Journal of Computer Networks, 2013, Vol. 1, No. 3, 38-45
Available online at http://pubs.sciepub.com/jcn/1/3/1

DOI:10.12691/jcn-1-3-1

Broadband Wireless Access Deployment Approach to Rural Communities

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Received August 03, 2013; Revised August 15, 2013; Accepted August 16, 2013

Abstract Broadband wireless access networks are enterprise level networks that provide more capacity as well as coverage. In rural inaccessible areas, wired networks are not at all cost effective. Wireless networking offers an alternative solution for such problem of information access in rural areas. They have definitely changed the way people communicate and share information among themselves by overcoming problems nowadays associated with distance and location. This paper describes the frame work for deploying Wi-Fi and WiMAX technologies in Jeddo, a rural community in Warri, Nigeria. Wi-Fi / WiMAX technologies have not only the potential to compete on a cost-per-megabyte basis with cable and Digital Subscriber Line (DSL), but also make ubiquitous broadband access a reality. If engineering and economics are correctly applied, a Wi-Fi network can be built around an entire rural community with a WiMAX backhaul, instead of providing limited coverage for hotspots. This paper further outline the technical aspects of WiFi and WiMAX, discuss the network planning issues to implement these technologies, survey their network infrastructure and different components as well as explore how they are leveraged by service providers to offer wireless broadband internet connectivity and services.

Keywords: *Wi-Fi, WiMAX, Broadband wireless access networks, Jeddo community*

Cite This Article: Ibikunle Frank, Jakpa Orunta, and Ike Dike, "Broadband Wireless Access Deployment Approach to Rural Communities." *Journal of Computer Networks* 1, no. 3 (2013): 38-45. doi: 10.12691/jcn-1-3-1.

1. Introduction

Presently, the use of Internet and mobile communication has increased tremendously, the statistics in Nigeria shows that there are more than 50 million internet and mobile users in Nigeria in May 2012 [1]. Nigeria has the highest number of internet and mobile users in Africa and ranks top 20 in the world, with a population of about 160 million people, the internet penetration ratio in Nigeria is about 27%, which is still low. Major population in Nigeria resides in remote areas where access to basicamenities like telephony, internet etc. are difficult to provide. Broadband wireless access have become the best way to meet the demand for rapid Internet connection and integrated data, voice and video services in remote and rural areas. Broadband wireless access can extend fiber-optic networks and provide more capacity than cable networks or digital subscriber line [1]. The free license band spectrum (IEEE 802.11b, 2.4 GHz Band) of Wi-Fi, the easy availability of Wi-Fi devices, and very good QoS features of WiMAX, makes it suitable to provide long range communications for rural areas and can satisfy bandwidth requirement at proper price that suits rural people. The benefits of this integration include cost-effective backhaul with long range, interference-free, licensed WIMAX and the cost effective access of Wi-Fi clients. In the technical white paper in [2], they analyzed various user scenarios for deployment models of WIMAX and Wi-Fi together. Dowdin [3] also discusses Wireless WAN/LAN solutions for schools using combined WIMAX and Wi-Fi. This paper is organized as follows. Section II gives an overview of WiMAX and Wi-Fi technologies. Section III highlights the network planning issues required to implement these technologies. Section IV gives the network architectural framework for the design of Wi-Fi and WiMAX integrated system in Jeddocommunity. While in Section V, we draw the conclusion on the paper.

2. Overview of WiMAX and Wi-Fi

2.1. Wi-Fi (Wireless Fidelity)

Wi-Fi stands for Wireless Fidelity and belongs to the IEEE 802.11 (an international standard describing the characteristics of a Wireless Local Area Network) family of standards which is primarily, a local area networking (LAN) technology that can be likened to a highly localized adaptation of MMDS, which does not require line of sight [5]. Today Wi-Fi has become the standard for broadband connectivity in homes, offices, and public hotspot locations [6]. Wi-Fi permits connectivity to the internet with speeds of up to 54 Mbps. Wi-Fi devices use technologies based on the IEEE 802.11 standard to transmit data with the aid of a wireless access point [7]. Wi-Fi functions within a low frequency range, its transmitters operate at low power and still achieve ranges

of up to 30m indoors and up to 450m outdoors. The first 802.11 wireless network standards were developed in 1997; it supported a maximum speed of up to 2 Mbps using Frequency hopping spread spectrum and direct sequence spread spectrum as modulation techniques [8]. The foremost use of Wi-Fi is to provide local wireless connection to communication equipment, e.g. PCs, VoIP within customer premises.

