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A PROPOSED DEPLOYMENT OF 3RD AND 4TH (LTE) GENERATION MOBILE NETWORK FOR EDUCATIONAL INSTITUTIONS – KNUST AS A CASE STUDY

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Abstract: *Most Educational Institutions patronize BWA (Wi-Fi) for academic research work and this has left them with the challenge of the most suitable technology and the cost of deploying it. Network Administrators and School's Management are tasked with offering the best services economically. Wi-Fi operates in the unlicensed spectrum and has low infrastructural requirements; it suits institutions with relatively small land size and small population. Its adoption to support wider coverage and a greater number of users is not advisable and as such the need to adopt a cellular approach that requires few Base Stations as to many Access points. This research focuses on some of the technically issues that define 3G and LTE and the cost considerations in a typical Educational Institution.*

A study of the theoretical strength and weaknesses of the physical and MAC layers of the 3G and LTE and a general overview of BWA, its history, benefits and challenges, and the current topology of BWA on Kwame Nkrumah University of Science and Technology (KNUST) campus is presented in this work.

This continues with a theoretical comparison of the modulation techniques, Bit Error rate (BER) and signal constellations backed with MATLAB simulations. There is also an in-depth assessment of the parameters that define the cost of deploying 3G and LTE in an Educational Institution; Capital Expenditure (CAPEX) and Operational (OPEX).

The CAPEX for both 3G and LTE are almost the same and the CAPEX consumes a larger percentage of the total initial cost but the OPEX will outweigh the initial outlay over time. Although, 3G and LTE operate in the licensed spectrum and require high infrastructural investment the CAPEX cost can be (as is always the case) amortized over the life span of the equipment this make it easier for most Institutions to bear the high initial CAPEX cost.

Index Terms: BWA, CAPEX, OPEX, 3G, 4G, LTE, BER

1. INTRODUCTION

Wireless means transmitting signals using radio waves and medium instead of wire or fibre. Broadband wireless is a point-to-multipoint system made of a base station and subscriber equipment. It offers an effective, complementary solution to wire line broadband and promises high-speed connection over the air [3]. 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, connection is quite limited due to the laying down of cables and the expensive nature of fibre-optics. The latest development in broadband internet is the incorporation of wireless which offers a better 'last mile' service to consumers. Broadband wireless access has encouraged 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. These emphasize the need to develop economically realistic network architecture for Educational Institutions.

3rd Generation (3G) cellular network is currently one of the most established cellular data services and comes with a smooth evolutionary path with 3rd Generation Partnership Project-Long Term Evolution (3GPP-LTE), a 4th Generation technologies that promise higher data rates, Quality of Service (QoS), Security, coverage.

2. History of the Generations' (G's)

The Advance Mobile Phone Service (AMPS) system is generally a 1G mobile system which use analogue FM transmission designed primarily to handle voice transmission. The 2G cellular mobile technology was digital and based on a digital TDMA and it addresses the capacity problems of the analogue 1G. The TDMA and CDMA - based systems designed to provide GSM with packet-switched capabilities are referred to as the 2.5G systems. The 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 WCDMA. It employs advance modulation and multiplexing techniques and multiple antenna techniques to achieve higher data rates and wide range of transmission.

3. Justification, Scope and Main Objective of Research

The National Communication Authority (NCA), Ghana in January, 2011, issued a release inviting potential buyers of BWA licenses in the 2.5GHz – 2.69GHz band for the

deployment of WiMAX and LTE. The digital migration team has worked to release spectrum for the deployment of LTE [1] this made the deployment of LTE in Ghana feasible. This begun the journey for LTE deployment and lately some Telecom industries have announced deployment of LTE.

Most educational institutions have deployed broadband wireless technologies using Wi-Fi but the challenges to meet campus requirements of concurrent users, higher data rates and wider range is ever present. Broadband Wireless Access has offered enormous benefits to Educational Institutions. It is the main drive for exchange of data (information) between personnel. The BWA in various Educational Institutions has;

- Enhanced teaching and learning; distance learning, e-conferencing, video-conferencing etc.
- Assisted students' research, access to on-line information–e-library, journals, and publications.
- Improved security through its close circuit television (CCTV) cameras system.

