KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

COLLEGE OF ENGINEERING

DEPARTMENT OF TELECOMMUNICATIONS ENGINEERING

THE TECHNICAL AND COST ASSESSMENT OF SOME BWA TECHNOLOGIES - A CASE STUDY OF KNUST

SUBMITTED FOR FULFILMENT OF THE DEGREE OF MSc. TELECOMMUNICATIONS ENGINEERING

BY

AKANBASIAM, APIGAGUA JOSHUA
(PG2652008)

SUPERVISOR:

KWAME OSEI BOATENG (PhD)

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DECLARATION

I hereby declare that, this submission is my own work except for specific references which have been duly acknowledged, this is the result of my own field research and it has not been submitted either in part or whole for any other degree in Kwame Nkrumah University of Science and Technology or any other educational institution elsewhere.

Signature…………………………………………   Date……………………………………

AKANBASIAM, APIGAGUA JOSHUA (BSc. Hons.)

(Candidate)

Signature…………………………………………   Date……………………………………

KWAME OSEI BOATENG (PhD)

(Supervisor)

Signature…………………………………………   Date……………………………………

P. Y. OKYERE (PhD)

(Head, Department of Electrical/Electronic Engineering)

ABSTRACT

The mobile wireless environment is evolving for new grounds with the emergence of 4G technologies; WiMAX and LTE are competing for supremacy or co-existence. The technologies are emerging from existing technologies with add-ons that give them comparable advantages over their parent technologies 3G and Wi-Fi – thus offer better; speed, data rates , range, security etc. A study of the theoretical strength and weaknesses of the physical and MAC layers of the various technologies under study and a general overview of BWA, its history, benefits and challenges and the current topology on Kwame Nkrumah University of Science and Technology (KNUST) campus is considered in this work. The work continues with a theoretical comparison of the technologies that offer excellent data rates based on modulation techniques, Bit Error rate (BER) and signal constellations and backed with MATLAB simulations. There is an in-depth assessment of the parameters that determine the cost of deploying various technologies - equipment and services and factors like, Capital Expenditure (CAPEX) and Operational (OPEX). These cost parameters were gathered from KNUST network planners, some telecommunication companies, RF planners, and some telecommunication equipment vendors, this was then compared with simulated figures from WIROI 20/20 and LTE calculator. Wi-Fi is cheap and better suited for Educational Institutions with relatively small land area (1 sq. Km). KNUST has a land area of over 10sq Km and is much suited for a cellular technology. The fact that WiMAX deployment has begun and offer low OPEX cost makes it an ideal technology for most Educational Institutions and also it continues their legacy network (Wi-Fi). On the other hand most telecommunication companies are opting for LTE; since it offers low CAPEX cost and continue their legacy network.

Index Terms: BWA, CAPEX, OPEX, Wi-Fi, WiMAX, 3G, 4G, LTE, BER

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LIST OF ACRONYMS

1G	First Generation
1xEV-DV	Evolved Data Optimized
2G	Second Generation
3G	Third Generation
3GPP-LTE	Third generation partnership project long term evolution
4G	Forth Generation
AA	Adaptive Array
AES	Advance Encryption Standard
AICH	Acquisition Indication Channel
AM	Acknowledgement Mode
AM	Amplitude Modulation
AMC	Adaptive Modulation and coding
AMPS	Advance Mobile Phone System
AP	Access Point
ARQ	Automatic Repeat Request
ASK	Amplitude Shift Keying
ATM	Asynchronous Transfer Mode
BER	Bit Error Rate
BPSK	Binary Phase Shift Key
BS	Base Station
BSC	Base Station Controller
BWA	Broadband Wireless Access
C/N	Carrier-to-Noise Ratio
CDMA	Code Division Multiple Access
Cdma one	Code Division Multiple Access One
Cdma2000	Code Division Multiple access 2000
CN	Core Network
CP	Cyclic Prefix
CPCH	Common Packet Channel
CPICH	Common Pilot Channel
CRC	Cyclic Redundancy Check
CSMA/CA	Carrier Sense Multiple Access /Collision Avoidance
CTS	Clear-to-Send
DFC	Distributed Coordinated Function
DHCP	Dynamic Host Configuration Protocol
DL	Down Link
DL	Down Link
DQPSK	Differential Quadrature Phase Shift Keying
DSL	Digital Subscriber Line
DSSS	Direct Sequence Spread Spectrum
EDGE	Enhance Data Rate for GSM Evolution
ENode	Evolved Node B

EPC	Evolved Packet Core
EPS	Evolved Packet System
E-UTRA	Evolved Universal Terrestrial Radio Access
E-UTRAN	Evolved Universal Terrestrial Radio Access Network
FDD	Frequency Division Duplex
FEC	Forward Error Correction
FHSS	Frequency Hopping Spread Spectrum
FM	Frequency Modulation
FSK	Frequency Shift Keying
GGSN	Gateway GPRS Support Node
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communication
GSN	GPRS Support Node
HSPA	High Speed Packet Access
I =	In-phase
IMS	IP Multimode Subsystem
IP	Internet Protocol
ISDN	Integrated Service Digital Network
ISI	Inter Symbol Interference
ISM	Instrument Scientific and Medical Band
ISP	Internet Service Provider
LAN	Local Area Network
LLC	Logical Link Control
LoS	Line of Sight
MAC	Medium Access Control
MIMO	Multiple Input Multiple Output
MME	Mobility Management Entity
MMS	Multiple Message Service
MSC	Mobile switching center
MSDU	MAC Service Data Unit
MTS	Mobile Telephone Service
NLoS	Non-Light of Sight
OFDMA	Orthogonal Frequency Division Multiple Access
PCI	Peripheral Component Interconnect
PCMCIA	Personal Computer Memory Card International Association
PDC	Personal Digital Cellular
PDN	Packet Data Network
PDU	Protocol Data Unit
P-GW	Packet Data Network Gateway
PHY SAP	Physical Layer Service Access Point
PICH	Pilot Indicator Channel
PKM	Private Key Management
PKMv2	Private Key Management Version Two
PM	Phase Modulation
PSK	Phase Shift Keying
PSTN	Public Switching Telephone Network

PTM	Point-to-Point
Q	Quadrature
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Key
RADIUS	Remote Authentications Dial User Service
RF	Radio Frequency
RLC	Radio Link Control
RNC	Radio Network Controller
RoHC	Robust Header compression
RRC	Radio resource control
RTS	Request-to-Send
SAE	System Architecture Evolution
SAS	Smart Antenna System
SB	Switch Beam
SC-FDMA	Single Carrier-Frequency Division Multiple Access
SDU	Service Data Unit
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SISO	Single Input Single Output
SM	Spatial Multiplexing
SNR	Signal-to-Noise Ratio
SS	Security Sub-layer
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
TM	Transport Mode
TV	Television
UE	User Equipment
UL	Up Link
UM	Un-acknowledgement mode
UMTS	Universal Mobile Telecommunication System
UNII	Universal National Information Infrastructure
USB	Universal Serial Bus
UTRA	Universal Terrestrial Radio Access
UWB	Ultra Wideband
VLAN	Virtual Local Area Network
VOIP	Voice over Internet Protocol
WCDMA	Wide Code Division Multiple Access
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless Fidelity
Wi-MAX	Wireless Interoperability for Microwave Access
WLAN	Wireless Local Area Network
CAPEX	**C**apital Expenditure
OPEX	Operational Expenditure
RRM	Radio Resource Management
NOC	Network operation center

ICT	Information and Communication Technology
NCA	National Communication Authority

DEDICATION

TO THE LATE AKANBASIAM AGYEMAN HUMPHREY AND THE LATE CHRISTIANA AKUNALA AYARIC

GLORY TO GOD ALMIGHTY; FOR TIMES HAVE BEEN HARD AND THE ROAD HAS BEEN ROUGH BUT YOU STOOD BY ME AND MADE IT ALL POSSIBLE THROUGH YOUR SON JESUS CHRIST

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CHAPTER ONE

1.1Introduction

The technical definition of broadband focuses on the speed of the connection. In the US, The Federal Communications Commission (FCC) defines a broadband connection as one that transmits data at rates of at least 200Kilobit per second (Kbps) in one direction [FCC, 2006]. Broadband connections can be symmetrical (with same upload and download speeds) or asymmetrical (typically the download speed is higher than the upload speed). The old dial-up connection is the only non-broadband internet service available. Broadband internet service is the most frequently used form of internet access because of its high speeds. It is offered in four different forms, Digital Subscriber Line (DSL), Fibre-optic, cable and satellite. Fibre-optic is the newest and fastest internet connection; however this type of internet connection is quite limited because of the laying down of the fibre-optic cables and the expensive nature of fibre-optics. One of the latest developments in broadband internet is the incorporation of wireless capabilities due to the versatility of wireless it offers a better ‘last mile’ service to consumers.

Broadband wireless access enables a new generation of distance learning and services including video-conferencing, real time distribution of classroom materials and collaboration with students in the classroom and other distance learners. There is therefore the need to develop economically realistic network architecture for Educational institutions.

There is the global campaign backed by national and regional campaign, Europe and Canada to achieve Broadband coverage for their citizens within a certain period. The long term evolution of internet services and the resulting traffic is hard to predict, and the demand for data rates, quality of services is on the ascendency.

Educational Institutions have been battling for a suitable alternative for their traditional wire-line technology. Broadband Wireless Access (BWA) has proven an alternative to meet this demand. Wireless Fidelity (Wi-Fi) and 3rd Generation (3G) cellular network are currently the most established for data services worldwide. World Wide interoperability for Microwave Access (WiMAX) and 3rd Generation Partnership Project-Long Term Evolution (3GPP-LTE) are the two near 4th Generation or 4th Generation technologies that promise higher data rates, Quality of Service, Security, coverage etc. Educational Institutions should be considering which of these Broadband Wireless Access (BWA) technologies would meet up to date demand for data services while considering the economics of such an option. The 3GPP-LTE evolved from the 3G whereas WiMAX promises to work as Wi-Fi. Wi-Fi and 3G have stood the test of time in terms of deployment, although they still have lapses in terms of data rates, mobility, security, Quality of Service (QoS), Range etc.

KNUST is used as a case study area since the campus has a fully-fledged Wi-Fi service in operation and has a land area capable of deploying any of the BWA under study. The information gathered on the cost of deploying and maintaining these services would offer an insight to the various educational institutions, telecom operators and the general public as to which option to consider to meeting the current demand for BWA services and would also continue their legacy network economically.

Wi-Fi also known as Wireless Ethernet IEEE 802.11b standard is a technology that was designed to handle wireless data transmission over a local area – Wireless Local Area Network (WLAN) and proved to handle voice transmission with its Voice over Internet Protocol, VOIP, services that has been in operation in most organisations and campuses e.g. KNUST.
To handle some of the lapses of Wi-Fi in terms of range and data rates, WiMAX (802.16) standard was developed to cover a wider range up to 50km and give a higher data rates of up to 75 Mbps using advance modulation and multiplexing techniques, adaptive- and Multiple Input Multiple Output (MIMO) - antenna system among others.

The Advance Mobile Phone Service (AMPS) system is generally called the first generation (1G) mobile systems which uses analogue-Frequency Modulation (FM) transmission designed primarily to handle voice transmission. The Second Generation (2G) cellular mobile technology was digital and based on a digital Time Division Multiple Access (TDMA) and it addresses the capacity problems of the analogue 1G. The TDMA and Code Division Multiple Access (CDMA) - based systems designed to provide Global System for Mobile Communication (GSM) with packet-switched capabilities are simply referred to as the 2.5G systems. The Third Generation (3G) system tackled issues of support for high data rates, efficient support for asymmetric traffic, packet-switched transmission at the air interface and higher spectrum efficiency.

The 3GPP-LTE is an evolution of the 3G based on Wide Code Division Multiple Access (WCDMA). It also employs advance modulation and multiplexing techniques and multiple antenna techniques to achieve its evolution from 3G in the area of data rates and range of transmission. The evolution path and a comparison on the various BWA under study is as shown in Figure 1-1 and Table 1-1 respectively.

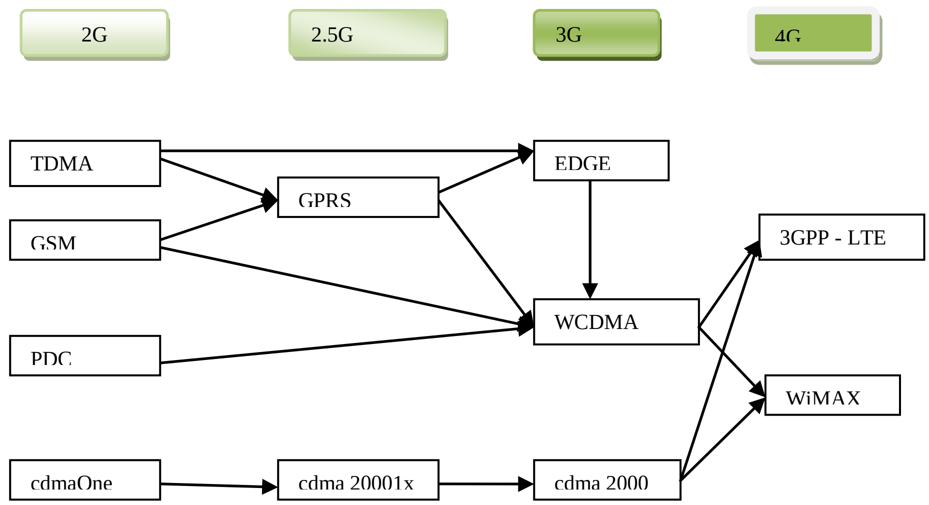


Figure 1-1 Evolution Path of Mobile Wireless Technology towards 4G

Table 1-1 Comparison Wi-Fi, 3G, WiMAX and LTE [21]

FEATURES	**WLAN (806.11b ,Wi-Fi)**	**WMAN(802.16,WiMAX)**	**3G**	**3GPP-LTE**
Packet data rate	802.11a,g=54kbps	UL = 70Mbps	UL=2Mbps	50Mbps
	802.11b =11mbps	DL = 70Mbps	DL=2Mbps	100Mbps
Bandwidth	20MHz	5/6GHz	5MHz	20MHz
Multiple access	CSMA/CA	OFDM/OFDMA	CDMA	WCDMA
Duplex	TDD	TDD	FDD/TDD	FDD/TDD
Mobility	LOW	LOW	HIGH	HIGH
Coverage	LOW	MID	LARGE	LARGE
Standardisation	IEEE 802.11X	802.16	3GPP	3GPP
Target Market	HOME/ENTERPRISE	HOME/ENTERPRISE	PUBLIC	PUBLIC

1.2 Problem Statements

Wi-Fi and 3G have stood the test of time in terms of deployment. The basic comparison is that Wi-Fi has proven to have good data rates but lacks in the range of coverage and number of concurrent users. On the other hand 3G also lacks in data rates but has a very good coverage and number of concurrent users. Recently these two technologies are making up for their lapses due to the improved physical layer technologies available. The result has given birth to new broadband wireless technologies thus WiMAX and LTE. There has been regional and industrial competition [38] to promote one of these technologies as the technology of choice for users. This work assesses the technical capabilities and cost of deploying these BWA technologies on KNUST campus.

1.3 Objective of Study

The objective of this research is to enable Educational institutions to be able to make technical and cost analysis based on this work as to which technology when considered would benefit them now and in the future.

1.4 Specific Objective

1. To assess the physical layer technologies of the various BWA under study and to examine the technologies that offer improved services to the evolved BWA, WiMAX and LTE with more emphasis on modulation techniques.
2. Further assess the cost of deploying each of these BWA technologies in a typical Educational Institution (KNUST) thus blending the technical qualities and the cost to make a case for a particular technology using a cost analysing tool.

1.5 Scope of Research

There are many BWA technologies but the ones considered in this work are; Wi-Fi, WiMAX, 3G and LTE. Making an informed judgement on the BWA technology of choice for Educational institutions, KNUST, there is the need to overlook the regional and industrial competition to promote a particular technology as the technology of choice for users. This therefore requires both technical and cost analysis of the various BWA under study. The technical assessment is carried out as simulations of BER and signal constellation of various modulation techniques-it's a factor that affects data range and range of coverage. The cost assessment is carried out by interviewing experts in various discipline of the telecommunication industries and educational institutions especially KNUST. This is supported with software cost analysing tool such as Interactive WiROI Business Case Analysing Tool and LTE calculator. KNUST is chosen as the case study area because it has an established Wi-Fi facility and has a land size capable of deploying a cellular technology – WiMAX, 3G and LTE.

1.6 Justification of Research

The National Communication Authority (NCA) of Ghana as at January, 2011, issued a release inviting potential buyers of BWA licences in the 2.5GHz – 2.69GHz band for the deployment of WiMAX and LTE. The digital migration team is also working to release spectrum that could be used for the deployment of LTE [46] this makes the deployment of WiMAX and LTE in Ghana feasible.

Most educational institutions have already deployed their own broadband wireless technologies (Wi-Fi) to meet their campus requirements. In 2007 Broadband Wireless Internet and voice telephony facility was inaugurated on KNUST campus known as the KNUST E-campus Network. The project is the first phase of a comprehensive ICT, which is aimed at integrating all educational institutions into the global ICT network with KNUST as the hub [39]. Broadband Wireless Access has offered enormous benefits to educational institutions. Since the introduction of Wi-Fi enabled laptops (computers) and PCMCIA and PCI, USB cards and USB dongles into the markets, Wi-Fi has become the main drive that facilitates the exchange of data (information) between personnel.