Figure 1. A Wi-Fi System

Table 1. 802.11 Wireless family standards widely used today and their properties [25]

STANDARD	PROPERTIES
IEEE 802.11b	1. High data rates of 11Mbps with a range of 100m to max of a few hundred meters. 2. Operates on 2.4GHz unlicensed band. 3. It uses the DSSS modulation technique that is more reliable than the FHSS.
IEEE 802.11g	1. Operates on 2.4GHz band and has corresponding range & properties as 802.11b. 2. It has a data rate of 54Mbps. 3. It has backward compatibility with 802.11b 4. It uses OFDM, making the 802.11b devices not able to pick the signal from the 802.11g devices.
IEEE 802.11a	1. Operates in the 5 GHz band with a maximum data rate of 54Mbps. 2. It cannot co-exist with 802.11b and 802.11g standards as they operate on different frequency bands.

Recent Wi-Fi standards support data rates up to 54Mbps and encryption software is used to provide user security. Wi-Fi hotspots are premises such as airports, restaurants which have set up local Wi-Fi connectivity to the internet. However, at present the 54Mbps per channel capability limits the end user to approximately 1Mbps data rate.

2.2. WiMAX (World-wide Interoperability for Microwave Access)

WIMAX stands for Worldwide Interoperability for Microwave Access and is characterized under the IEEE 802.16 working group. It is a broadband wireless access technology that provides fixed, nomadic, reliable and mobile communication across wired and wireless connectivity. The 802.16 group was created to attend to specifications for wireless Metropolitan Area Networks (WMANs). This implies that 802.16 is intended to reach out to areas more like mobile networks, and many advocates of WIMAX view it as a possible choice for the next generation of cellular networks. Orthogonal Frequency Division Multiplexing (OFDM) is the central modulation technique used in WiMAX, both systems utilize multiple input multiple output (MIMO) techniques [10]. It is designed to deliver Wi-Fi type connectivity over a much greater range and thereby compete as a point-to-multipoint last mile broadband wireless access solution. WIMAX is promoted by the WIMAX forum; it has been designed to be a cost-effective way to transport broadband access over a large area. It is intended to handle high voice, data and video services while offering a high QoS. WIMAX products can allow fixed and mobile usage models across a range of applications. The IEEE 802.16 standard was introduced to deliver NLOS connectivity between a subscriber station and base station [11].

WIMAX operations are defined over frequencies between 2 and 66 GHz, Line of Sight (LOS) at a range up to 50 km (30 miles) and 2 to 11GHz non-Line of Sight (NLOS) typically up to 6 - 10 km (4 - 6 miles) for fixed Customer Premises Equipment (CPE). It is able to provide radio coverage distance of almost 50 kilometers and data throughput up to 75 Mbps. The data rates for the fixed standard will support up to 75 Mbps per subscriber in 20 MHz of spectrum, but typical data rates will between 20Mbps and 30Mbps. The mobile applications will support 30 Mbps per subscriber, in 10MHz of spectrum,

although typical data rates will be 3 - 5 Mbps [12]. WIMAX specifies two classes of services and they are fixed WIMAX and mobile WIMAX. The fixed WIMAX is created to deliver wireless connection that is fixed through backbone network and IP network. The mobile WIMAX ensured the implementation of mobile connectivity service for computers and Personal Digital Assistants through cellular network with the same output. WIMAX integrates its wide coverage area with Quality of Service (QoS) potentials to provide various application services like VOIP, data service, IPTV, streaming media service. WIMAX uses air-interface technology to enable point-to-multipoint connectivity with the advantage of Non-Line-of-Sight (NLOS) from the base station. WIMAX also delivers last mile broadband connections, hotspots, high-speed enterprise connectivity for residential and business users and WIMAX networks are often used to backhaul data from Wi-Fi access points [13].

