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**PERFORMANCE ANALYSIS OF INTEGRATED WIFI/WIMAX MESH NETWORK  
WITH DIFFERENT MODULATION SCHEMES**

**Mr. Jogendra Raghuwanshi\*, Mr. Girish Tiwari**

\* Research Scholar UEC Ujjain.  
Associate Professor UEC Ujjain.

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**ABSTRACT**

Wireless communication technology has been growing remarkably well day by day. Wi-Fi has led wireless communication to a long way due to its high data rate capacity. Wi-Fi has a high penetration in market but it is connected to Internet or other networks with wired connections making its deployment complex and expensive. WiMAX, on the other hand, is new emerging wireless technology which provides wider coverage area but its deployment is also expensive. To overcome the individual shortcomings and using the capabilities of Wi-Fi and WiMAX, we have proposed an Integrated Wi-Fi/WiMAX network with mesh capabilities to form wireless mesh network.

In this paper we are using mesh topology at Wi-Fi/WiMAX Routers (WWRs) so that WiMAX SS, inbuilt in WWRs, can communicate directly with each other without the intervention of WiMAX Base Station. The transmission is carried under influence of AWGN channel and propagation path loss. Wi-Fi/WiMAX mesh network is simulated and its performance is evaluated by Bit Error Rate with respect to Signal to Noise ratio and distance between WiMAX SS for different modulation schemes and distances between Wi-Fi AP and stations.

**KEYWORDS:** BER, SNR, Wi-Fi, WiMAX.

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**INTRODUCTION**

Recently wireless access technology has greatly evolved to reach the exponential growth. Although wireless access technology has grown, there are still significant limitations that make it difficult to exploit its potential benefits. The main difficulty regarding expanded coverage is that WiMAX (IEEE 802.16) is not available in all regions. But WiMAX delivers high speed Wireless Metropolitan Area Network (WMAN) connectivity and offers a variety of services to users.

Wireless networks based on IEEE 802.11, known as Wireless Local Area Network (WLAN), has a huge market in providing different data services with high speed connection for local/indoor users. WLAN (Wi-Fi hotspots) are connected to Internet and/or other networks through wired infrastructure network. But deployment of such wired infrastructure network, in remote and rural areas with low population density, is expensive and complex. One strategy to solve problem of deployment of wired infrastructure is to employ WiMAX in its place so that Wi-Fi can connect to Internet or other networks through it. So the integration of Wi-Fi and WiMAX can introduce a new flexible wireless network, to support broadband wireless Internet connectivity, especially in the remote and rural areas where wired infrastructure are unavailable and their deployment is not cost effective.

The integration of Wi-Fi/WiMAX can overcome their individual shortcomings in terms of coverage, deployment cost, etc. and can exploit their potential benefits to provide seamless and high speed Internet connectivity with large coverage area at cheap investments. The deployment of an integrated Wi-Fi/WiMAX architecture, [1] that allows both Wi-Fi and WiMAX to interoperate, presents several advantages to users and service providers. The operators would form large coverage area at high speed connectivity with cheap investment, while users would benefit from ubiquitous network access with guaranteed services.

In this paper, we are using Integrated Wi-Fi/WiMAX network with mesh topology at Wi-Fi/WiMAX Routers (WWRs) so that WiMAX SS, inbuilt in WWRs, can communicate to each other without intervention of WiMAX Base Station. In this paper, we first provide a brief theoretical overview on the technologies which we are use using in section II. Integrated Wi-Fi/WiMAX Mesh architecture is explained under section III. In section IV, we explain simulation setup and parameters. Performance of system is evaluated in section V. Finally conclusion and future work in section VI.

## THEORETICAL FOUNDATION

### FREE SPACE PATHLOSS

In NLOS environments, the received signal power typically decays with distance at a rate much faster than in LOS conditions. This distance dependent power loss, called free space pathloss [2], depends on a number of variables, such as terrain, foliage, obstructions, and antenna height. Pathloss also has an inverse-square relationship with carrier frequency. Given that many broadband wireless systems will be deployed in bands above 2GHz under NLOS conditions, systems will have to overcome significant pathloss. Assuming that an isotropic antenna is used, free space path loss is given by

$$L_f = \frac{P_t}{P_r} = \left( \frac{4\pi d f_c}{c} \right)^2$$

Where

$P_t$  = signal power at the transmitting antenna

$P_r$  = signal power at the receiving antenna

$d$  = propagation distance between antennas

$f_c$  = carrier frequency

$c$  = speed of light ( $3 \times 10^8$  m/s)

