Comparative Analysis of Alternative Last Mile Broadband Access Technologies (Wi-Fi and WiMAX).

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ABSTRACT

Broadband wireless access networks are considered to be enterprise-level networks providing more capacity and coverage. Wireless networking has offered an alternative solution to the problem of information access in remote inaccessible areas where wired networks are not cost-effective. They have changed the way people communicate and share information by eliminating worrisome factors of distance and location. This paper provides a technical analysis of alternatives for implementing last-mile wireless broadband services. It provides detailed technical differences between 802.11 (Wi-FI) wireless networks with 802.16 (WiMAX), a new technology that solves many of the difficulties in last-mile implementations.

(Keywords: broadband wireless, last mile access, rural connectivity, WiMAX, Wi-Fi, digital divide)

INTRODUCTION

The explosive growth of the Internet over the last decade has lead to an increasing demand for high-speed, ubiquitous Internet access. Broadband wireless access (BWA) is increasingly gaining in popularity as an alternative "last-mile" technology to DSL lines and cable modems. Following the hugely successful global deployment of the 802.11 wireless local area network standard, deployment of the IEEE 802.16d and 802.16e wireless metropolitan area network standards is currently in progress. This technology aims to provide broadband wireless access to residential and small business applications, as well as enable Internet access in countries without any existing wired infrastructure in place. The latter version (802.16e) attempts to provide mobility to the end user in a MAN environment.

Wireless technologies need to be examined from two perspectives: that of access network and the backhaul network [1]. Even the access networks are principally categorized into two groups. There is the cellular network group and the broadband wireless access goup, popularly known as the 802.xx family [2]. The 802.xx family has seen the proliferation of different standards since its inception. Such diversity has been necessitated by the number of properties desired from them.

Desired properties include range, bandwidth, costs of deployment, and time taken to complete deployment. Range determines the maximum area that can have full coverage. As more and more network applications emerge, bandwidth becomes critical to network efficiency. Different network standards have been developed to provide needed bandwidth. Bandwidth of a network is responsible for a number of Quality of Service (QoS) attributes that the network exhibits. Deploying a network is associated with a lot of costs. These costs determine the viability of a project and efforts are directed to balance the investment tradeoffs. Cost of deploying infrastructure is proportional to the time taken to complete deployment. For that reason, different IEEE 802.11x (WiFi) and IEEE 802.16x (WiMAX) standards have been developed.

The paper is organized to describe the standards and technology associated with various wireless technologies usage models. The paper then gives a technical overview of the two popular broadband wireless technologies (i.e., IEEE 802.11x and IEEE 802.16x). The next section provides a comparative analysis of the two wireless technologies. The paper then shows how the two technologies can be combined to provide broadband access to remote areas and then ends with the author's overall conclusions.

WIRELESS TECHNOLOGY USAGE SEGMENTS

The reasons behind wireless deployments are as diverse as the wireless technologies being offered today. Each wireless technology is designed to serve a specific usage segment:

i. Personal area networks (PANs)
ii. Local area networks (LANs)
iii. Metropolitan area networks (MANs)
iv. Wide area networks (WANs)

The requirements for each usage segment are based on a variety of variables, including bandwidth needs, distance needs, power, user location, services offered, and network ownership. Optimized applications exist for each usage segment. For example, in some locations it is possible to seamlessly use a third-generation handset while traveling from country to country in a wireless WAN environment. Figure 1 shows the wireless standards organizations, the standards, and their capabilities (bandwidth and distance) mapped to the four usage segments [3].