This research will aid some Educational Institutions to make technical and cost decision in their choice of BWA technology. This is achieved by assessing the physical layer technologies with more emphasis on modulation techniques, BER and a further assessment of the cost of deploying these technologies in a typical Educational Institution (KNUST). The BWA considered in this research work are 3G and LTE. Making an informed judgement on the BWA technology of choice for Educational Institutions, KNUST requires both technical and cost analysis. 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.

4. 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. 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 [4].

The 1G technology had very low speed and supported voice only and analogue features. The 2G had speeds less than 29Kbps and utilized features like push-to-talk, voice, conference calls, call ID and SMS. 2.5G technology had 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 had speeds 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 with speeds ranging from 384Kbps up to 14.04Mbps offered video conferencing and Video-on-demand. The 3GPP-LTE (4G) has speeds ranging from 100Mbps to 1Gbps and offers high quality Video conferencing, streaming, voice-over-IP telephony and mobile TV.

4.1. G and LTE – Physical and MAC Layer Technologies

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. The 3G physical layer offers service to the RLC layer by means of the logical channels [9]. LTE physical and MAC layers are designed to meet carrier needs for high-speed data and media transport as well as high-capacity voice support. LTE employs OFDM for downlink data transmission and SC-FDMA for uplink transmission. The principal improvement being that the SC-FDMA has a lower PAPR over conventional OFDM - approximately 2 dB than OFDM [8].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 [9][10].

5. KNUST Campus and the Pros and Cons of Various Technologies

Wi-Fi is the available BWA for academic research work on KNUST campus though some students use USB dongles and tethering (smart mobile devices). The number of users outnumbers the total number of practical users the Wi-Fi services can support. Also the bandwidth data intensive requirements of students and staffs calls for a technology that can offer these services with ease. These Wi-Fi hotspots are concentrated at the various halls of residence and the faculties. There is the need for a campus wide coverage of BWA services with an excellent data rate that would offer staff and students the comfort of working anywhere on the campus. It justified that Wi-Fi generally the following limitations;

- It can support relatively few concurrent users
- It has a micro footprint (low coverage per hotspot)
- It has greater interference with other services in the unlicensed spectrum.

- It has poor security, especially with its WEP.

Since the Wi-Fi services on campus are inadequate, most staffs and students have resorted to data services offered by the various telecommunication industries. In view of the limitations the current Wi-Fi system offers, there is the need for KNUST to migrate to an advance cost effective technology that can mitigate the limitation of Wi-Fi.

3G is one of the technologies used to offer data services by most telecommunication industries. It has stood the test of time in its 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 - when one cannot connect to the Wi-Fi services due to congestion or work at a location due to limited coverage.

The 3G system offers these advantages over the current Wi-Fi system on campus; wider footprint (wider coverage), support a comparatively greater number of concurrent users, solves interference problems with other microwave or cordless phones with its licensed spectrum and good security policy. This mean 3G could serve as the BWA technology of choice to meet campus data services.

6. Methodology

The primary data collection method was used and experts within various field of BWA were interviewed. Information about certain key factors that affect the deployment of 3G and LTE in the study area was collected. These include;

- The cost of deploying the current KNUST BWA – Wi-Fi
- The total land size of KNUST and the current Wi-Fi topology of KNUST
- 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
- The population of students on campus and an estimate of the population of student with BWA enabled devices
- 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 NOC and the School Registry. The information collected was used to established the inadequacy of the current BWA deployed and 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

6.1. Establishing Cost Parameter for 3G and LTE deployment

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 3G and LTE. Telecommunication equipment vendors were made to elaborate on their views on the cost of deploying 3G and LTE in KNUST. Some of these questions are; Cost of establishing a BTS in Ghana, Cost of erecting tower in Ghana, the effect of the terrain on the number of BTS to establish, the effect of the population on the number of BTS to establish, the cost of establishing Core Network, the cost establishing backhaul provisioning, cost of maintaining the network, cost range of a customer premise equipment [13]

Answers to this information among others were used to build up the cost of deploying 3G and LTE 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 honored the interview. Some of the experts gave cost values in ranges, stating company policies as reasons why they cannot be specific. As a result a second opinion was sought, thus a cost analysing tool that closely reflects the views of interviewees; Interactive WiROI LTE/WiMAX Case Analysis Tool GUI- demo version [6].

