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An Exploration on Wi-Fi/802.11b and WiMAX/802.16 Networks with Performance Enhancements

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Abstract

The present scenario in wireless network is changing rapidly owing to several factors like high data rate, mobility, and range being some of them. Wireless Networks has huge diversity ranging from Wi-Fi (802.11) covering small areas to WiMAX (802.16) that covers several miles. WIRELESS world became more diverse with the introduction of IEEE 802.16 (known as WiMAX) technologies several years ago. The idea was to cover the gap in the metropolitan areas, which was left between Wireless Local Area Networks Wi-Fi (such as IEEE 802.11) as well as mobile cellular networks (such as 3G and beyond). This was a revolution in the wireless world in the first decade of the 21st century. The IEEE 802.16 WiMAX (World Wide Interoperability for Microwave Access) standard is based on global interoperability and is an emerging technology that delivers 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 Quality of Service in wireless networks. This paper does an exploration on Wi-Fi and WiMAX networks with possible performance enhancements.

Keywords: Wireless Local Area Networks, Wi-Fi, WiMAX, Interoperability.

Introduction

Wireless Networks and Broadband Wireless Access (BWA)

Since the final decades of the twentieth century, data networks have known steadily growing success. After the installation of fixed Internet networks in many places all over the planet and their large expansion, the need is now becoming more important for wireless access.

The concept of wireless access networks emerged in the late 1980s as a by product of cellular wireless technology. As the demand for cellular service exploded worldwide, the cost of wireless network components decreased, while the cost for deploying and maintaining the conventional copper-based subscriber network increased. It is very recent that the concept of mobile wireless access network was introduced. [1]

Different Types of Data Networks

A large number of wireless transmission technologies exist, other systems still being under design. These technologies can be distributed over different network families, based on a network scale. In Figure 1, a now-classical representation (sometimes called the 'eggs figure') is shown of wireless network categories, with the most famous technologies for each type of network.

A ***Personal Area Network*** (PAN) is a (generally wireless) data network used for communication among data devices close to one person. The scope of a PAN is then of the order of a few metres, generally assumed to be less than 10 m, although some WPAN technologies may have a greater reach. Examples of WPAN technologies are Bluetooth, UWB and Zigbee.

A ***Local Area Network*** (LAN) is a data network used for communication among data devices: computer, telephones, printer and personal digital assistants (PDAs). This network covers a relatively small area, like a home, an office or a small campus (or part of a campus). The scope of a LAN is of the order of 100 metres. The most (by far) presently used LANs are Ethernet (fixed LAN) and Wi-Fi (Wireless LAN, or WLAN).

A ***Metropolitan Area Network*** (MAN) is a data network that may cover up to several kilometres, typically a large campus or a city. For instance, a university may have a MAN that joins together many of its LANs situated around the site, each LAN being of the order of half a square kilometre. Then from this MAN the university could have several links to other MANs that make up a WAN. Examples of MAN technologies are FDDI (Fiber- Distributed Data Interface), DQDB

(Distributed Queue Dual Bus) and Ethernet-based MAN. Fixed WiMAX can be considered as a Wireless MAN (WMAN).

A *Wide Area Network* (WAN) is a data network covering a wide geographical area, as big as the Planet. WANs are based on the connection of LANs, allowing users in one location to communicate with users in other locations. Typically, a WAN consists of a number of interconnected switching nodes. These connections are made using leased lines and circuit-switched and packet-switched methods. The most (by far) presently used WAN is the Internet network. Other examples are 3G and mobile WiMAX networks, which are Wireless WANs. The WANs often have much smaller data rates than LANs (consider, for example, the Internet and Ethernet).

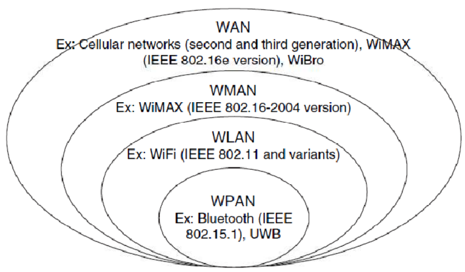

Fig 1. Illustration of network types [2]

The paper gives a technical overview of the two popular broadband wireless technologies, Wi-Fi and WiMAX (i.e., IEEE 802.11b and IEEE 802.16). The next section provides a detailed study of the two wireless technologies. The paper then shows a comparative analysis of the two technologies. Further we also detail the suggested solutions to improve the performance of these networks.