### ADDITIVE WHITE GAUSSIAN NOISE (AWGN)

Additive white Gaussian noise (AWGN) is the most basic impairment present in any communication channel. Since the amount of thermal noise picked up by a receiver is proportional to the bandwidth, the noise floor seen by broadband receivers is much higher than those seen by traditional narrowband systems. The higher noise floor, along with the larger pathloss, reduces the coverage range of broadband systems.

$$N = kTB$$

Where

$k$  = Boltzmann's constant =  $1.38 \times 10^{-23}$  J/K

$B$  = Bandwidth (Hertz)

$T$  = temperature, in Kelvin

### ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING (OFDM)

The basic idea of multicarrier modulation is quite simple and follows naturally from the competing desires for high data rates and ISI-free channels. Orthogonal Frequency Division Multiplexing (OFDM) [3] is a modulation scheme that is especially suited for high-data-rate transmission in delay-dispersive environments. It converts a high-rate data stream into a number of low-rate streams that are transmitted over parallel, narrowband channels that can be easily equalized. It first divides the transmit data into blocks of  $N$  symbols. Each block of data is subjected to an Inverse Fast Fourier Transformation (IFFT), and then transmitted. This approach is much easier to implement with integrated circuits.

### WI-FI

Wireless network standard, known as Wi-Fi, is IEEE802.11. Due to the use of un-licensed frequency bands (2.4 GHz with 14 distinct channels) in IEEE 802.11g, providing up to 54 Mbps data rate, Wi-Fi [4] networks have gained much attention. IEEE 802.11g [5] deploys OFDM and offers attractive data rate adjustment capability, to lower data rate, as per connection requirement.

The IEEE 802.11 MAC layer deploys the Distributed Coordination Function (DCF) as a default access technique. In this contention based scheme, Wi-Fi STAs associated with the Access Point (AP) use their air interfaces for sensing channel availability. If the channel is idle, the source STA sends its data to the destination STA through the associated

AP. If more than one STA try to access the channel simultaneously a collision occurs. The standard uses the Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) mechanism to avoid collisions.

Point Coordination Function (PCF) is another technique that may be used in the MAC layer. In PCF, the data transmission is arbitrated in two modes: (i) centralized mode, where the AP polls each STA in a round-robin fashion, and (ii) contention based mode, which works similarly to DCF. In addition, the Request To Send (RTS)/Clear To Send (CTS) mechanism is applied to solve the hidden node problem.

**WIMAX**

WiMAX [6][7] is a standard typically based on global interoperability including ETSI HIPERMAN, IEEE 802.16d-2004 for fixed, and 802.16e for mobile high-speed data. WiMAX is gaining popularity as a technology which delivers carrier-class, high speed wireless broadband [8] at a much lower cost while covering large distance than Wi-Fi. It has been designed to be a cost effective way to deliver broadband over a large area. It is intended to handle high-quality voice, data and video services while offering a high QoS [9].

WiMAX 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). 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.

**PROPOSED ARCHITECTURE**

In this section, we first explain structure and working of Wi-Fi/WiMAX Router (WWR). Then our proposed architecture based on this device is explained.

**WI-FI/WIMAX ROUTER (WWR)**

The internal structure of a WWR is shown in Figure 1, where the WWR plays the role of an SS in the IEEE 802.16 network and AP in the IEEE 802.11 network. To support the functions of an Access Point, the WWR in the IEEE 802.11 network also contains QoS parameters for transmitting and receiving data. When the AP receives a request from the STA, the message contains a traffic identifier (TID) to express the QoS service in the application flow. The AP will forward the message to the Mapping Module (MM) to transform the service flow parameters into the corresponding QoS parameters supported by IEEE 802.16. When the SS receives a response message from a service flow, it forwards this message to the MM, which will link the Service Flow Identifier (SFID) to the TID received from a service. The mapping between the SFID and the service’s TID will continue until the data transmission is completed.

