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Enhancing Metropolitan Wireless Communications with WiMAX Technology: A Performance Analysis of MIMO Systems and Advanced Modulation Techniques

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ABSTRACT

WiMAX, or IEEE 802.16, is a significant development in wireless digital communications that is primarily intended for "Metropolitan Area Networks". This technique increases broadband wireless connectivity up to 50 km for fixed stations and 5-15 km for mobile stations, much exceeding the range constraints of Wi-Fi-802.11 standards, which normally provide coverage within 30-100 meters. WiMAX, a cutting-edge solution recognized globally, has been ratified by the IEEE 802.16 group and is now operational in a number of regions. It can handle a wide range of applications, including next-generation cellular communications, personal area networks, local area networking, and digital broadcasting. This study looks at the integration of several antenna technologies, specifically MIMO systems, with different modulation schemes such as BPSK, QPSK, 8-QAM, and 16-QAM. The performance of various setups is evaluated in the presence of Additive White Gaussian Noise (AWGN), with an emphasis on the effect on bit error rate relative to signal-to-noise ratio. The findings demonstrate WiMAX robust capabilities as well as prospective wireless transmission advancements.

KEYWORDS: *Additive White Gaussian Noise Channel (AWGN), Broadband Wireless Access (BWA), Orthogonal Frequency Division Multiplexing (OFDM), Modulation Technology, Multiple-Input and Multiple Outputs (MIMO)*

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I. INTRODUCTION

WiMAX (World Interoperability for Microwave Access), which is critical to the evolution of broadband wireless networks, embodies the IEEE 802.16 standard and provides both fixed and mobile platforms for broadband internet access worldwide [1]. This technology assures that consumers have access to broadband internet at all times and from any location. The IEEE 802.16 standard covers a wide frequency range, from 2 GHz to 11 GHz for fixed applications and 2 GHz to 6 GHz for mobile applications [2-3], resulting in adaptable and strong wireless communication capabilities suited for a variety of settings and applications. It is considered the most interesting opportunity which is able to provide data throughput up to 70 Mbps and radio coverage distances of almost 50 kilometers, and to complete wired network architectures, ensuring a cheap flexible solution for the last-mile. WiMAX can be seen as the fourth generation (4G) of mobile communications systems [3-6]. WiMAX is an IEEE 802.16 standard based technology responsible for bringing the Broadband Wireless Access (BWA) to the world as an alternative to wired broadband. WiMAX is expected to have an explosive growth, as well as the Wi-Fi, but compared with the Wi-Fi WiMAX provides broadband connections in greater areas, measured in square kilometers, even with links not in line of sight. For these reasons WiMAX is a MAN, highlighting that “metropolitan” is referred to the extension of the areas and not to the density of population and Wireless technology enables high-speed, high-quality communication between mobile devices [6-7]. Potential wireless applications include cell phones, 802.11-based wireless Local Area Networks (LANs), Bluetooth, smart homes and appliances, voice and data communication over the Internet, and video conferencing [8].

Fig. 1: Technical diagram illustrating WiMAX technology using different types of wireless antennas

Here is the technical diagram illustrating WiMAX technology using different types of wireless antennas as shown in Fig.1. This diagram includes various antenna types like omnidirectional, directional, and MIMO, and shows how they connect with fixed and mobile stations within a metropolitan area.

Benefits key of wireless technology [9-12]

1. **Greater flexibility and mobility for users**: Office-based wireless workers can be networked without sitting at dedicated PCs.
2. **Increased efficiency**: Improved communications leads to faster transfer of information within businesses and between partners/customers.
3. **You are rarely out of touch**: you don't need to carry cables or adaptors in order to access office networks.
4. **Reduced costs**: Relative to 'wired', wireless networks are, in most cases, cheaper to install and maintain.

II. MULTIPLE INPUTS AND MULTIPLE OUTPUTS

Multiple Input Multiple Output (MIMO) systems use multiple antennas on both the transmitter and receiver ends of a wireless communication system to improve signal quality and speed up data delivery. These systems can be implemented in a variety of configurations, which are broadly classified into three groups. The first form of MIMO system is intended to provide spatial variety, which considerably increases communication signal dependability while also increasing power efficiency. This category contains numerous coding and signal processing techniques [12]:

Space Time Block Code (STBC): This method involves encoding data using multiple transmission antennas, distributing the data across time and space dimensions to reduce the error rate and enhance signal robustness.