WI-FI and WIMAX Overview

Wi-Fi

The IEEE standard 802.11 has been developed by the IEEE 802.11 WG on WLAN since 1991. The first standard was published in 1997, and since then, the 802.11 WG has been developing many amendments to enhance this technology in various ways, including higher speed, QoS support, and security enhancement. The Wi-Fi Alliance, which started in 1999, has been testing and certifying the interoperability of IEEE 802.11-based WLAN products. Wi-Fi stands for "wireless fidelity". However since most of our WLANs are based on those standards, the term Wi-Fi is used generally as a synonym for WLAN. Wi-Fi is a popular technology which allows any electronic device to exchange and transfer data wirelessly over the network giving rise to high speed internet connections. Any device which is Wi-Fi enabled (like personal computers, video game consoles, Smartphone, tablet etc.) can connect to a network resource like the internet through a wireless network access point. [5]

IEEE 802.11 WLAN, or Wi-Fi, is probably the most widely accepted broadband wireless networking technology, providing the highest transmission rate among standard-based wireless networking technologies. Today's Wi-Fi devices, based on IEEE 802.11a and 802.11g provide transmission rates up to 54 Mbps and, further, a new standard IEEE 802.11ac , which supports up to 1.3 Gbps, is being standardized [7]. The transmission range of a typical Wi-Fi device is up to 100m, where its exact range varies depending on the transmission power, the surrounding environments, and others. The 802.11 devices operate in unlicensed bands at 2.4 and 5 GHz, where the exact available bands depend on each county.

The most typical applications of the 802.11 WLAN include Internet access of portable devices in various networking environments, including campus, enterprise, home, and hot-spot environments, where one or more *access points* (APs) are deployed to provide Internet service in a given area. The 802.11 could be used for a peer-to-peer communication among devices where APs are not deployed. For examples, laptops and PDAs in proximity can use the 802.11 to share their local files. Also, people in proximity can do networked gaming using their gaming devices with the 802.11 interface.

WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a telecommunications protocol that provides fixed and mobile Internet access. The name "WiMAX" was created by the WiMAX Forum. The forum describes WiMAX as "a standards based technology enabling the delivery of last mile wireless broadband access as an alternative to cable and DSL" [6]. There are two main types of WiMAX today, *fixed WiMAX* (IEEE 802.16d — 2004), and *Mobile WiMAX* (IEEE 802.16e — 2005).

Fixed WiMAX is a point-to- multipoint technology, whereas mobile WiMAX is a multipoint-to-multipoint technology, similar to that of a cellular infrastructure. Mobile WiMAX uses orthogonal frequency division multiple access (OFDMA) technology which has inherent advantages in latency, spectral efficiency, advanced antenna performance, and improved multipath performance in, an NLOS environment. Scalable OFDMA (SOFDMA) has been introduced in IEEE 802.16e to support scalable channel bandwidths from 1.25 to 20 MHz. Mobile WiMAX supports roaming service in metropolitan and regional networks, so allows mobile connectivity to mobile users. Mobile WiMAX systems offer scalability in both radio access technology and network architecture, thus providing a great deal of flexibility in network deployment options and service offerings. Some of the salient features supported by WiMAX are:

- **High data rates.** The inclusion of multi-input multi-out (MIMO) antenna techniques along with flexible sub-channelization schemes, advanced coding and modulation all enable the mobile WiMAX technology to support peak downlink data rates of 63 Mbps per sector and peak uplink data rates of up to 28 Mbps per sector in a 10 MHz channel.
- **Quality of service (QoS)**. The fundamental premise of the IEEE 802.16 MAC architecture is QoS. It defines service flows which can map to DiffServ code points or MPLS flow labels that enable end-to-end IP based QoS.
- **Scalability.** Mobile WiMAX is designed to be able to scale to work in different channelization from 1.25 to 20 MHz to comply with varied worldwide requirements as efforts proceed to achieve spectrum harmonization in the longer term.
- **Security.** Support for a diverse set of user credentials exists including SIM/ USIM cards, smart cards, digital certificates, and user name/password schemes based on the relevant extensible authentication protocol (EAP) methods for the credential type.
- **Mobility.** Mobile WiMAX supports optimized handoff schemes with latencies less than 50 ms to ensure that real-time applications such as VoIP can be performed without service degradation. Flexible key management schemes assure that security is maintained during handoff. [4]

Comparison between WI-FI and WIMAX

Radio Technology

WiMAX differs from Wi-Fi in the radio technology sector. The IEEE 802.11 WLAN standards describe four radio link interfaces that operate mainly in unlicensed radio band having range from 2.4 G to 5 GHz .The WiMAX 802.16a standard released in January 2003 operates between 2 GHz and 11 GHz. The lower frequency bands support Non-line-of-sight (NLOS) for that reason customer unit need not be aligned with base station.