6.2. The Cost Analysis Tool – The Wireless 20|20 WiROI™ Business Case Analysis Tool

WiROI is a Wireless Return on Investment (ROI) Analysis tool used by BWA 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.

Figure 1: Wireless Return on Investments (WIROI) 3G – LTE CAPEX [6]

6.3. Technical Assessment of BWA – Modulation Techniques

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, BER and antenna techniques used. A comparison of the 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 modeling analysis.

6.4. 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 100 m and a practical range of 50 m 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.

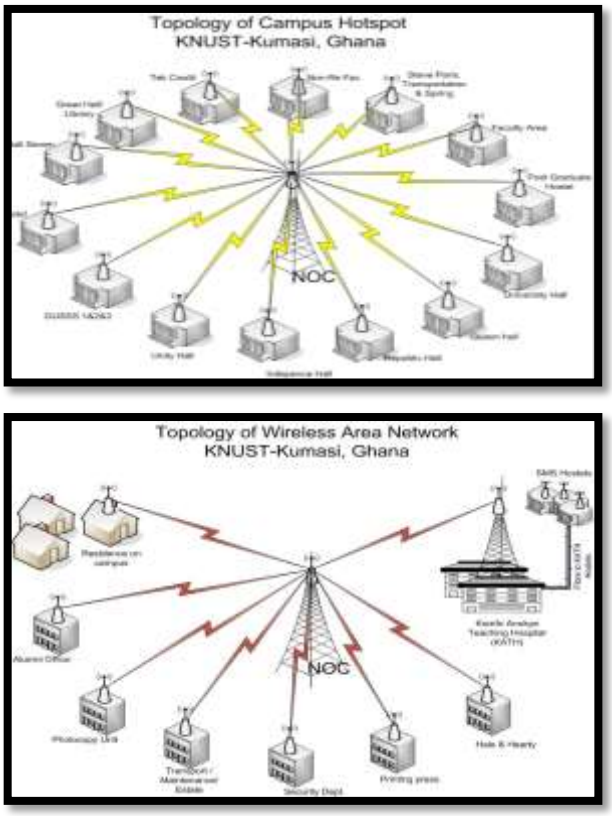

Figure 2: Topology of Campus Hotspot and Hotspot Serving Students in KATH – KNUST Kumasi, Ghana

*KATH – Komfo Anokye Teaching Hospital

6.4.1. 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 [7], 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.

KNUST has a reasonable land size that can support the deployment of a cellular infrastructure3G has its own technological disadvantages or limitations;

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

These limitations of 3G call for a technology that solves these limitations and is most importantly economical – 3GPP-LTE. 3GPP-LTE and is the technologies considered to meet up to date demand of data services and to resolve the

critical limitations of 3G. LTE 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 LTE enhanced data rates, foot-print (coverage) and spectral efficiency etc.

6.5. 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; Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK) and Phase Shift Keying (PSK)

6.5.1. 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 an angle of 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 [11].

6.5.2. Quadrature Phase Shift Key (QPSK)

This modulation technique is sometimes called quaternary PSK. It is effectively two independent BPSK systems (I and Q) and therefore exhibits the same performance but twice the bandwidth efficiency. It also has variations that include Offset QPSK, Pi/4-QPSK, and DQPSK.

6.5.3. 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 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 [5]. 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.

