

Table 4.3.1 illustrates the BER performance using the Markov Model (MM) based on MATLAB\Simulink to enhance the cell edge performance of LTE users. It is observed from the table that the method achieves a more improved BER value of $10^{-1.3}$, which is followed by inter-carrier aggregation in HetNet using turbo coding (TC) based on a downlink physical layer block diagram of an LTE-Advanced Release 12 physical (PHY) specifications developed by 3GPP for data transmission [39].

Table 4.3.1 Comparison of average BER with prior works

Reference	Cell Edge Strategy	SNR(dB)	BER
Proposed	Markov Model(MM)	2	$10^{-1.3}$
		20	10^{-8}
[26]	Heterogeneous Network(HN)	2	$10^{-1.5}$
		19	10^{-4}

It is observed that carrier aggregation done with the HN turns out to produce a low BER of 10^{-4}. While the proposed method has a low BER of 10^{-8} . It can be seen that the proposed model achieved better BER performance than HN.

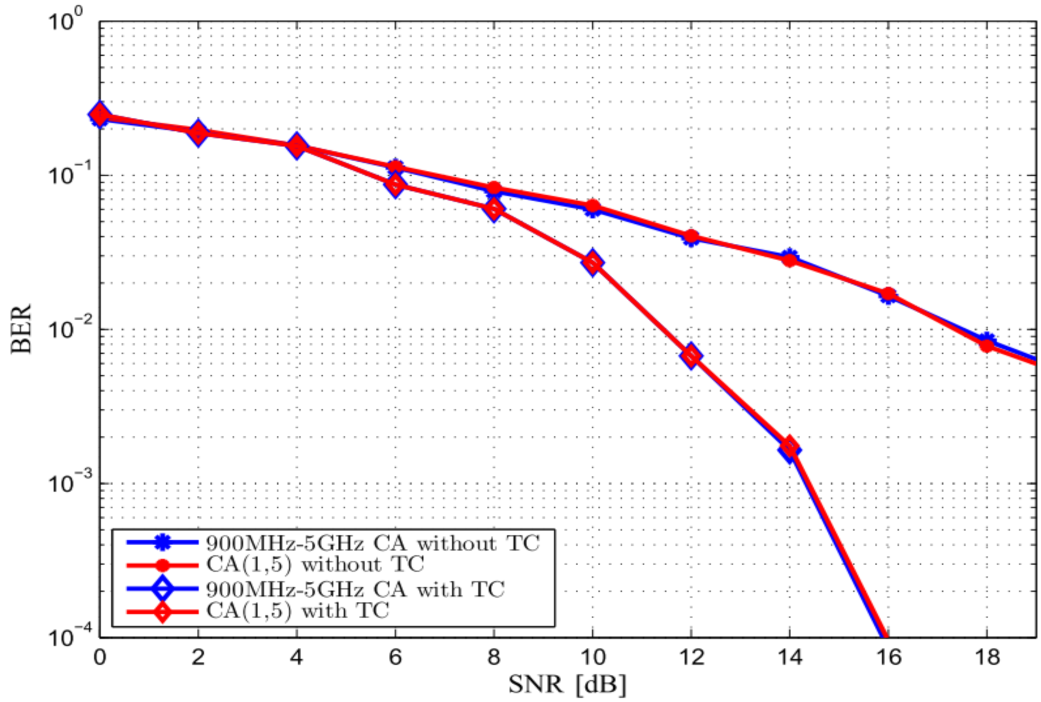

Fig 4.10 Performance of two inter-band CA scenarios over-dispersed bands; i) licensed CA(1, 5) and ii) unlicensed 900 MHz - 5 GHz, with or without Turbo Coding (TC) and total bandwidth in both cases equal to 20 MHz in Heterogeneous Network (HN) [26].