Space Frequency Block Code (SFBC): Similar to STBC, SFBC distributes the signal across both space and frequency, helping to combat frequency-selective fading and improving the efficiency of frequency use.

Space Time Trellis Code (STTC): This technique combines trellis-coded modulation (TCM) with spatial diversity to provide a robust coding scheme that enhances signal integrity over multiple transmission paths [13].

Delay Diversity Systems: These systems introduce intentional delays into the transmitted signals across different antennas. This diversity in time helps in combating fading and improving the detection reliability at the receiver [13].

The second of MIMO system implements spatial multiplexing to increase its transmission rate. Independent data streams are transmitted over a group of antennas. At the receiver, signals from several antennas are detected and the transmitted information recovered. In the last type of MIMO system, some capacity gain can be achieved over non-MIMO systems [14] by pre-processing the signals to be transmitted according to the channel characteristics and then decoding the received signals accordingly. MIMO has become an essential element of wireless communication standards including IEEE 802.11n (Wi-Fi), WiMAX (4G). Multiple Input Multiple Output (MIMO) model for wireless communication. The diagram illustrates a transmitter with multiple antennas sending signals to a receiver with multiple antennas, including signal paths and labels for key components. In Fig. 2 shows the MIMO system.

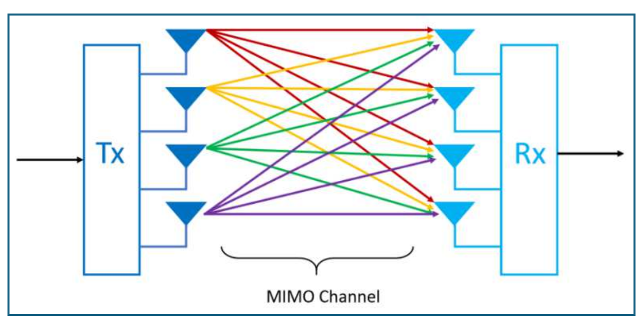

Fig. 2 MIMO Model

In MIMO systems, the transmit and receive antennas can both be used for diversity gain. Multiplexing exploits the structure of the channel gain matrix to obtain independent signaling paths that can be used to send independent data [15-16]. A narrowband point-to-point communication system of Nt transmit and Nr receive antennas is shown in Figure 1. The transmitted matrix is a $Nt \times 1$ column matrix X, where Xi is the i^{th} component transmitted from the antenna i.

Since each of the receive antennas detects all of the transmitted signals, there are N x N independent propagation paths, where there are transmit and receive antennas. This allows the channel to be represented as N x N matrix. Again using a 2 x 2 System as an example, the matrix below is obtained as:

$$H = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad (1)$$

Each of the elements in the channel matrix is define an independent propagation path. The transmitted signal can be represented as a vector, as can the received signal. Hence, the system can be represented as the following equation.

$$Y = HX + n \quad (2)$$

Where Y is the received signal vector, H is the channel Matrix, X is the transmitted signal vector, and n is the noise. The transmitted signals in the vector Y are complex signals, as the channel matrix values and the received signals in vector X.

III. OFDM

In order to overcome the difficulties caused by frequency-selective channel impairments, current digital communication systems frequently employ the sophisticated modulation technology known as orthogonal frequency division multiplexing, or OFDM. An outline of OFDM's benefits and operation is provided below [16-18]:

A. How OFDM Works

OFDM operates by splitting a high-data rate signal into several lower-data rate streams that individually modulate a set of orthogonal subcarriers. These subcarriers are orthogonal to each other, meaning that their cross-correlation is zero—thereby preventing interference between them and enabling efficient use of the spectrum.

Subcarrier Modulation: The high-data rate signal is divided into multiple slower data streams. Each of these streams modulates a separate subcarrier.

Multiplexing: These narrowband signals are then multiplexed together, forming a single signal that is transmitted over the channel. This multiplexing is done in such a way that the subcarriers are orthogonal, meaning they do not interfere with each other despite being closely spaced in frequency.

Transmission: The multiplexed signal is transmitted through the channel, where it may encounter frequency-selective fading and other forms of interference.

Demultiplexing at Receiver: At the receiver, the process is reversed. The signal is demultiplexed back into the original low-data rate streams, which are then combined to reconstruct the original high-data rate signal.