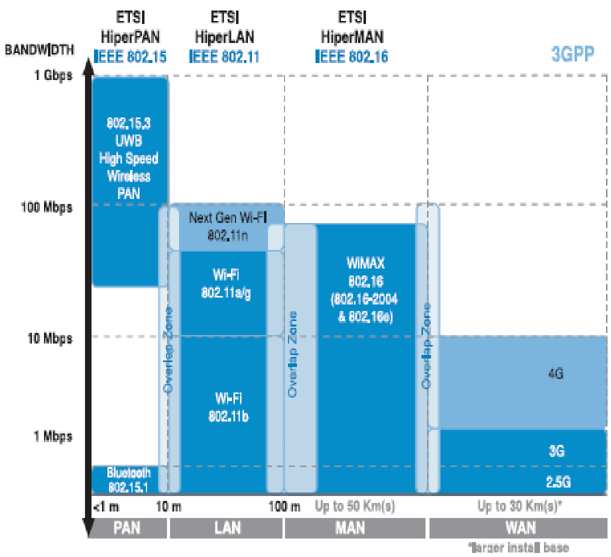

Figure 1: Wireless Technologies Target Segments.

The three standards organizations depicted in Figure 1 are: Institute of Electrical and Electronics Engineers (IEEE), European Telecommunications Standards Institute (ETSI), and Third-Generation Partnership Project (3GPP). The IEEE and ETSI standards are interoperable and focus primarily on wireless packet-based networking. The 3GPP standard focuses on cellular and third-generation mobile systems. Each usage segment has a corresponding wireless standard, but segment overlaps do exist. For example, ultra-wide band (UWB) supports faster file transfers and could allow a user to transport files faster than when using Wi-Fi or WiMAX.

OVERVIEW OF WI-FI AND WIMAX

The IEEE 802.11 (Wi-Fi): Over the last several years, the explosion of Wireless Fidelity (Wi-Fi) devices made possible the discovery of the wireless network world. In the WLAN field, the only major competition comes from HIPERLAN II. The Wi-Fi standard family allows wireless network over short distances. These standards are sometimes associated with directional antennas to establish point-to-point connections. WLANs based on the IEEE 802.11 standard are expected to be a major component to enable an integrated office, hospital, home networks and for campus buildings. The 802.11 WLANs operate in the ISM (industrial scientific and medical) bands, with several flavors of physical layer available. The first 802.11 wireless network standards were developed in 1997 as an extension to the Local Area Network [4]. It was known as wireless Ethernet that only supported a maximum speed up to 2 Mbps. Frequency Hopping Spread Spectrum (FHSS) and Direct Sequence Spread Spectrum (DSSS) were the modulation techniques supported. There are three well known 802.11 wireless family standard widely used today (Table 1).

The IEEE 802.11b- A refined standard for the original 802.11 and was successful due to its high data rates of 11 Mb/s - range of 100 m to a maximum of a few hundreds meters, operates on 2,4 GHz unlicensed band. 802.11b is the most widely deployed wireless network within the 802.11 wireless families [4, 5]. It uses the DSSS modulation technique that is more reliable than the FHSS.

The IEEE 802.11g- The IEEE 802.11g wireless standard also operates on the 2.4 GHz band and has similar range and characteristics as the 802.11b. It has a data rate of 54Mbps. The 802.11g has backward compatibility with 802.11b and differs only on the modulation technique; it uses Orthogonal Frequency Division Multiplexing (OFDM). This then makes the 802.11b devices not able to pick the signal from the 802.11g devices [6].

The IEEE 802.11a- Operates in the 5 GHz band with a maximum data rate of 54Mbps [7]. The major disadvantage in deploying 802.11a with the other 802.11 standards b and g is that, they cannot co-exist, as they operate on different frequency bands. 802.11b/g operates on the 2.4 GHz spectrum. There are some wireless card and access points which are compatible to all the three standards thereby supporting the 2.4GHz and 5GHz frequencies [8]. The benefits of using Wi-Fi for last-mile solutions are:

1. Off-the-shelf 802.11 standard products are currently available

2. Initial investment is cost effective for small deployments

3. Flexibility over wired installations can be achieved

Table 1: The 802.11 Family Standard Evolutions.