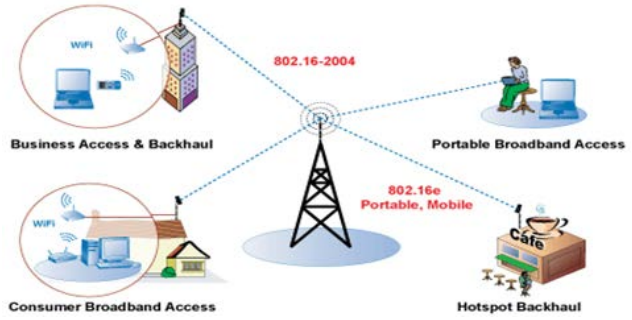

Figure 2. An example of WIMAX providing Internet Access [14]

The WIMAX MAC layer uses an intelligent scheduling algorithm that allows subscriber stations to compete only once for initial entry into the network. Furthermore, this maintains balance in overloaded circumstances which results in better bandwidth efficiency. OFDMA is a multiuser version of OFDM (it has the ability to dynamically assign a subset of subcarriers to individual users) that was added in the 802.16e revision of WIMAX which permits multiple users to transmit concurrently at low data rates. The 802.16e revision integrated support for MIMO smart antenna technology. This technology divides individual signals into sub-channels so they can support multiple users at once. Multiple antennas are used to improve speed and range, enabling WIMAX to carry more data traffic [15].

2.3. WiMAX and Wi-Fi Interworking

The inter-working between WiMAX and Wi-Fi enable Internet Service Providers to deliver consistent, effective, and reliable broadband services to their subscribers. Achieving this requires two key elements; multi-mode subscriber devices that can communicate on both networks and the ability to provide service across both networks when users move between them. Each WiMAX base station is primarily intended to deliver very high bandwidth to a relatively few number of endpoints. WiMAX bandwidth and distances covered vary inversely, and are both significantly impacted by local topology. The high speeds and long distances claimed for WiMAX are primarily for line-of-sight installations. In contrast, real-world installations must deal with hills, foliage, and other obstructions. For this reason, it is often necessary to use larger numbers of wireless nodes to provide continuous coverage in the desired areas. Wi-Fi wireless mesh nodes offer an easy way to provide wider coverage using the unlicensed spectrum, delivering the WiMAX bandwidth more broadly. This combination leverages the best of both Wi-Fi and WiMAX in the combined network, each technology contributing to better efficiency, lower cost, and broader coverage. Bandwidth is delivered to multiple points in the Wi-Fi wireless mesh network via high-speed WiMAX links rather than via wires or fiber drops. End-user devices, equipped only for Wi-Fi, can then access the network through the Wi-Fi wireless mesh. This merged network topology may deliver far better overall performance and lower overall cost than would a networkbuilt on either WiMAX or Wi-Fi wireless mesh alone [16]. WiMAX and Wi-Fi internetworking architecture is shown in Figure 3.

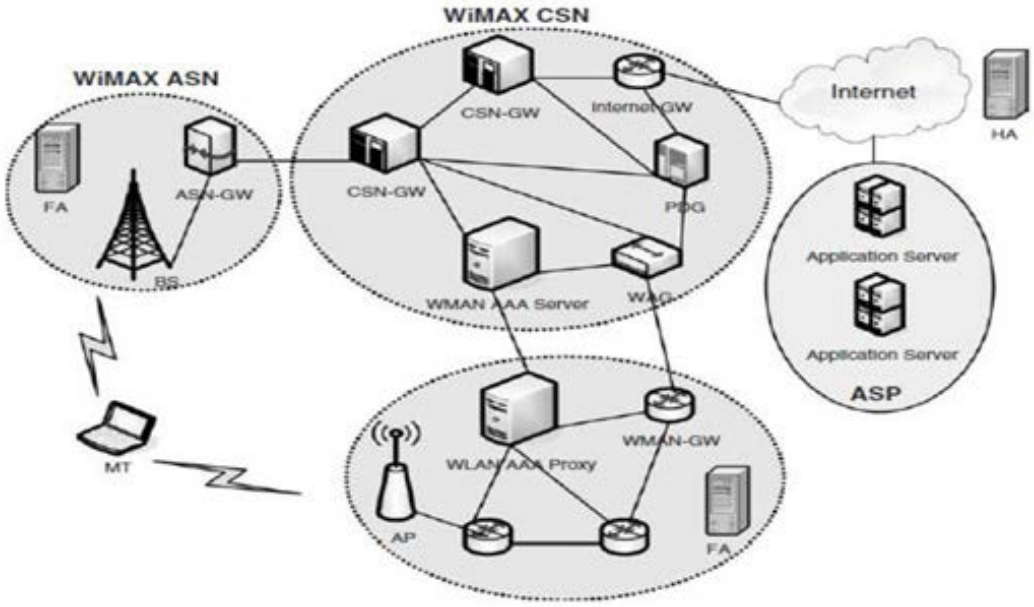

Figure 3. WiMAX and WI-FI Internetworking Architecture [16]

