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Technical and cost assessment of deploying Wi-Fi and WiMAX on educational institutions- KNUST as a case study

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Abstract

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) has been the most sought for technology in most Education Institutions and has offered enormous benefits to these Institutions [10]. It has facilitated the exchange of information (voice and data) among personnel's in the university community. There are many issues to consider when choosing a broadband wireless access for personal or enterprise usage; the physical layer data rates, effective data rates at MAC SAP, network capacity, quality of service, interference, coexistence, technology maturity, operating range, scalability, security etc. Many Broadband Wireless Access (BWA) service providers have cost of deploying and maintaining the network and its services as a core issue to consider for BWA deployment. This paper looks at the technical appraisal and cost of deploying and maintaining BWA (Wi-Fi and WiMAX) in a typical Education Institution setting, taking KNUST as a case study.
It was observed that it is possible for KNUST to implement a cellular infrastructure BWA since the cost of equipment can be amortized over the life span of the equipment. Also, in the case of an Educational Institution such as KNUST, some of the cost components can be waived. Therefore, some of these Institutions can deploy WiMAX at a much cheaper cost than envisaged. This research would help inform the school's administration and the network administrators as to the benefits of the services to consider and how possible it's (financially) to deploy.

Keywords: CAPEX, OPEX, BWA, WiMAX, Wi-Fi.

1. Introduction

The technical definition of broadband focuses on the speed of connection. The Federal Communications Commission (FCC) in US defines a broadband connection as one that transmits data at rates of at least 200 kilobit per second (kbps) in one direction [4][9]. Broadband internet service is the most used form of internet access because of its high speed and the incorporation of wireless and the versatility of wireless offer a better 'last mile' service to consumers.
Broadband Wireless Internet and voice telephony facility was inaugurated in 2007 on Kwame Nkrumah University of Science and Technology, KNUST, campus known as the KNUST E-campus Network. The project was the first phase of a comprehensive ICT policy, which is aimed at incorporating all Educational Institutions in the country into the global ICT network with KNUST as the hub [1][2]. The choice of BWA for Educational Institutions should include one that has a smooth evolutional path, and should also meet up to date demand for data services while considering the economics of such an option [10]. Wi-Fi was designed to handle wireless data transmission over a local area – Wireless Local Area Network (WLAN) but was improved to handle voice transmission with its Voice over Internet Protocol (VOIP) services. Although it has some lapses in terms of mobility, security, quality of service (QoS), range of coverage etc.it has stood the test of time and as such is used in most organizations and campuses [13]. The solution to some of the lapses of Wi-

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Fi (Wireless Fidelity) in terms of range and data rates is WiMAX (802.16) standard – World Wide Interoperability for Microwave Access, is a 4th Generation technology, developed to cover a wider range, up to 50 km and give a higher data rates, up to 75 Mbps, using advance modulation and multiplexing techniques [12].
In-view of the lapses of Wi-Fi and the opportunities WiMAX presents, this paper seeks to independently look at the technical concerns and cost of deploying and maintaining these BWA (Wi-Fi and WiMAX) in a typical Education Institution setting. Since many BWA service providers have cost of deploying and maintaining the network and services of a particular technology as a primary question to cogitate for BWA 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. Recently Wi-Fi technology is making up for its lapses due to the improved physical layer technologies available [11]. The result of this has given birth to a new broadband wireless technology - WiMAX. An evaluation of the technical capabilities and the cost of deploying these BWA on an Educational Institution like KNUST, would offer the benefit of choice for deployment.

2. Background

Wireless is becoming the preferred network access method among most mobile users on our educational institutions. It is stated earlier that in comparing wireless technologies some of the key features to consider are the cost of deployment, physical and MAC layer technologies. The physical layer defines the radio wave modulation and signaling characteristics for data transmission, while the data link layer defines the interface between the machine's bus and the physical layer, thus defines an access method close to that of Ethernet standard and sets rules for communication between the stations of the network [3].

2.1 Introduction to 802.11 (Wi-Fi)

IEEE, in 1997, provided a set of specification and standards for Wi-Fi under the title 802.11. 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. These changes in the original protocol have resulted in other specifications of the standard such as 802.11a, b, c, e etc.