The Wi-Fi in various Educational Institutions has;

1. Facilitated students research, given them access to on-line information – e-library, journals, white papers, publications.
2. Facilitated the communication of staff and students on campus with its VOIP system thereby improving employees' timesaving and productivity efficiencies.
3. Helped improve on security through its close circuit television (CCTV) cameras system.
4. Expanded teaching and learning through distance learning

There are many issues to consider when choosing a BWA for personal or enterprise usage; the physical layer data rates and effective data rates at MAC SAP, network capacity and quality of service, interference and coexistence, technology maturity, operating range and scalability, security among others. Many BWA service providers have cost of deploying and maintaining the network and services as a core issue to consider for BWA. This is why it has become necessary to look at the technical and cost of deploying and maintaining BWA in a typical educational institution setting, using KNUST as a case study.

1.7 Thesis Structure

Chapter one introduces the thesis by elaborating on general overview of the thesis objective and how the thesis is structured

Chapter two reviews literature on Wi-Fi and WiMAX, basically introducing the two technologies and their physical and MAC layer architecture

Chapter three reviews literature on the 3G and LTE technologies and their physical and MAC layer architecture

Chapter four presents the research methodology

Chapter five takes a look at the current technology-Wi-Fi at the study area-KNUST, the prospects of a 3G, WiMAX and LTE on KNUST, Bit error rate of the various modulation techniques employed by the various technologies, constellations points and cost parameters in establishing BWA infrastructure on KNUST campus. It also contains tables of cost of deploying the various technologies and MATLAB simulation diagram comparing BER of modulation techniques and constellation diagrams.

Chapter six draws conclusion on the thesis some recommendations and suggestions on future works

CHAPTER TWO

2.1 Brief Introduction to Broadband Wireless Access (BWA)

Wireless means transmitting signals using radio waves and medium instead of wire or fibre. Broadband Wireless is a technology that promises high-speed connection over the air [24] and these include Wi-Fi (802.11), WiMAX (802.16), Third Generation (3G), Third Generation Partnership Project – Long Term Evolution (3GPP-LTE), Ultra Wide Band (UWB) etc. Broadband Wireless is a point-to-multipoint system which is made up of a base station and subscriber equipment. It offers an effective, complementary solution to wire line broadband.

2.2 Terminologies

The journey through BWA would require us to review some terms that one constantly come across and some of these are;

2.2.1 Frequency Hoping Spread Spectrum (FHSS)

FHSS technology divides a radio signal into small segments and 'hops' from one frequency to another many times per second as it transmits those segments. The transmitter and the receiver establish a synchronized hopping pattern that sets that sequence orders in which they will use different sub-channels. FHSS systems overcome interference from other user by suing a narrow carrier signal that changes frequency many times every second. Additional transmitter and receiver pairs can use different hopping patterns on the same set of sub-cannels at the same time. At any given point in time, each transmission is probably using a different sub-channel, so there's no interference between signals. When a conflict does occur, the system resend the same packet until the receiver gets a clean copy and sends a confirmation back to the transmitting station. For wireless data services, the unlicensed 2.4 GHz band is split into 75 sub-channels, each of them 1 MHz wide. Because each frequency hop adds overhead to the data stream, FHSS transmissions are relatively slow [9].

2.2.2 Direct Sequence Spread Spectrum (DSSS)

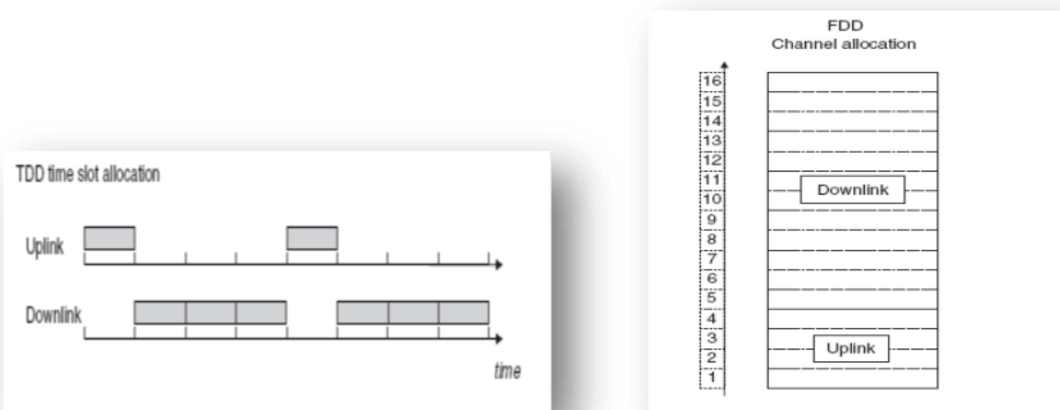
DSSS technology uses a method called an 11-chip Barker sequence to spread the radio signal through a single 22 MHz –wide channel without changing frequencies. Each DSSS link uses just one channel, without any hopping between frequencies. DSSS transmission uses more bandwidth but less power than a conventional signal. A DSSS transmitter breaks each bit in the original data stream into a series of redundant bit patterns called chips and transmits them to a receiver that reassembles the chips back into a data stream that is identical to the original [9].

2.2.3 Orthogonal Frequency Division Multiplex (OFDM)

OFDM is a digital modulation technique that combats frequency selective fading by splitting the transmission flow on parallel orthogonal flat narrowband channels, named sub-carriers [43]. Each transmitted OFDM symbol has a cyclic prefix (CP) that completely eliminates inter-symbol interference (ISI) as long as the CP duration is longer than the channel delay spread. An OFDM symbol is made up of three different types of sub-carriers: data, pilot and null. OFDM allows sub-carriers to be adaptively modulated depending on distance and noise level.

2.2.4 Time Division Duplex (TDD) and Frequency Division Duplex (FDD)

In Time Division Duplex (TDD), a frame is divided into uplink sub-frame and a downlink sub-frame as shown in the Figure 2-1 (a). Base station to subscriber station transmission happens in the downlink sub-frame and subscriber station to base station transmission happens in the uplink sub-frame. This division of a frame into downlink and uplink sub-frames in TDD can be static or dynamic- adapted to transmission load in either direction. In Frequency Division Duplex (FDD), the uplink and downlink transmissions occur on separate carrier frequencies and this division between uplink and downlink is static [31]



(a) TDD frame structure (b) FDD Frame Structure

Figure 2-1 TDD and FDD diagrams

2.2.5 SC-FDMA

Single-Carrier FDMA (SC-FDMA) is chosen to reduce Peak to Average Power Ratio (PAPR), which has been identified as a critical issue for use than OFDMA in the uplink where power-efficient amplifiers are requires in mobile devices. Another important requirement is to maximize the coverage. Thus for each time interval, the base station scheduler assigns a unique time-frequency interval to a terminal for the transmission of user data, thereby ensuring intra-cell orthogonality. Slow power control, for compensating path loss and shadow fading, is sufficient as no near-far problem is present due to the orthogonal uplink transmission. The chosen SC-FDMA solution is based on using a cyclic prefix to allow high-performance and low-complexity receiver implementation in the e|NodeB. As such, the receiver requirements are more complex than in the case of OFDMA for similar link performance, but this is not considered to be a problem in the base station. The terminal is only assigned with contiguous spectrum blocks in the frequency domain to maintain the single-carrier properties and thereby ensure power-efficient transmission. This approach is often referred to as blocked or localized SC-FDMA.

2.2.6 Multiple Antenna Technologies

Some BWA technologies support multiple antenna technologies in order to provide higher data rates and spectral efficiencies, which distinguish it from other wireless technologies. Multiple Antenna Technologies are easy to implement in some BWA technologies. This is because the simplicity in OFDM and OFDMA based physical layers exhibit orthogonality between subcarriers and support for flexible bandwidths. This technologies help increase the range, capacity, diversity, data rates, and efficiency of the system as compared to single carrier antenna system. Multiple Antenna Techniques are normally divided into three types; Smart Antenna System (SAS), Diversity Techniques, Multiple Input Multiple Output (MIMO).

2.2.6.1 Smart Antenna System (*SAS*)

Traditional omni-directional antennas allow only one network node to use the medium to transmit data packets. Smart antennas on the other hand allow multiple nodes to transmit simultaneously reducing co-channel and inter-symbol interference. This improves capacity and transmission quality. There are two varieties of SAS – switched beam (SB) and Adaptive Array (AA). A Switched Beam antenna has an array of antenna elements each with a predefined beam pattern that has a main lobe and a side lobe and then switching between beams allows the antenna element that provides the best gain in direction of the target node to be selected. Adaptive Array also known as beam-forming antenna has two or more antenna elements in an array and adjusts its radiation pattern to offer maximum gain towards a target using a beam-forming algorithm e.g. the Minimum Mean Square Error Criterion is based on the Adaptive Weight Control Algorithm.

2.2.6.2 Diversity Techniques

The most commonly used diversity techniques is space diversity where the antennas propagate in different special zone just as in sector antennas. Others are time diversity and frequency diversity.

2.2.6.3 Multiple Input Multiple Output – MIMO

This technique exhibit both transmits and receives diversity and this multiplies the throughput of a radio link. Multiple antennas (and multiple RF chains accordingly) are used at both transmitter and receiver and employs Spatial Multiplexing (SM) to allow signal (coded and modulated data stream) to be transmitted across different spatial domains. A MIMO system with similar count of antennas at both the transmitter and the receiver in a point-to-point link is able to multiply the system throughput linearly with every additional antenna [14]. Thus a 2x2 MIMO doubles the throughput of SISO and 4x4 MIMO double that of 2x2 MIMO etc. Some of the variants of this technique are; SISO, SIMO and MISO. Figure 2-2 and 2-3 show MIMO and SIMO respectively.

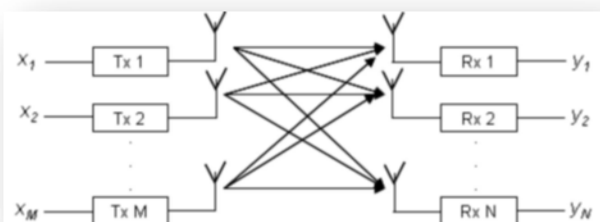


Figure 2-2 Multiple Input Multiple Outputs - MIMO

2.2.6.4 Single Input Single Output (SISO)

This radio transmission traditionally uses one antenna at the transmitter and one antenna at the receiver – no diversity techniques. Both the transmitter and the receiver have one RF chain (that's coder and modulator) and it's relatively simple and cheap to implement. This has been used age long since the inception of radio technology. It is used in personal wireless technologies (e.g. Wi-Fi and Bluetooth) and low data rate applications.

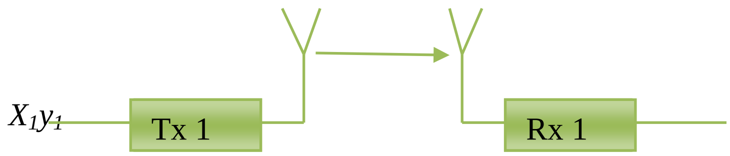


Figure 2-3 Single Input Single Outputs [14]

2.3 Introduction to 802.11 (Wi-Fi)

Wireless is becoming the preferred network access method among most mobile users on our educational institutions. The commonest is the IEEE 802.11 (Wi-Fi) standards. In 1997 IEEE provided a set of specification and standards for Wi-Fi under the title 802.11. Wi-Fi is not a technology, but rather a certification mark, or 'stamp of approval' given to equipment based on a different set of IEEE standards from the 802.11 working group for wireless local area networks (WLAN). The suit of 802.11 standards defines the 'over-the-air interface' between users' devices and the base station or access point (AP) for a WLAN. The standard has evolved to include functionalities such as mobility, higher data rates, security, wider coverage etc.

Technological advancement has brought about changes in the original protocol that has resulted in other specification of the 802.11.

802.11a: This standard was ratified in September 1999 and offers high speed wireless LAN standard. It supports 54 Mbps data rates using OFDM modulation in the 5 GHz ISM band.

802.11b: was ratified in September 1999 and is the original Wi-Fi standard, providing 11 Mbps using DSSS and CCK on the 2.4 GHz ISM band.

802.11g: offered enhanced data rates to 54 Mbps using OFDM modulation on the 2.4 GHz ISM band. It was ratified in June 2003 and interoperable in the same network with 802.11b equipment.

802.11n: 802.11n was ratified in October 2009. It provides higher data rates of up to 600 Mbps using MIMO radio frequency technology, wider RF channels and protocol stack improvements, while maintaining backward compatibility with 802.11 a, b and g.

802.11e: This standard addressed quality of Service (QoS) requirements for all 802.11 radio interfaces, providing TDMA to prioritize and error-correction to enhance performance of delay sensitive applications.

802.11i: This addressed the security weaknesses in user authentication and encryption protocols. The standard employs advance encryption standard (AES) and 802.1x authentication. [6] [7]

There are other standards notations in the IEEE 802.11 Standard suite the span letter like; 802.11 (d, f, h, j, k, p, r, s, T, u, v and w). The different notations identify different flavours of the 802.11 standard.

Table 2-1 gives some other characteristics of the various specifications (802.11. a, b, g and n).

Table 2-1 Characteristics of the various 802.11 specifications (a, b, g and n) [12]

Characteristics	802.11	802.11a	802.11b	802.11g	802.11n
Spectrum Band	ISM: 2.4 to 2.4835 GHz	UNII: 5.15-5.25GHz, 5.25 – 5.35GHz, and 5.725 – 5.835	ISM: 2.4 to 2.483 GHz	ISM: 2.4 to 2.483GHz	**ISM: 2.4 AND 5GHz**
Application	Wireless data networking	Broadband LAN access	Wireless data networking	Wireless data networking	**Wireless data networking**
Modulation scheme	FHSS or DSSS	OFDM	DSSS	OFDM or DSSS	**OFDM**
Number of channels	79 channels with FHSS; 3 or 6 with DSSS	12	3	3	
Optimum Data Rates (Mbps)	2	54	11	54	**54 – 600**
Range (metres)	100	50	100	100	**70 -250**
Date Established (market ready)	July 1997	September 1999	September 1999	January 2002 – draft specification; finalized in January 2003	**October 2009**
Compatibility	802.11 only	208.11a	802.11g	802.11b	**802.11 a, b and g**
Scalability		**Enterprise scale; many users per AP**	**Small number of users per AP**	**Small number of user per AP**	**Enterprise scale; many users per AP**

2.4 Wi-Fi (802.11) Physical and Data Link Layer Architecture

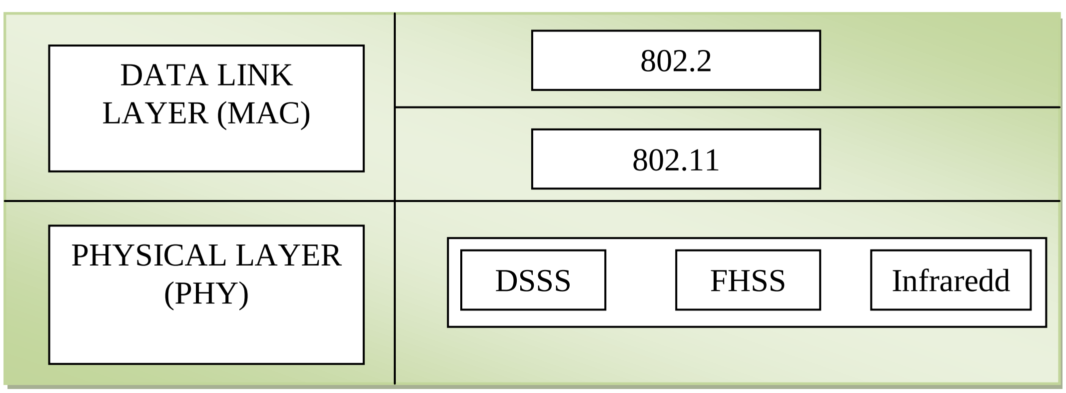


Figure 2-4 Wi-Fi physical and data link layer architecture [12]

The data link layer within 802.11 consists of two sub layers:

1. Logical Link Control (LLC) and
2. Media Access Control (MAC)

802.11 use the same 802.2 LLC and 48-bit addressing as other 802 LANs. This allows for bridging from wireless to IEEE wired networks, although the MAC is unique for WLANs. The 802.11 MAC is similar in concept with 802.3. It is designed to support multiple users on a shared medium, by having the sender sense the medium before accessing it. The 802.3 Ethernet LAN implements the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) [29] protocol. 802.11 WLAN, collision detection is not possible due to what is known as the "near/far" problem: to detect a collision, a station must be able to transmit and listen at the same time, but in radio systems that transmission drowns out the ability of the station to "hear" a collision hence the use of Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) or the Distributed Coordination Function (DCF).

The 'hidden node' is another MAC-layer problem specific to wireless. Two stations on opposite sides of an access point can both "hear" activity from an access point, but not from each other, usually due to distance or an obstruction. The 802.11 specifies an optional Request to Send/Clear to Send (RTS/CTS) protocol at the MAC layer and also provide for two other MAC layer robustness features, Cyclic Redundancy Check (CRC) checksum and packet fragmentation [9] [11].

