

# Broadband Access Technologies for Rural Connectivity in Developing Countries

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**Abstract:** Rural areas especially those of the developing countries provide challenging environment to implement communication infrastructure for data and Internet based services. The main challenges are the high cost of network implementation and lack of customer base, as rural areas are characterized by low income, highly scattered and low population density. This situation drives network operators to establish network infrastructures in urban/city centers leaving rural areas as underserved community. This paper surveys the available connectivity technologies with potentials to offer broadband access network to rural areas. The scope of this survey is on wireless access technologies, due to the fact that they are efficient in terms of cost, time of deployment and network management for rural environment. We provide comparison of the surveyed technologies in terms of their capacity (data rates) and coverage. We also discuss the current deployment of WiMAX and 3G technologies in Africa, which is a home to most of the developing countries. The survey results indicate potential broadband access technologies for rural areas of the developing countries.

**Keywords:** access network, broadband, developing countries, rural.

## 1. Introduction

A connectivity network can be categorized as a backhaul or an access network. The access networks provides the so called "last mile" connectivity that connect end users to the backhaul network which finally connect to the internet. The existing access network technologies constitute of enhanced copper wires based on Digital Subscriber Line (xDSL), coaxial cable, fixed and mobile wireless, satellite based wireless and fiber optic technologies.

The xDSL technologies use existing Public Switched Telephone Network (PSTN) infrastructure to provide broadband data service. In xDSL, the telephone line carries both voice and data signals/packets; there is a splitter at the end user premise where voice and data services are separated. The xDSL systems cover various technologies such as asymmetric DSL (ADSL), very-high-speed DSL (VDSL), and high-bit-rate DSL (HDSL). Their theoretical peak data rates (downlink/uplink in Mbps) are: 2/1.05 (HDSL), 8/0.8 (ADSL) and 52/26 (VDSL) respectively. Cable modem technology uses coaxial cable to provide Internet data services along with digital TV. The theoretical peak bandwidth is up to 30 Mbps. It is worth to note that wired technologies have distance limitations. Therefore the data rates provided depends on the distance covered. The data rate decreases as soon as the distance covered exceed the specified range.

Optical fiber technology is another option for access networks; it provides a huge amount of bandwidth in the range of Gbps. A single strand of fiber offers total bandwidths of 25,000 GHz. Passive Optical Networks (PONs) are widely deployed to implement the fiber optic access networks [2]. A PON is usually viewed as the final segment of optical fiber-to-the home (FTTH) or close to it (FTTx). Commercially available and widely deployed PON access networks are the IEEE 802.3ah Ethernet PON (EPON) with a symmetric rate of 1.25 Gb/s, or the ITU-T's G.984 Gigabit PON (GPON) with an upstream rate of 1.244 Gb/s and a downstream rate of 2.488 Gb/s [2].

The xDSL and coaxial cable infrastructures are well established in developed countries. For example in most of the European countries and USA almost all households have twisted-pair cabling and the entire cities are connected by POTS (Plain Old Telecommunication System). In addition, almost all households have wiring for cable services. However this is not the case in the rural areas of developing countries, which are characterized by low density and sparsely populated areas. Characteristics of rural areas of the developing countries, provide a challenging environment in terms of network costs and time of deployment to implement wired technologies such as xDSL, coaxial cables and optical fibers. Therefore, wireless technologies are envisioned as suitable technologies for rural environment.

Wireless access technologies that are candidates for broadband rural access networks include: Wireless Fidelity (WiFi), Worldwide Interoperability for Microwave Access (WiMAX), cellular mobile wireless networks and satellite based technologies such as Very Small Aperture Terminal (VSAT). The access technologies surveyed in this paper are those with potentials to connect rural areas, especially those of the developing countries. The scope is limited to wireless technologies that have been proposed as candidates for rural connectivity [3,4].

The rest of this paper is organized as follows: In section 2 we investigate broadband wireless technologies that may potentially provide rural connectivity. The investigation is based on the widely deployed technologies as well as the emerging ones. Section 3 indicates the current deployment status of WiMAX and 3G technologies. In addition, there is a comparison of the surveyed wireless technologies in terms of capacity and coverage. Then, the survey conclusion and direction for future research are presented in section 4.