Standard	802.11b	802a	802.11g
Year Standardized	1999	1999	2003
Frequency	2.4GHz	5GHz	24GHz
Wireless Speeds	11Mbos	54Mbps	54Mbps
Real World Speeds	4-6 Mbps	15-22Mbps	15-22Mbps
Indoor Range	30-50 Meters	30-50 Meters	30-50 Meters
Interoperable Standards	802.11g	N/A	802.11b
Advantages	Interoperable with 802.11g Inexpensive	Reduced Wi-Fi Interference More Non-Overlapping Channels	Interoperable with 802.11b High Speed Wireless Data Communication
Idea Solution for	Home Users Connecting to the Internet Wirelessly Network	Home/Office Users Experiencing interference with Existing 802.11g Wireless Networks	Home/Office Users Needed Faster Local Network Access for Multimedia Applications
Hot Spots Available	Yes	No	Yes

<u>The IEEE 802.16 (WiMAX)</u>: Wireless networks adapted for covering cities and villages, arrived a few years after the Wi-Fi type WLAN. The IEEE 802.16 WiMAX (World Interoperability for Microwave Access) standard is based on global interoperability including ETSI HIPERMAN, IEEE 802.16d-2004 for fixed, and 802.16e for mobile high-speed data [9, 10]. It is an emerging technology that delivers carrier–class, high speed wireless broadband at a much lower cost than the cellular services while covering large distances than Wi-Fi. It has been designed to be a cost-effective way to deliver broadband over a wide area. It is intended to handle high-quality voice, data and video services while offering a high QoS.

WiMAX is classified as the Wireless Metropolitan Area Network (WMAN) that operates in between 10 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) [11]. Both the fixed and mobile standards include the licensed (2.5, 3.5, and 10.5 GHz) and unlicensed (2.4 and 5.8 GHz) frequency spectrum. However, the frequency range for the fixed standard covers 2 to 11 GHz while the mobile standard covers below 6 GHz. Depending on the frequency band, it can be Frequency Division Duplex (FDD) or Time Division Duplex (TDD) configuration. 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 be 20 to 30 Mbps. The mobile applications will support 30 Mbps per subscriber, in 10 MHz of spectrum, but typical data rates will be 3 - 5 Mbps.

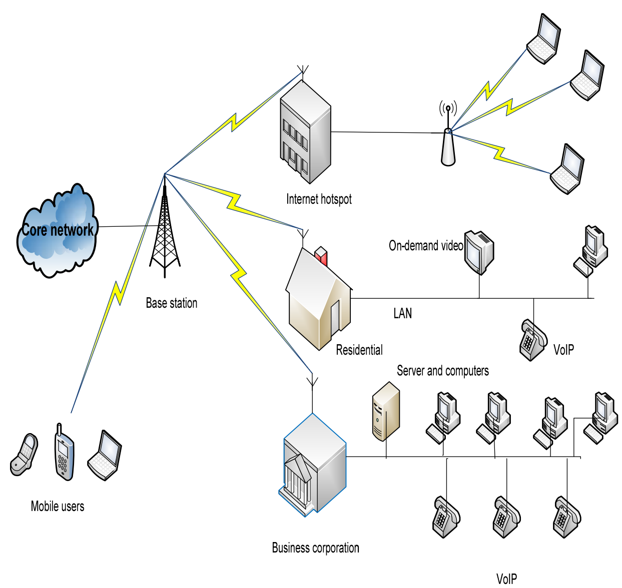

Figure 2: Example of WiMAX Deployment.

The base station will support up to 280 Mbps to meet the needs of many simultaneous users. Table 2 below summarizes in detail the differences in the evolution of 802.16 standards [11].

Table 2: Overview of the Evolution of IEEE 802.16 (WiMAX) Standards.

Standard	802.16	802.16e
Completed	December2001	Mid-2005
Spectrum	10-66 GHz	2-6 GHz
Application	Backhaul	Mobile Internet
Channel Conditions	Line of sight only	Non Line of sight
Bit Rate	32 –134 Mbps at 28MHz channelization	Up to 15 Mbps at 5MHz channelization
Modulation	QPSK, 16QAM and 64QAM	Scalable OFDMA
Mobility	Fixed	Pedestrian Mobility-Regional Roaming
Channel Bandwidths	20, 25 and 28 MHz	Selectable channel bandwidths between 1.5 - 20 MHz with UL sub-channels to conserved power
Typical Cell Radius	1-3 miles	1 - 3 miles

PHY (Physical) Layer: Apart from the usual functions such as randomization, forward error correction (FEC), interleaving, and mapping to QPSK and QAM symbols, the standard also specifies optional multiple antenna techniques. This includes space time coding (STC), beam forming using adaptive antennas schemes, and multiple input multiple output (MIMO) techniques which achieve higher data rates. The OFDM modulation/demodulation is usually implemented by performing fast Fourier transform (FFT) and inverse FFT on the data signal.