2.5 Introduction to 802.16 (WIMAX)

WiMAX stands for Worldwide Interoperability for Microwave Access; is a wireless digital communication system, also known as IEEE 802.16 that is intended for wireless “metropolitan area network”. WiMAX can provide broadband wireless access (BWA) up to 30 miles (50 km) for fixed stations, and 3-10 miles (5-15 km) for mobile stations. WiMAX is expected to deliver broadband access services to residential and enterprise customers in an economical way and operates in both licensed and non-licensed frequencies. WiMAX would operate similar to Wi-Fi but at higher speed, over greater distances and for a greater number of users. WiMAX uses adaptive modulation and coding (AMC) techniques, multiple antenna and adaptive (advance) antenna system to achieve these speeds and range.

WiMAX has two forms of services; the line-of-sight service that is stable and uses higher frequencies from 10 to 66GHz (licensed bands), and the non-line-of-sight which operates at low frequencies from 2 to 11GHz (unlicensed frequency bands) and works like Wi-Fi.

Just as Wi-Fi, WiMAX is a term used for 802.16 standards and technology but in strict speaking it applies to systems that meet specific conformance criteria laid down by the WiMAX Forum.

WiMAX currently includes 802.16-2004 also known as fixed WiMAX and 802.16e known as mobile WiMAX. WiMAX promises to support services such as; Video conferencing, Teleconferencing, Video surveillance, SMARTGRID (Automatic Electricity monitoring) etc. The various WiMAX standards are;

802.16: This was ratified in 2001 for fixed wireless broadband air interface in 10 – 66 GHz. It supports Line-of-sight (LOS) only and Point-to-Multi-Point

802.16a: This standard was ratified in January 2003. It provided extension for 2 – 11 GHz spectrum and targeted for non-line-of-sight (NLOS), Point-to-Multi-Point applications like "last mile" broadband access.

802.16b Extension (Wireless HUMAN Initiative): This standard was approved in 2001 and promises higher data rate in the licensed-exempt spectrum between 5.15- and 5.25 GHz and 5.725- and 5.825- GHz frequencies.

802.16c: This was ratified in 2002 and is an 802.16 amendment of WiMAX system profiles in the 10 – 66 GHz spectrum.

802.16REVd (802.16-2004): was ratified in October 2004 and adds WiMAX system profiles and Errata for 2 – 11 GHz.

802.16e (802.16-2005): Ratified in December 2005 and provides MAC/PHY enhancements to support subscribers moving at vehicular speeds.

The table below describes the various IEEE 802.16 (WiMAX) standards.

Table 2-2 Characteristic of various IEEE 802.16 specifications [8]

	802.16	**802.16a**	**802.16e**
Spectrum	10 – 66 GHz	2 – 11 GHz	< 6 GHz
Configuration	Line of Sight	Non line of Sight	Non- Line of sight
Bit Rate	32 to 134 Mbps (28 MHz channels)	<= 70 or 100 Mbps (20 MHz channels)	Up to 15 Mbps
Modulation	QPSK, 16-QAM, 64-QAM	256 Sub-Carrier OFDM using QPSK, 16-QAM, 64-QAM. 256-QAM	256 Sub-Carrier OFDM using QPSK, 16-QAM, 64-QAM. 256-QAM
Mobility	Fixed	Fixed	<= 75 MPH
Channel Bandwidth	20, 25, 28 MHz	Selectable 1.25 to 20 MHz	5 MHz (planned)
Typical cell Radius	1-3 miles	3-5 miles	1-3 miles
Completed	Dec, 2001	Jan, 2003	2^{nd} Half of 2005

2.6 802.16 Physical and Data Link Layer Architecture

The 802.16 also known as WiMAX solves a whole host of problems that were introduced with 802.11. WiMAX solves the primary problem of Line of Sight (LoS) transmission. WiMAX LoS is not needed for high bandwidth capacity because the standard makes use of constructive multipath interference and uses OFDM for enhanced transmission assurance.

At 5GHz and above, Multipath interference becomes so crippling to a system that normal standards can't compensate, thus limiting data rates. This is resolved through the use of OFDM (Orthogonal Frequency Division Multiplexing) where data is split into multiple carrier frequencies and adjacent bits of data are carried on non-adjacent channels. This ensures that if one channel encounters interference, the data as a whole is not severely compromised. Figure 2.5 shows the IEEE 802.16 protocol layering.

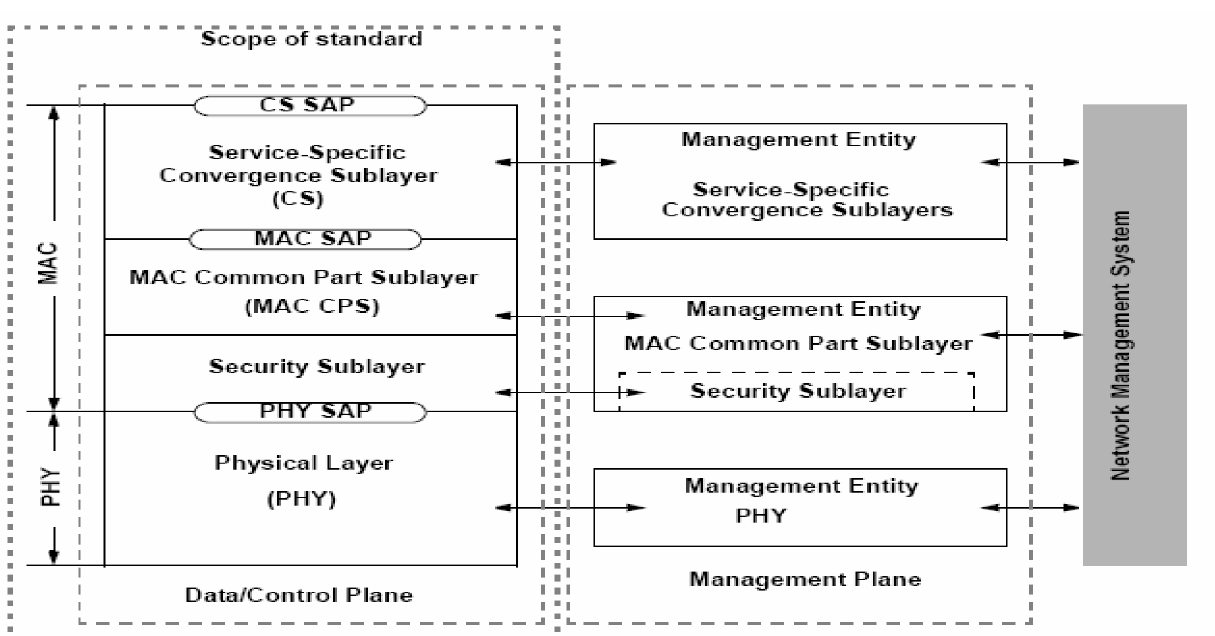


Figure 2-5 IEEE 802.16 protocol layering [8]

2.6.1 Physical Layer

The 802.16 Physical Layer is defined in a wide range of frequencies from 2 to 66 GHz. The 10 to 66 GHz is use for Line-of-Sight (LoS) communications. Below 10GHz the 802.16a standard specifies non-LoS usage with the use of three specifications which include: Single Carrier Modulation, OFDM, 256 Point Transform and OFDMA, 2048 Point Transform.

FEC (Forward Error Correction) is used along with Read Solomon Code (RSC) and Inter Block Convolution Code to provide trustworthy transmission method for critical data.

2.6.2 Data Link Layer

The 802.16 Data Link Layer also known as the Media Access Control Layer is designed for mesh and point to multipoint network models. The MAC/DLL Layer is Connection Oriented thus when a user enters the network the Subscriber Station (SS) create a connection. The data are then transmitted over this connection to the Base Station (BS); the MAC/DLL Layer schedules this connection for QoS purposes. Maximizing data throughput and minimizing BER, 802.16 uses Automatic Repeat Request (ARQ) Queries.

2.6.3 MAC Layer

The primary function of the WiMAX MAC layer is to provide an interface between the physical layer and the transport layer. It takes MAC Service Data Units (MSDUs) packets from this higher layer and prepares it for transmission over the air. The MAC layer comprise of three sub-layers, Service-Specific Convergence sub-layer (SSCs), MAC Common Part Sub-layer (MAC cps) and the Security Sub-layer (SS). It is designed to support Point-to-Multipoint (PTM) BWA applications and address the need for very high bit rate for both the Up-link and Down-link.

2.6.3.1 Service-Specific Convergence Sub-layers:

The IEEE 802.16 defines two general Service-Specific Convergence sub-layer for mapping services to and from 802.16 MAC connections;

- The ATM convergence sub-layer for ATM services and
- The packet convergence sub-layer for packet services such as IPv4, IPv6, Ethernet and VLAN.

The primary task is to classify services Data Units (SDUs) to the proper MAC connection, preserve or enable QoS, enable bandwidth allocations and payload header suppression and reconstruction to enhance air-link efficiency.

2.6.3.2 Common Part Sub-layer (MAC CPS)

This is responsible for connection establishment and maintenance, system access and proper bandwidth management. It is designed for PTM connections and connection oriented. The connection oriented architecture provides mechanism for routing data to the proper convergence sub-layer and also enable s requesting bandwidth and maintaining QoS. With the downlink, several subscriber stations are multiplexed to the base station and on the uplink, subscriber stations share different channel from the base station in a TDMA fashion.

2.6.3.3 Security Sub-layer (SS)

This layer provides authentication, service key exchange, encryption and integrity of the system. A secure distribution of keying data from base station (BS) to subscriber station is assured by providing an authentication and Privacy and Key Management (PKM) protocol. It also runs a digital certificate to strengthen the privacy of the data and also in the base station the PKM is assured the conditional access to the network service and applications. PKMv2 is an improved version of the PKM with additional features which strongly controls integrity, mutual authentication and handover. This offers WiMAX a better security than its parent technology, Wi-Fi.

CHAPTER THREE

3.1 Introduction to 3G and 3GPP-LTE

The first mobile radio system was designed to accommodate only very few users. The first Mobile Telephone Service (MTS) was installed in cars, used half duplex, had limited range, operated at 150MHz using 6 channels and had downlink transmit power of 250W.

In 1972 Bell labs (today Lucent Technologies) laid the foundations for today's second and third generation mobile radio systems [29]. Instead of a single base station illuminating a large area, each base station should only cover a small area. This reduced the antenna height and allowed for frequency reuse, enabling coverage for a greater number of subscribers.

The 1G technology includes Advance Mobile Phone System (AMPS). It has very low speed that supports voice only and analogue features. The 2G technology includes iDen, CDMA and GSM. It has speeds less than 29Kbps which utilizes features like push-to-talk, voice, conference calls, call ID and SMS. 2.5G technology includes EDGE, GPRS and 1xRTT that has speeds from 30Kbps to 90Kbps and utilizes features like Multiple Message Service (MMS), Web browsing, images, short video and audio clips, applications, ring tone downloads and games. The 3G technology includes UMTS and 1xEV-DO ranging from 144Kbps up to 2Mbps. Some of its features include full-motion video, quick web browsing, 3D games and streaming music. The 3.5G technology includes HSDPA which is an upgrade for UMTS and 1xEV-DV, with speeds ranging from 384Kbps up to 14.04Mbps. Some of the features it supports includes; video conferencing and Video-on-demand.

The 3rd Generation partnership project (3GPP) began a project in November 2004 to determine the long-term evolution of UMTS cellular technology. The specifications related to this effort are formally known as the evolved UMTS terrestrial radio access (E-UTRA) and evolved UMTS terrestrial radio access network (E-UTRAN), more commonly referred to by the project name LTE. 3GPP-LTE (4G) have speeds ranging from 100Mbps to 1Gbps and offers high quality Video conferencing, high quality streaming video and voice-over-IP telephony and mobile TV. The table below compares the various G's.

Table 3-1 Characteristics of the various G's (1, 2, 3, 4) [36][40]

Technologies	1G	2G	2.5G	3G	4G
Design Began	1970	1980	1985	1990	2000
Implementation	1984	1991	1999	2002	2010
Cellular services	Analog Voice, Synchronous Data to 9.6Kbps	Digital Voice, Short Messages Service	Higher Capacity, Packetized Data	Higher Capacity, Broadband Data up to 2Mbps	Higher Capacity, completely IP Based, Multimedia Data
Versions	AMPS, TACS, NMT, etc.	TDMA, CDMS, GSM, PDC	GPRS, EDGE, 1xRTT	WCDMA, CDMA-2000	OFDM, UWB
Bandwidth	1.9Kbps	14.4Kbps	384Kbps	2Mbps	10Mbps – 20Mbps
Multiplexing	FDMA	TDMA, CDMA	TDMA, CDMA	CDMA	FDMA, TDMA, CDMA
Core network	PSTN	PSTN	PSTN, Packet Network	Packet Network	All – IP Network

3.2 3G Networks – Introduction

3G (3rd Generation) which is also known as International Mobile Telecommunications 2000 (IMT – 2000), ITU represents the convergence of various 2G wireless telecommunication systems into a single global system such as UMTS, GPRS and EDGE. In the mobile environment, all of these standards provide some services, which are Voice, fax, video calls and data through wireless. If we compare 3G with its previous generations such as 2G and 2.5G, 3G is providing more data rate service with a wide range of coverage by using the best spectral efficiency. It also provides good quality of voice with multiple usage of speech at the best spectral efficiency as well as high level of security. The UMTS (Universal mobile Telecommunication System) is specified by 3GPP (3rd Generation Partnership Project).It uses WCDMA (Wide Code Division Multiple Access) technology as the underlying air interface for transmission. It supports more efficient modulation than GSM (Global System for Mobile Communication), hence offer greater data transfer rate.

3.3 3G Networks – Architecture

The network consists of three major elements, Core Network, Radio Network Subsystem (RNS) and User Equipment (UE). In 3G network architecture UE, is usually handset or can be a laptop computer with support to UMTS interface. When UE tries to connect to a 3G network, it first establishes connection with Node B, same as BTS in 2G which works as transceiver in one cell for communication with User's Equipment (UE) and the Node B is further directly connected to the backend – RNC (Radio Network Controller) which is same as BSC in 2G, via lub interface. The RNC;

1. Manage the resources of radio and the function of mobility.
2. Perform encryption and decryption of users' data to protect it from eavesdropping.
3. Establishes the GPRS tunnel with SGSN (Serving GPRS Support Node) of the Core Network [20].
4. It is the packet switched element which performs mobility management and also manage sessions which is used for Quality of Service (QoS) and Packet Data Protocol (PDP).
5. It also manages connections of different data packets which are in between SGSN and radio network controller through luPs interfaces [20].

The SGSN further creates a GPRS tunnel with GGSN (Gateway GPRS Support Node). The Gateway GPRS Support Node is the 'last port of call' in the GPRS network before a connection between an Internet Service Provider (ISP) and corporate network's router occurs. The GGSN is basically a gateway, router and firewall rolled into one. It also confirms user details with RADIUS or DHCP servers for security. In practice the two GSN devices may be a single unit. Data services are run from the terminal device over IP through to the 3G SGSN to the GGSN. Voice is embedded into ATM from the edge of the network (node B) and is transported over ATM out of the RNC to the 3G MSC and to PSTN/ISDN. The lu interfaces are split into 2 parts for circuit switching and packet switching. Figure 3.1 shows the 3G network architecture.

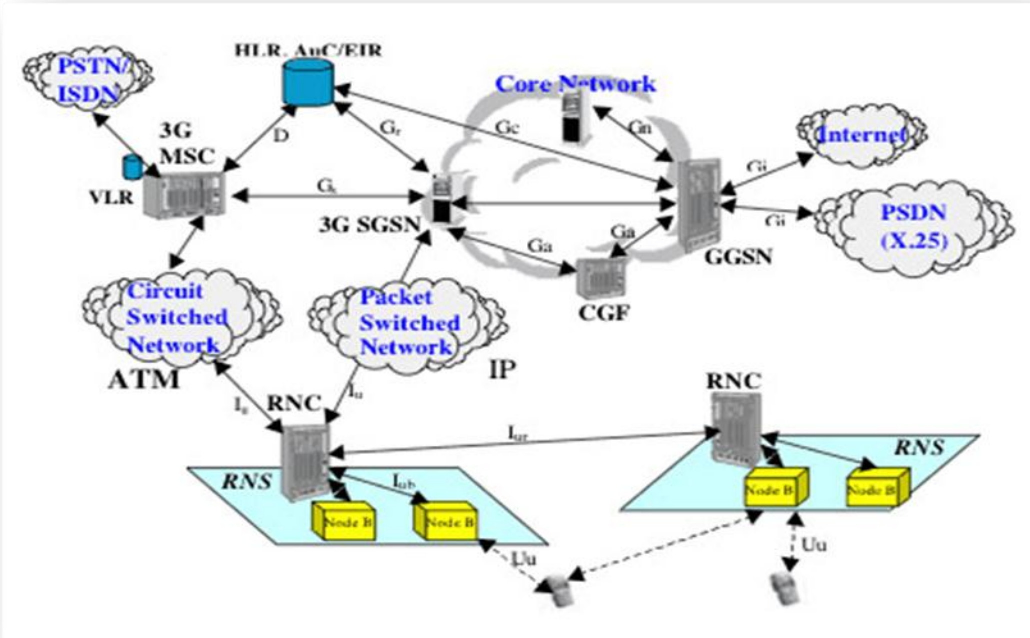


Figure 3-1 UMTS 3G Network Architecture

3.4 3G physical and MAC layer

The physical layer is the main discussion topic when different cellular networks have been compared, since physical layer defines the fundamental capacity limits. Its structure relates to the achievable performance issues and has a direct relation on equipment complexity. It offers services to the MAC layer via transport channels. The MAC layer selects modulation format, code rate, MIMO rank and power level. It also offers service to the RLC layer by means of the logical channels. A description of some features of the 3G physical and MAC layer include;

Radio Resource Control (RRC): performs the control plane functions including paging, maintenance and release of an RRC connection-security handling, mobility management and QoS management.