## 2. Broadband Access Technology for Rural Connectivity

WiFi technology, also known as IEEE 802.11 was specifically designed for wireless local area network standard. The WiFi technology offer theoretical peak data rate of 54/11/54/600 Mbps for IEEE 802.11a/b/g/n standards respectively. Other technologies, either wired or wireless, can serve as access networks to deliver data over long distance and then WiFi is used to deploy local network in order to distribute the data service locally. WiFi networks use unlicensed spectrum, which raises the possibility of interference from other devices. Its coverage is limited in most cases to only 30 - 100 meters. Another option for broadband access network is the wireless mesh network (WMN). The WMN is a communications network made up of radio nodes organized in a mesh topology. It interconnects stationary and/or mobile clients and optionally provides access to the Internet. Characteristic of a WMN is that the nodes at the core of the network are forwarding data to and from the clients in a multihop fashion. WMNs can be built up by using existing wireless technologies, such as the commonly used IEEE 802.11 (WiFi). Similar to WiFi, WMN is also challenged by coverage limitation. Since the scope of this paper is on access technology to cover the last mile connectivity of a rural area, then WiFi and WMN technologies are not discussed here. On the other hand, satellite based wireless technology such as VSAT have been proved from literature to be the relatively expensive option for rural connectivity [5]. Therefore, VSAT is also out of scope of this paper. The remaining wireless technologies discussed are the WiMAX and cellular mobile technologies. The hybrid fiber-wireless network is also discussed as a potential emerging access technology for rural connectivity.

### 2.1. The Worldwide Interoperability for Microwave Access

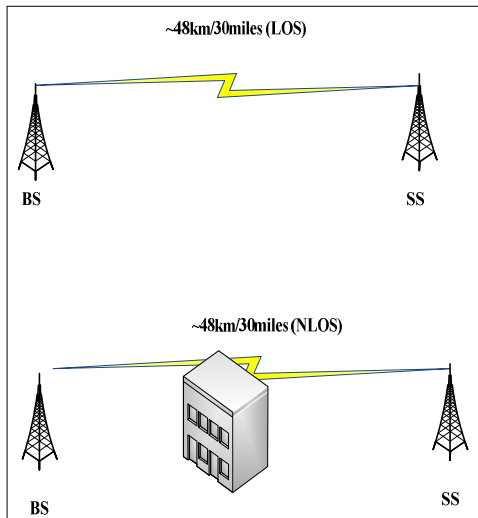
WiMAX, also known as IEEE 802.16, is a wireless communications standard that is intended for wireless Metropolitan Area Networks (MAN). WiMAX provides broadband wireless access of approximately up to 48km for fixed stations, and 5 - 15 km for mobile stations. The IEEE 802.16 standard has undergone different amendments for improvements which at the end results into the earlier amendments, the IEEE 802.16a/b/c standards to be withdrawn. The current available standards are 802.16d, 802.16e, 802.16m [1]. Their respective brief description and data rates are shown in Table 1.

**Table 1.** IEEE 802.16 Standard Description

| Standard                     | Description                                                                                                             | Data Rates                                                         |
|------------------------------|-------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------|
| <b>802.16d (802.16-2004)</b> | This amendment is also known as 802.16-2004 because it was released in 2004. The standard only support fixed operation. | 70 Mbps                                                            |
| <b>802.16e (802.16-2005)</b> | This standard, also known as 802.16-2005 in view of its release date, designed for nomadic and mobile use.              | 15 Mbps                                                            |
| <b>802.16m</b>               | This is an amendment to the air interface; it can support both fixed and mobile users.                                  | 100 Mbps for mobile applications and 1 Gbps for fixed applications |