B. Advantages of OFDM

Efficiency in Bandwidth Use: The orthogonality of subcarriers allows them to be packed closely together without fear of interference, which makes OFDM very bandwidth-efficient.

Mitigation of Frequency Selectivity: By converting a frequency-selective fading channel into multiple flat-fading channels, OFDM simplifies the equalization process. Each narrow-band subcarrier typically experiences flat fading, which is much easier to correct compared to frequency-selective fading.

Flexible Data Rate Allocation: The granularity provided by having multiple subcarriers enables service providers to offer different data rates and services tailored to specific needs. For instance, some subcarriers could be allocated more bandwidth to carry higher data rate services like video, while others carry lower data rate services like voice.

Robust Channel Estimation and Equalization: The presence of pilot signals in OFDM systems aids in efficient channel estimation and equalization. Since the channel is treated as several flat-fading channels, simpler equalizers like the one-tap equalizer can be employed effectively. In Fig. 3 shows the OFDM model.

Service providers can use granularity (due to several narrow band subcarriers) available to offers variety of data rate depending on the service types (e.g. data, voice, video, etc) and Quality of Service (e.g. reliability, priority, etc). Discrete-time OFDM signal can be written as in equation 3 [11].

$$x_n = x\left(\frac{nT}{JN}\right) = \frac{1}{\sqrt{N}}\sum_{k=N/2}^{N/2-1} X_{(k+N)} \times \exp\left(\frac{j2\pi nk}{JN}\right),$$

$$n = 0,1,2,5,5,\ldots\ldots\ldots JN-1 \quad (3)$$

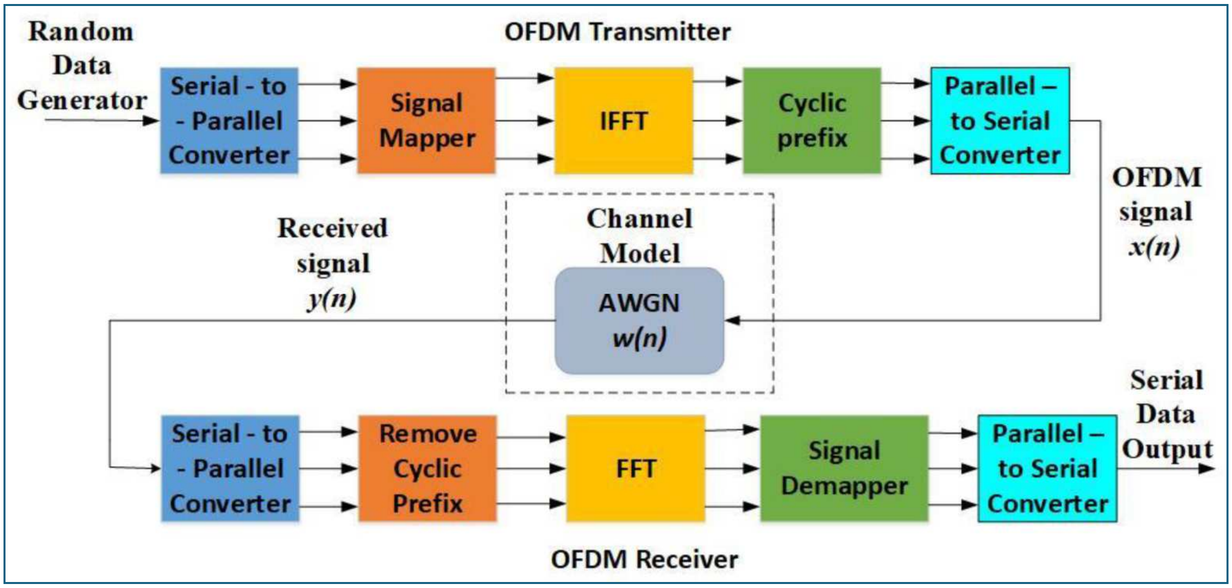

Fig. 3 Concept of OFDM in WIMAX Technology

IV. RESULTS AND ANALYSIS

Results of Performance for Various M×N System Combinations: The primary goal of this thesis is to evaluate WiMAX (OFDM-M×N systems) performance in relation to the various simulation parameters taken into account and to derive simulation outcomes. Using the AWGN channel, we looked into the BER vs. SNR plot. Table 1 displays the parameters used in the WiMAX model analysis performance. Using an AWGN channel and a MIMO system, the performance of various modulation schemes is displayed in Figs. 4 to Fig. 7.