Wi-Fi mainly operates in unlicensed frequency bands, but WiMAX can operate in both licensed and unlicensed spectrum.

Within IEEE 802.16a's 2-11 GHz range, four bands are most attractive:

- Licensed 2.5-GHz MMDS
- Licensed 3.5-GHz Band
- Unlicensed 3.5-GHz Band
- Unlicensed 5 GHz U-NII Band

Duplexing techniques

WiMAX systems can be configured for dual-channel (inbound/outbound) Frequency Division Duplex (FDD) or single channel Time Division Duplex (TDD) operation. In TDD operation, separate timeslots are assigned for inbound and outbound transmissions so the channel is essentially full duplex. While it does reduce the transmission rate by more than 50%, TDD systems use half the radio bandwidth of FDD systems. The WiMAX standards also define an optional mesh configuration.

All Wi-Fi networks are contention-based TDD systems Half Duplex, where the access point and the mobile stations all vie for shared media use of the same channel. Because of the shared media operation, all Wi-Fi networks are half duplex.

Radio Modulation

Wi-Fi systems use two primary radio transmission techniques:

- **802.11b (≤11 Mbps):** The 802.11b radio link uses a direct sequence spread spectrum technique called complementary coded keying (CCK). The bit stream is processed with a special coding and then modulated using Quadrature Phase Shift Keying (QPSK).
- **802.11a and g (≤54 Mbps):** The 802.11a and g systems use 64-channel orthogonal frequency division multiplexing (OFDM). In an OFDM modulation system, the available radio band is divided into a number of sub-channels, and some of the bits are sent on each. The transmitter encodes the bit streams on the 64 subcarriers using Binary Phase Shift Keying (BPSK), Quadrature Phase Shift Keying (QPSK), or one of two levels of Quadrature Amplitude Modulation (16-, or 64- QAM). Some of the transmitted information is redundant, so the receiver does not have to receive all of the sub-carriers to reconstruct the information. The original 802.11 specifications also included an option for frequency hopping spread spectrum (FHSS), but that has largely been abandoned.

The 802.16a standards define three main options for the radio link:

- **SC-A:** Single Carrier Channel

- **OFDM:** 256-Sub-Carrier Orthogonal Frequency Division Multiplexing
- **OFDM-A:** 2,048-Sub-Carrier Orthogonal Frequency Division Multiplexing

Channel Bandwidth

The Wi-Fi standards define a fixed channel bandwidth of bandwidth 25 MHz for 802.11b and 20 MHz for either 802.11a or g networks. In WiMAX, the channel bandwidths are adjustable from 1.25 MHz to 20 MHz. That will be particularly important for carriers operating in licensed spectrum.

Quality of Service

WiMAX Quality of Service or WiMAX QoS is a key element in the delivery of service over the WiMAX medium. With techniques such as Internet Protocol being used, delays or latency and jitter can be introduced into the data transmission arena. To overcome the effects of latency and jitter, the concept of quality of service is used. For WiMAX Qos several techniques and definitions are at the core of implementation.

In order to categorize the different types of quality of service, there are five WiMAX QoS classes that have been defined.

- **Unsolicited Grant-Real Time:** The Unsolicited Grant Service, UGS is used for real-time services such as Voice over IP, VoIP for applications where WiMAX is used to replace fixed lines such as E1/T1.
- **Real Time Polling:** This WiMAX QoS class is used for real-time services including video streaming. It is also used for enterprise access services where guaranteed E1/T1 rates are needed but with the possibility of higher bursts if network capacity is available. This WiMAX QoS class offers a variable bit rate but with guaranteed minimums for data rate and delay.
- **Variable Bit Rate-Non-Real Time:** This WiMAX QoS class is used for services where a guaranteed bit rate is required but the latency is not critical. It might be used for various forms of file transfer.
- **Variable Bit Rate-Best Effort:** This WiMAX QoS is that used for Internet services such as email and browsing. Data packets are carried as space becomes available. Delays may be incurred and jitter is not a problem.
- **Extended Real Time Polling:** This WiMAX QoS class is referred to as the Enhanced Real Time Variable Rate, or Extended Real Time Packet Services. This WiMAX QoS class is used for applications where variable packet sizes are used – often where silence suppression is implemented in VoIP. One typical system is Skype. [11]