3. WiMAX and WI-FI Network Planning

3.1. Description of Jeddo Community

Jeddo community is located at 5° 35' 30.41"N, 5° 42' 51.07"E with an elevation of 41ft in Warri-South Local Government Area of Delta State, Nigeria, behind or adjacent to the Warri Refinery with a population of about 3,000 people. The community is close to the Warri River that leads to Warri Sea Port. Economic activities in this community include fishing, agriculture, and so on. The infrastructures/buildings and social amenities in Jeddo community which we will be considering for our network design include the Jeddo Community Town Hall, JeddoGrammer School, Jeddo Nursery and Primary School, Jeddo Market, and so on. Figure 4gives the Google Earth view of the Jeddo community.

Figure 4. Google Earth Image of Jeddo community

3.2. WiMAX and Wi-Fi Network Planning Process

The process flow diagram for the design of a WiMAX and WI-FI network for Jeddo community is as shown in Figure 5.

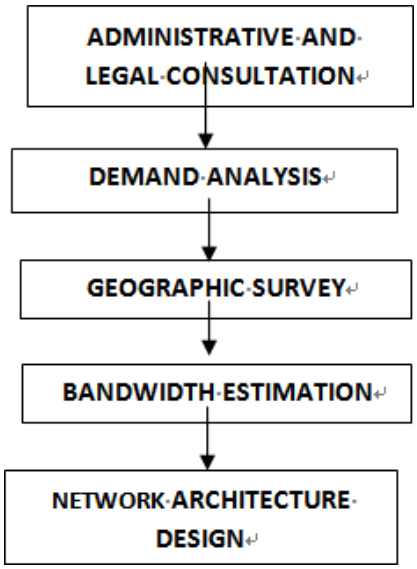

Figure 5. Flow Diagram of WIMAX and Wi-Fi Network Planning Process

3.2.1. Administrative and Legal Consultation

The policy maker must certify that appropriate legal framework and administrative laws are in place before the infrastructure can be erected and operated and determine the type of services to be provided. Also the licensed spectrum (frequency range) used to operate the network must be able to provide all services in the region intended for coverage, in this case the region is Jeddo [17].

3.2.2. Demand Analysis

People in rural areas want to communicate with both people in the rural and urban areas for many reasons because communication is a vital part of their daily social, political, and economic activities. As a result of this, there is a high demand for high speed internet access [17]. Demand studies are used in developing broadband projects to determine, and must take into consideration the following:

(i) The level of demand for different internet services at acceptable prices, so that the rural population can afford it.

(ii) The minimum level of financial costs needed to satisfy the demand.

There are four basic steps in determining demand in rural areas like Jeddo, they include:

i) Collect and analyse the quantifiable statistics of the given population of the rural area, the economic position of individuals in the community, geography (terrain), traffic and tariffs.

ii) Collect, compile and analyse primary micro economic data of the population of the rural area involved, including companies and institutions, by means of information gathering tools like questionnaires and interviews.

iii) Use econometric modelling techniques to determine the demand functions

iv) Appraise and put forward the results, with an evaluation of their relevance to the goals of the institutions that require the demand estimates for the provision of the internet access.

3.2.3. Geographical Survey

Select and determine the precise location of all settlements in the rural community. This can be done using advanced Geographic Information Systems (GIS) techniques. A geographic information system (GIS) is used to combine software, hardware, and data for capturing, managing, analyzing, and displaying all forms of geographically referenced information. GIS allows for viewing, interpreting, and visualizing data in many ways that reveal relationships, patterns, and trends in the form of maps, globes, reports, and charts. A GIS is used to deal with problems by viewing data in a way that is quickly understood and easily shared.GIS technology can be incorporated into any enterprise information system framework [18]. Modern GIS technologies use digital information, for which various digitized data creation methods are used. The most common method of data creation is digitization, where a hard copy map or survey plan is transferred into a digital medium through the use of a CAD program, and geo-referencing capabilities. With autho-rectified imagery becoming more accessible, heads-up digitizing is becoming the main avenue through which geographic data is retrieved [19].