2.1.1 Wi-Fi Physical and Data Link Layer

The physical layer modulation formats and coding rates determine how the 802.11 data is sent over the air and at what data rates. For example, Direct-Sequence Spread Spectrum (DSSS) was used in the early 802.11 standards, while Orthogonal Frequency Division Multiplexing (OFDM) is being used by many of the recent standards [3]. The physical layer defines the radio wave modulation and signaling characteristics for data transmission, while the data link layer defines the interface between the machine's bus and the physical layer [3]. The data link layer within 802.11 consists of two sub layers: the logical link control (LLC) and the media access control (MAC). 802.11 uses the same 802.2 LLC and 48-bit addressing as other 802 LANs, allowing for bridging from wireless to IEEE wired networks, but the MAC is unique for WLANs. The 802.11 MAC is similar in concept with 802.3, in that 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 LANs, the Carrier Sense Multiple Access with Collision Detection (CSMA/CD) [14] protocol is used where as in an 802.11 WLAN, collision detection is not possible, as such the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) or the Distributed Coordination Function (DCF) is used.

2.2 Introduction to 802.16 (WIMAX)

WiMAX also known as IEEE 802.16 is intended for wireless "metropolitan area network" (MAN). 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 operates in both licensed and non-licensed frequencies and 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 its speed and range. It offers 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 just like Wi-Fi.

2.2.1 802.16 Physical and Data Link Layer Architecture

The 802.16 solves some of the problems that were introduced with 802.11. WiMAX solves the primary problem of Line of Sight (LoS) transmission. WiMAX LoS is needed for high bandwidth capacity because the standard makes use of constructive multipath interference and uses OFDM for enhanced transmission assurance [10]. At 5GHz and above, Multipath interference becomes so crippling to a system that normal standards can't compensate, thus limiting data rates. This is solved through the use of OFDM (Orthogonal Frequency Division Multiplexing), the data is split into multiple carrier frequencies where 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 [9].

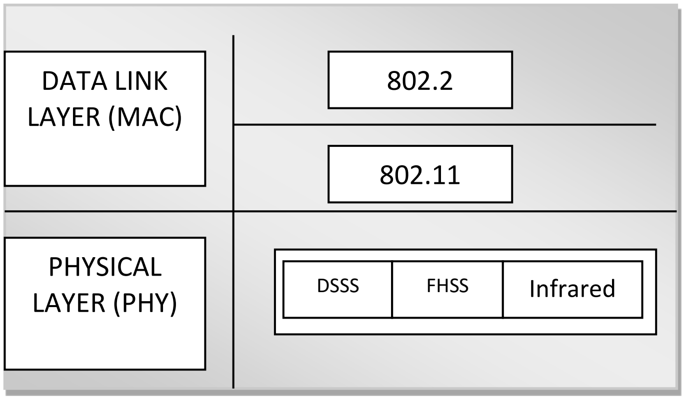


Figure 1: Wi-Fi physical and data link layer [3]

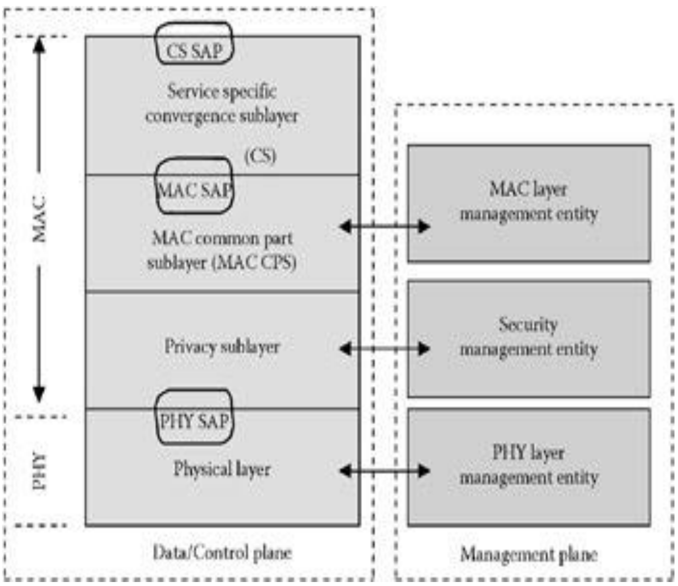


Figure 2: IEEE 802.16 protocol layering [7]

3. KNUST Campus: The Challenges of Wi-Fi Services

Students in the annexes (more than eight floors storey building) 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 of resident far outnumber the total number of practical users the Wi-Fi services on campus can support, coupled with students not adopting best practices (disconnecting Wi-Fi services when not actively using the network) calls for enormous pressure on the system. Also the data requirements of students and staffs like multimedia services, streaming data and so on require higher bandwidths and hence a technology that can offer these services with ease. The Wi-Fi service on campus is inadequate and this is seen from the fact that less than ten per cent (10%) of the student's population use Wi-Fi as seen in Figure 3.