4.3 Throughput for User Equipment (UE)

It was observed that the throughput for users was better in the 0.8 GHz than the 2.6 GHz in EPA, EVA, and the ETU delay profiles, this was due to the good penetration or propagation features of the 0.8 GHz frequency and low BER for the 0.8 GHz than the 2.6 GHz frequency. The throughput decline with decreasing SNR for both frequencies, however, the 0.8 GHz is more efficient in its radio spectrum than the 2.6 GHz. The graphs for the various scenarios are presented in the following pages. Measurement performed for various propagation models revealed that the throughput of UE was better when the SNR is good, however, when the signal deteriorates due to movement from the base station the throughput becomes worse and the UE suffers poor performance. Both EVA, EPA, ETU UE has different speed of movement in the cellular network which must be served with a frequency that can provide them with a good signal and the expected throughput. The analysis revealed that EPA has the fastest speed for the UE, followed by the EVA, and lastly ETU recorded the lowest speed for the UE.

4.3.1 UE Throughput Performance For Pedestrian on 0.8 GHz and 2.6 GHz Carriers

Table 4.3.1 and Fig 4.10 show the throughput experience of UE by a pedestrian, as the signal is transmitted from the BS to the UE, it can be observed that the throughput in multipath fading performs lower than the throughput in the non-multi-path fading channel. The throughput in the multipath fading which our analysis mainly concentrates on has a gradual decline of performance value as the user moves alongside the road further from the BS, nonetheless, the 0.8 GHz has better performance than the 2.6 GHz on the same fading channel. The throughput for the UE in the non-multipath fading environment is better than that of the multipath fading signal due to fewer penetration losses in that environment. The throughput for the 0.8 GHz in the non-multipath fading channel also outperforms the throughput in the 2.6 GHz frequency band. Pedestrian users far from the base station can be best served by the 0.8 GHz frequency with good throughput in both multipath and non-multipath fading environment while pedestrian users close to the base station are best served by the 2.6 GHz frequency band.

Table 4.3.1 Experimental Throughput Result For Pedestrian on 0.8 GHz and 2.6 GHz Carriers

L(m)*1000	SNR(dB) for 0.8GHz	SNR(dB) for 2.6GHz	UE(Mbps) 0.8GHz in Non Fading channel	UE(Mbps) 2.6GHz In Non Fading channel	UE(Mbps) 0.8GHz Fading channel	UE(Mbps) 2.6GHz Fading channel
01.00	20.0	20.486	100.0	100.00	98.00	100.0
02.00	14.480	13.553	98.89	97.99	85.89	95.00
04.00	08.120	7.1811	97.79	93.94	78.33	91.34
06.00	04.125	3.9547	96.78	92.90	73.56	90.45
08.00	1.1768	0.6988	95.75	91.87	72.57	87.85
10.00	0.4720	0.2924	94.55	90.33	70.00	80.00