3.2.4. Bandwidth Estimation

Bandwidth can be explained as the data rate based on the network connection or the interfaces that connect to the network i.e. it represents the capacity of the network connection. Bandwidth is denoted in terms of bits per

second (bps). When estimating bandwidth, it is vital to understand the distinction between theoretical throughput and real-world throughput [20]. Bandwidth is one of the more critical factors in the design and maintenance of a functional network. Unlike a server, which can be configured, bandwidth is one of those elements of network design that is normally utilized efficiently by configuring the network correctly from the onset. In deploying broadband in Jeddo, estimate the traffic structure and the daily traffic per person in the community. The daily traffic multiplied by the population of the intended rural area (Jeddo) and by 365 days makes up the estimated annual demand for the internet services. With this data, the amount of bandwidth required for the deployment can be determined. To determine how much bandwidth you will need, the process begins with inquiry about what the users will be doing on the network. A network analyzer can be used to detect the amount of traffic applications sent across a network [20].

Another method to determine bandwidth is to manually download a file from an email or from a trusted website. Observe the transfer rate and compute the highest and lowest rates to determine the average actual bandwidth. Run an automated speed test using a site that pings, this is a more easier way to figure out your bandwidth as it is entirely automated [21].

3.2.5. Network Architecture Design

Network architecture refers to the design of the layout of the network, comprising of the hardware, software, connections, communication protocols involved and mode of transmission, which can be wired or wireless [22]. It is vital to know about the network architecture because it displays a framework for the provision of the network's physical components and their configuration, its operational methods, as well as data format used in operating the network [23]. In designing the architecture used for deployment of WiMAX and Wi-Fi in Jeddo community, the process has to be divided into stages with each stage handling core areas of the design.

4. WiMAX and WI-FI Network Design

4.1. Stage Oneof Network Design

WIMAX has been efficiently designed to deliver quality NLOS coverage. WiMAX's advanced technology provides a suitable coverage range of up to 50 km under LOS conditions and typical cell radius of up to 8 km under NLOS conditions [24]. This is the first stage of deployment; it involves the transmission of internet access from the internet service provider to the community via two Line-of-Sight WiMAX base stations. The ISP's base station is situated at the Service Providers Network Operating centre [25]. Using a Point-to-Point (P2P) technology, the first WiMAX base station is pointed to the ISP with an effective Line-of-Sight (this is done to create quality signal). The second WiMAX base station is connected to the first WiMAX base station using P2P technology and an effective line of sight [6]. This is because the LOS WiMAX base station can transmit about 50km signal range, to increase the strength of the signal two base stations would be used, from the second WiMAX base station, PMP technology is used to transmit signals to the different buildings in the community via the NLOS base stations and Wi-Fi access points. There are several advantages that make NLOS deployments preferable in the case of the buildings in Jeddo community. For instance, strict planning requirements and antenna height restrictions in this community might not allow the antenna to be positioned for LOS reception. In this deployment, where frequency re-use is important, lowering the antenna is necessary to reduce the co-channel interference between adjacent cell sites. LOS systems cannot reduce antenna heights because doing so would disrupt the line of sight from the subscriber station to the base Station. NLOS technology would also help to reduce the installation expenses and the difficulty of locating adequate subscriber station mounting locations. Finally, Network Operating Centre's (NOC) are situated at different base stations to enable efficient management, troubleshooting and administration of the network.

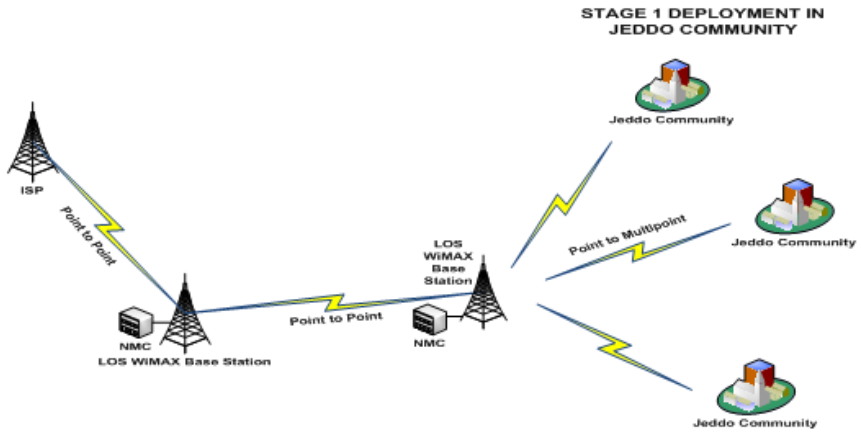

Figure 6. Stage one Deployment to Jeddo Community

4.2. Stage Two Network Design

This stage involves the deployment within the community after which internet access has already reached the community from the internet service provider. This stage is solely concerned with distributing the internet access in the community. From Figure 7, two LOS WiMAX base stations can be seen; the first is connected to the service provider. The second connects to the NLOS WiMAX subscriber stations in the different buildings and also to the specially configured Wi-Fi routers which provide Wi-Fi internet access to users that