Table 1: Performance of IEEE 802.16e Physical layers Parameters

Parameters	Value
Communication Channel	AWGN
Modulation Techniques	BPSK, QPSK, 8-QAM and 16-QAM
IFFT (Input port size)	256
CC Code Rate	1/2
Radio Technology	OFDM
Used Scheme	Alamouti
System (Single and Multiple)	SISO, SIMO, MISO and MIMO
Model	WiMAX 802.16e
Calculation Parameters	BER V/s SNR
Simulation-Used Tool/Software	Matlab (R2023a)

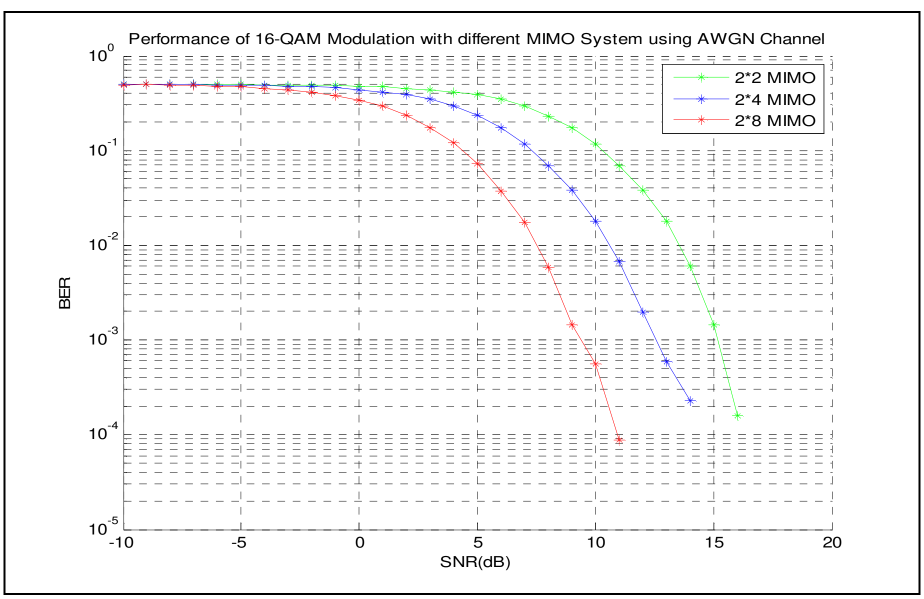

Fig. 4 Performance of 16-QAM Modulation with different MIMO system

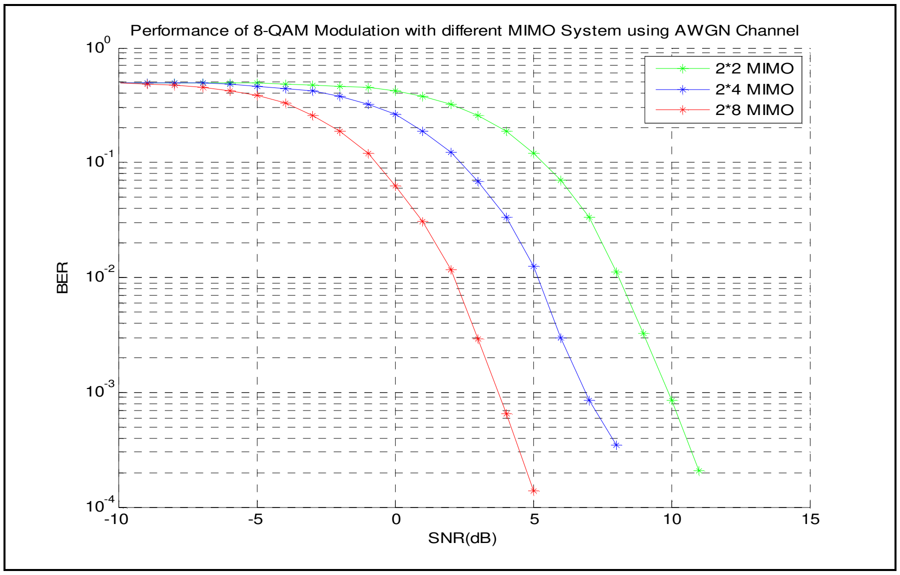

Fig. 5 Performance of 8-QAM Modulation with different MIMO system

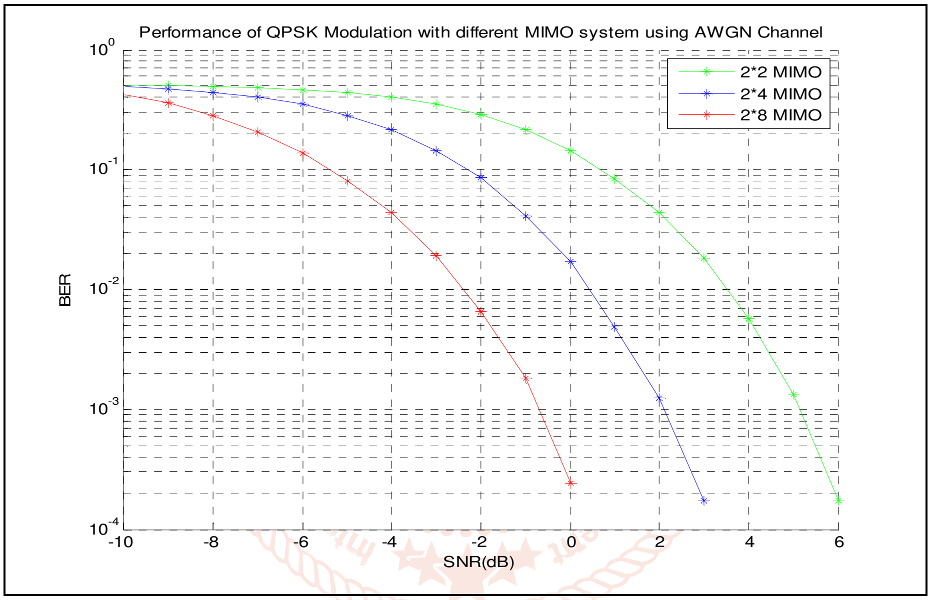

Fig. 6 Performance of QPSK Modulation with different MIMO system