The MAC layer used by WiMAX is based on a time division multiple access (TDMA) mechanism to allow a homogeneous distribution of the bandwidth between all the devices which is more effective and support several channels compared to the mechanism used by Wi-Fi (CSMA-CA). This makes it possible to obtain a better optimization of the radio spectrum with better efficiency (bits/seconds/Hertz). Thus, WiMAX has an efficiency of 5 Bps/Hz compared to the 2.7Bps/Hz of Wi-Fi that makes it possible to transmit 100 Mb/s on 20 MHz channel.

Applications of fixed WiMAX (802.16-2004) include wireless E1 enterprise backhaul and residential 'last mile' broadband access, while applications for mobile WiMAX (802.16e) include nomadic and mobile consumer wireless DSL service. Other WiMAX applications include: connecting Wi-Fi hotspots with each other and to other parts of the Internet; providing a wireless alternative to cable and DSL for last mile (last km) broadband access. There is both flexibility and cost effectiveness, that makes the technology suitable for remote areas. On flexibility, WiMAX can be deployed in any terrain across all geographical areas.

WI-FI AND WIMAX COMPARISON

From the technical overview of the two wireless technologies given in previous section, it can be seen that they are not addressed to the same market but are very complementary. Wi-Fi allows the implementation of wireless local area network for a house or a small building. It can also be used to carry out a public hot spot allowing mobile points to connect in a hotel, an airport, etc. WiMAX is a metropolitan technology whose objective is to interconnect houses, buildings or even hot spots to allow communication between them and with other networks (Internet, etc).

Although not being targeted on the same use, more recently WiMAX technology has several advantages compared to Wi-Fi. Such as: a better reflection tolerance; a better penetration of obstacles; and an increased in the number of interconnections (a few hundreds of equipment rather than some tens of equipment for Wi-Fi). It's obvious that the WiMAX standard goal is not to replace Wi-Fi in its applications but rather to supplement it in order to form a wireless network web. Despite the similarity in equipment cost, WiMAX technology requires a costly infrastructure while Wi-Fi can be easily install using low cost access points. These two wireless technologies have common components in their operations with a major difference in the communication range. Table 3 below gives the detailed comparative analysis of the two broadband wireless access networks (WiFi and WiMAX) suitable for rural connectivity.

DEPLOYING THE TECHNOLOGIES FOR LAST-MILE RURAL ACCESS SOLUTIONS

Figure 3 shows the topology that could be used by a municipality that wants to extend broadband connectivity to two new rural community centers. The municipality wants to provide free Internet service to local residences and staff to promote education, cultural arts and local businesses. A combination of WiMAX and Wi-Fi mesh network topology provides the best solution for this situation. WiMAX can be used to aggregate the community centers. WiMAX extends the reach of broadband, while the proprietary Wi-Fi mesh network can provide mobile client access throughout the community centers. As dual-mode Wi-Fi and WiMAX cells are introduced into high-capacity network centers in licensed or unlicensed bands.

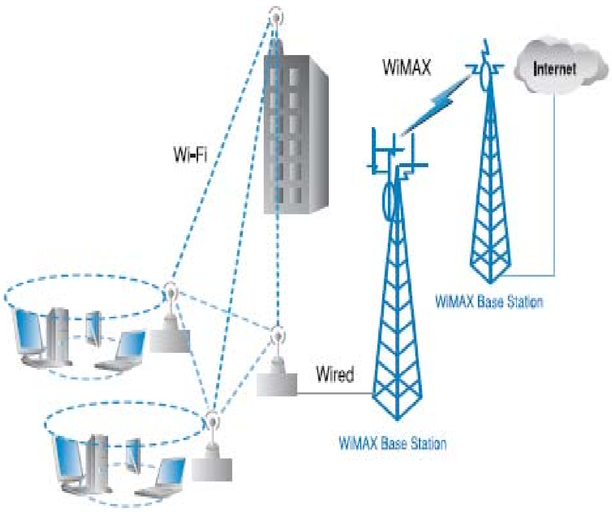

Figure 3: WiMAX Backhaul for a Wi-Fi Topology.