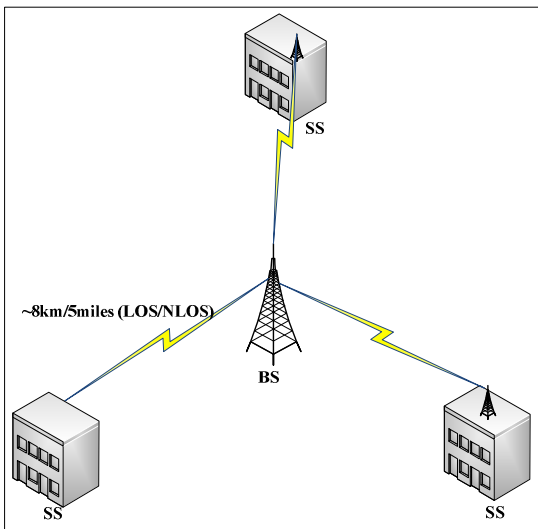
There are three topologies for WiMAX network: fixed point-to-point (P2P), fixed point-to-multipoint (P2MP) and mobile WiMAX. The WiMAX network consists of two key components: a base station and a subscriber device. The WiMAX base station is mounted on a tower or tall building to broadcast the wireless signal. The subscriber can receives the signals on a WiMAX-enabled notebook or mobile Internet device (MID). For fixed WiMAX deployments, a Customer Premises Equipment (CPE) is needed to act as a wireless modem providing interface to the WiMAX network for a specific location, such as a home, cafe, or office.

A point-to-point (P2P) topology consists of a dedicated long-range, high-capacity wireless link between two sites. The central site hosts the base station (BS), and the remote site hosts the subscriber station (SS), as shown in Figure 1. The BS controls communications and security parameters in establishing the link with the SS. The P2P topology is used for high-bandwidth wireless backhaul services at a maximum operating range of approximately 48 km using line of sight (LOS) or non-line of sight (NLOS) signal propagation [6].



**Figure 1.** WiMAX Point to Point (P2P) Topology

An example of point-to-multipoint (P2MP) topology, composed of a central BS supporting multiple SSs, providing network access from one location to many other locations. It is commonly used for last-mile broadband access such as private enterprise connectivity to remote offices, and long-range wireless backhaul services for multiple sites. P2MP networks can operate using LOS or NLOS signal propagation. Each P2MP BS has a typical operating range of 8 km [6]. Figure 2 illustrates the P2MP topology.

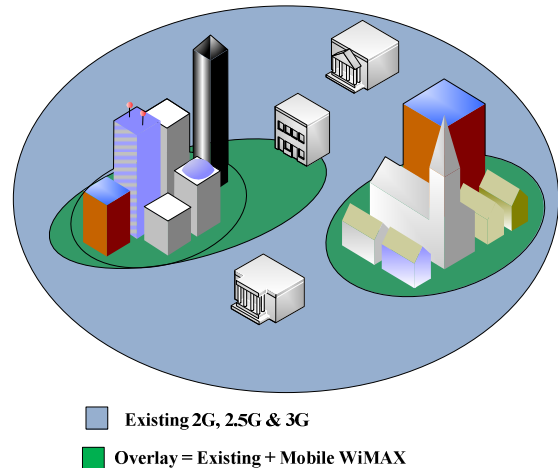


**Figure 2.** WiMAX Point to Multipoint (P2MP) Topology

A mobile WiMAX topology is similar to a cellular network due to the fact that multiple BSs collaborate to provide seamless communications over a distributed network to both SSs and mobile subscribers (MSs). Coverage for a geographical area is divided into a series of overlapping areas called cells. Each cell provides coverage for users within its vicinity. The wireless connection is handed off from one cell to another when a user is crossing the border between two cells. Each BS radial coverage area is approximately 8 km.

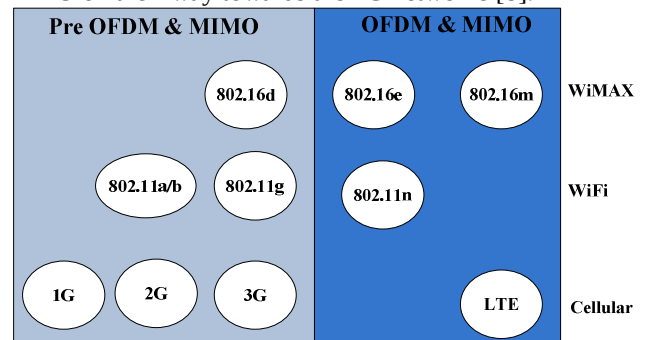
The deployment of fixed WiMAX networks model to address last mile broadband access has been highly successful. However, up to date, this deployment scenario is

mostly used in urban areas. The reason for this is, WiMAX was specifically designed for metropolitan area network although it has lots of potential to connect rural areas as well [7]. Deployment costs are the main limiting factor for implementing WiMAX networks in rural areas. However, there exists a strategic deployment of WiMAX networks in rural areas, which is envisioned as a cost-effective technique. This is an overlay network topology made up by co-existence of cellular mobile networks with mobile WiMAX network as shown in Figure 3. The mobile WiMAX in an overlay network operate in the Orthogonal Frequency Division Multiplexing (OFDM) & Multiple-Input and Multiple-Output (MIMO) antenna capabilities.