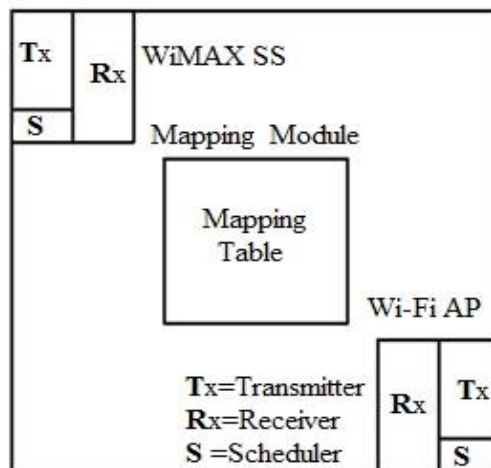


Figure.1. Wi-Fi/WiMAX Router (WWR) architecture

### WI-FI WIMAX MESH NETWORK

The architecture, shown in Figure 2, includes a WiMAX BS, WWRs and Wi-Fi STAs. Wi-Fi mobile STAs, that are able to connect to their allotted WWR. In Wi-Fi/WiMAX mesh architecture, it is the ability of two WWRs to connect to each other without the intervention of the BS. Mesh connectivity between WWRs provides mesh capabilities in WiMAX segment of our proposed architecture.

In this architecture, we can have three types of connections: (i) between Wi-Fi STAs in the same WWR domain, (ii) between Wi-Fi STAs of two different WWR domains, and (iii) between the WiMAX SSs and Wi-Fi STAs. In the first type of connection, STAs are able to simply connect to each other through the AP component of WWR through Wi-Fi link. In the second type of connection, the source STA should send its request packet to the WWR, which forwards the packet to the other WWR instead of forwarding it to the BS. The intended WWR simply forwards the packet to the destination STA. In this connection STAs connect to their respective AP component of WWR through Wi-Fi link, while WWRs connect each other through SS component of WWR through WiMAX link. In the last type of connection, the WiMAX SS sends its request packet to the BS, which forwards it to the destination STA through the allotted WWR. In the case that a STA wants to make a connection with a SS, it should send its request packet to the BS by means of WWR. In this connection STAs connect to their respective AP component of WWR through Wi-Fi link, while BS connect to SS component of WWR and BS connect to SS through WiMAX link.

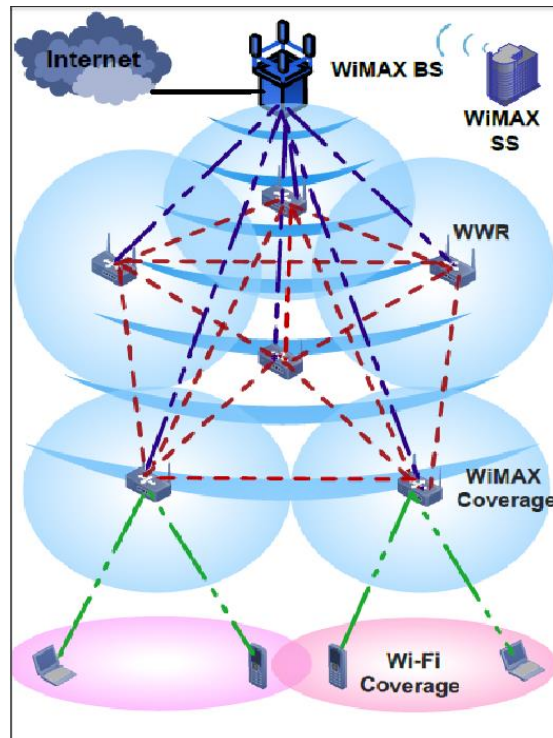


Figure.2. Integrated Wi-Fi/WiMAX Mesh network architecture

### SIMULATION METHODOLOGY

In order to investigate the performance of Integrated Wi-Fi/WiMAX Mesh network, we simulate the network using MATLAB platform. We present simulation using IEEE 802.16d for WiMAX and IEEE 802.11g for Wi-Fi. WiMAX is the network with high bandwidth large coverage area whereas Wi-Fi has small coverage area. In our simulation we consider variable coverage area of WiMAX up to 1000m and Wi-Fi up to 200m in diameter. Our simulation model comprise of an integrated network with AWGN wireless channel having free space pathloss for both Wi-Fi and WiMAX.