Packet Data Convergence Protocol (PDCP): It handles IP header compression and decompression based on Robust Header Compression (ROHC) protocol, ciphering of data and signalling and integrity protection for signalling. There is only one PDCP entity at the Node-B and the UE per bearer

Radio Link Control (RLC): This sub layer segments and concatenates data units, error connection through the Automatic Repeat re-Quest (ARQ) protocol and in-sequence delivery of protocols to the higher layers. It operates in three (3) modes; Transport Mode(TM)-for random access, Un-acknowledgment mode(UM) also for detection of packet lose but does not requires retransmission of missing PDU and Acknowledgement mode(AM) which requires retransmission of missing PDUs. There is only one RLC entity at the Node B and the UE per bearer

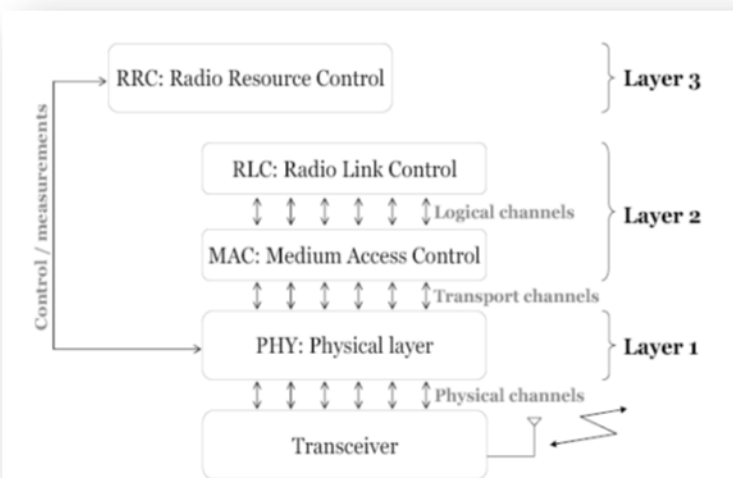


Figure 3-2 Physical layer in the UTRA protocol stack [4]

Data generated at higher layers like layer 3 are carried by logical channels through the transport channels in layer 2 (MAC layer) which are mapped onto the physical channel in Layer 1 (physical layer).

Logical Channels: Are used by the MAC to provide services to the RLC. Each logical channel is defined based on the type of information it carries. LTE has two categories of logical channels depending on the services they provide namely logical control channels and logical traffic channels.

Transport Channels: The transport channels are 'defined' how and with what characteristics data is transferred over the radio interface. They are used by the PHY layer to offer services to the MAC. Two types of transport channels exist - dedicated channels and the common channels. The common channels is a resource divided between all or a group of users in a cell where as a dedicated channel resource is identified by a certain code on a certain frequency where is reserved for a single user only. Compared to UTRA the number of transport channels in LTE is reduced since no dedicated channels present.

Physical Channels: The physical channels carry actual transmission of resource elements. They access the transport channel via the PHY SAP (service access point) [31].

Table 3-2 3G Physical Transport and Logical Channels [20][33]

PHYSICAL CHANNEL	TRANSPORT CHANNELS	LOGICAL CHANNEL
PCCPCH	BCH	BCCH
SCCPCH	FACH	PCCH
PRACH	PCH	DCCH
DPCH	RACH	CCCH
DPDCH	DCH	CTCH
DPCCH	DSCH	DTCH
PDSCH	CPCH	
PCPCH		

There are not bi-univocal mapping between logical and transport channels as well as transport and physical channels. Physical channels that do not have higher layer associated channels and all are downlink channels that support functionalities associated explicitly with layer 1.

Table 3-2 Physical channels without higher layers associated channels

Physical Channels
SCH
CPICH
AICH
PICH
CPCH–SICH (CSICH) CD/CA – ICH

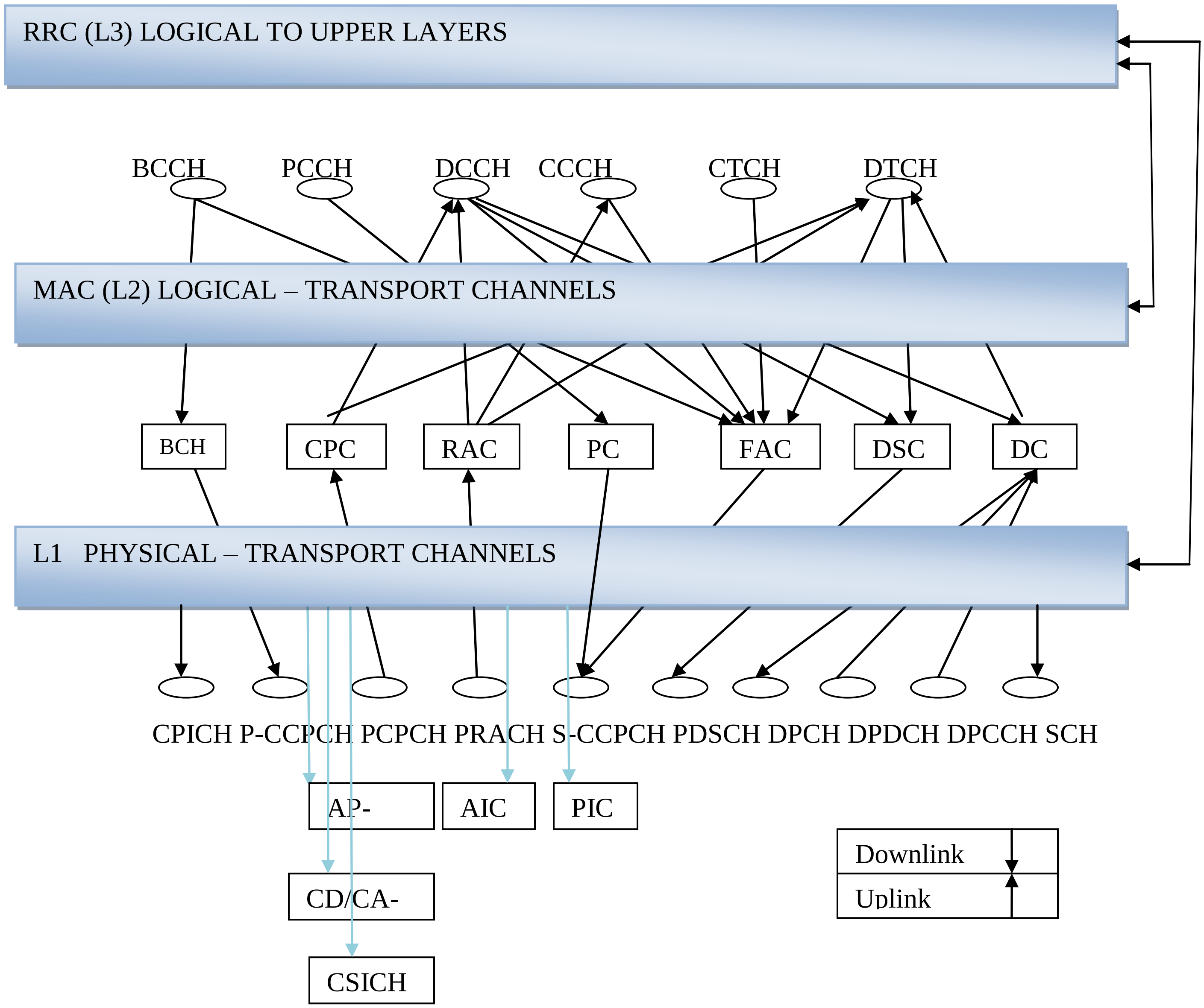


Figure 3-3 3G Logical ->Transport -> Physical Channel Mapping [32]

3.5 LTE Network –Introduction

LTE stands for Long Term Evolution and to maintain competition in future,in November 2004 3GPP began a project to define the long term evolution of UMTS cellular technology. The specifications related in this effort are formally known as the Evolved UMTS terrestrial radio Access (E-UTRA) and Evolved UMTS Terrestrial Radio Access Network (E-UTRAN), but are more commonly referred to by the project name LTE. The first version of LTE is documented in Release 8 of the 3GPP Specification.

A parallel 3GPP project called System Architecture Evolution (SAE) defines a new all-IP packet only Core Network (CN) known as Evolved Packet Core (EPC). The combination of the EPC and the evolved RAN (E-TRA plus E-TRAN) is the evolved packet system (EPS). The name of the system is often written as LTE/SAE or simply LTE. LTE is developed to satisfy market needs and it's meant to operate current 3G spectrum as well as new spectrum (2.6GHz and digital dividend spectrum at 700MHz) or re-farmed GSM band with bandwidth from 1.4MHz to 20MHz. The multiple access of LTE is OFDM with cyclic prefix in the downlink and Single-Carrier FDMA (SC-FDMA) in the uplink. Both FDD and TDD are supported and the modulation techniques in the Downlink (DL) and Uplink (UL) are QPSK, 16QAM and 64QAM.

3.6 LTE Network Architecture

The LTE network architecture is designed to optimize network performance, improve cost efficiency and facilitate the uptake of mass –market IP-based service

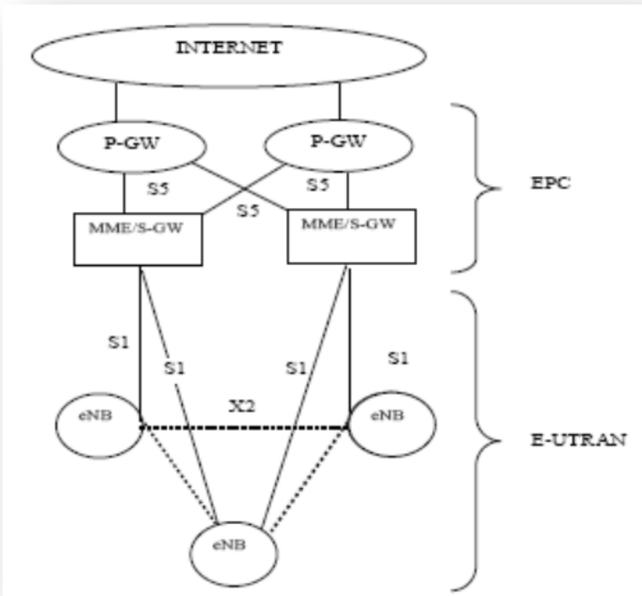


Figure 3-4 LTE simplified network architecture [2]

Interfaces: The interfaces in the architecture Uu, is the air interface between UE and e-Node-B. The interface x2 enables direct communication between the e-Node-Bs. S1 interfaces the E-TRAN and the EPC by connecting e-Node-Bs to MME and S-GW element through a many-to-many relationship. S5 provides an interface between the two gateways S-GW and P-GW.

MME (Mobility Management Entity): is the key control node for the LTE access network. It is responsible for idle mode UE tracking and paging procedure, including retransmissions. It is the bearer activation/deactivation process and also responsible for choosing the S-GW for a UE at the initial attach and at time of intra-LTE handover involving core network node relocation

Serving and PDN Gateways (S-GW and P-GW): The S-GW acts as a local mobility anchor, forwarding and receiving packets to and from the eNB where the UE is being served. The P-GW, in turn interfaces with the external PDNs, such as the Internet and IP Multimedia Subsystem (IMS). It is also responsible for several IP functions, such as address allocation, policy enforcement, packet classification and routing, and it provides mobility anchoring or non-3GPP access network.

Evolved-Node B (e-Node-B or eNB): It merges the functionality of the RNC and Node B in a 3G mobile network to achieve higher latency with fewer hops in data path as well as distribution of RNC processing load into multiple eNBs. It is responsible for header compression, ciphering and reliable delivery of packets. The control plane functions such as admission control and radio resource management are also incorporated into the eNB. The EPC is made up of the MME and the gateways (S-GW and P-GW)

3.7 LTE Radio Interface Architecture

The LTE radio interface protocol architecture has the same components (block diagram) as the 3G UMTS but differ in the physical-transport and transport-logical channel mappings. See Figure 3.3 and 3.5. Figure 3.5 shows the LTE Logical to Transport and Physical channel mapping

Table 3-3 LTE Logical Channels Name and Functions [41][42]

DL-CHANNELS	FULL NAME	PURPOSE
PCCH	Paging control channel	Transmit paging control information when the location cell of UE is unknown to the network
BCCH	Broadcast control channel	Broadcast system control information to the mobile terminals within a cell
CCCH	Common control channel	Regular transmission of control information between UE and eNodeB
DCCH	Dedicated control channel	Transmit dedicated control information to the specific UE
DTCH	Dedicated transport channel	Transmit user information dedicated to one UE
MCCH	Multicast control channel	Transmit MBMS control information from network to UE for one or several multicast traffic channel
MTCH	Multicast traffic channel	Transmit user data to the DL MBMS service
UL-CHANNELS	**FULL NAME**	**PURPOSE**
CCCH	Common control channel	Regular transmission of control information between UE and eNodeB
DCCH	Dedicated control channel	Transmit dedicated control information from the specific UE
DTCH	Dedicated transport channel	Transmit user information dedicated to one UE

Table 3-4 LTE Transport Channels Name and Function [41][42]

DL CHANNELS	FULL NAME	PURPOSE
PCH	Paging channel	Transmit paging information to the device from RRC_IDLE state to RRC_CONNECTED state
BCH	Broadcast channel	Used to broadcast system parameters to enable devices accessing the system
DL-SCH	DL-shared channel	Support ARQ , semi-static and dynamic resource allocation, varying coding and modulation
MCH	Multicast channel	Transfer multicast data to UE and provide support for MBSFN
UL CHANNELS	**FULL NAME**	**PURPOSE**
RACH	Random access channel	Carries control information and may be lost due to collision
UL-SCH	UL shared channel	Support ARQ , semi-static and dynamic resource allocation, varying coding and modulation

Table3-5 LTE Physical Channels Name and Functions [41]

DL CHANNEL	FULL NAME	PURPOSE
PBCH	Physical broadcast channel	Carries cell-specific information
PDSCH	Physical downlink shared channel	Payload
PMCH	Physical multicast channel	Carries the MCH transport channel
PDCCH	Physical downlink control channel	Scheduling, ACK/NACK
PCFICH	Physical control format indicator channel	Defines number of PDCCH OFDMA symbols per sub frames (1,2,3, or 4)
PHICH	Physical hybrid ARQ indicator channel	Carries HARQ ACK/NACK
UL-CHANNEL	**FULL NAME**	**PURPOSE**
PRACH	Physical random access channel	Call setup and small data packets
PUSCH	Physical uplink shared channel	Payload
PUCCH	Physical uplink control channel	Scheduling ACK/NACK

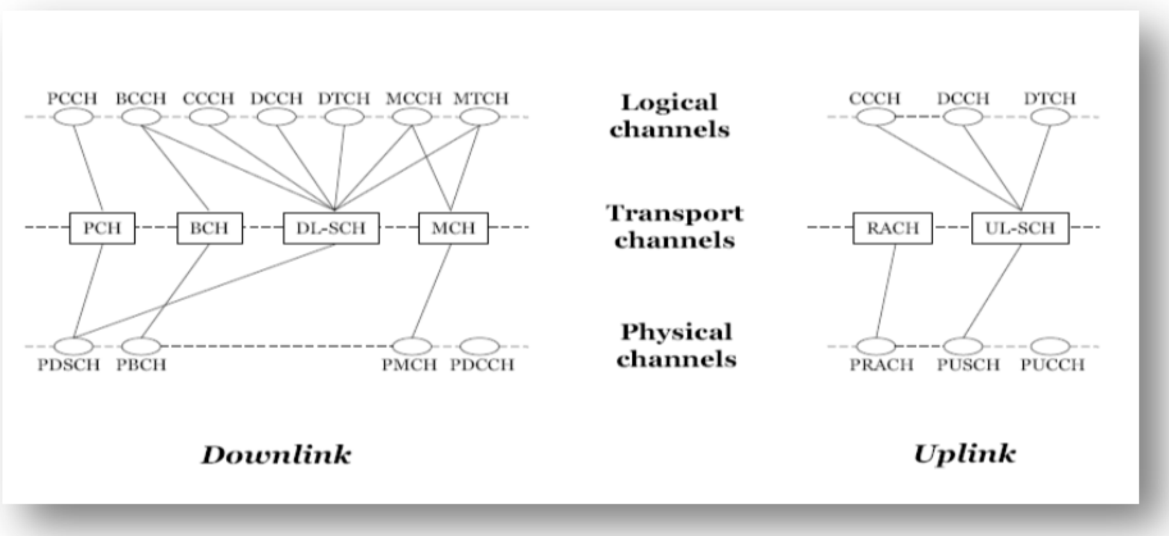


Figure 3-5 LTE Logical Transport and Physical Channel Mapping [4][23][42]

CHAPTER FOUR

1.0 METHODOLOGY

The main objective of this thesis is to offer an independent technical and cost assessment of BWA (Wi-Fi, 3G, WiMAX and LTE) technologies in a typical educational institution.