**Figure 3.** WiMAX as a data overlay network to the existing cellular networks [8]

The OFDM and MIMO antenna capabilities have emerged as the technologies of choice to satisfy the growing demand of mobile broadband data due to the increases of mobile devices and applications like social networking, which combine rich internet-based multimedia and mobility[8]. The OFDM and MIMO technologies are currently used in WiMAX, long term evolution (LTE) standardized by the third generation partnership project (3GPP) as well as for Wi-Fi (802.11n), as illustrated in Figure 4. Authors in [8] report that, combination of OFDM and MIMO is highly scalable and systems based upon it are best positioned to satisfy the huge requirements for mobile broadband data over the next coming years. For this reason, IEEE 802.16, 3GPP and 3GPP2 standards bodies are all adopting OFDM and MIMO on their way towards the 4G networks [8].



**Figure 4.** Technology evolution towards OFDM & MIMO [8]

Implementation of broadband overlay network involves deployment of new WiMAX base station, end user (client) equipments and an upgrades to the core network to support high amounts of IP (Internet Protocol) traffic. That means, existing mobile operators can co-locate WiMAX base station equipment in their existing 2G cell sites. A real world overlay mobile WiMAX commercial deployments by KT Wibro network in Seoul, South Korea have experienced a cell site re-use rate of 70% [9]. With overlay networks, subscribers need to have multi-mode handsets and modems to enjoy the best of both worlds: coverage (2G) and high speed (WiMAX). For portable devices such as laptops, the multi-mode combination of Wi-Fi and WiMAX will be the common embedded solution for ensuring coverage [8].

The wide coverage of approximately 8km up to 48 km and high data rate are the potential capabilities for a WiMAX technology to offer rural connectivity. In addition to that, the co-existence of WiMAX with 2G and 3G (overlay network) provide a cost effective approach as much of the capital expenditure will be already covered by the existing mobile cellular network. Technically, the WiMAX technology; be it in fixed, mobile or an overlay topology have great potential to offer broadband access networks to areas underserved by wired technologies.

## 2.2. The Cellular Mobile Wireless Technologies

The world has experienced an ever-going evolution of cellular mobile wireless technology from first generation 1G in late 70s to the fourth generation 4G in 2010. The first generation cellular system was an analog mobile phone system working at 850 MHz, developed by AT&T Bell Laboratories in the late 1970s [10,11]. The system was mainly used for the basic telephone voice services. To maintain the first generation subscriber service quality, especially in a heavily populated area, was difficult due to tremendous system complexity and lack of control. As a result, these analog networks were switched off in 2000 [10,12]. The second generation (2G) cellular wireless network was developed in early 1990s which also marked the beginning of fully digital systems. The Global System for Mobile Communication (GSM) is one of the 2G cellular mobile network widely deployed in Europe, which later gained worldwide acceptance and became the world's most popular mobile technology.

End terminals in the 2G networks could only process audio/voice as input data. Therefore, users had to use a modem to transfer data traffic via GSM at a rate of 9.6 kbps. This method of data transport is quite inefficient to support modern multimedia rich Internet applications, like web browsing, videoconferencing and multimedia streaming. Therefore some new standards have been developed based on 2G technologies, such that the existing 2G equipment can be upgraded to provide higher transmission rates. They are generally categorized as 2.5G mobile communication systems, namely; General Packet Radio Service (GPRS) and Enhanced Data Rates for GSM Evolution (EDGE), offering data rate (downlink/uplink in Kbps) of 40/14 and 384/53 respectively. The 2.5G technologies only served as temporary data solution for the exploding internet services which eventually lead to evolution of 3G systems. The 3G

systems provide much higher data rates from 384 Kbps to 10Mbps in the downlink direction as well as much more services. The fourth generation (4G) is expected to offer up to 100Mbps in high speed mobiles and up to 1Gbps for fixed or low mobility [13].