*Table I Wi-Fi network configuration*

Node Feature	Setting
Frequency Used	2.4 GHz ISM band
Channel Bandwidth	20 MHz
Data Rate	up to 54 Mbps
Modulation	BPSK, 16 QAM, 64 QAM etc.
Antenna	Omni directional
Mobility	Yes
Range	200m
Usage	WLAN
Multiple Access	CSMA/CA
Mode	Half Duplex

*Table II WiMAX network configuration*

Node Feature	Setting
Frequency Used	2-11 GHz ISM band
Channel Bandwidth	20 MHz
Data Rate	up to 75 Mbps
Modulation	BPSK, 16 QAM, 64 QAM etc.
Antenna	Omni directional
Mobility	No
Range	5 km
Usage	WMAN
Multiple Access	OFDMA
Mode	Half Duplex

## PERFORMANCE EVALUATION

The performance of our integrated Wi-Fi/WiMAX mesh network is evaluated by Bit Error Rate (BER). We have investigated BER vs. Signal to Noise ratio (SNR), for different distances between Wi-Fi APs and STAs, and for different modulation schemes, such as BPSK, and QAM. Also BER vs. Distance between WiMAX SSs is also investigated for different distances between Wi-Fi APs and STAs, and for different modulation schemes.

### BER vs. Distance between WiMAX SSs for varying distance between Wi-Fi APs and STAs (for BPSK and QAM):-

In Figure.3 and Figure.4, BER is evaluated with respect to distance for BPSK and QAM modulation. From these figures it is clear that for Wi-Fi distance up to 50m BER, start from zero; attain 0.325 for QAM, and 0.375 for BPSK at 1000m WiMAX SSs distance. But for Wi-Fi distance above 50m BER attains, 0.1 and 0.2 at starting and reaches to 0.4 for QAM, 0.3 and 0.4 at starting and reaches to 0.475 for BPSK.

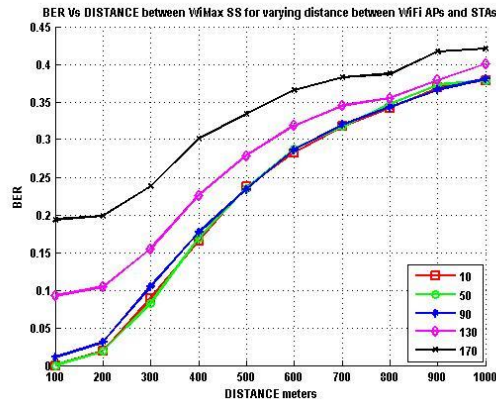


Figure.3. BER vs. Distance for BPSK

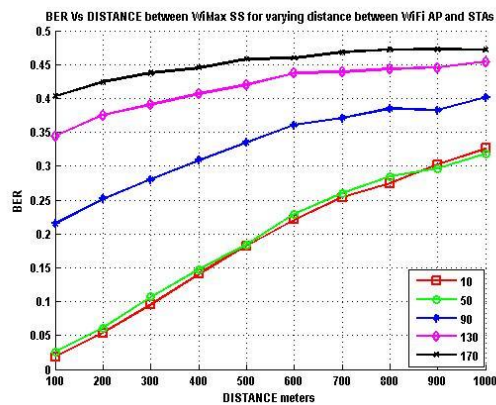


Figure.4. BER vs. Distance for QAM

**BER vs. SNR for varying distance between Wi-Fi APs and STAs (for BPSK and QAM):-**

In Figure.5 and Figure.6 BER is evaluated with respect to SNR for BPSK and QAM modulation. From these figures it is clear that, for Wi-Fi distance up to 50m BER start from 0.3at SNR of -8dB attain, 0.05 for QAM, and 0.09 for BPSK at SNR of 7 dB. But for Wi-Fi distance above 50m BER attains, 0.5 at SNR of -8dB and reaches to 0.37 for QAM, 0.4 at SNR of -8dB and reaches to 0.1 for BPSK.