4.1 Facts about Case Study Area: KNUST

The primary data collection method was used and experts within various field of BWA were interviewed face-to-face. A number of methods were employed to achieve the goals of this research. First there was the need to collect information about KNUST and to ascertain key factors that affect the deployment on any BWA in the case study area. Some of the information gathered includes;

1. The cost of deploying the current KNUST BWA – Wi-Fi
2. The total land size of KNUST and the current Wi-Fi topology of KNUST
3. The type of terrain in KNUST; whether its hilly, moderately hilly or flat, and also a survey of the height of trees available on the campus
4. The population of students on campus and an estimate of the population of student with Wi-Fi enabled laptops
5. The history of BWA in KNUST and the pros and cons of the currently deployed BWA technology

Information was collected by interviewing experts in the various area of interest; the KNUST estate department, the KNUST NOC and the School registry. The information collected is used to establish whether the current BWA deployed is adequate. This also aided in the way questions were directed to telecommunication experts and equipment vendors thus affecting contributions made, like numbers of BTS required to reflect KNUST's scenario.

4.2 Technical Assessment of BWA – Modulation Techniques

Secondly, there is the need to look at the technological benefit of the BWA under study for a typical educational institution. The main technical issues considered in this work are effective data rates and ranges of coverage. These are implemented in the physical layer. The physical layer is the main discussion point when different cellular networks are compared. It defines the fundamental capacity limits and its structure relates to the achievable performance issues. The physical layer properties that affect these qualities are basically modulation techniques and antenna techniques used. This work seeks to compare simulations of some modulation techniques – QAM, PSK and so on using MATLAB. MATLAB is widely considered the program of choice for technical computing. It solves problems faster than traditional programming languages like C, C++ and has wide range of tools used for applications such as data analysis and communication modelling analysis.

4.3 Cost ***Parameters and Values of BWA under Study***

Thirdly, a number of experts in the various telecommunication industries disciplines in Ghana were interviewed mainly to come-up with the cost components for the deployment of the various BWA technology under study, their views on cost were considered. Telecommunication equipment vendors were made to elaborate on the cost of deployment of the various BWA technologies in KNUST. Some of the questions asked include;

1. Cost of establishing a BTS in Ghana
2. Cost of erecting tower in Ghana
3. The effect of the terrain on the number of BTS to establish
4. The effect of the population on the number of BTS to establish
5. The cost of establishing Core Network for WiMAX, 3G and LTE
6. The cost establishing backhaul provisioning for WiMAX, 3G and LTE
7. Cost of maintaining the network.
8. Cost range of a customer premise equipment [46]

Answers to this information among others were used to build up the cost of deployment of the various BWA technologies on campus. Six (6) telecommunication industries and six (6) telecommunication equipment vendors were tabled to be interviewed on the cost parameters and the cost in the deployment chain of BWA. Experts of three (3) telecom industries and two (2) equipment vendors honoured the interview. Some of the experts were reluctant with some specific cost information and gave some values in ranges, stating company policies as reasons why they cannot be specific. As a result a second opinion was sough, thus a cost analysing tool that closely reflects the views of interviewees; Interactive WiROI LTE/WiMAX Case Analysis Tool GUI- demo version [45][18].

WiROI is a wireless ROI Analysis tool for use by LTE and WiMAX service providers to deploy a Broadband Wireless network. It provides an easy to use and interactive user interface which allows the user to fine tune; the key performance Indicators (KPI) of a network in order to optimize key financial parameters of a broadband wireless business case. The tool features a dashboard-style Graphical User Interface (GUI) which provides the user the ability to easily control the key input parameters of choice and to dynamically visualize the results immediately. The Capital Expenditure, CAPEX, Operational Expenditure, OPEX, Total Cost of Ownership, TCO, are among the few results that can be viewed on the dashboard. The complete WiROI has over 250 input variables many of these input variables are fixed. A selected set of variables are user controlled on the dashboard. The technical and cost information gathered is used to draw conclusion on the various BWA considering KNUST and other educational institutions in general.

CHAPTER FIVE

5.1 Broadband Wireless Access (BWA) On KNUST Campus

KNUST deployed its first Wi-Fi services at the premises of the Department of Pharmacy in 2004 as a pilot project. It was a Linksys WRT54 series which was first released in December 2002 and came with a 4+1 port network switch. The Linksys WRT54 had a theoretical range of 100m and a practical range of 50m and could practically support 10-50 users concurrently. This was too small for the total population of students and specifically those with Wi-Fi enabled computers (devices). The campus adopted full BWA with Wi-Fi in 2008 and currently has Mikrotik Radius that offers Wi-Fi services at all halls of residence, the university's private hostels and other location on and off campus. The Mikrotik Radius is able to serve 80% of land area in the main halls excluding the annexes. It supports data rates of 54Mbps but 25Mbps due to CSMA overhead and up to 200+ concurrent users theoretically and 150 users practically.

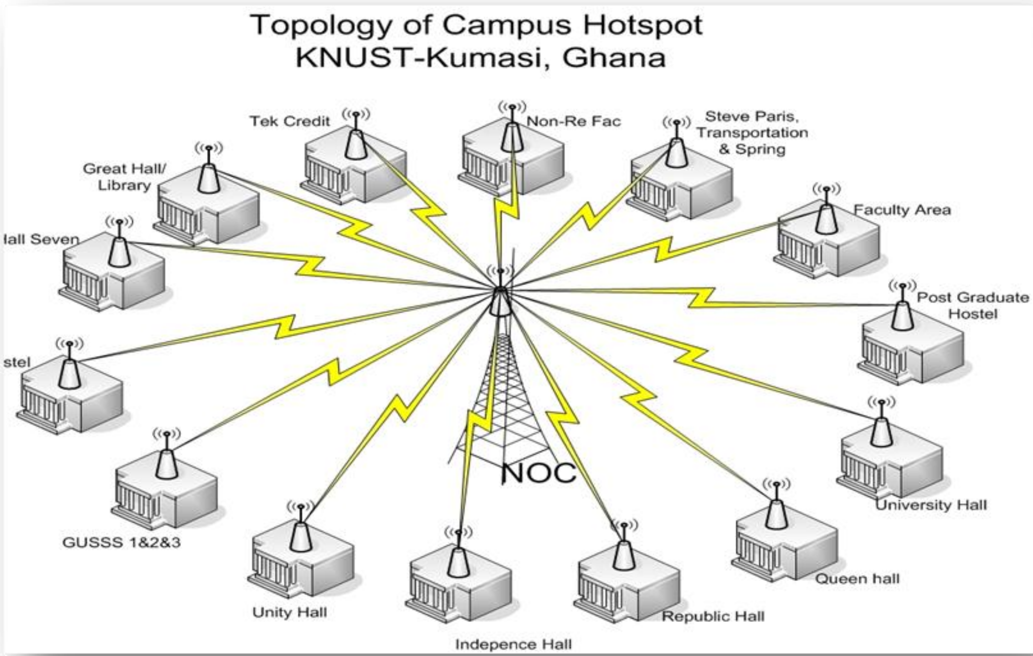


Figure 5-1 Topology of Campus Hotspot KNUST-Kumasi, Ghana

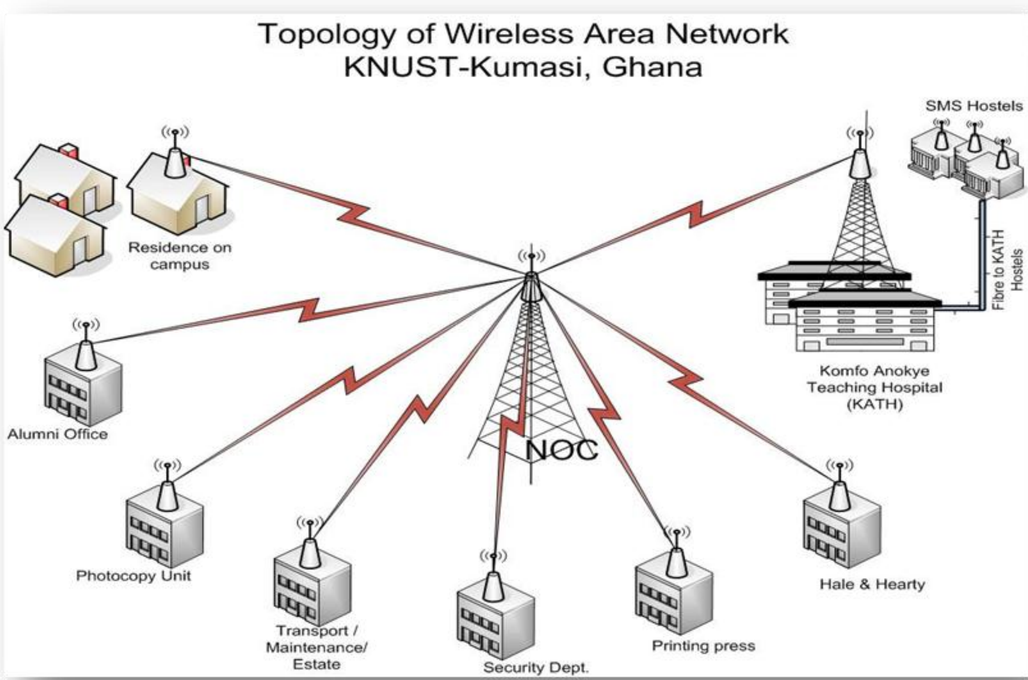


Figure 5-2 Topology of Campus Hotspot KNUST Serving Students in KATH - Ghana

The topology in figure 4.1 and 4.2 gives an insight to some locations in the university which offer data service. KNUST has 22 hotspot [17] linked with a Microtik radius to offer data and other BWA service in and around campus. Besides these, there are about 8 more Wi-Fi which is not linked with the microtik radius and a wire line broadband access that accounts for about 400 users at the main ICT centre, various faculty computer labs and offices on campus. If all hotspots can hold 150 concurrent users practically coupled with the 400 additional users over the total student population that stands at about 26000 then we are taking about 20% of the student population that could have access to broadband services. The ease in the deployment of BWA makes it an ideal solution for plan campus coverage for broadband services and to continue with the current Wi-Fi system require about 139 hotspots to serve the remaining 80% [Appendix A] and this excludes staffs.

5.2 KNUST Campus and the Pros and Cons of Various Technologies

As it stands those in the annexes of the various halls would have to move down to the main halls to gain access to the Wi-Fi services available for their academic research work. However since the number of users at the various halls far outnumbers the total number of practical users the Wi-Fi services on campus can support, coupled with students not adopting best practices (not disconnecting Wi-Fi services when not actively using the network) calls for enormous pressure on the system. One of the immediate effects of pressure on the system is that it “hangs” and always require rebooting. Also the bandwidth intensive data requirements of students and staffs like multimedia services, streaming data and so on require higher bandwidths and a technology that can offer these services with ease.

These Wi-Fi hotspots are concentrated at the various halls of residence of students and other locations at the faculties for studies. In this era of technological advancement, the change around nations is based on researches carried out by students and lecturers. Looking at educational institutions and their great research prowess there is the need for a campus wide coverage of BWA services with an excellent data rate to assist both staffs and students alike in their various research areas. This would offer staff and students the comfort of working anywhere on the campus rather than their offices and specific locations on campus.

From above among others Wi-Fi generally has proven to have these limitations;

1. It can support relatively few concurrent users
2. It has a micro footprint (low coverage per hotspot)
3. It has greater interference with other services in the unlicensed spectrum.
4. It has poor security, especially with its WEP.

The Wi-Fi services on campus is inadequate, to supplement this inadequacy most staffs and students have resorted to data services offered by the various telecommunication industries in the country that offer 2.5 or 3G services and other internet service providers. This is seen from the fact that less than 10 percent of the student's population on campus resort to the Wi-Fi as shown in Figure 5-3. In view of the limitations the current Wi-Fi system offers, there is the need for KNUST to migrate to a more advance cost effective technology that can mitigate the limitation that Wi-Fi offers.

3G is one of the technologies used to offer data services in the country by most telecommunication industries. It has stood the test of time in deployment worldwide. Students and staffs on campus patronize 3G USB dongles to augment the inadequate Wi-Fi on campus and also meet some of the limitations in areas of footprints and concurrent users.

The 3G system offers these advantages over the current Wi-Fi system on campus

1. Wider footprint (wider coverage)
2. Support a comparatively greater number of concurrent users
3. Solves interference problems with other microwave or cordless phones with its licensed spectrum
4. Good security policy

Looking at the benefits, 3G could serve as the BWA technology to meet campus data services. This work would also access the possibility of KNUST deploying its own BWA technology infrastructure to support data services on campus.

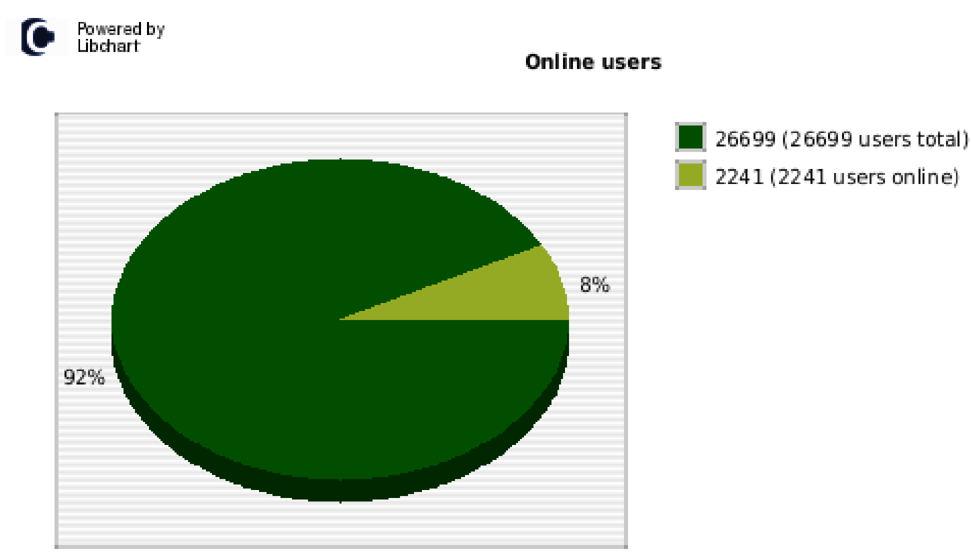


Figure 5-3 Total number of students using KNUST Wi-Fi; 6th October 2010 12:30pm [17]

5.3 *Overview of KNUST (Study) Land Area*

KNUST has a total land area of about 16.024sq. Km. and 10.371sq km is developed. The current student population is about 26,602 and the estimated number of students and staff with Wi-Fi enables devices is about 5000 [17], this suggests that the current Wi-Fi system would still not be able to support these users and also meet coverage demands at certain locations on campus. Achieving campus coverage, there is the need for the campus to look at a cellular approach to meet this demand.

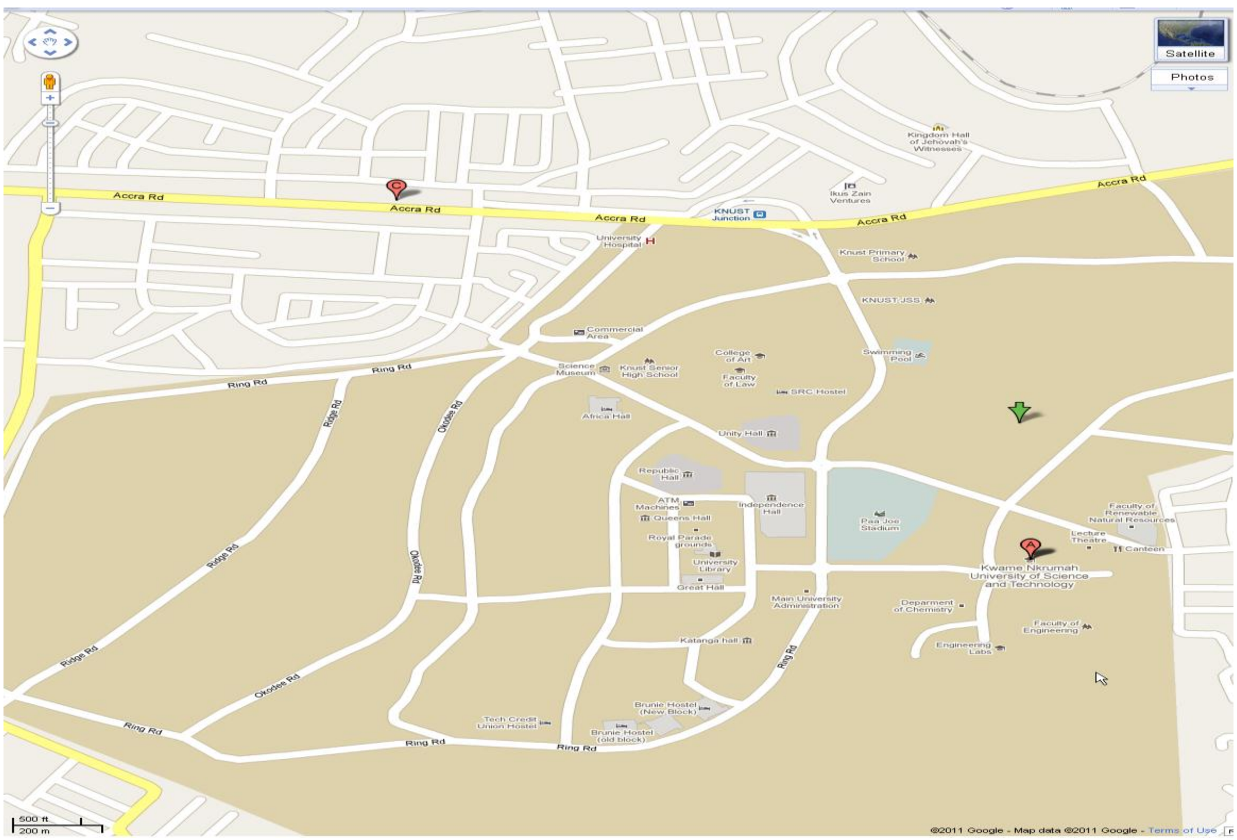


Figure 5-4 Google map of KNUST land area [37]

KNUST has a reasonable land size that can support the deployment of a cellular infrastructure. See Figure 5.4. 3G has its own technological disadvantages or limitations;

1. Compared to Wi-Fi it offers lesser data rates – maximum of 7.2Mbps
2. WCDMA used by 3G has higher power requirement at the UE than Wi-Fi

These limitations of the two technologies – Wi-Fi and 3G call for a technology that solves the limitations of both technologies and is most importantly economical.