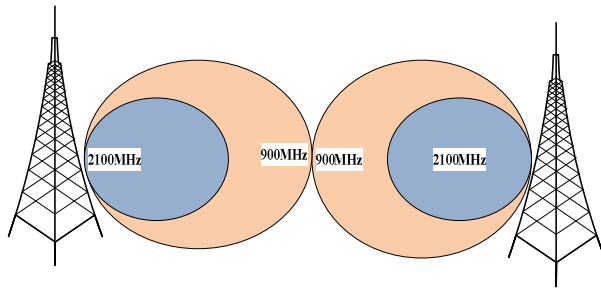
The second generation, GSM network, is widely deployed worldwide except in USA where the IS-95 also known as cdmaOne technology was their choice for 2G technology. For data communication or internet based services, 2.5G and its successors (3G and 4G) are envisioned to be viable candidates. However in most of the existing deployments of cellular mobile wireless technology, especially the 3G variants, are faced by coverage challenges. The most deployed 3G systems are implemented at 2100MHz frequency band. At this high frequency, the radio waves propagation path loss is high, which results in a shorter distance coverage. As a results, the 3G networks are mainly deployed in urban areas and in major cities; this is a business strategies to tap a large number of customers in small single area. Nevertheless, the coverage challenge of the existing 3G networks can be addressed by deploying the 3G networks in lower frequencies such as 900MHz frequency band. This is an emerging technique which has the potential to address the coverage problem as well as providing 3G data capacity and services [8].

The technique to implement 3G network at 900MHz bring about an added advantage of making use of the existing GSM sites, to implement 3G networks, especially in rural areas. The practical experience is pioneered by Nokia Siemens Networks which implemented a pilot project for Elisa, the Finnish mobile operator, which demonstrated a deployment of 3G Wideband Code Division Multiple Access (WCDMA) in 900 MHz, without impairing 2G services running on the same band [14].

A growing number of mobile operators are deploying UMTS/HSPA services alongside with their existing GSM networks operating in the 900 MHz band. According to [15], there are around 10 operators (in Australia, Estonia, Finland, Iceland, New Zealand, Thailand and Venezuela) - commercially running UMTS/HSPA operations in 900MHz band. It has been demonstrated that GSM and UMTS/HSPA networks can co-exist in the same frequency bands without technical problems such as interference [14]. Deploying UMTS with HSPA in rural areas by re-using the existing GSM sites is a cost-effective solution for mobile operators to offer mobile broadband services, such as high data rate multimedia services. By re-using the existing lay-out of the GSM infrastructures within the existing service area generates further benefits such as quicker network deployment, limited impact on capital expenditure by re-using existing antenna systems and feeders and limited impact on operational expenditure through re-use of network management systems. Costs are lowered and roll out is faster through re-using the existing sites which, eliminates site acquisition costs and civil works [14, 15]. From an implementation point of view, operators only need either to add a new UMTS base station cabinet, or to replace the existing GSM base station by a multimode GSM+UMTS/HSPA base station subject to site situation or manufacturer's design [15]. For the existing GSM operator, the most cost-effective solution is to re-use the existing GSM

site for UMTS deployment. The existing antennae and feeders can be reused and the UMTS base station operating in 900MHz can be added.

Another significant benefit of UMTS/HSPA deployment in the 900 MHz band comes from the fact that radio wave propagation path-loss in 900 MHz frequency band is much smaller. Therefore at the lower frequency, cell sizes are two to three times larger than that of a UMTS/HSPA at 2100MHz. This wider cells enable coverage with fewer sites [15]. This is illustrated in Figure 5. The wider coverage is a useful feature especially to rural areas where customers/subscribers are scattered.



**Figure 5.** UMTS/HSPA at 900MHz enhances coverage

According to UMTS forum [15], in order to offer the same service (same data rate) and equal coverage, the required number of base station sites in 900 MHz band is reduced by 60% compared to that needed by 3G UMTS at 2100 MHz, as shown in Table 2.