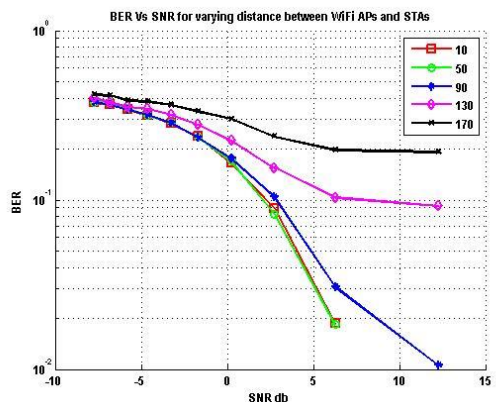


Figure.5. BER vs. SNR for BPSK

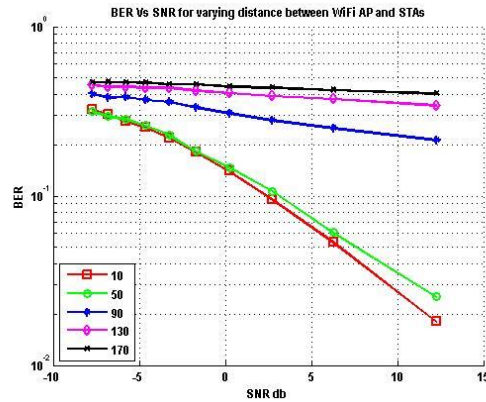


Figure.6. BER vs. SNR for QAM

In this part, we have analysed BER vs. SNR and BER vs. Distance between WiMAX SSs for BPSK, QPSK, 16-QAM, 64-QAM modulation schemes keeping distance between Wi-Fi APs and STAs constant.

**BER vs. Distance between WiMAX SSs for different modulation (for Wi-Fi AP and STA distance constant):-**

From the three figures shown below, for Wi-Fi AP and STA distance of 50, 100, and 150 m, BER vs. Distance between WiMAX SSs is analysed. For BPSK, curve start from 0, 0.01, and 0.03 attains the same value of 0.32 for 50, 100, 150 m. respectively. For QPSK, curve start from 0, 0.03, 0.14 and attains 0.41, 0.42, 0.43 for 50, 100, 150 m. respectively. For 16-QAM, curve start from 0.14, 0.18, 0.25 and attains 0.4, 0.42, 0.43 for 50, 100, 150 m. respectively. At last for 64-QAM, BER starts from 0.09, 0.13, 0.21 and attains 0.4, 0.43, 0.45 for 50, 100, 150 m. respectively.

From the figures, for WiMAX distance up to 275m, performance of 64-QAM is better than 16-QAM.