In recent years there has been the call for a near 4G or 4G technology that would meet the challenges of 3G and Wi-Fi, thus an all IP infrastructure that would provide ubiquitous data service. 3GPP-LTE and WiMAX are the technologies considered to meet up to date demand of data services and to resolve the critical limitations of 3G and Wi-Fi. One of the first considerations for these new technologies would be spectrum; the NCA of Ghana has started leasing spectrum for the deployment of WiMAX and LTE [46] and also the digital migration by 2015 would leave re-farmed spectrum for LTE which can operate in the already existing GSM spectrum. Multiple Antenna Techniques and smart antennas, OFDM and OFDMA, advance digital modulation techniques are some of the factors that have offered WiMAX and LTE enhanced data rates, foot-print (coverage) and spectral efficiency etc. The cost of deployment of the various BWA technologies is studied.

5.4 Modulation Techniques

The variation or changing of the property of a signal, such as its amplitude, frequency or phase is called modulation or the process of encoding information from a message source in a manner suitable for transmission. Different types of modulation techniques are available; the most basic modulation techniques used are the analogue. These are Amplitude Modulation (AM), Frequency Modulation (FM) and Phase Modulation (PM). Modern mobile communication systems use digital modulation techniques and the central of which are;

1. Amplitude Shift Keying (ASK)
2. Frequency Shift Keying (FSK) and
3. Phase Shift Keying (PSK)

5.4.1 Amplitude Shift Key (ASK):

In the ASK the amplitude difference is used to modulate the carrier signal; the phase and the frequency are kept constant [35].

$$A\cos(2\pi f_c t) = 1$$

$$0 = 0 \qquad (4.0)$$

5.4.2 Frequency Shift Key (FSK):

For the FSK the amplitude and phase are kept constant and the frequency is used to modulate the carrier frequency [35].

$$A\cos(2\pi f_1 t) = 1$$

$$A\cos(2\pi f_2 t) = 0 \qquad (4.1)$$

5.4.3 Phase Shift Key (PSK):

The phase of the carrier signal is digital modulation scheme which conveys data by modulating or changing of carrier wave. The most commonly use are BPSK and QPSK.

$A\cos(2\pi f_c t) = 1$

$A\cos(2\pi f_c t + \theta) = 0$ (4.2)

5.4.4 Binary Phase Shift Key (BPSK):

This is the simplest form of phase modulation, very effective and robust against noise. It is also known as two-level PSK since it uses two phases separated at by 180 degrees to represent binary digits. It is used in low data applications as it can modulate only 1 bit per symbol and as such unsuitable for high data rate applications when bandwidth is limited.

Table 5-1 Phase and Data (bits) of BPSK

PHASE (degrees)	DATA (bits)
0	0
180	1

5.4.5 Quadrature Phase Shift Key (QPSK):

This modulation technique is sometimes called quaternary PSK. The "quad" in QPSK refers to four phases in which the carrier is sent – 45^0, 135^0,225^0, 315^0. Because of the four possible states, QPSK is able to encode two bits per symbol. It is effectively two independent BPSK systems (I and Q) and therefore exhibits the same performance but twice the bandwidth efficiency. It may be used to double the data rates of compared BPSK system while maintaining the same bandwidth of the signal or to maintain the data rate of BPSK but halve the bandwidth needed. It also has variations that include Offset QPSK, Pi/4-QPSK, and DQPSK.

Table 5-2 Phase and Data (bits) of QPSK

PHASE (degrees)	DATA (bits)
45	00
135	01
225	11
315	10

5.4.6 Quadrature Amplitude Modulation (QAM)

It refers to a QPSK with Amplitude Modulation. Basically, it is a mix of phase modulation and amplitude modulation. There are basically two types, 8-QAM and 16-QAM. The 8-QAM encodes 3 bits of data (2^3 = 8) and the 16-QAM encodes 4 bits of data (2^4 = 16). Modulation techniques like QPSK, QAM can be used to increase the capacity of communication systems like Wi-Fi, 3G, WiMAX and LTE. The fact remains that, different modulation techniques come with specific advantages and as such some systems have adopted Adaptive Modulation Techniques [33].

5.4.7 Adaptive Modulation Techniques

This is a package of different modulation techniques that allow a particular wireless technology to send more bits per symbol and thus achieve higher throughputs or better spectral efficiency. The use of adaptive modulation allows a wireless system to choose the highest order modulation depending on the channel conditions. As range increases the system steps down to a lower modulation – BPSK but as one is closer the system it utilizes higher order modulations like 64-

QAM for increased throughput. Also an adaptive modulation allows the system to choose modulations that overcome fading and interference.

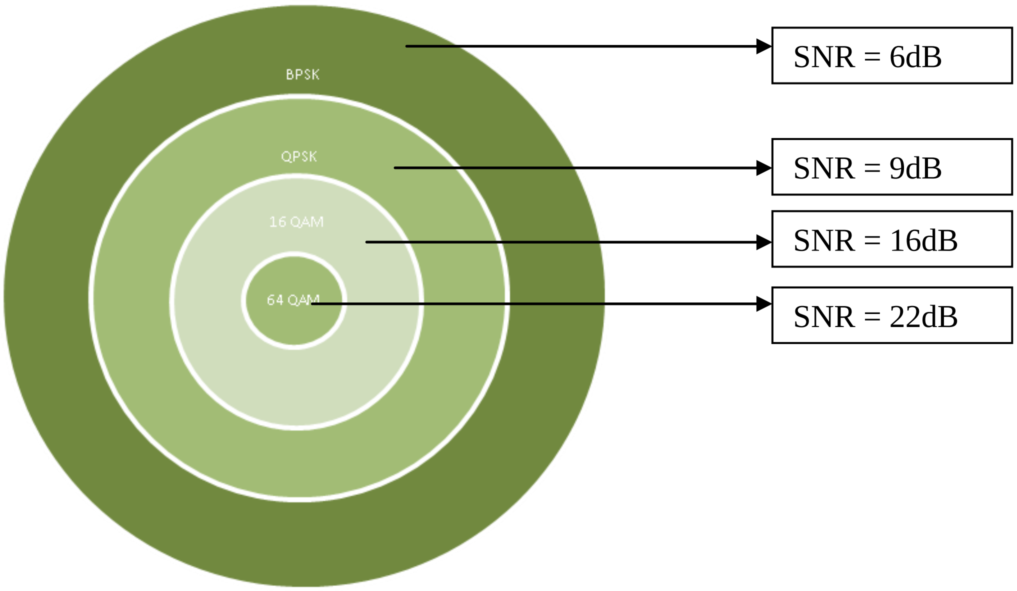


Figure 5-5 Comparison the range of various modulation techniques [33]

Table 5-3 Comparison of modulation techniques of various BWA [35][36]

WIRELESS TECHNOLOGIES	Versions	Modulation technique- uplink
WLAN	802.11a	BPSK, QPSK, 16-QAM
	802.11b	QPSK
	802.11g	BPSK, QPSK, 16-QAM
WiMAX	802.16	BPSK, QPSK,16-QAM, 64-QAM
	802.16a	QPSK, 16-QAM, 64-QAM
	802.16e	QPSK, 16-QAM, 64-QAM, 256-QAM
Cellular system	1G	Analogue – FM, PM, AM
	2G	GMSK
	3G	QPSK, 8-PSK
	3GPP-LTE	BPSK,8-PSK,QPSK,16-QAM 64-QAM

In comparing the performance various modulations techniques, we will take a look at

1. The Energy per bit to noise power spectral density (Eb/No) also termed SNR or “SNR per bit”. This is useful when comparing the Bit Error Rate (BER) performance of different digital modulation schemes without taking bandwidth into account. Eb/No is closely related to Carrier to Noise ratio (C/N).

$$\frac{c}{n} = \frac{Eb}{No} * \frac{fb}{B} \quad (4.1)$$

fb = channel data rate

B = channel Bandwidth

$$\frac{c}{n} = 10log10(\frac{Eb}{No}) + 10log10(\frac{fb}{B}) \quad (4.2)$$

2. Signal constellation diagram: This is a coordinated system to monitor common modulation schemes. The performance of the coding scheme depends on which signal constellation is used e.g. BPSK, 4-PSK (QPSK) etc. The constellation points could employ grey coding which play important role in error correction since data is transmitted in symbols. The constellation diagram is arranged so that the bit patterns conveyed by adjacent constellations points differ by only one bit. This with Forward Error Correction (FEC) makes a receiver correct any transmission errors that cause a constellation point to deviate into the area of an adjacent point. In interpreting a signal constellation diagram;

- Possible signal are plotted as points.
- Signal power is proportional to distance from origin.
- Probability of mistaking one signal for another is related to the distance between signal points.
- Decision are made on the received based on the distance to signal points in the constellation.

The BER per Eb/No in decibel (dB) diagram and that of selected signal constellation diagrams plotted using MATLAB codes as shown in Figure 5-6 to 5-12.