The 802.11e standard includes two operating modes, either of which can be used to improve service for voice:

- **Wi-Fi Multimedia Extensions (WME)** - Mandatory
- **Wi-Fi Scheduled Multimedia (WSM) –** Optional

Security

The other major difference between Wi-Fi and WiMAX is privacy or the ability to protect transmissions from eavesdropping. Security has been one of the major deficiencies in Wi-Fi, though better encryption systems are now becoming available. In Wi-Fi, encryption is optional, and three different techniques have been defined:

- **Wired Equivalent Privacy (WEP):** An RC4-based 40- or 104-bit encryption with a static key
- **Wi-Fi Protected Access (WPA):** A new standard from the Wi-Fi Alliance that uses the 40- or 104-bit WEP key, but changes the key on each packet to thwart key crackers. That changing key functionality is called the Temporal Key Integrity Protocol (TKIP).
- **IEEE 802.11i/WPA2:** The IEEE 802.11i standard is based on a far more robust encryption technique called the Advanced Encryption Standard.

Virtually all WiMAX transmissions will be encrypted. The initial specification calls for 168-bit Digital Encryption Standard (3DES), the same encryption used on most secure tunnel VPNs. Advanced Encryption Standard (AES), Privacy Key management (PKM) are other options. [3]

Mac layer/ Data Link layer

In Wi-Fi the MAC uses contention access – all subscriber stations that wish to pass data through a wireless access point (AP) are competing for the AP's attention on a random interrupt basis. This can cause subscriber stations distant from the AP to be repeatedly interrupted by closer stations, greatly reducing their throughput. This makes services such as VoIP or IPTV, which depend on an essentially constant QoS depending on data rate and interruptibility, difficult to maintain for more than a few simultaneous users. [9]

In contrast, the 802.16 MAC uses a scheduling algorithm for which the subscriber station need compete once (for initial entry into the network). After that it is allocated an access slot by the base station. The time slot can enlarge and contract, but remains assigned to the subscriber station which means that other subscribers cannot use it.

The 802.16 scheduling algorithm is stable under overload and over-subscription (unlike 802.11). It can also be more bandwidth efficient. The scheduling algorithm also allows the base station to control QoS parameters by balancing the time-slot assignments among the application needs of the subscriber stations. [10]

Table I [3], [5], [8]
Comparison Of Wi-Fi And Wimax Technologies

Parameters	Comparison of Wi-Fi and WiMAX Technologies	
	802.11 (Wi-Fi)	802.16 (WiMAX)
Primary Application	Wireless LAN	Wireless MAN mainly designed for broadband wireless
Range and Coverage	Mainly designed for indoor Optimized for 100 meters	Designed for outdoor NLOS performance Optimized for 50 km
Scalability	Unlicensed Band 2.4 GHz to 5 GHz	Licensed and Unlicensed Band 2 GHz to 11 GHz
Channel Bandwidth	On the range from 20-25 MHz	Adjustable range from 1.25 to 20 MHz
Radio Technique	OFDM 64 channels and Direct Sequence Spread Spectrum	OFDM 256 Channels
Security	Security is optional here. Better encryption technique like WPA and WEP available now	3 DES (128 bit), AES, PKM
Modulation technique	QPSK, BPSK, 16-QAM, 64-QAM	QPSK, BPSK, 16-QAM, 64-QAM, 256-QAM
Quality of Service	VoWi-Fi is emerging and 802.11e a proposed standard by IEEE for QoS.	Inbuilt QoS for voice and multimedia applications.
MAC layer	In Wi-Fi the MAC uses contention access	The 802.16 MAC uses a scheduling algorithm
Application	Household and corporate needs of interconnectivity. Connects printers to computer, gaming consoles to router etc.	Provide internet services to a larger area where it can serve households, mobile phones and even Wi-Fi spots.