are mobile in the community (laptops, PDA's, Tablets, etc.) via point to multipoint technology. The individual WiMAX Subscriber Stations act as receiver systems for the signal from the LOS WIMAX base stations. Their functions include routing of internet traffic within the major buildings in the community.

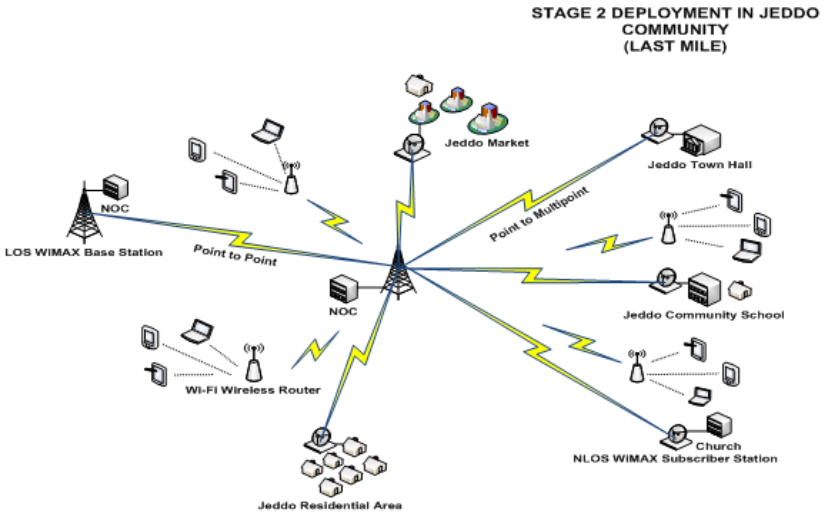

Figure 7. Stage Two Deployment of WIMAX as Last mile

On the other hand, the link between the Wi-Fi routers and the base station is shared among the wireless LAN (WLAN) nodes with the WiMAX base station acting as backhaul connectivity for Wi-Fi [26]. Network Management Centres are situated at each base station for administration purposes. Due to cost and installation reasons, the NLOS Subscriber stations are used as they can transmit up to 10km signal range.

4.3. Stage Three Network Design

In this phase, routing internet traffic within the buildings in the community is the main priority. The NLOS WiMAX subscriber acts as the internet access for the local area network in each building. The local area network topology is divided into a three-Layer hierarchical model as specified by Cisco (world's leading vendor in networking technologies). They are the core layer, the distribution layer and the access layer. At the top of the hierarchy, the core layer is responsible for transmitting huge amounts of traffic efficiently. The main purpose of the network's core layer is to switch traffic in the network as fast as possible [27]. In Figure 8, the firewall is responsible for blocking malicious software or persons from gaining access to the network. The AAA server performs authentication in the network for users, the dynamic host configuration protocol (DHCP) server assigns dynamic IP addresses to users in the network, the domain name server (DNS) is responsible for converting domain names (websites) into IP addresses and vice versa. The Core layer is also concerned with high reliability, redundancy, fault tolerance, low latency and good manageability and quality of service (QoS) in the network [28].