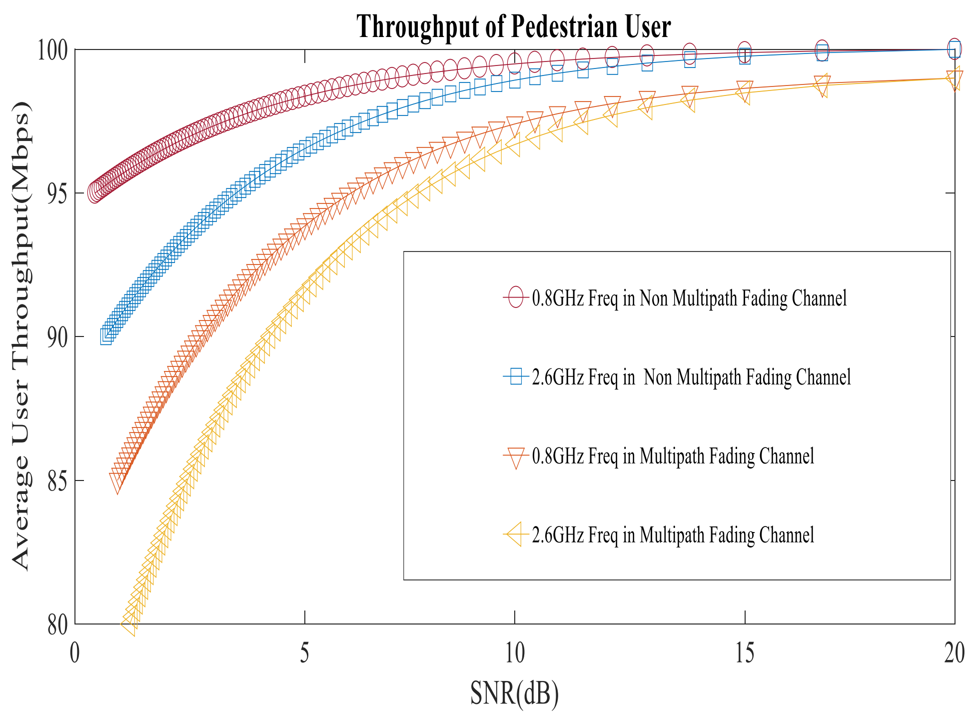

Figure 4.11 Throughput Performance on 0.8 GHz and 2.6Hz as SNR approaches 0dB for Pedestrian users.

4.3.2 UE Throughput Performance in Vehicle on 0.8 GHz and 2.6 GHz Carriers

Table 4.3.2 and Fig.4.11 show the throughput experience of UE in a vehicle, as the signal is transmitted from the BS to the UE. It can be observed that the throughput in multipath fading performs lower than the throughput in the non-multi-path fading channel. As the vehicle moves away from the base station the throughput reduces and the user experience begins to deteriorate. This is because the signal from the base station encounters a series of obstacles before reaching the passenger's user equipment. However since the penetration losses of the 0.8 GHz are lower than that of the 2.6 GHz, users have a better throughput on the 0.8 GHz as the vehicle continues to move from the base station.

Table 4.3.2 Experimental Throughput Result For Vehicular Users on 0.8 GHz and 2.6 GHz Carriers

L(m)*1000	SNR(dB) for 0.8GHz	SNR(dB) for 2.6GHz	UE(Mbps) 0.8GHz in Non Fading channel	UE(Mbps) 2.6GHz in Non-Fading channel	UE(Mbps) 0.8GHz Fading channel	UE(Mbps) 2.6GHz Fading channel
01.00	20.0	20.486	100.00	100.00	98.00	98.0
02.00	14.480	13.553	97.99	97.99	98.89	95.00
04.00	08.120	7.1811	93.94	95.94	91.93	91.34
06.00	04.125	3.9547	92.90	92.90	90.56	90.45
08.00	1.1768	0.6988	91.87	87.91	80.57	75.85
10.00	0.4720	0.2924	90.33	85.90	75.00	70.00