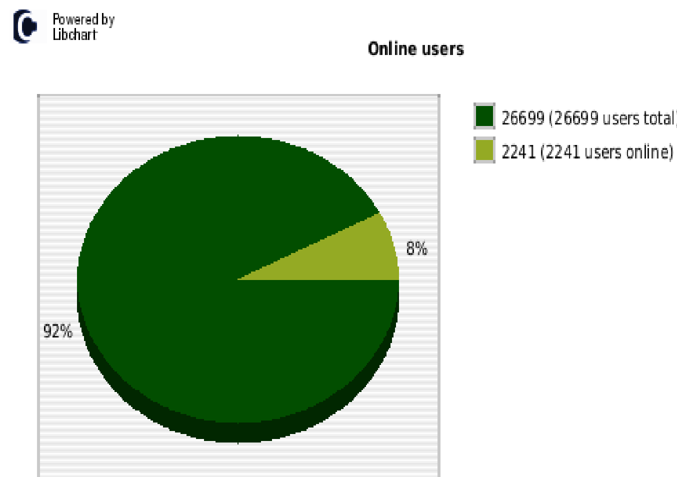


Figure 3: Total number of students using KNUST Wi-Fi on 6th October 2012 12:30pm [2]

4. Modulation Techniques

The variation or changing of the property of a signal, such as its amplitude, frequency or phase is called modulation. The most basic modulation techniques used are the analogue and 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; Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK) [5].

Table 1: Comparison of modulation techniques of some BWA (WLAN and WiMAX) [3], [11], [12]

Wireless Technologies	Versions	Modulation technique- uplink	Range	Data Rates (Mbps)
WLAN	802.11a	BPSK, QPSK, 16-QAM	10 m – 70 m	Jun-54
	802.11b	QPSK	50 m – 500 m	11-Jan
	802.11g	BPSK, QPSK, 16-QAM	27 m – 400 m	Jun-54
WiMAX	802.16	BPSK, QPSK,16-QAM, 64-QAM	10 km - 50 km	32 – 134.4
	802.16a	QPSK, 16-QAM, 64-QAM	5 km - 15 km	Jan-75
	802.16e	QPSK, 16-QAM, 64-QAM, 256-QAM	5 km - 15 km	Jan-75

5. Methodology

The primary data collection method is used, thus, experts within the various field of BWA were interviewed. This approach, though expensive but offers the opportunity to establish rapport with experts and gain their cooperation, clarify ambiguous answers and seek follow up information.
There was the need to ascertain key factors that affect the deployment on any BWA in the case study area. Some of these can be seen in table 2; and others are;

- The current BWA technology deployed; its history and the pros and cons.
- The population of students on campus and the population of student with Wi-Fi enabled devices
- The type of terrain in KNUST; is described as moderately hilly and also survey of the height of buildings and trees available on the campus

Information was collected by interviewing experts in the areas of interest; the KNUST Estate Unit, Network Operation Centre (NOC) and the Registry. This information aided in the way questions where directed to telecommunication experts and equipment vendors thus affecting contributions made like numbers of Base Transmission Stations (BTS) required for the case of KNUST.
The main technical issues considered in this work are effective data rates and range of coverage; these are implemented in the physical layer. The physical layer properties that affect these qualities are basically modulation techniques and antenna techniques used. Comparisons of simulations of some modulation techniques – QAM, PSK etc. using MATLAB were analyzed. MATLAB being one of the programs of choice for technical computing.

Table 2: Some Cost Questions directed to Equipment Vendors and Telecommunication Industries

1. Cost of establishing a BTS in Ghana	5. The cost of establishing core network for Wi-Fi and WiMAX
2. Cost of erecting tower in Ghana	4. The effect of the population on the number of BTS to establish.
3. The effect of the terrain on the number of BTS to establish	6. The cost establishing backhaul provisioning for Wi-Fi and WiMAX
7. Cost of maintaining the network	

Experts of three (3) telecom industries and two (2) equipment vendors honored the interviews. 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 sought, thus a cost analyzing tool that closely reflects the views of interviewees; Interactive WiROI LTE/WiMAX Case Analysis Tool GUI- demo version.
Wireless Return on Investment (WiROI) is an analysis tool for use by WiMAX service providers planning to deploy a Broadband Wireless network. It provides an easy to use, 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. [6]

5.1 Overview of KNUST Land Area

KNUST has a total land area of about 3,959.525 acres (16.024sq. km) where the campus is situated is about 2,562.814 acres (10.371sq km) and the remaining is the School farm not developed. The student population is about 27,000 and the estimated number of students and staff with Wi-Fi enables devices is around 5000[2], this clearly points to the fact that the current Wi-Fi system is inadequate. For coverage there is the need for the campus to look at a cellular approach to meet total campus coverage – WiMAX which is a Metropolitan Area Network. Figure 3 supports the inadequacy of Wi-Fi services on KNUST campus.