**Table 2.** Required Cell Site (Base Station) [15].

| Service                   | 2100MHz band | 900 MHz band | Number of Site Reduction (%) |
|---------------------------|--------------|--------------|------------------------------|
| Circuit Switched, 64kbps  | 224          | 90           | 60%                          |
| Packet switched, 384 kbps | 468          | 181          | 61%                          |

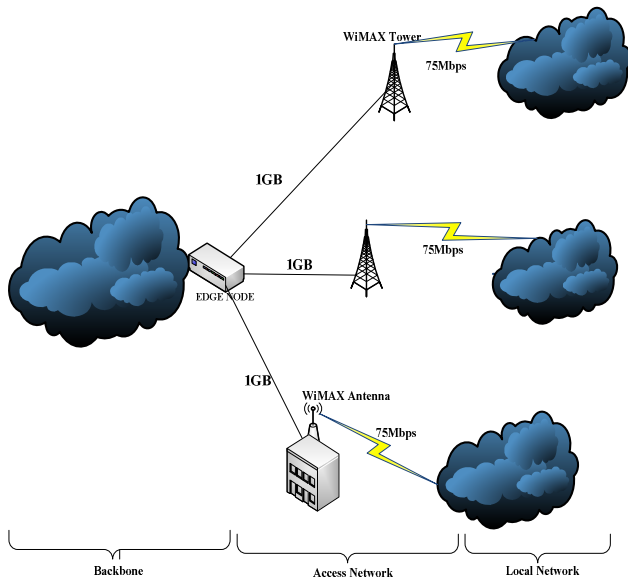
It can be concluded that, the 3G networks at 2100MHz are the viable option to offer connectivity in rural areas due to their high data rate and diversity of services supported. However, they are not widely deployed, especially in the rural areas of developing countries. This is due to high frequency used that provide shorter distance coverage (smaller cells), which consequently leads to high cost of network implementation. The emerging technique to implement 3G network at low frequency; the 900MHz, which can co-exist with the widely deployed 2G GSM cell site, is envisioned as a cost-effective approach to bridge the 3G network coverage to the underserved rural community.

### 2.3. The Hybrid Fiber-Wireless Access Network

Recent advances in fiber optic technology have led to significant increase in capacity of optical networks. Data can be carried at terabits per seconds (Tbps) bandwidth across long distances. However, carrying information to the residential customer still depends on legacy low-bandwidth access networks. The situation is even worse in rural context where the reach of fiber optic backbone is rather limited. While fiber optic technologies offer high bandwidth, they cannot be deployed everywhere due to their implementation constraints such as distance limitation and time taken to lay down cables. On the other hand, wireless have a potential to reach everywhere, providing mobility as well as faster deployment. Therefore, combining these two technologies implies reaping benefits of both. To cater for the increasing bandwidth requirement and to reach the isolated rural areas where implementing wired network is not possible, then a hybrid Fiber-Wireless (FiWi) broadband access network is considered to serve the purpose [16]. The hybrid FiWi is a broadband access architecture which captures the best of both; the optical and wireless worlds. By combining the capacity of optical fiber networks with the ubiquity and mobility of wireless networks, FiWi networks form a powerful platform to support the emerging as well as future applications and services [2]. Furthermore, the integrated fiber-wireless architecture is envisioned as an economic way to bridge the connectivity gap between rural and urban area [17].

The hybrid FiWi network can be implemented by using either WiFi or WiMAX technology as the wireless front-end connected to a fiber optical backhaul. Currently, IEEE 802.11 a/b/g WiFi technologies are widely exploited due to their low cost, technological maturity, and high product penetration. However, since these protocols were originally designed for wireless local area networks (WLANs), they cannot be efficiently optimized for outdoors long distance access networks. For outdoor long distance networks, proprietary wireless technologies and WiMAX have been used instead. Unlike WiFi, IEEE 802.16 (WiMAX) allows for point-to-multipoint wireless connections and can be used for longer distances. WiMAX also expands the scope of wireless access by operating in both licensed and unlicensed frequency bands [2].