Suggested Solutions to Enhance the Performance of Wi-Fi and WiMAX Networks

WiMAX is a part of the evolution from voice-only wireless communications systems to ones that provide additional services like web browsing, streaming media, gaming, instant messaging, and other content. The 802.16 standard offers adjustable data rate to and from each user while maintaining the required quality of service (QoS). WiMAX uses a combination of adaptive modulation schemes and coding ranging from 1/2 rate QPSK to 5/6 rate 64QAM. Assigning modulations based on the link conditions increases the overall capacity of the system. The use of variable or adaptive modulations to increase capacity is a trend also observed in other recently developed mobile phone and data standards like WCDMA. [15]

Provisions have been made to include advanced antenna systems in the WiMAX standard to improve throughput and link reliability. 802.16 allows for several antennas to be used at the transmitter and the receiver to create a Multiple-Input Multiple-Output (MIMO) system. [14]Techniques such as space-time coding (STC) can be used to reduce the occurrence of deep fades in the signal level across the transmission band. An increase in throughput can be achieved by spatially multiplexing (SM) different data streams on each of the transmit antenna elements at the same time on the same frequency. A multiple antenna receiver (with at least the same number of elements as unique transmitted data streams) could separate these signals resulting in an increase in data rate proportional to the number of antennas at the receiver. Antenna beam forming is a third supported option in the standard in which pattern maximas are electronically steered in the direction of the desired source while nulls are placed in the direction of the interfering sources. [15]

Mobile WiMAX supports frequency reuse of one, i.e. all cells/sectors operate on the same frequency channel to maximize spectral efficiency. Multicast and Broadcast Service (MBS) supported by Mobile WiMAX can combine the best features of DVB-H, MediaFLO and 3GPP E-UTRA and satisfy the following requirements: [13]

- High data rate and coverage using a Single Frequency Network (SFN)
- Flexible allocation of radio resources
- Low MS power consumption
- Support of data-casting in addition to audio and video streams
- Low channel switching time

Most 802.11 systems utilize Omni-directional antennas that radiate energy equally in all directions. This is highly inefficient and creates interference for neighbouring networks. Moreover, with 802.11n, omni-directional transmissions by multiple radio chains can actually have a negative effect on system performance and reliability if the antennas are insufficiently spaced or improperly oriented.

There are several techniques used by Wi-Fi to improve capacity and speed:

- **Number of spatial streams: 1, 2, 3 or 4:** This results in a two to four-fold increase of data rates in some environments. By controlling the signal path direction and timing, smart antenna arrays provide an important value-add in multipath operations for Wi-Fi. The availability of a large number of antenna configurations and the ability to select the best de-correlated patterns allow smart antennas to maximize successful spatial multiplexing operations to maintain the highest data rates.
- **Effect of Channel bandwidth:** This result in roughly doubling the physical data rate in some environments. In 802.11n, channel bonding boosts bandwidth by combining two adjacent 20 MHz channels into a single 40 MHz channel. The capacity increase is actually a bit more than double since the guard band between the two bonded channels can also be utilized. At small communication distances, throughput increases with channel width. But again, decreasing the channel increases communication range. Also, narrower channel widths consume lesser battery power when sending and receiving packets, as well as in the idle states. A 5 MHz channel width consumes 40% lesser power when idle, and 20% lesser power in sending packets than 40 MHz channel.[16]
- **Space-time block coding options (STBC)**: STBC is another diversity technique for improving SNR, but is applied when the number of transmitting antenna chains exceeds the number of receive antennas. STBC uses coding to transmit different (but known) copies of the data-stream from different antennas; assuming the receiver knows the code; it will be able to extract the original data with fewer errors than when a single transmit antenna is used.
- **Transmit beam forming:** It steers an outgoing signal stream towards the intended receiver by concentrating transmitted RF energy in a given direction. This technique leverages additive and destructive environmental impacts, exploiting RF phenomena like signal reflection and multipath to improve received signal strength and sustain higher data rates.
- **Variable guard interval:** It is the time between transmitted symbols (the smallest unit of data sent at once). This Guard Interval is necessary to offset the effects of multipath that would otherwise cause Inter-Symbol Interference (ISI). 802.11a/g devices use an 800 ns guard interval, but 802.11n devices have the option of pausing just 400 ns. Shorter Guard Intervals would lead to more interference and reduced throughput, while a longer guard Interval would lead to unwanted idle time in the wireless environment. A Short Guard Interval (SGI) boosts data rate by 11 percent while maintaining symbol separation sufficient for most environments.
- **Frame aggregation:** Improves effective throughput at higher PHY rates. Frame aggregation combines multiple small packets into one large frame — increasing packet efficiency with less overhead.
- **Routing Protocols:** Routing Protocol efficiency may or may not directly affect data routing performance of wireless networks. Several routing protocols in use are AODV, DSDV, DSR, ZRP, GRP etc. The performance of these routing protocols differs in varying environment. [17]
- **Block acknowledgment:** Block acknowledgment allows the receiver to acknowledge a group of frames instead of a single frame. Acknowledgments reduce the airtime efficiency because of the delayed response time. By acknowledging multiple frames at a time, 802.11n allows for a more efficient use of the medium.