5.2 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. It had a theoretical range of about 100m and a practical range of 50m and could practically support 10-50 users concurrently [2]. This could not support the total number of students and staffs with Wi-Fi enabled devices.

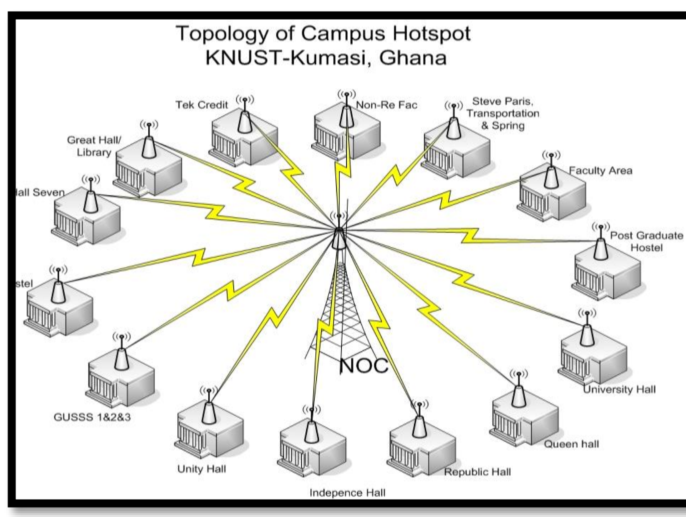


Figure 4: Topology of Campus Hotspot KNUST-Kumasi, Ghana [2]

Table 3 Typical Wi-Fi and WiMAX Cost – KNUST Campus [6]

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**

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

5.3 Bit Error Rate for the Various Modulation Techniques

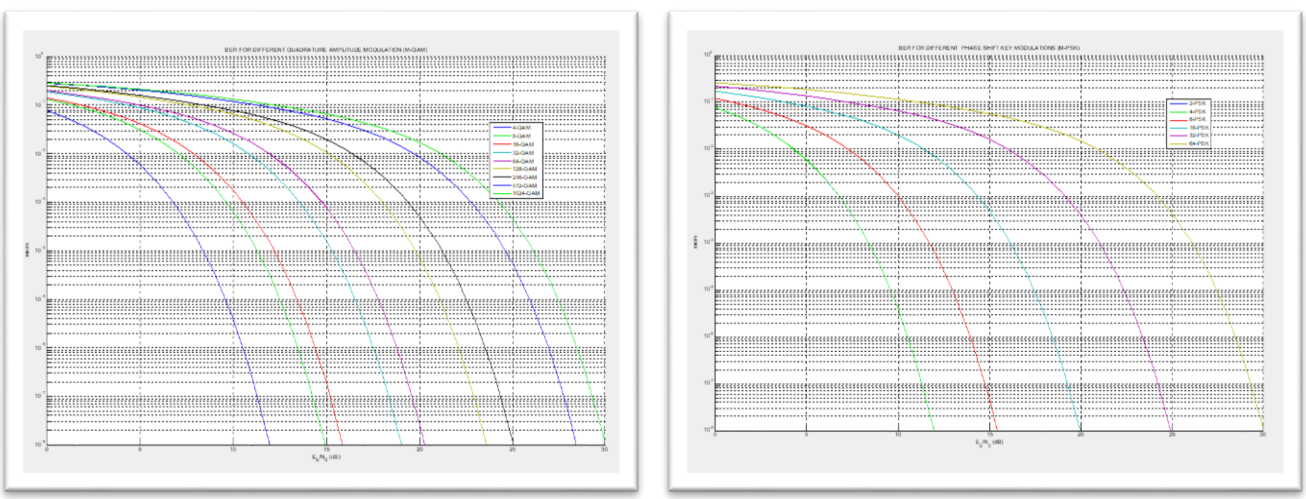
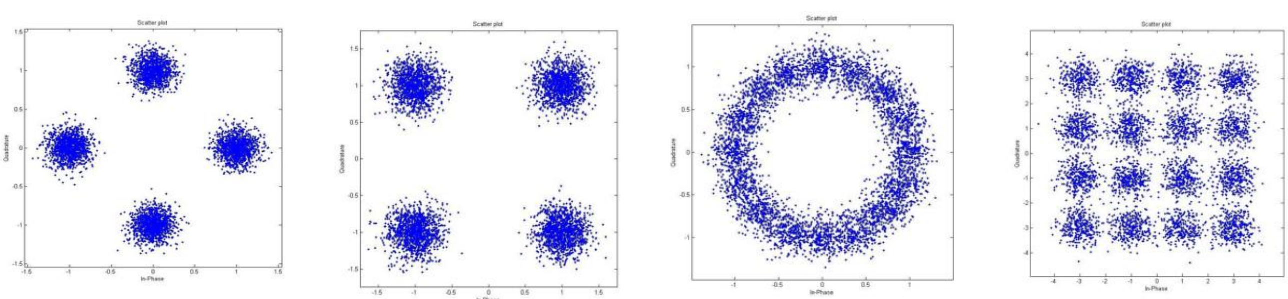