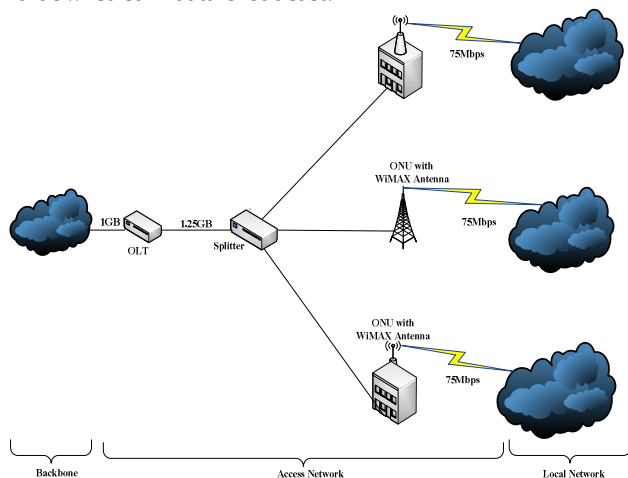
There are two possible architecture to enable FiWi integration: The first option, illustrated in Figure 6, is for optical fiber to run from an edge node, probably in a central office, to WiMAX base station's antennas that can each serve a relatively large number of subscribers in a relatively large cell. Local upstream traffic from the end users is aggregated at the antenna locations while network management is centralized at the edge node. Multiple optical interfaces at the edge node are necessary to support the deployment of multiple WiMAX cells [17].



**Figure 6.** Optical fiber and WiMAX integration.

The second approach, shown in Figure 7, is to employ passive optical network as the access networking, supporting WiMAX base station antennas in the lower tier. A PON segment is headed by an Optical Line Terminal (OLT) which drives several Optical Network Units (ONUs) which in turn serve end users. PON lowers the cost of network deployment and maintenance by eliminating multiplexers and demultiplexers, this is a replacement of active electronic components with the less expensive passive optical splitters. This technique makes the passive optical network to be the cost-effective choice for fiber access network deployment [17]. Standardized by both ITU and IEEE, PON covers longer distance from the service provider central offices to the customer sites, and provides up to 2.5 Gbps transmission data rate [2, 18].

In contrast to the traditional PON architecture, in which the optical network unit (ONU) bridges the local users using wired connections; in this hybrid mode as proposed by authors in [18], the ONU is a combination of fiber with WiMAX to facilitate wireless communications. The OLT in the central office enables upstream local data aggregation and downstream data broadcast.



**Figure 7.** PON and WiMAX integration.

The two deployment architectures discussed above are compatible with the FTTx framework. Such integration offers centralized management at the edge node and simplified processing at the access point, resulting in a faster deployment and lower system cost. The PON and WiMAX integration presents an added advantage of cost saving by using passive equipments. The use of passive equipment is a low-cost option for the rural area access networks.

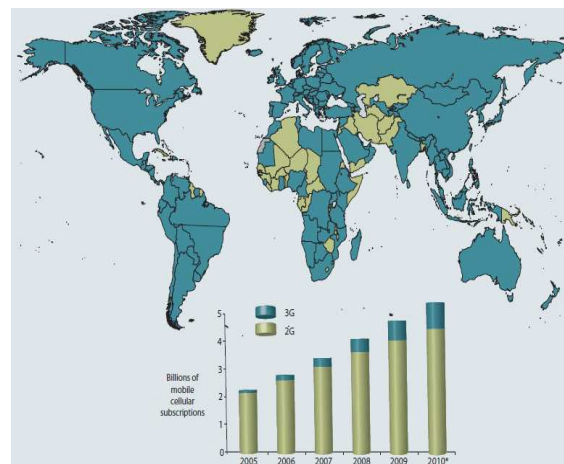
### 3. Deployment of WiMAX and 3G Technologies

WiMAX and 3G systems seem to be the principle wireless technologies that are also evolving into emerging technologies such as mobile WiMAX and Long Term Evolution (LTE), then LTE-Advanced respectively. They can also co-exist with other technologies to form overlay network such as the cellular network with mobile WiMAX and 3G at 900MHz with GSM network. From this point of view, it is important to identify the current deployment status of WiMAX and 3G technologies as well as their time line trend. Table 3 shows the current (as of October, 2010) state of WiMAX deployments around the world.