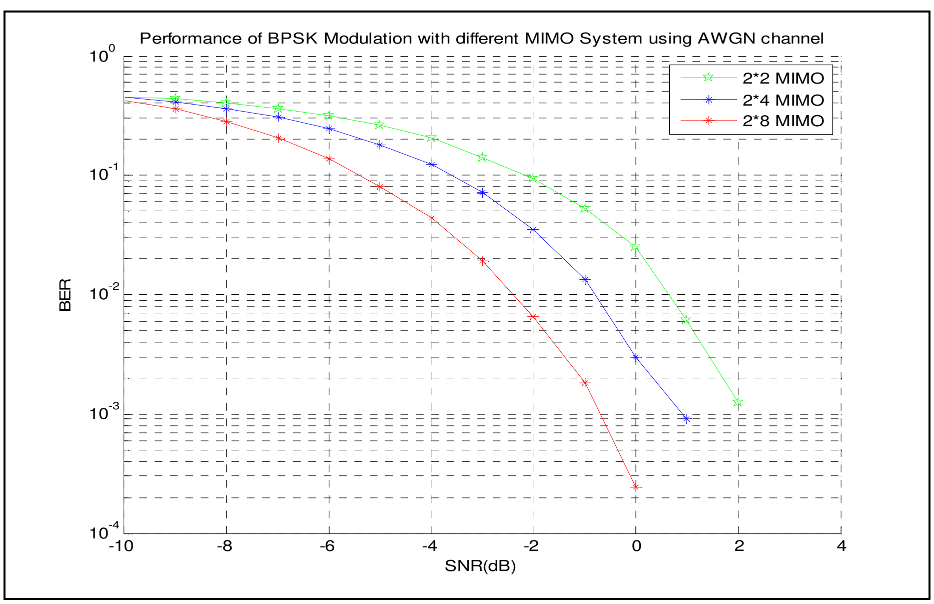

Fig. 7 Performance of BPSK Modulation with different MIMO system

V. CONCLUSION

Multiple-Input Multiple-Output (MIMO) systems offer considerable increase in data throughput and link range without additional bandwidth or transmit power by using several antennas at transmitter and receiver to improve wireless communication system performance. At the same time, Orthogonal Frequency Division Multiplexing (OFDM) has becoming a very popular multi-carrier modulation technique for transmission of signals over wireless channels. Finale we conclude 2*2 MIMO systems was better SNR for 16-QAM modulation.

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