5.5 The Bit Error Rate for the Various Modulation Techniques

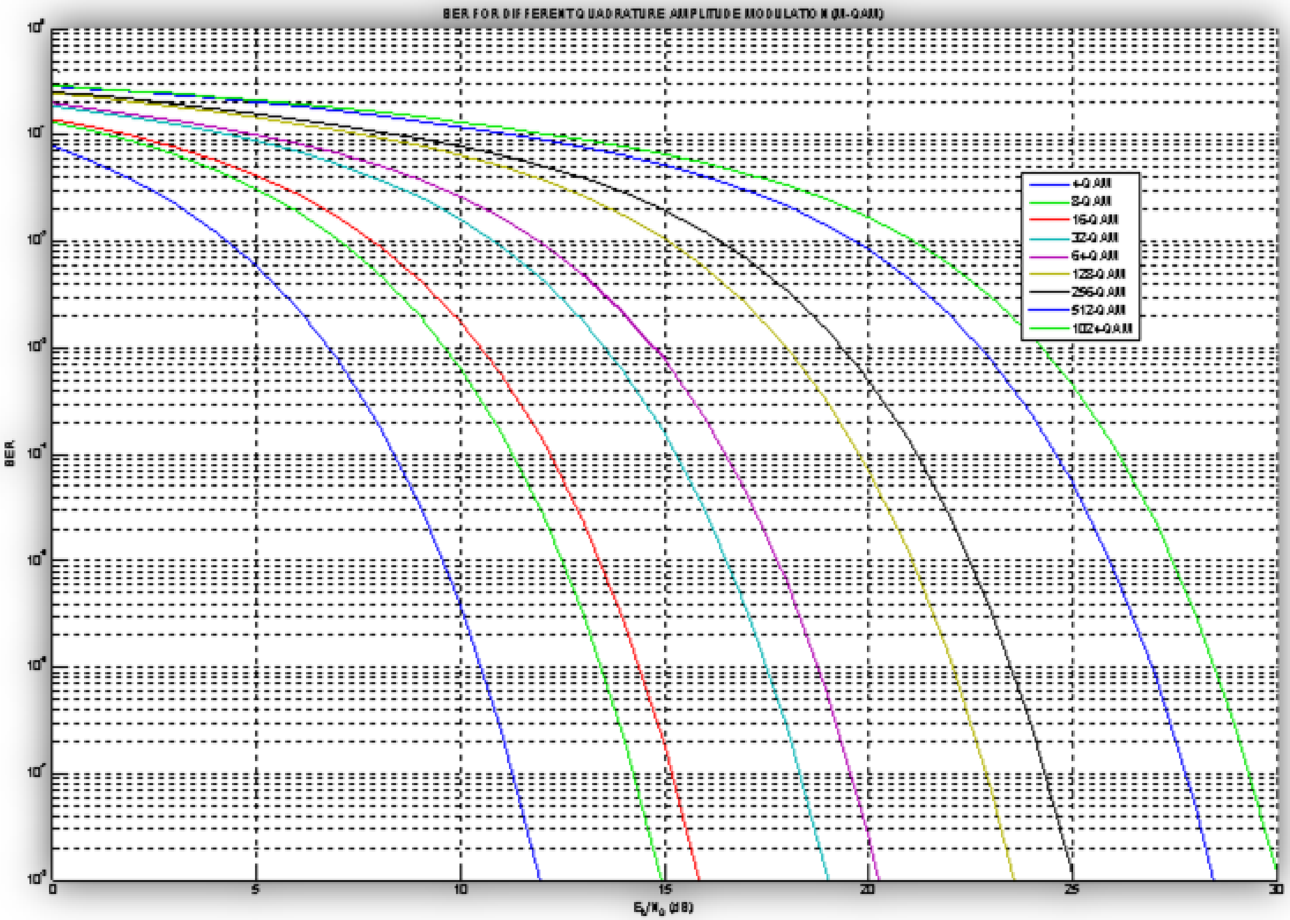


Figure 5-6 Comparison of various M-QAM modulation techniques

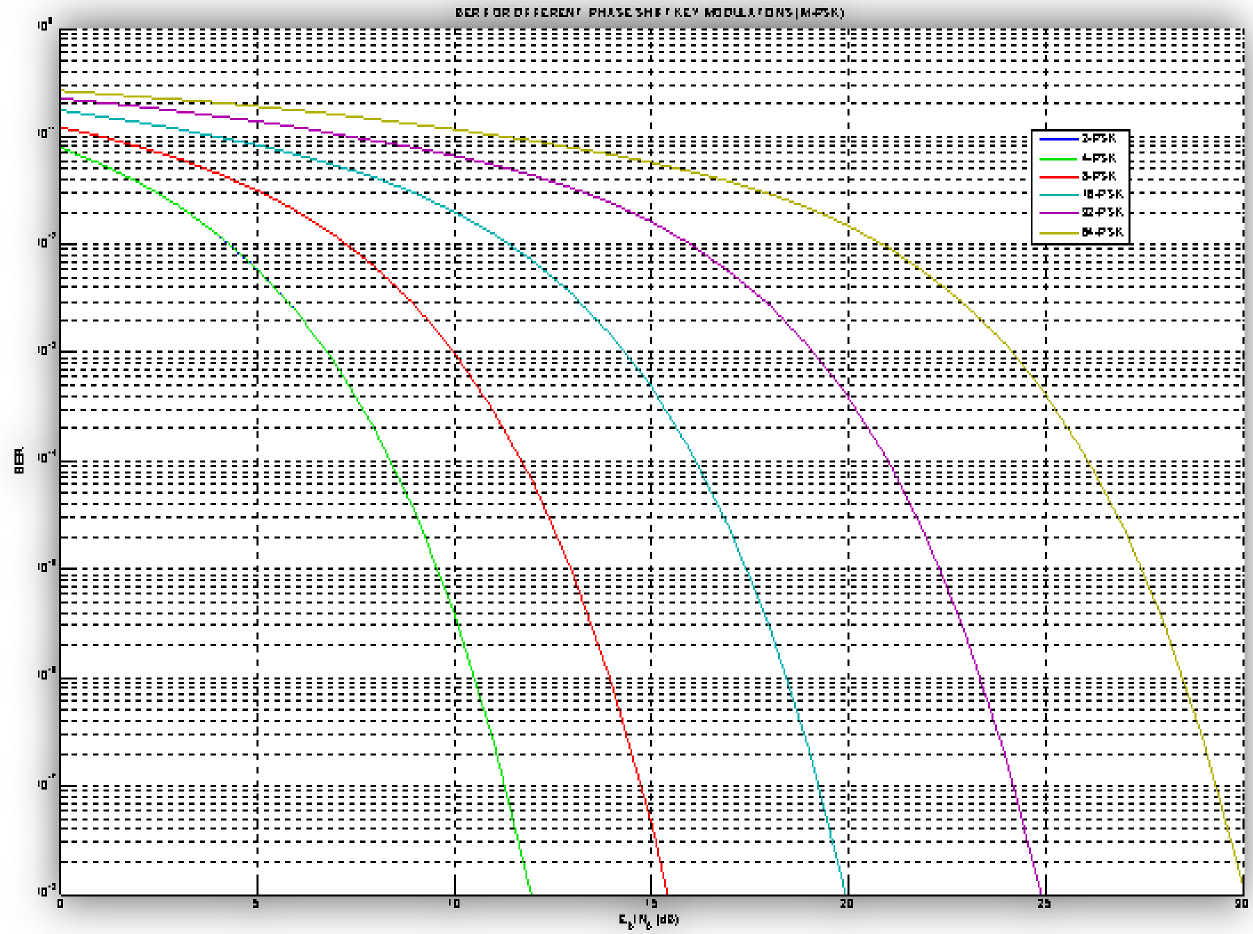


Figure 5-7   Comparison of M- PSK modulation techniques

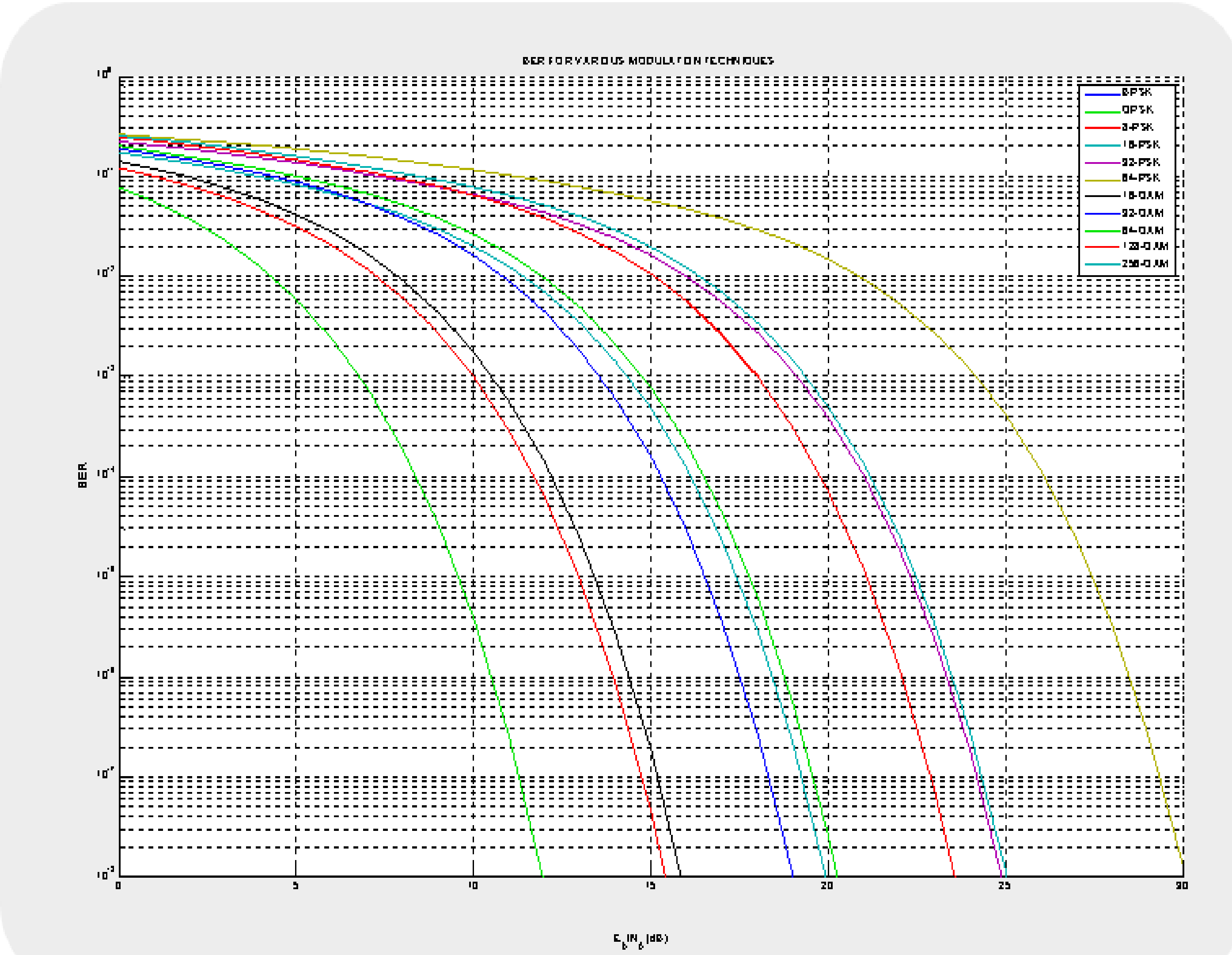


Figure 5-8 Comparison of both M-QAM and M-PSK modulation techniques

A graphical representation of the signal set is termed signal constellation. It provides a graphical representation of the complex envelope of each possible symbol state. The X-axis of a constellation diagram represents the in-phase component of the complex envelop and the Y-axis represents the quadrature component of the complex envelope.

Figure 5-1 and 5-2 represent M-QAM and M-PSK respectively, where M is the number of points in the signal constellation. Mathematically, M is represented as M= 2k where K is the number of bits per symbol. Basically the BER for QAM = PSK + ASK hence can be seen from the graphs above that 4-PSK has almost the same BER as in 4-QAM; this can be interpreted clearly with the signal constellation diagrams in figures 5-4 and 5-5 since both modulations are implemented as 1-amplitude with 4-phase. But for higher levels of M, PSK are implemented as 1-amplitude whereas QAM is implemented with different amplitude based on the values of M. 8-QAM is implemented as 2-amplitudes and 4-phases whereas 16-QAM is implemented as 4-amplitudes and 4-phases. M-PSK schemes are more susceptible to implementation loses as compared to M-QAM schemes with the same number of symbols. The performance of 8-PSK is similar to 16-QAM and that of 16-PSK is similar to 64-QAM. Transmitting the same number of constellation in both 16-PSK and 16-QAM the distance between constellations points for 16-QAM is around 1.6x the value for 16-PSK modulation [44]. The more the distance between the constellation points, the greater is the chance of a constellation point getting decoded correctly, see Figure 5-6 and 5-7.

5.6 Constellation Diagrams using MATLAB

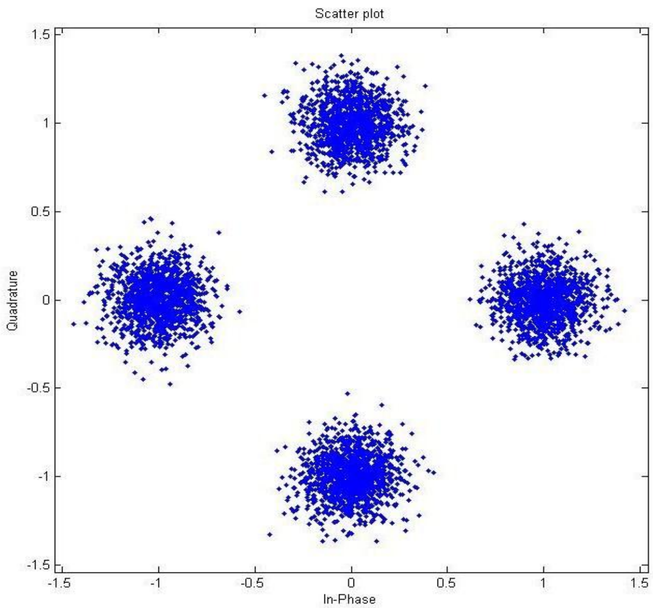


Figure 5-6 Signal Constellation Diagram showing 4-PSK using MATLAB

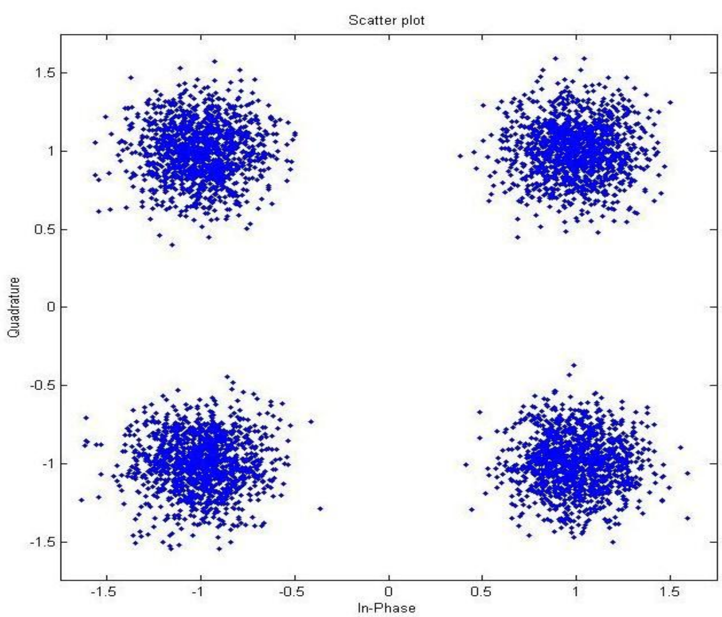


Figure 5-7 Signal Constellation Diagram showing 4-QAM using MATLAB

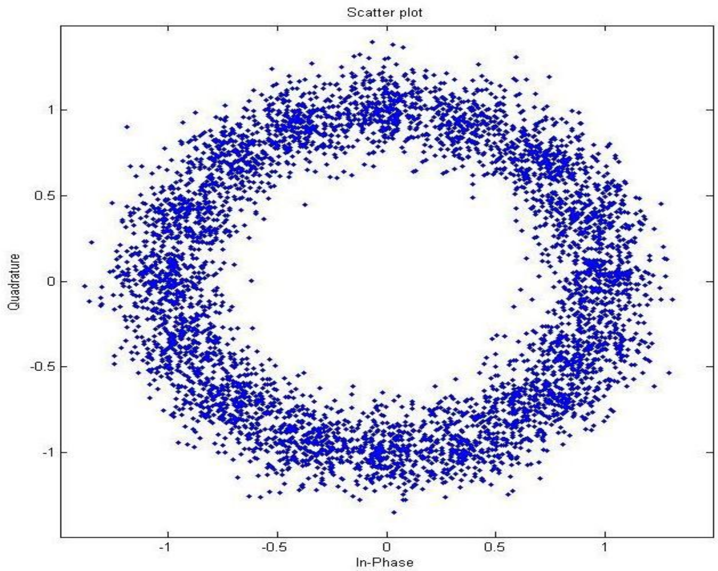


Figure 5-8 Signal Constellation Diagram showing 16-PSK using MATLAB

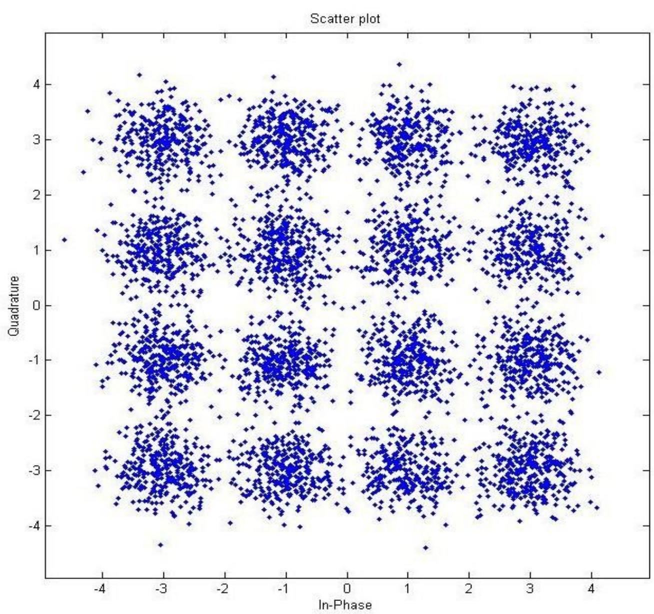


Figure 5-9 MATLAB constellation diagram showing 16-QAM constellation points

Now that some of the modulation techniques employed in BWA are assessed there is the need to look at the cost of deployment on KNUST campus.

5.7 Cost of Deploying BWA

The initial investment on a BWA deployment focuses largely on capital components associated with procuring the necessary equipment throughout the network and systems architecture and acquiring the required Service provider to deploy various services across the network as presented in Table 5-3.

Table 5-2 Equipment and service cost for deployment outline

EQUIPMENT	SERVICES
Transmission backbone	Site Preparation and Civil Works
IP backbone	System Implementation and Engineering
VoIP	Site Engineering for Remote Office Sites
Data Center/ NOC	Services for IDC construction and Integration
Information security System	Training
Monitoring and Environmental Equipment	Managed Services
Network Management System	
DC Power and Generator Set	

The cost of deployment always involves a host of factors which are divided into two broad categories

1. Capital expenditure - CAPEX
2. Operational expenditure – OPEX

The components that make up the CAPEX and OPEX are summarized in Table 5-4

Table 5-3 CAPEX and OPEX cost components

CAPEX	OPEX
Base Station	Base Station maintenance
Base Station Equipment	Network Maintenance
Core Network Equipment	Backhaul Installation
Wireless Backhaul Equipment	Backhaul Costs
Site Acquisition Development Costs	Site Rentals and Utilities
	Device Subsidies
	Support and Warranty
	BSS/OSS
	Marketing and Advertising

Analysing the cost is based on the broad components or blocks in a network infrastructure which may include both equipment purchases and service provisioning.

The CAPEX normally consumes a larger percentage of the total cost but the operating expenses will outweigh the initial capital outlay over time. The CAPEX cost tables are bulk cost. For example the core network cost involves IP Core Routers, IP Aggregate routers, ASN Gateways, Home Agent (HA), Firewall, DHCP Server(s), AAA Servers, Billing Servers, NMS/EMS Servers, VOIP Servers etc. The cost of BS includes site acquisition, equipment cost, site civil work, air conditioners, DC Power, generators and so on.

5.8 *Interactive WiROI LTE/WiMAX Case Analysis Tool - Parameters used*

Typical Parameters used to arrive at the cost tables for WiMAX and LTE are listed below

Core Network: Traditional

Access Network: Traditional

Spectrum - 2.5GHz; since these are the current spectrum available leased by The National Communication Authority, Ghana.

Channel Bandwidth 10MHz

Link Budget – 134dB

Spectral Efficiency – 1.8bps/Hz

Sector Macro BTS cost - $45000; that of LTE is not editable by WiROI2020 trial version and as such WiMAX is maintained at the same figure to allow for a better comparison

Percentage of cell using existing sites – 0%; we assume Greenfield deployment

Cost of upgrade Existing site – 0%; assuming Greenfield deployment

Site Acquisition –Greenfield site – 0.This is considered as Zero because educational institutional own their lands and as such do not have to lease lands for BWA deployment

Residential Penetration Factor – 100% Students and staffs are all considered residents of the educational institution.

Business Penetration Factor – 0%;this is set to Zero because the educational institutional is traditionally not a money making institutions and selling BWA is not considered.

Number of cell achieved for the case of WiMAX is 16 and that of LTE is 30 and the numbers of subscribers are 17,700 and 19,000 persons respectively.

5.9 Cost of Deploying Various Technologies on KNUST

Table 5-4 Typical Wi-Fi cost - KNUST

ITEM	QUANTITY	UNIT PRICE ($K)	AMOUNT($K)
Spectrum	-	-	-
Base Station			
Mast	1	10 - 20	10 – 20
Sectorial Radius	6	3.1 – 4.167	18.6 - 25
Power plant	1	10 - 25	10- 25
CPE			
Materials, poles, digging, UTP cables, cabinet switch	15	2 – 5 (bulk)	2 - 5 (bulk)
Switch Room			
Servers	2	5 - 10	5 - 20
Subtotal			**45.6 - 95**
Workmanship			
Network Setup + System setup + planning	15	.5 – 1.0	**75 - 15**
Subtotal			**53.1 – 110**

Table 5-6 Typical 3G costs - KNUST

ITEM	UNIT PRICE($K)	TOTAL PRICE ($K)
Spectrum Cost		
	CAPEX	
Base Station	20 – 35	495 – 600
Backhaul Provisioning	6 – 10	95 – 102
Core Networking	-	2,982 – 2,985
Maintenance	10 – 12	200 - 250
Site Development		295 - 300
	OPEX	
Networking Operating		490 - 550
Sales and Maintenance		218 – 250
CPE Subsidy		170 – 190
G and A		209 - 350

Table 5-7 Typical WiMAX Cost - KNUST [18]

ITEM	TOTAL PRICE ($K)
Spectrum Cost	
CAPEX	
Base Station	800 - 975
Backhaul provisioning	170 -215
Core Networking	2,987- 2,994
Maintenance	207 -220
Site Development	295–300
OPEX	
Network Operating	264 – 270
Sales and Marketing	218 – 392
CPE subsidy	169 – 338
G and A expenses	197 - 331

Table 5-8 Typical LTE Cost - KNUST Campus [18]

ITEM	TOTAL PRICE ($K)
Spectrum Cost	
CAPEX	
Base Station	495 – 500
Backhaul Provisioning	90 -100
Core Networking	2,982 – 2,989
Maintenance	178- 180
Site Development	295 – 300
OPEX	
Networking Operating	484 – 515
Sales and Marketing	235 – 374
CPE Subsidy	144 – 322
G and A	172 - 278

5.10 DISCUSSION OF COST RESULTS

Wi-Fi has been the most sought technology for BWA by most educational institutions because it has very low infrastructural cost, Figure 5-5; the fact that it also operates in the unlicensed spectrum makes it much cheaper. It has been exhausted earlier that Wi-Fi lack greatly in coverage and number of concurrent users as such it would not be an ideal technology to meet campus coverage in KNUST.