**Table 3.** Wimax Deployment by Regions [19]

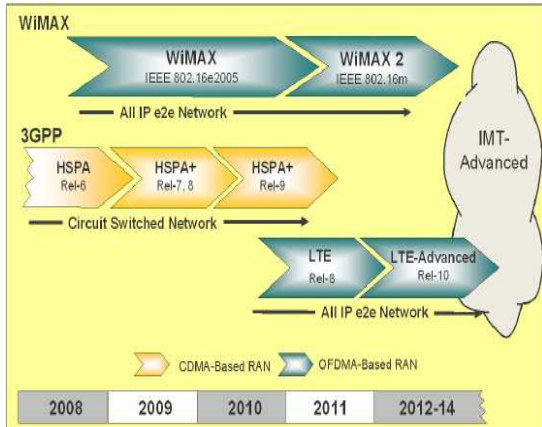
| Region                       | Deployments | Countries |
|------------------------------|-------------|-----------|
| Africa                       | 117         | 43        |
| Asia-Pacific                 | 109         | 23        |
| Eastern Europe               | 86          | 21        |
| Western Europe               | 76          | 17        |
| North America (USA + Canada) | 53          | 2         |
| Middle East                  | 29          | 10        |

On the other hand, 3G technology is also widely deployed worldwide. Figure 8 indicates deployment of 3G technology in a worldwide map. The map shows countries that are offering 2G/3G services commercially. Observing this map it is clear that 3G technologies are currently available in most of the African developing countries, while 2G is available in all countries.



**Figure 8.** Countries that are offering 2G/3G services commercially [20].

WiMAX and 3G future trends are shown in Figure 9. The two technologies adopt MIMO and OFDM antenna capabilities as noted earlier in Figure 4 and they are all heading towards IMT-advanced.



**Figure 9.** Timeline for Mobile WiMAX and 3G [21].

All the surveyed technologies: WiMAX, overlay network of cellular systems and mobile WiMAX, the third generation (3G) cellular systems at 2100MHz, the emerging 3G at 900MHz, and the hybrid fiber-wireless (FiWi) access technologies have shown enough potential and capabilities in terms of coverage and data rates to offer broadband access networks to rural areas. The capabilities are summarized in Table 3 in the form of comparison among the surveyed technologies.

**Table 3.** Comparison of Broadband Access Technologies

| Technology                        | Data Rates (Mbps) | Coverage / Cell range        |
|-----------------------------------|-------------------|------------------------------|
| WiMAX                             | 75                | 8km P2P<br>48km P2MP         |
| Overlay (Cellular + Mobile WiMAX) | 75                | 8km                          |
| 3G at 2100MHz (HSDPA)             | 14.4              | 2 - 3 km                     |
| 3G at 900MHz                      | 1                 | 2 - 3 times of 3G at 2100MHz |
| Hybrid Fi-Wi                      | 75                | 8km                          |

## 4. Conclusion

The survey carried out in this paper suggest that, the more attractive options for rural connectivity, are the emerging overlay network of cellular and mobile WiMAX and the 3G network at 900MHz technologies. Deployment of these emerging technologies is technically feasible as it was already demonstrated in some countries. Typical examples are the implementation of 3G at 900MHz in countries such as Finland, Estonia, Iceland, New Zealand and Australia [15] and the overlay network implementation in Seoul, South Korea [9]. Deployment of these emerging technology offer an added advantages of co-existing with the 2G network which implies a cost-effective deployment model. The cost-effectiveness is due to reduction in capital expenditure

(CAPEX) as well as operation expenditure (OPEX). The CAPEX costs are reduced due to cell re-use. On the other hand, OPEX costs are cut down due to centralized management. However, it will be useful to analyze the economic standpoint and how the emerging technology will compete with the existing WiMAX and 3G for the market share. The analysis will help to forecast the future wireless technological dominance and hence identify which will be the feasible and sustainable wireless technology capable of connecting rural areas.

Based on the survey conducted by this paper, the 3G at 900MHz technology is suggested as the best technology for rural areas of the developing countries. Both overlay network of cellular with Mobile WiMAX and 3G at 900MHz have the advantage of a wide coverage and cost-efficiency as a results of co-existence. However, the 3G at 900MHz outperform the overlay network due to the fact that the GSM network, which is a precondition for 3G at 900MHz is widely deployed in the developing countries.

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