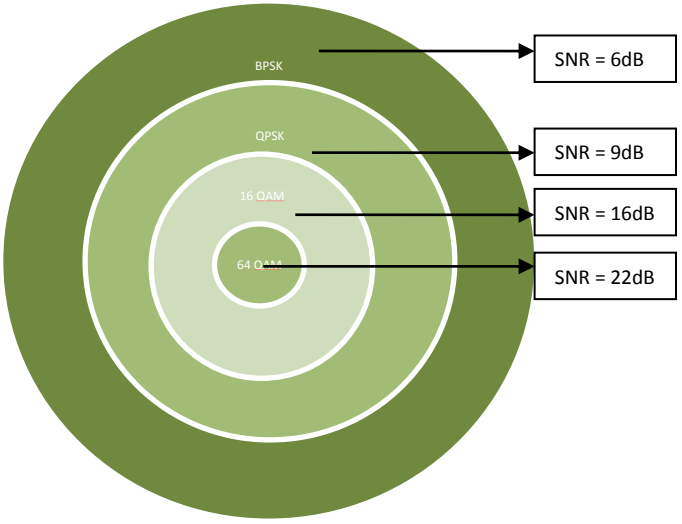

Figure 1 Comparison the range of some modulation techniques [12]

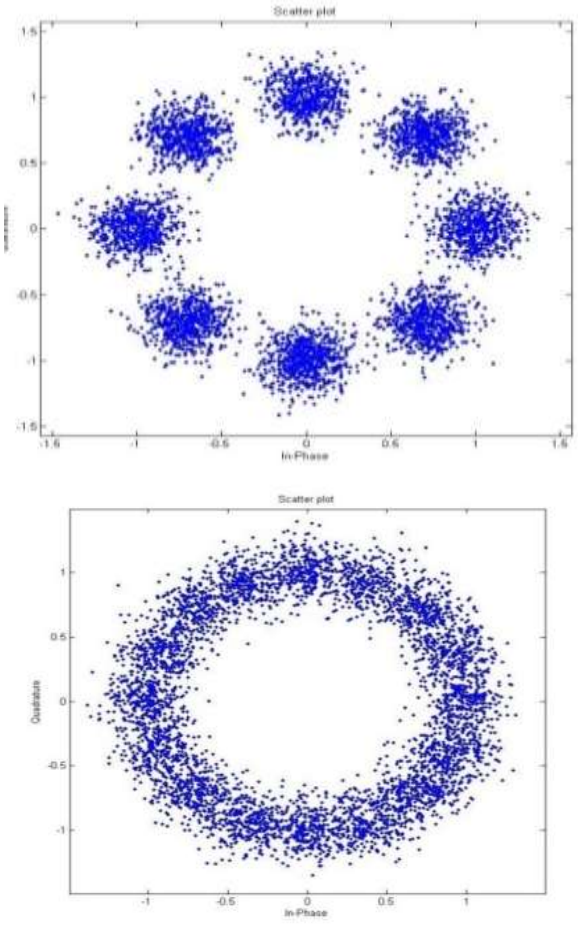

Figure 4: Signal Constellation Diagram showing 16-PSK using MATLAB

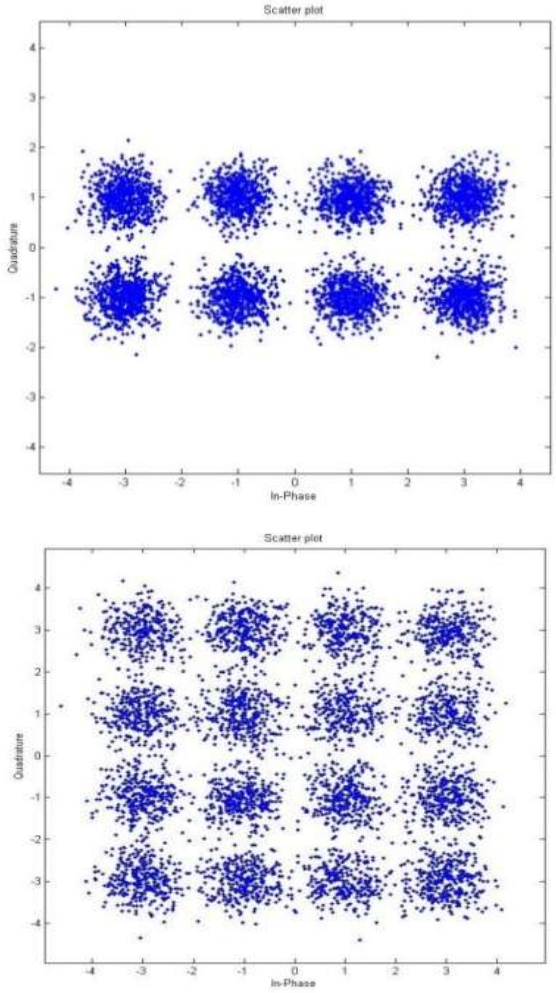

Figure 5: Signal Constellation Diagram showing 16-QAM using MATLAB

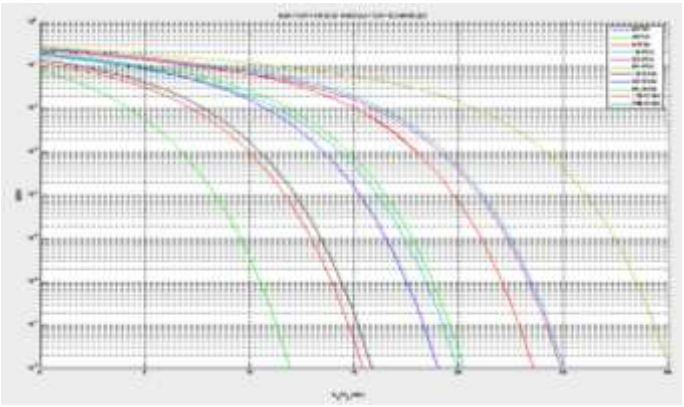

Figure 6: Simulation of and Bit Error Rate and Energy per noise spectral density of some PSK and QAM

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. The cost of deployment always involves a host of factors which are broadly categorised as; CAPEX and OPEX. The CAPEX normally consumes a larger percentage of the total cost but the operating expenses will outweigh the initial capital outlay over time. 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 etc.

Table 1 (a) Typical 3G costs – KNUST Campus [6]

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

(b) Typical LTE Cost - KNUST Campus [6]

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

6.6. Discussion of Cost Results

Wi-Fi is the most implemented BWA since it has very low infrastructural cost and also operates in the unlicensed spectrum. The challenge of Wi-Fi can be compensated for by using a cellular technology – 3G and LTE. The 3G infrastructural cost is similar to LTE but LTE is a 4G technology that meets up-to-date demand for data rates, range and support for concurrent users. Also LTE Self Organizing Network (SON) features, allows automation of previously manual tasks in 3G – this minimizes OPEX on LTE

Base Station: 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 3G 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 3G is almost the same as that of LTE.