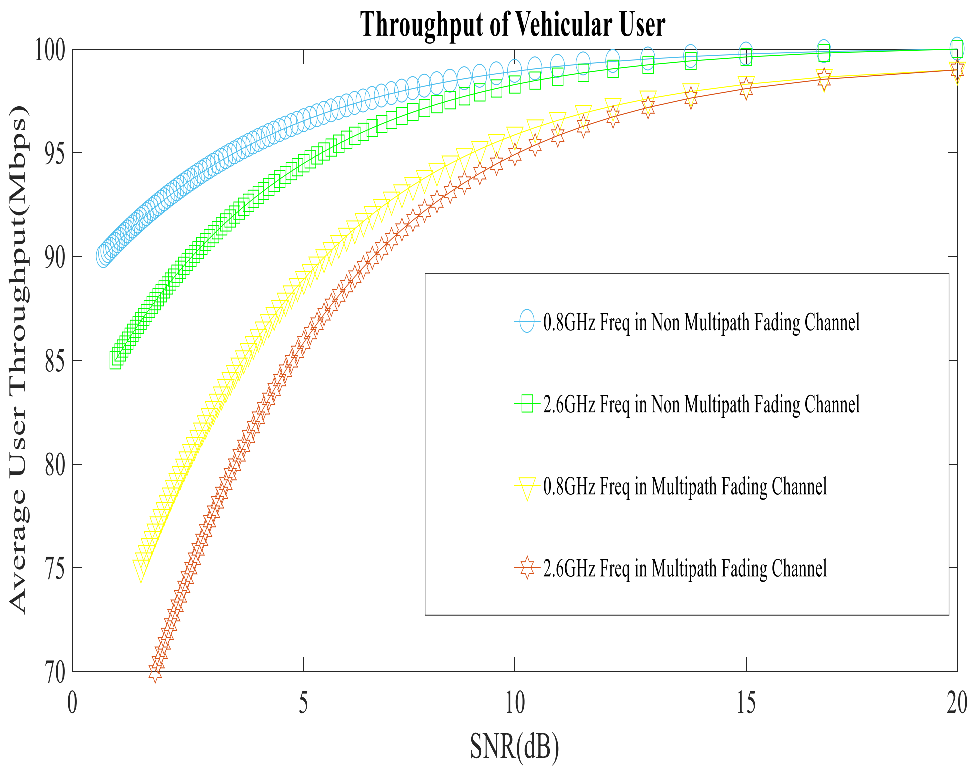

Figure 4.12 Throughput Performance on 0.8 GHz and 2.6 GHz as SNR approaches 0dB for users in the vehicle.

4.3.3 UE Throughput Performance in Building on 0.8 GHz and 2.6 GHz Carriers

Table 4.3.3 and Figure 4.12 reveals the throughput performance on 0.8 GHz and 2.6 MHz as SNR approaches 0dB for users in urban environments (in the building). As the signal is transmitted from the BS to the UE. It can be observed that the throughput in multipath fading performs lower than the throughput in the non-multi-path fading channel. The throughput in the multipath fading has a gradual decline of performance value as the user enters into an urban environment and also gets into the building; nonetheless, the 0.8 GHz has better performance than the 2.6 GHz on the same fading channel. Users in a building that are close to the base station experience better signal and enhanced throughput while users in a building that are far from the base station experience better signals on the 0.8 GHz frequency band.

Table 4.3.3 Experimental Throughput Result For Home Users on 0.8 GHz and 2.6 GHz Carriers

L(m)*1000	SNR(dB) for 0.8GHz	SNR(dB) for 2.6GHz	UE(Mbps) 0.8GHz in Non Fading channel	UE(Mbps) 2.6GHz in Non-Fading channel	UE(Mbps) 0.8GHz Fading channel	UE(Mbps) 2.6GHz Fading channel
01.00	20.0	20.486	100.00	100.00	98.00	98.0
02.00	14.480	13.553	98.99	97.99	98.89	95.00
04.00	08.120	7.1811	96.94	95.94	91.93	85.34
06.00	04.125	3.9547	94.90	90.90	90.56	82.45
08.00	1.1768	0.6988	90.00	85.91	80.57	75.85
10.00	0.4720	0.2924	85.33	75.90	70	65.00