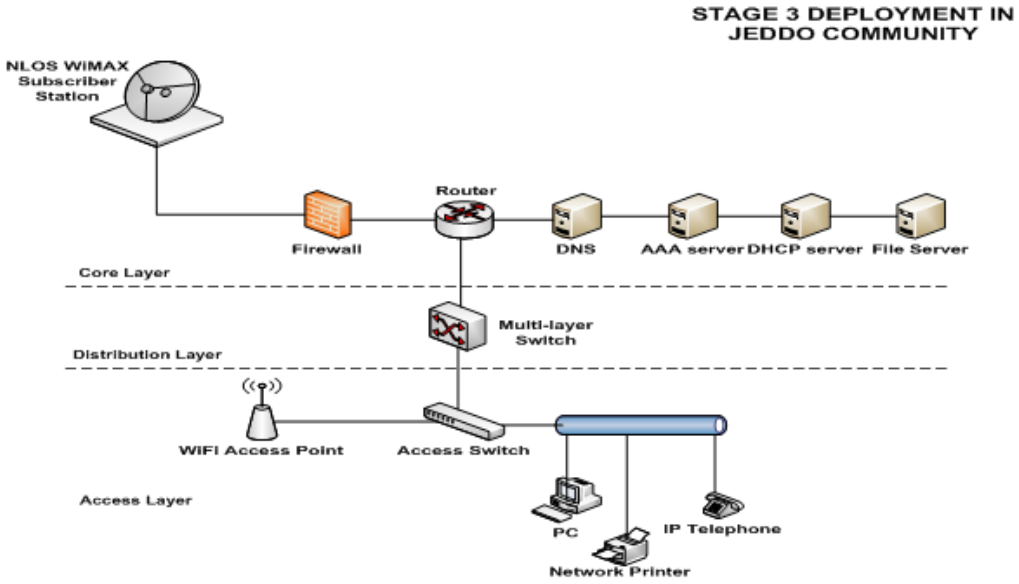

Figure 8. Stage Three Deployment of Customer Equipment in the Community

The router operates in layer 3 (the network layer of the OSI model) and is used for transferring packets across different networks. The distribution layer is the communication point between the access layer and the

core layer. The multilayer switch in Figure 8 is a switch that is capable of performing routing capabilities. The primary functions of the distribution layer are to provide routing, filtering, and WAN access and implement policies for the network. Functions of the distribution layer also include routing, implementing access lists, packet filtering, implementing security and network policies, including address translation and firewalls, redundancy and load balancing, redistributing between routing protocols and routing between VLANs. The access layer connects the end user to the distribution layer. The network resources most users need will be available locally in this layer. The following are some of the functions of the access layer: high availability, port security, broadcast suppression, QoS and spanning tree [28]. The access switch is connected to the patch panel which in turn connects the end user via the RJ45 jack. Indoor Wi-Fi access points are also connected to the access switch to provide indoor internet access. Figure 9 gives a summary of the stages required for the Network Design of WIMAX and Wi-Fi in Jeddo community.

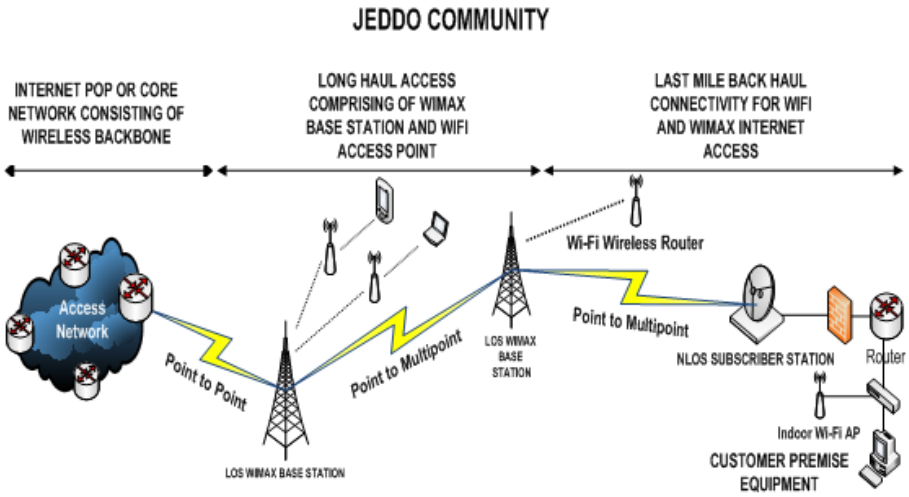

Figure 9. Summary of the Stages of Network Design

Table 2. Features of WiMAX and Wi-Fi [29]