Backhaul Provisioning: The equipment cost for backhaul provisioning for 3G and LTE are almost the same [see table 5]. LTE has the advantage of operating in a wider spectrum including the current 3G spectrums as well as re-farmed spectrum after the digital divide. 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; diagnosing, troubleshooting and repairing components that do not work as planned. The cost of maintaining LTE is comparatively cheaper since the level of automation is high and its backward compatible with 3G, also they have similar architecture as such little training is required to upgrade personnel to handle LTE systems. The CAPEX normally consumes a large percentage of the total cost but the operating expenses will outweigh the initial outlay over time.

Notable 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 enjoy significant infrastructural cost savings 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. LTE implements OFDMA in the downlink which is power inefficient due to high Peak-to-average Power ratio (PAPR). In the uplink LTE implement SC-FDMA (Single Carrier Frequency Division Multiple Access) which offer lower PAPR that saves power.

5. LTE will interoperate with existing 3G, offering handover across access platforms including Wi-Fi, GSM and CDMA.

6.6.1. Conclusion

The challenge that the BWA deployed on KNUST faces have been enumerated and the technical and cost analysis of 3G and LTE technologies compared for a typical Educational Institutions. The technical analysis was performed using MATLAB to evaluate modulation techniques and BER under Additive White Gaussian Noise (AWGN). Data collected from interviews and supported with that of a cost analysis tool, WIROI 20/20 3G and LTE Calculator is used to offer the cost comparison. It is feasible for some Educational Institutions to consider 3G or LTE for campus coverage. 3G has stood the test of time but LTE is a 4G technology that offers better coverage and data rates.

KNUST would deploy 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 bear the high initial CAPEX cost.

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