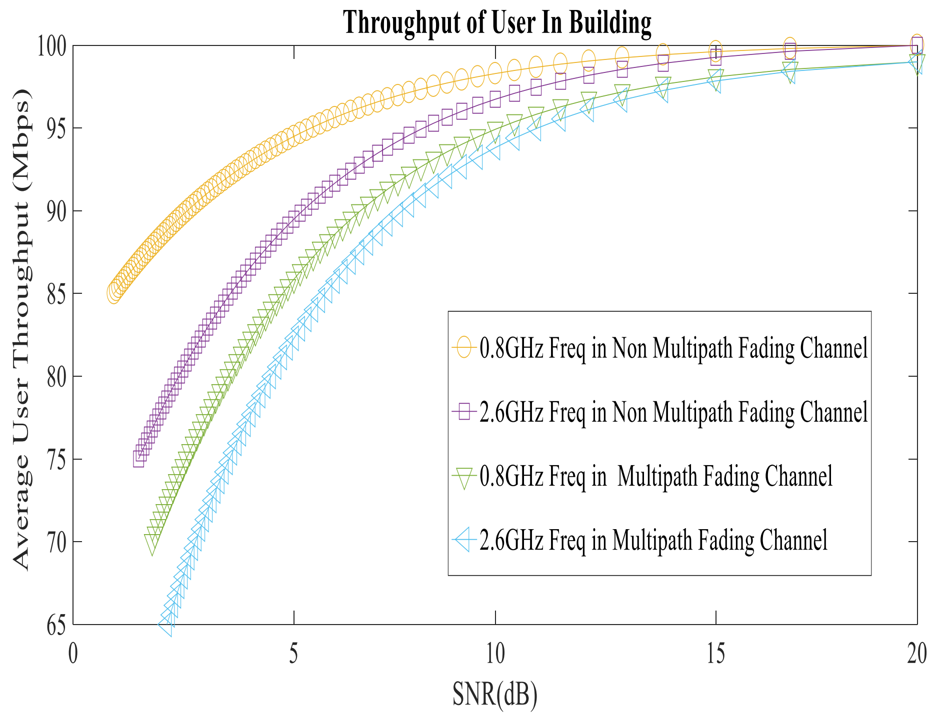

Figure 4.13 Throughput Performance on 0.8 GHz and 2.6 GHz as SNR approaches 0dB for users in the building.

4.4 Comparison of Average Throughput with prior works

Table 4.4, Fig 4.13, and Fig 4.14 illustrate the throughput performance of UEs in different scenarios. The proposed model achieves a more enhanced average throughput for the user; this is followed by the G-Factor model. Fractional Power Control (FPC) falls short in terms of throughput compared with the others as seen in Table 4.4. The result demonstrates that the proposed model is very robust in terms of improving throughput for cell-edge users to access the LTE network.

Table 4.4 Comparison of average throughputs and target with prior works

Reference	Cell Edge Strategy	Target User Throughput(Mbps)	Average User Throughput(Mbps)
Proposed	Markov Model(MM)	100	90
[64]	G-Factor Model(GFM)	100	77
[2]	Fractional Power Control(FPC)	100	0.75