3G is an alternative technology that has stood the test of time in deployment but its infrastructural cost is similar to improved technologies such as LTE and WiMAX, Tables 5-6 to 5-8. A Greenfield deployment of BWA for educational institutions with land area capable of cellular network would need to deploy a 4G technology to meet up-to-date demand for data rates, range and support for concurrent users. Besides, LTE Self Organizing Network (SON) features, allows automation of previously manual tasks (3G) linked to planning, development, optimization and operation. This will maximize the Operation and Maintenance (OPEX) of LTE. In addition LTE has a common customer care system and a single billing system that can also lead to substantial OPEX savings both in personnel and training.

Base Station: WiMAX BS cost is higher than LTE BS cost Tables 5-7 and 5-8. The considerations for the base station cost such as; erecting of Towers (masts), site civil works, network and electrical cabling, backup power (generator or solar) and so on would be similar for both WiMAX and LTE. The main difference in cost is technological specific equipment such as radii, transceivers etc. The above tables show that, the equipment cost for WiMAX stand higher than that of LTE.

Backhaul Provisioning: The equipment for backhaul provisioning would be the main reason for the difference in cost with backhaul for WiMAX and LTE. The spectrum for both technologies is set to 2.5GHz. LTE has the advantage of operating in a wider spectrum, 3G spectrums as well as re-farmed spectrum after the digital divide by 2015. The spectrum availability would offer considerable cost savings for the LTE backhaul.

Maintenance: this basically includes functionality that ensures that the network and communication services operate as they are supposed to. This involves diagnosing, troubleshooting and repairing components that do not work as planned. The cost of maintaining the LTE is comparatively cheaper than that of WiMAX since most alarms are backward compatible with the current 3G infrastructure, tried and tested. Another important factor is personnel to handle both networks. The LTE is similar in architecture and operations as 3G and as such would need little training to upgrade personnel to handle LTE systems. WiMAX on the other hand is similar in architecture with Wi-Fi but similar in operations with a cellular network. There is a high cost is personnel training to handle the WiMAX systems.

The CAPEX for LTE is relatively cheaper than that of WiMAX. A greater part of this has been argued out as equipment specific hence WiMAX equipment is higher than LTE. The cost of ancillaries and site acquisition can be as high as 10 times the cost of the BTS. The OPEX of WiMAX is relatively cheaper than LTE. The CAPEX normally consumes a large percentage of the total cost but the operating expenses will outweigh the initial outlay over time.

5.10.1Notable Considerations

1. In case of an educational institution the Base Station cost components such as; site acquisition (significant CAPEX), site lease (significant OPEX), does not apply since the land is owned by the school.
2. Cost such as sale and marketing would not be allocated such funds as captured by cost tables since the institutions in most cases is not a profit making organisation. Staff remuneration that comes under General and Administration (G and A) comes as a fixed cost as salaries of IT staffs.
3. An educational Institution such as KNUST would save a huge infrastructural cost in building masts since there are many tall buildings on campus that can be used to carry radii (transmission equipment) and maintain Line-of-Sight. KNUST has an already established building that houses its NOC. Core network components such as servers, IP core routes, firewalls that are non-technological specific can be used.
4. Mobile devices run on batteries and would subscriber for a technology that does not sap battery power. Power saving mechanisms is essential in any standard that supports devices running on batteries. Both LTE and WiMAX implement OFDMA in the downlink which is power inefficient due to high Peak-to-average Power ratio (PAPR). In the uplink WiMAX implement OFDMA while LTE implement SC-FDMA (Single Carrier Frequency Division Multiple Access) which offer lower PAPR that saves power.
5. Both LTE and WiMAX will interoperate with existing wireless technologies, offering handover across access platforms including Wi-Fi, GSM and CDMA. A number of companies are working on creating devices that bridge across the difference between

LTE and WiMAX. Besides both technologies use OFDMA, MIMO, Adaptive modulation techniques, thus they have a substantial foundation in common.

In all these, KNUST is looking at deploying any of these two technologies at a much lesser cost than depicted by the cost tables. The CAPEX cost can be (as is always the case) amortised over the life span of the equipment this make it easier for KNUST to shoulder the high initial CAPEX cost.

CHAPTER SIX

6.0 Conclusion

Wi-Fi is cheap, operate in unlicensed spectrum and has no high infrastructural requirements, some 802.11 standards offer good data rates, 802.11n.The technology is designed for data communication service and would suite the educational institutions with relatively small land size 1sq Km. Wi-Fi has range limitations and as such many Access Points are required to achieve up to 10sq Km land area coverage, in the case of KNUST. Although the cost of Wi-Fi deployment and maintenance is cheaper but the collective cost to achieve a wider coverage like 10sq Km and support a greater number of user like a population of 20,000 is not advisable and as such would be better to adopt a cellular approach that would require fewer Base Station as to many Access Points [Appendix A].

3G offers good coverage and is suited for 10sq Km coverage and has limited data rates, 2Mbps. 3G is expressly designed as an upgrade technology for wireless voice telephony network, not data. 3G operates in the licensed spectrum and also require high infrastructural investment as in WiMAX and LTE as such offer high deployment cost. Both LTE and WiMAX promise to increase transmission rates by tenfold over their respective previous standards, hence the technologies of choice for cellular infrastructure for educational institutions e.g., KNUST.

Simulation results put both WiMAX and LTE at an almost equal footing and ahead of their parent technologies, Wi-Fi and 3G respectively. Since both implement adaptive modulation techniques. The cost table on the other hand spelt some difference in the deployment of WiMAX and LTE. The Capital Expenditure of WiMAX is higher than that of LTE but its Operational Expenditure is lesser. The capital expenditure consumes a larger percentage of total initial cost but the OPEX will outweigh the initial outlay over time. Besides the CAPEX cost can be amortized over the life span of the equipment hence a less capital intensive initial outlay for KNUST.

WiMAX has the advantage of continuity of the legacy of the KNUST network. It also offers lower Operational Expenditure which spans the entire life of the network. It also has a two year lead over LTE hence the availability of WiMAX solutions in the market today provide operator with a distinct time to market advantage for deploying high capacity wireless broadband. It also has the backing of IT or computer industry and would come as WiMAX laptop.

LTE has the advantage of continuity with the Telecommunication industries. It offers some technological advantages over the WiMAX; the SC-FDMA in the uplink that tends to offer very low PAPR and the fact that there is or will be spectrum availability. LTE has the backing of several Telecommunication industries which has a larger share of the BWA market.

Although both competing 4G technologies have pronounced difference in their air interface design, the overall radio performance is rather equal. The deployment cost grades LTE with low CAPEX and High OPEX and the reverse for WiMAX. The future cost is not certain but promises to be brighter, CAPEX and OPEX will hit significantly lower cost values, as a result of the battle between the two 4G technologies for supremacy.

Any of WiMAX and LTE can be a technology of choice for BWA in an Educational Institution. On a lighter note WiMAX with the continuity of the Wi-Fi legacy network, the time to deploy advantage and lower OPEX cost, which span the entire life of the network, is preferable in an Educational Institution like KNUST.

In conclusion, the challenges that the BWA deployed in KNUST faces have been enumerated. The main objectives were achieved through both technical and financial analysis of the various BWA technologies. The technical analysis was performed using MATLAB to evaluate the performance of the physical layer technologies of the various BWA under Additive White Gaussian Noise (AWGN). The thesis also presented a detailed cost analysis for the deployment of each technology using data collected through interviews and supported with that of cost analysis tools, WIROI 20/20 and LTE calculator

6.1 Observations and Recommendations

The competition between WiMAX and LTE for supremacy, co-existence or for one to render the other obsolete has come as a benefit (cheaper equipment prices) to operators, which is being passed on to user. Educational institutions have the opportunity to tap into these benefits.

Educational institutions with small campus size like, 1 Sq. Km can deploy improved versions on Wi-Fi, 802.11n, that offer good data rates. The cost of the core network for LTE and WiMAX would not change greatly irrespective of the land size. Educational institutions with large campus size and population like, KNUST, University of Ghana, and University for Development Studies can adopt a cellular approach to meet their data demand and keep other centres connected.

Both WiMAX and LTE are currently designed to co-exist with Wi-Fi; as such KNUST can maintain the current Wi-Fi infrastructure and deploy WiMAX or LTE mainly as a backhaul technology on campus.

6.2 Future Works

Several cost saving techniques have been proposed in this project. Further analysis should be carried out to reveal each cost saving component.

Simulations that consider different deployment scenarios to solve the coverage and capacity problem can be performed. The Physical layer technologies such as the BER, multiple antenna techniques, OFDMA can be modelled using OPNET to evaluate the performance of the various BWA and the specific cost of implementation of each technology.

When these issues are researched into it would give a clearer view to the deployment of either a 4G technology;

- Conducting subscriber forecasting.
- Network dimensioning base on capacity, traffic and coverage objectives.
- RF site surveys and LoS surveys and height of tall buildings on campus to augment as mast.
- Detail planning including equipment configuration, network parameters and frequency planning

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APPENDIX A

If the area of a circle = πr^2

Each Wi-Fi covers a theoretical distance of 100m and a practical distance of 50m

1. **Theoretically**

Area of each of the Wi-Fi = $22/7*0.1^2$*number of hotspots

For 15 hotspots

Area = $22/7*0.1^2*15$

= 0.4714 Sq. Km

The percentage of KNUST land covered by Wi-Fi

= (0.4714/10.371) * 100

= 4.5454%

2. **Practically**

The area covered by 15 hotspots

= $(22/7)*0.05^2 * 15$

= 0.1179 Sq. Km

The percentage of KNUST land covered by Wi-Fi

= (0.1179/10.371) * 100

= 1.1364%

3. The Wi-Fi could support about 150 users (students) practically

Hence, the total number of students covered by 15 Wi-Fi

= 15* 150

= 2250 students

The percentage of students covered by Wi-Fi

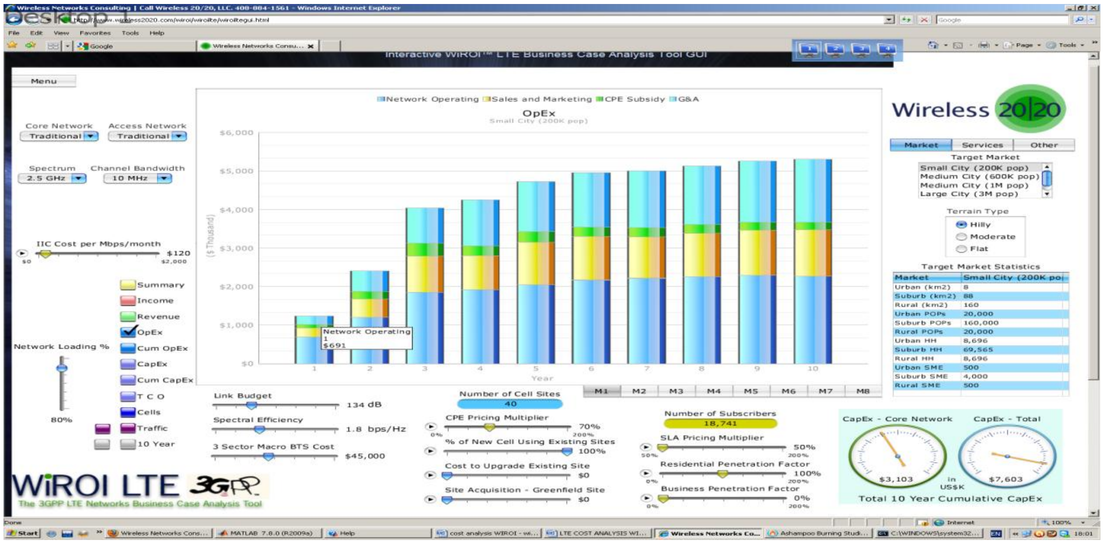
= (2250 * 26302) * 100

= 8.5545%

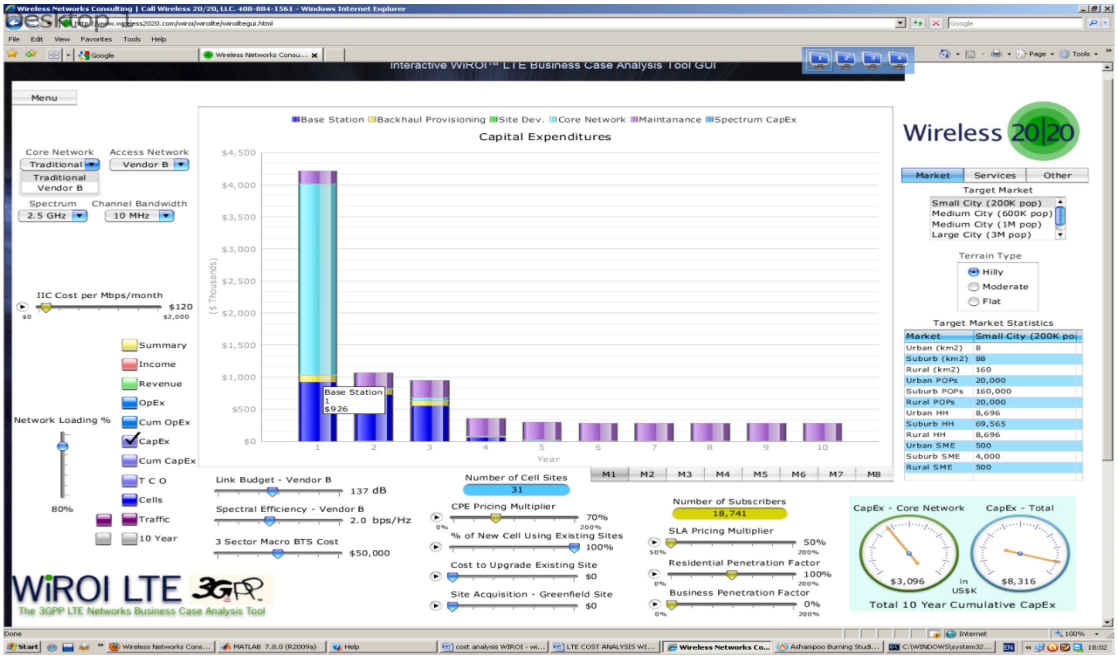
APPENDIX B

Interface of WIROI WiMAX and LTE business model

OPEX



CAPEX


Interactive WiROI™ LTE Business Case Analysis Tool GUI
Menu
Base Station Backhaul Provisioning Site Dev. Core Network Maintanance Spectrum CapEx
Capital Expenditures
($ Thousands)
Year
Core Network
Access Network
Traditional
Vendor B
Spectrum
Channel Bandwidth
2.5 GHz
10 MHz
IIC Cost per Mbps/month
$120
Summary
Income
Revenue
OpEx
Cum OpEx
CapEx
Cum CapEx
T C O
Cells
Traffic
10 Year
Network Loading %
80%
Link Budget - Vendor B
137 dB
Spectral Efficiency - Vendor B
2.0 bps/Hz
3 Sector Macro BTS Cost
$50,000
Number of Cell Sites
31
CPE Pricing Multiplier
70%
% of New Cell Using Existing Sites
100%
Cost to Upgrade Existing Site
$0
Site Acquisition - Greenfield Site
$0
Number of Subscribers
18,741
SLA Pricing Multiplier
50%
Residential Penetration Factor
100%
Business Penetration Factor
0%
Wireless 20|20
Market
Services
Other
Target Market
Small City (200K pop)
Medium City (600K pop)
Medium City (1M pop)
Large City (3M pop)
Terrain Type
Hilly
Moderate
Flat
Target Market Statistics
CapEx - Core Network
CapEx - Total
$3,096
$8,316
in US$K
Total 10 Year Cumulative CapEx
WiROI LTE
The 3GPP LTE Networks Business Case Analysis Tool

APPENDIX C – MATLAB CODE

a. Matlabbertool

b.
```
% Create a random digital message
M = 4; % Alphabet size
x = randint(5000,1,M);

% Use 4-QAM modulation to produce y.
y=modulate(modem.qammod(M),x);

% Transmit signal through an AWGN channel.
ynoisy = awgn(y,15,'measured');

% Create scatter plot from noisy data.
scatterplot(ynoisy);

% Demodulateynoisy to recover the message.
z=demodulate(modem.qamdemod(M),ynoisy);
```

c.
```
% Create a random digital message
M = 16; % Alphabet size
x = randint(5000,1,M);

% Use 16-QAM modulation to produce y.
y=modulate(modem.qammod(M),x);

% Transmit signal through an AWGN channel.
ynoisy = awgn(y,15,'measured');

% Create scatter plot from noisy data.
scatterplot(ynoisy);

% Demodulateynoisy to recover the message.
z=demodulate(modem.qamdemod(M),ynoisy);
```

d. % Create a random digital message

```
M = 4; % Alphabet size
x = randint(5000,1,M);

% Use 4-PSK modulation to produce y.
y=modulate(modem.pskmod(M),x);

% Transmit signal through an AWGN channel.
ynoisy = awgn(y,15,'measured');

% Create scatter plot from noisy data.
scatterplot(ynoisy);

% Demodulateynoisy to recover the message.
z=demodulate(modem.pskdemod(M),ynoisy);
```

e. % Create a random digital message

```
M = 16; % Alphabet size
x = randint(5000,1,M);

% Use 16-PSK modulation to produce y.
y=modulate(modem.pskmod(M),x);

% Transmit signal through an AWGN channel.
ynoisy = awgn(y,15,'measured');

% Create scatter plot from noisy data.
scatterplot(ynoisy);

% Demodulateynoisy to recover the message.
z=demodulate(modem.pskdemod(M),ynoisy);
```