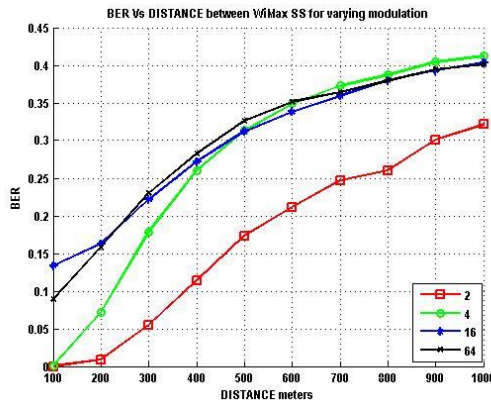


Figure.7. BER vs. Distance for d=50

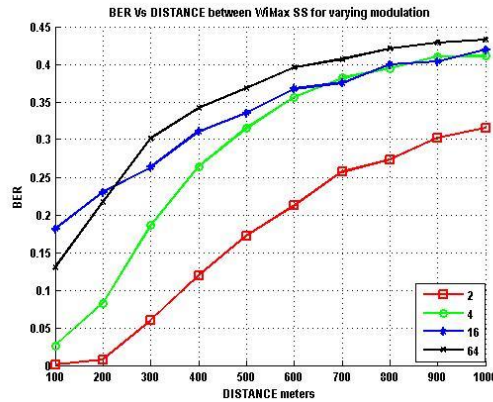


Figure.8. BER vs. Distance for d=100

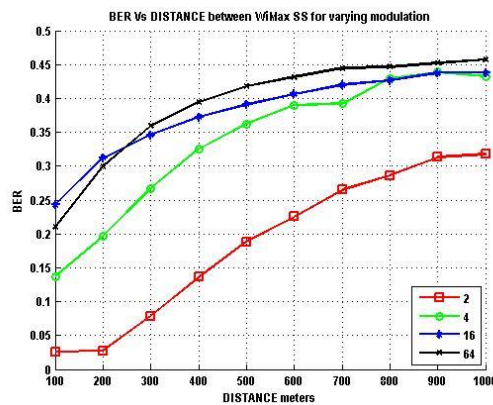


Figure.9. BER vs. Distance for d=150

**BER vs. SNR for different modulation (for Wi-Fi AP and STA distance constant):-**

From the three figures shown below, for Wi-Fi AP and STA distance of 50, 100, and 150 m, BER vs. SNR performance is analysed. For d=50, 100, 150 m BPSK has lower BER than QPSK, 16-QAM and 64-QAM. At SNR= -11dB, BPSK start from BER=0.8 while other curve start from BER=0.7. At SNR of 4dB and d=100m BER value, for BPSK is  $10^{-2}$ , for QPSK is 0.08, for 16-QAM and 64-QAM is 0.15. At SNR of 4dB and d=50m BER value, for BPSK is  $10^{-2}$ , for QPSK is 0.07, for 16-QAM and 64-QAM is 0.2. At SNR of 4dB and d=150m BER value, for BPSK is 0.03, for QPSK is 0.2, for 16-QAM and 64-QAM is 0.3. On increasing SNR above 4dB BER decreases sharply. From the figures, it is also clear that for SNR above 4dB performance of 64-QAM is better than 16-QAM.

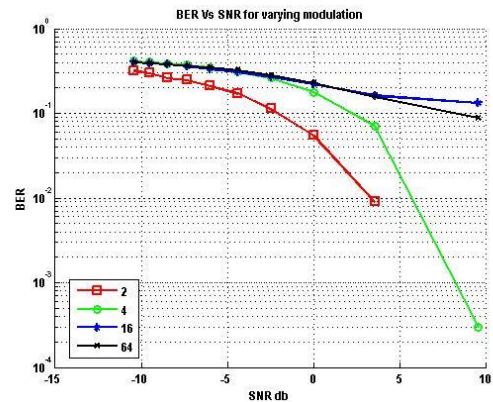
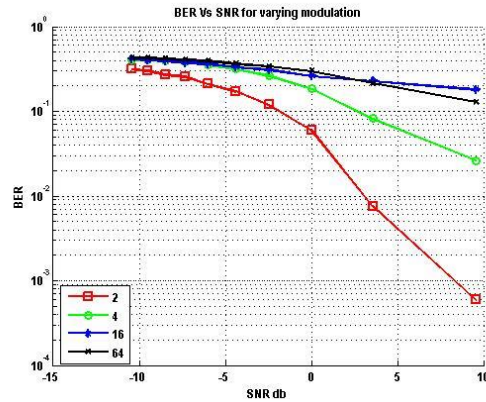
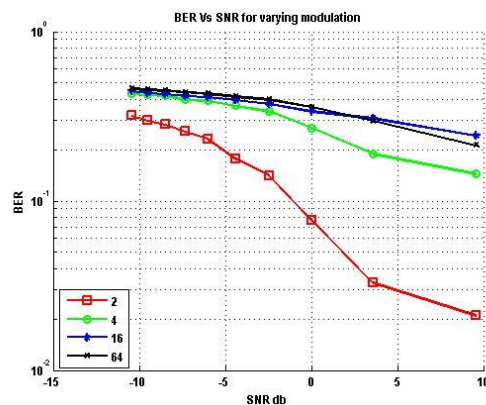


Figure.10. BER vs. SNR for d=50



Figure.11. BER vs. SNR for  $d=100$ Figure.12. BER vs. SNR for  $d=150$ 

## CONCLUSIONS

In this paper, the performance of, Integrated Wi-Fi/WiMAX mesh network over AWGN channels has been observed. The analysis is based on the study of Bit Error Rate (BER) vs. Signal to Noise Ratio (SNR) and BER vs. Distance between WiMAX SSs. This analysis is carried for different, distances between Wi-Fi APs and STAs, modulation. Also at last we conclude our work with the help of graphs. From the results obtained, it is concluded that the BER decreases as the SNR increases. The BPSK has an overall better performance as compared to QPSK, 16-QAM and 64-QAM techniques. That means lower order of modulation techniques is better to use in communication system if spectral efficiency is not considered or taken in an account. Also BER decreases as distance decreases. From graphs it is clear that BPSK perform better than QPSK, 16-QAM, and 64-QAM.

But considering the high data rate requirement, theoretically 64-QAM performs better than 16-QAM, QPSK, and BPSK. From the graphs it is also clear that, for Wi-Fi and WiMAX distance up to 100m and 300m respectively and SNR above 4dB, 64-QAM per better than 16-QAM .

Hence it can be concluded that the Integrated Wi-Fi/WiMAX mesh network performs better with higher modulation as 64-QAM for Wi-Fi distance up to 100m, WiMAX distance up to 300m, and SNR above 4dB. Also above Wi-Fi distance of 100m and WiMAX distance of 300m it is better to go for lower modulation schemes, for better performance but at cost of low data rate and spectral efficiency.

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