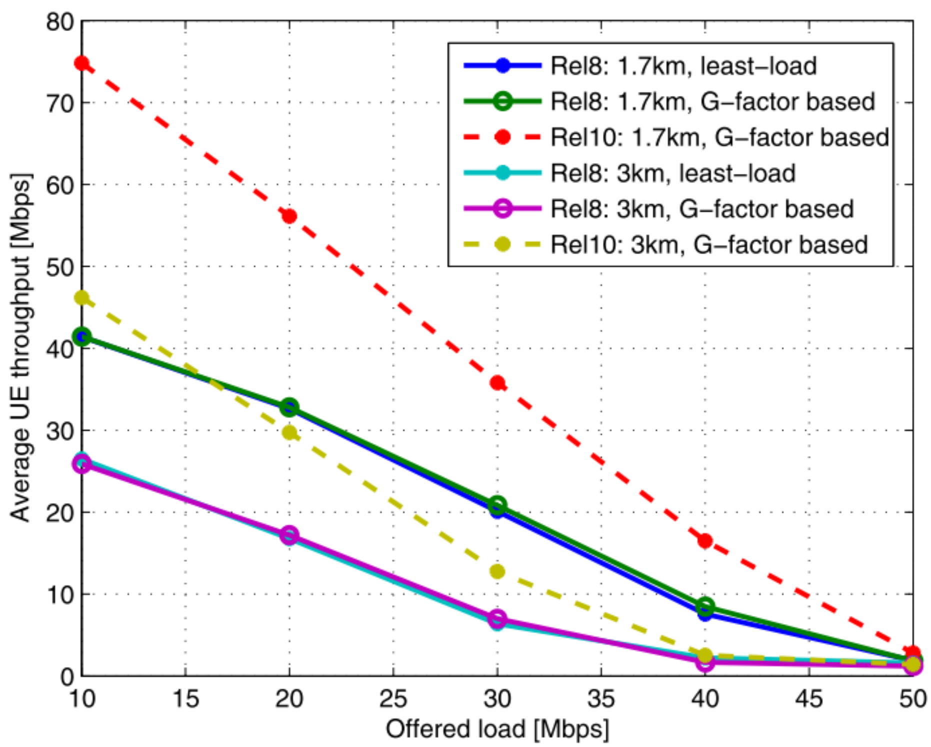

Fig 4.14 Average user throughputs under different traffic loads in different scenarios, with 800&2100MHz frequency carriers [64].

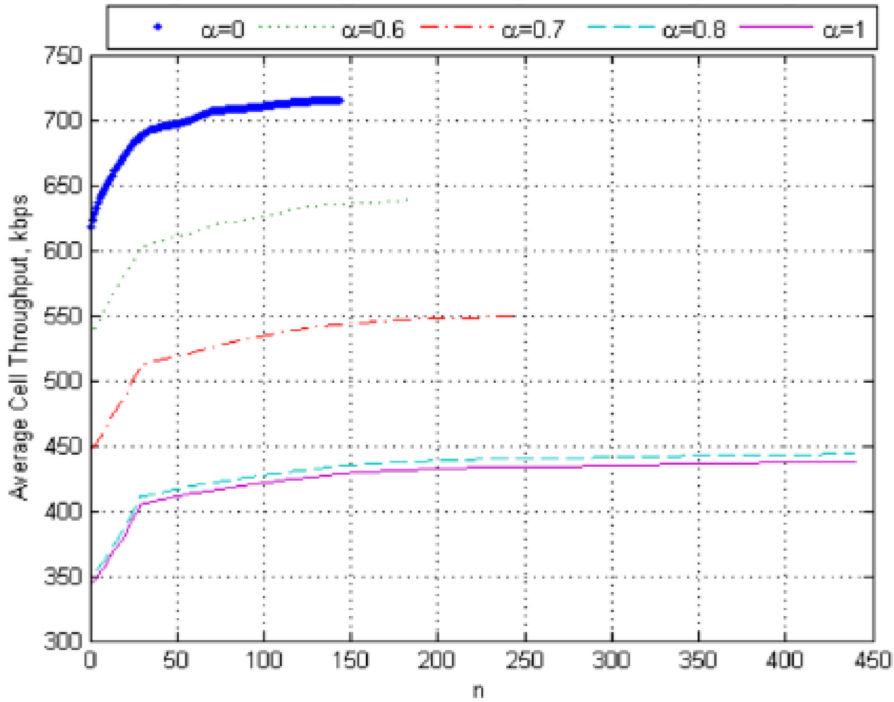

Fig 4.15 Fractional Power Control average throughput for users(α is a compensating factor for the attenuation experienced by each UE and n is the number of requests to the base station by users)[2].

Chapter 5

5.0 Conclusions And Recommendations

MATLAB simulation results achieved for the SNR, BER, and throughput using carrier aggregation have improved values for UEs to experience a high data rate from the base station in a fading channel environment. It was observed that the 2.6 GHz frequency band performs better in terms of SNR, BER, and throughput when the UE is closer to the BS. The frequency begins to deteriorate as the UE moves further from the BS, this introduces a lot of errors in the message transmitted from the base station to the user. As more errors occurred in the system, it increases the latency of data delivery and hence affects users' performance. In all the simulations UEs performance in terms of BER was better in AWGN, than Rayleigh and Rician.