Figure 5 Comparison of modulation techniques (M-QAM and M-PSK)



4-PSK 4-QAM 16-PSK 16-QAM

Figure 6: Constellation diagrams using MATLAB

6. Results and Discussions

In comparing the performance of various modulations techniques, we will take a look at the energy per bit to noise power spectral density (Eb/No) also termed as SNR. This is useful when comparing the Bit Error Rate (BER) performance of different digital modulation schemes without taking bandwidth into account.

$$\frac{c}{n} = \frac{Eb}{No} * \frac{fb}{B} \quad (1)$$

fb is the channel data rate   B is the channel Bandwidth

$$\frac{c}{n} = 10\log10\left(\frac{Eb}{No}\right) + 10\log10\left(\frac{fb}{B}\right) \quad (2)$$

The technical analysis was performed using MATLAB to evaluate the performance of the physical layer technologies of the BWA under Additive White Gaussian Noise (AWGN). 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 and 6

A graphical representation of the signal set is termed signal constellation and 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 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 show in figure 5, thus 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]. The more the distance between the constellation points, the greater is the chance of a constellation point getting decoded correctly, see Figure 5.

Wi-Fi has been the most sought technology for BWA by most educational institutions because it has very low infrastructural cost, Table 3; the fact that it also operates in the unlicensed spectrum makes it much cheaper. The Capital Expenditure of WiMAX is also higher than that of Wi-Fi but the physical layer technologies can achieve almost similar data rates for both technologies; this is seen in table 1. The CAPEX cost can be amortized over the life span of the equipment hence a less capital intensive initial outlay for KNUST. Also the capital expenditure consumes a larger percentage of total initial cost but the OPEX will outweigh the initial outlay over time.

6.1 Notable Considerations

- The campus is owned by the state and as such cost such as site rent (lease) would not apply
- The cost of a base station (BS) might not necessary include the cost of erecting a high mast since the high buildings on campus can be used and will reduce the tower height and hence construction cost.
- In the case of OPEX the campus has an established ICT department with a NOC that handle maintenance and other works on the current Wi-Fi and as such the budget for personnel would only be looked at in terms of training to handle more advance systems in the new technology (WiMAX).
- WiMAX will interoperate with existing wireless technologies, offering handover across access platforms including Wi-Fi. A number of companies have worked on creating devices that bridge across the difference between Wi-Fi and WiMAX.

7. 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 and would suit 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. 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 considerations to adopt WiMAX that would require fewer Base Stations would be better. WiMAX transmission rates is by far better than its respective previous standards, hence the technologies of choice for cellular infrastructure for educational institutions like KNUST. Simulation results put WiMAX ahead of its parent technologies, Wi-Fi. Although both technologies can implement adaptive modulation techniques but the cost tables on the other hand spelt some difference in the deployment of WiMAX.

Observations and Recommendations

Educational institutions with small campus size like, 1 Sq. Km can deploy improved versions on Wi-Fi, 802.11n, that offer good data rates. Educational institutions with large campus size and population like, KNUST, University of Ghana, and University for Development Studies in Ghana can adopt a cellular approach to meet their data demand and coverage. WiMAX is currently designed to co-exist with Wi-Fi; as such KNUST can maintain the current Wi-Fi infrastructure and deploy WiMAX as a backhaul technology on campus.

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