Using Wi-Fi to complement WiMAX can provide advantages that improve indoor coverage. One of the ways of going about this is to use a WiMAX-Wi-Fi combination modem also known as WiMAX Integrated Access Device (IAD) which enables WiMAX-In-Wi-Fi-Out. [12]

Conclusion

This paper has presented an overview of two popular broadband wireless technologies (i.e., IEEE 802.11b and IEEE 802.16). Detailed technical comparative analysis between the 802.11b (Wi-Fi) 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. Further we have also analysed ways to improve the performance of the existing real-time Wi-Fi and WiMAX systems. Though there are several ways to improve the performance of these networks, performance enhancement of one factor is usually at the cost of the other and also they differ with varying environment. For example, one aspect that affects the routing protocol performance is mobility. DSR protocol packet loss is less in case of low mobility environment, whereas as mobility increases the performance of DSR becomes poor. Thus we conclude that performance enhancements totally depend on the specified application and the necessity that one choose.

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References

[1] Byeong Gi Lee, Sunghyun Choi., "*Broadband Wireless Access and Local Networks*", Artech House Inc, 2008.

[2] Professor Loutfi Nuaymi., "*WiMAX: Technology for Broadband Wireless Access*", John Wiley & Sons Inc,2007

[3] Michael F. Finneran., "*WiMax versus Wi—FI A comparison of Technologies, Markets and Business Plan*" dBrn Associates, Inc.

[4] Vijay K. Garg., "*Wireless Communication and Networking*" Elsevier Inc. 2007

[5] Sourangsu Banerji , Rahul Singha Chowdhury "*Wi-Fi & WiMAX: A Comparative Study*" Indian Journal of Engineering, Vol.2, Issue. 5, 2013.

[6] Daniel Minoli., "*Building the Internet of Things with IPv6 and MIPv6: The Evolving World of M2M Communications*" Wiley Inc, June 2013

[7] *802.11ac: The Fifth Generation of Wi-Fi*, Available online at: http://www.cisco.com/en/US/prod/collateral/wireless/ps5678/ps11983/white_paper_c11-713103.html

[8] Syed A. Ahson, Mohammad Ilyas ., "*WiMAX: Applications*" Taylor and Francis Group LLC, 2008

[9] G.S.V. Radha K. Rao, G. Radhamani ., "*WiMAX: A Wireless Technology Revolution*" Taylor and Francis Group LLC, 2008

[10] Zhu Han, K. J. Ray Liu ., "*Resource Allocation for Wireless Networks: Basics, Techniques and Applications*", Cambridge University Press, 2008

[11] Fazil Sarfaraz, Tarranum Parveen ., "*Wireless Communication and Security in Wimax*" IOSR Journal of Electronics and Communication Engineering (IOSRJECE), Volume 2, Issue 2 (July-Aug 2012)

[12] "*Improving Indoor Coverage: How WiMAX Modems Can Play a Major Role in the Subsystem*" Available online at: http://www.wimaxforum.org/sites/wimaxforum.org/files/document_library/Improving%20Indoor%20CoverageHow%20WiMAX%20Modems%20Can%20Play%20a%20Major%20Role%20in%20the%20Subsystem.pdf

[13] Emmanuelle Vivier, Guillaume Vivier "*Radio Resources Management in WiMAX: From Theoretical Capacity to System Simulations*" John Wiley & Sons, 28-Mar-2013

[14] Neha Rathore, Dr. Sudhir Kumar, Abhishek Choubey" *Performance evaluation of WIMAX MAC layer: IEEE- 802-16e*" IJECT Vol. 2, Issue 3, Sept. 2011

[15] Kai Dietze Ph.D., Ted Hicks, and Greg Leon "*WiMAX System Performance Studies*" EDX Wireless, LL

[16] Ranveer Chandra, Ratul Mahajan, Thomas Moscibroda, Ramya Raghavendra , Paramvir Bahl "*A Case for Adapting Channel Width in Wireless Networks*" Microsoft Research, Redmond, WA.

[17] Sabina Baraković, Suad Kasapović, and Jasmina Baraković "*Comparison of MANET Routing Protocols in Different Traffic and Mobility Models*" Telfor Journal, Vol. 2, No. 1, 2010