The WiMAX cells will interoperate seamlessly with existing Wi-Fi cells; always selecting the best path for delivering maximum user throughput end-to-end. A combined Wi-Fi mesh and WiMAX deployment, as shown in Figure 3, offers a more cost-effective solution than a sole Wi-Fi directional-antenna deployment or a Wi-Fi mesh network with wired backhaul to extend the LAN or cover the last mile.

CONCLUSIONS

This paper has presented a precise description of the different developing wireless access networks to determine how these technologies may collaborate together to form an alternatives for implementing last-mile wireless broadband services. Detailed technical comparative analysis between the 802.11 (WiFI) and 802.16 (WiMAX) wireless networks that provide alternative solution to the problem of information access in remote inaccessible areas where wired networks are not cost-effective has been looked into. The work has proved that the WiMAX standard goal is not to replace Wi-Fi in its applications but rather to supplement it in order to form a wireless network web.

Table 3: Comparison Between Broadband Wireless Access Technologies.

Properties	802.11 (WiFi)	802.16 (WiMAX)
Frequency Band	Used in unlicensed band, 2.4GHz ISM (b/g), 5 GHz U-NII (a) and 5GHz ISM	Used in icensed/unlicensed band: 2 GHz to 11GHz
Typical Use/Primary application	Designed to extend mobility to LANs	Designed to provide basic carrier-delivered metro services. (Broadband wireless access, fixed wireless access, portability and mobility)
Range	Optimized for approx. 100m. No distance compensation. Designed to handle indoor multipath (delay speed of 0.8µs). Optimized around Physical and MAC layers for 100m range. Range can be extended by cranking up the power- Non standard MAC.	Optimized for up to 50Km Designed to handle many users spread out over kilometers. Designed to tolerate greater multipath delay speed reflection) up to 10.0µs. Physical and MAC designed with multipath-mile range in mind. Standard MAC.
Coverage	Optimized for indoor performance. No mesh topology support within ratified standards.	Optimized for outdoor NLOS performance. Standard supports mesh network topology. Standard supports advanced antenna techniques.
Scalability (Channel Bandwidth)	Fixed Wide Channels (20MHz - a/g). (25 MHz- b) MAC designed to support tens of users	Adaptive Channel band (sectorization). Adjustable bandwidth from 1.5MHz to 20MHz. MAC independent of the channel bandwidth. MAC designed to support hundreds of users.
Security (Encryption)	Existing standard is WPA + WEP Optional - RC4 AES implemented in 802.11i	Triple DES (128-bit) & RSA (1024-bit) Optimal – AES
QoS Management (Multiple Access)	Contention based MAC (CSMA/CA). No guaranteed QoS Standard cannot guarantee latency for voice, video (PCF not implemented) Standard does not allow for differentiated service levels for each user TDD only – asymmetric QoS is prioritized only in 802.11e	Grant request MAC. Designed to support voice and video. Supports differentiated service levels: E1 for business customers, best effort for residential. TDD/FDD/HFDD– Symmetric or asymmetric Centrally– enforced QoS
Radio Technology	DS-SS 802.11b OFDM (64 –channel) for 802.11a/g	OFDM (256 channels)
Modulation	QPSK – 802.11b BPSK, QPSK, 16QAM, 64 QAM	BPSK, QPSK, 16, 64, 256-QAM
Data Rate (Physical layer)	802.11a/g – 54Mbps/20MHz channel 802.11b – 11Mbps	802.16a – 75Mbps 802.16e – 15Mbps

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