Feature	WiMAX (802.16a)	Wi-Fi (802.11b)	Wi-Fi (802.11a/g)
Primary Application	Broadband Wireless Access	Wireless LAN	Wireless LAN
Frequency Band	Licensed/Unlicensed 2 G to 11 GHz	2.4GHz ISM	2.4GHz ISM(g) 5GHz U-NII(a)
Channel	AdjusTable 1.25 M to 20 MHz	25MHz	20MHz
Half/Full Duplex	Full	Half	Half
Radio Technology	OFDM (256-channels)	Direct Sequence Spread Spectrum	OFDM (64-channels)
Bandwidth Efficiency	<=5bps/Hz	<=0.44 bps/Hz	<=2.7 bps/Hz
Modulation	BPSK,QPSK,16-,64-,256-QAM	QPSK	BPSK,QPSK,16-,64-QAM
FEC	Convolutional Code Reed-Solomon	None	Convolutional Code
Encryption	Mandatory-3DES Optional-AES	Optional-RC4 (AES in 802.11i)	Optiona-RC4 (AES in 802.11i)
Mobility	Mandatory WiMAX (802.16e)	In development	In development
Mesh	Yes	Vendor Proprietary	Vendor Proprietary
Access Protocol	Request/Grant	CSMA/CA	CSMA/CA

4.4. System Performance Metrics

After the design and using the features of WiMAX and Wi-Fi as given in Table 2 as a basis for evaluation, the system performance is evaluated with respect to the following metrics [29,30]:

4.4.1. Delay

Defined as the time taken by the packets to reach the receiver from the transmitter and vice versa. The main sources of delay can be categorized as propagation delay, source processing delay, network delay and destination processing delay. As a result of delay some packets losses energy in the form of noise. End to end delay could be measured as the difference in packet arrival and packet start time. Equation 1 below shows the calculation of average end to end delay [29].

$$Delay = \sum packet\ arrival\ time - packet\ start\ time \quad (1)$$

4.4.2. Packet Delay variance (Jitter)

Jitter could be defined as the variation in delay or the variation in the time between packets arriving. The value of jitter is calculated from the end to end delay. Measuring jitter is an important way to determine the reliability of a network and the QoS the network offers. Jitter is normally used as an indicator of consistency and stability of a network. Equation 2 below shows how to calculate jitter in a WIMAX network [30].

$$Jitter = \frac{\sum square\left(Delay\left(i\right) - Delay\right)}{N} \quad (2)$$

4.4.3. Packet Delivery Ratio

Explains the total number of packets successfully delivered to the destination. Equation 3 below shows how to calculate PDR (Packet Delivery Ratio).

$$Packet\ Delivery\ Ratio = \frac{\sum Packets\ Delivered \times 100}{\sum Packets\ Sent} \quad (3)$$

4.4.4. Packet Loss Ratio

Packet loss impacts on the desired quality of the application. Some of the packets lost are as a result of congestion in networks, noise and bit errors in an erroneous network. Packet loss ratio should be minimum, so as to keep the successful delivery of high quality of service.

$$Packet\ Loss\ Rario = \frac{\sum Packets\ Lost \times 100}{\sum Packets\ Sent} \quad (4)$$

4.4.5. Throughput: An Important QoS Parameter

Throughput is a measure of the number of packets successfully delivered in a network. It is measured in terms of packets/second. The value of throughput should be high for data transmission. Equation 5 below shows how to calculate throughput.

$$Throughput = \frac{\sum Packets\ Delivered}{\sum Packets\ Arrival - Packet\ Start\ Time} \quad (5)$$

5. Conclusion

This research proposed an architectural framework to support the integration of Wi-Fi and WiMAX technologies in rural communities using Jeddo community as a case study. In the proposed framework, a wireless router device is used to interconnect Wi-Fi hotspots with a WiMAX backhaul service through a common protocol making WiMAX an excellent complement to other wireless technologies. In our ever changing world of continuous development, the drastic and continuous change in the area of communications has helped in bridging the gap in our society, as this has better improved the various sectors in our economy including; business, education, health. This work focuses on bridging the gap between the urban (developed areas) and rural areas (the under developed areas) with Jeddo community as case study. The workis on the implementation of wireless broadband access, with WiMAX and Wi-Fi. Other cable and digital Subscriber Line (DSL) technologies could also be implemented, but it comes along with issues of security, and high cost due to the distance from the ISP to the destination. WiMAX solves this problem, as it is used for last-mile delivery of wireless broadband access. The benefits of WiMAX is in its ability to address the network requirements presently, having a wider coverage area compared to other wireless technologies, and its popular backhaul feature, which makes it stand out amongst other wireless technologies. Wi-Fi in this research is implemented for indoor and outdoor broadband coverage. Since majority of devices today comes with in-built Wi-Fi capability. It is used to make the wireless connection easily accessible by mobile users.

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