The 0.8 GHz has appreciably high performance in terms of SNR, BER, and throughput than the 2.6 GHz. It was observed that the bit error rate in 0.8 GHz frequency was lower compared to that of 2.6 GHz and hence achieves less latency rate and high data delivery for the UE. The combined use of 2.6 GHz and 0.8 GHz has a tremendous benefit of achieving throughput and coverage for the UE simultaneously. When the UE is close to the BS with less environmental obstruction and frequency deterioration, the UE can receive a better signal from the 2.6 GHz and achieves a maximum data rate. At a far distance, the BS performs handover and releases data delivery to the 0.8 GHz which is robust with fewer propagation losses and has a better performance metric in a wireless environment.

5.1 Performance Metric in 2.6 GHz and 0.8 GHz Carrier Frequencies

Bit Error Rate is very low, medium, and high for signal in Additive White Gaussian, Rician, and Rayleigh fading channel respectively. Low-order modulation schemes such as PSK and FSK had low BER for users whereas higher-order modulation schemes such as DPSK, QAM, and OQPSK had high BER on both 0.8 in the AWGN channel as seen in Fig 4.2, which can be used to improve the bandwidth of the users close to the BS. Users at the cell edge benefit tremendously by configuring the base station with PSK and FSK modulation which had low BER and can effectively transmit data to users at the cell edge with low BER.

There was a marginal performance difference in the BER signal for 0.8 GHz over 2.6 GHz frequency bands in Rayleigh, Rician, and AWGN Channel. User Performance is low in Rayleigh and Rician Fading Channel, while user performance is high in the AWGN Channel. Throughput is very high, medium, and low as the UE moves along the road, in a vehicle, and enters in building vicinity respectively. Fading increases as the UE enters more obstructed areas. UE with a better SNR achieves a higher data rate than those at the cell edge. LTE carrier aggregation should be best deployed in Rayleigh fading channel because the fading is very high in that channel than in AWGN and Rician fading channel. The combination of the 2.6 GHz and the 0.8 GHz produce a better signal for customers to be able to access the BS, the lower frequency can reach customers at the cell edge than the higher frequency given the same channel conditions. Carrier aggregation provides redundant means for cell-edge users to access radio resources from the base station through handover from a fading frequency to a stronger frequency.

5.2 Key Findings

i. The use of multiple carriers from the same frequency group achieves higher throughput for only customers closer to the BS. 2.6 GHz provides higher bandwidth and PRB to customers but the frequency is easily attenuated, and hence users at the cell edge experience poorer network service or no coverage at all.

ii. The lower frequency has fewer radio resource blocks (PRB) and hence introduces congestion into the network when there are hundreds of UEs to be served by the base station, yet the lower frequency can travel further than a high frequency. Lower frequency (0.8 GHz) achieved better coverage, in the case where 2.6 GHz could not perform better on the same radio channel conditions.

iii. The implementation of the higher and lower frequency band by LTE operators in Ghana is the best way to improve throughput and bit error rate efficiency and also increase the number of subscriber bases that a cell can accommodate on the network. In this thesis, because two categories of different frequencies have been used, in multi-path fading channel conditions where the wave meets a lot of obstacles, users are served by the best signal from any of the frequencies from the base station.

iv. This work can also be implemented on a campus where the higher frequency band can serve college building and the lower frequency serve students departing from the college environment. This helps to achieve better network performance and drastically reduce network congestion.

v. This work can serve well in the city where we have high buildings, in such type of environment; the building reduces the signal reaching the customer especially the high frequency which easily fades away. Since two types of frequency carriers are configured on the BS, their varying penetration properties can serve customers inside the building.

5.3 Recommendation and Future Work

This work was done in a city environment to determine the performance of LTE frequency carriers with throughput and coverage under consideration. The same work can be done in a town or village setting, where the people might need internet access to operate their business, after which comparison can be made on which frequency type (low or high band) is best and suitable to be applied in the city, village, or town environment where we have fewer buildings and no skyscrapers, less vehicular movement, and fewer population. Again MATLAB simulation for the two frequency bands was done for 2 by 2 MIMO antenna configuration. Future work can be done for the two frequencies in Massive MIMO to see the effect of throughput on the users at the cell edge.

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