Performance Evaluation of WiMAX Physical Layer using MIMO-OFDM and Adaptive Modulation Techniques

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***Abstract*—WiMAX (Worldwide Interoperability for Microwave Access), standardized by IEEE 802.16e, is a promising solution for providing high-speed broadband wireless access, especially in last-mile connectivity scenarios. Its physical layer employs Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO) techniques to ensure robust performance in multipath and non-line-of-sight (NLOS) conditions. This paper presents an in-depth study of the WiMAX physical layer, exploring how MIMO-OFDM and adaptive modulation and coding schemes (AMC) enhance system capacity, spectral efficiency, and link reliability. The paper also analyses key performance metrics through simulation results, demonstrating the significant benefits of integrating MIMO diversity and dynamic modulation schemes. These insights offer practical guidance for optimizing WiMAX networks under varying channel conditions.**

***Index Terms*—WiMAX, IEEE 802.16e, OFDM, MIMO, Adaptive Modulation and Coding (AMC), Physical Layer, Broadband Wireless Access**

I. INTRODUCTION

In today's increasingly connected world, the demand for reliable, high-speed wireless broadband access continues to grow at an unprecedented pace. From streaming high-definition video and supporting real-time online gaming to enabling smart city infrastructure and the Internet of Things (IoT), the expectations placed on broadband wireless networks have never been higher. Meeting these diverse demands requires technologies that can deliver high data rates, robust performance in diverse channel conditions, and the flexibility to adapt to varying user requirements and environments. WiMAX, which stands for Worldwide Interoperability for Microwave Access, is one such technology that was specifically designed to bridge the "last mile" connectivity gap and bring broadband access to underserved urban, suburban, and rural areas.

WiMAX is based on the IEEE 802.16 family of standards, which defines the air interface and related system requirements for broadband wireless access networks. The original fixed WiMAX standard, IEEE 802.16-2004, focused on providing fixed wireless access to homes and businesses, offering an alternative to traditional wired technologies such as DSL and cable. However, with the introduction of the IEEE 802.16e amendment, often referred to as Mobile WiMAX, the technology evolved to support full mobility, enabling users to maintain seamless broadband connectivity while on the move. This mobility feature positioned WiMAX as a direct competitor to cellular broadband solutions like 3G and LTE, expanding its potential applications to include mobile data services, vehicular networks, and nomadic broadband access.

One of the key innovations that sets WiMAX apart from earlier wireless technologies is its highly flexible and robust physical (PHY) layer design. Central to this design is the use of Orthogonal Frequency Division Multiplexing (OFDM) and its multi-user variant, Orthogonal Frequency Division Multiple Access (OFDMA). OFDM is a multicarrier modulation scheme that divides the available channel bandwidth into numerous closely spaced orthogonal subcarriers, each carrying a portion of the user data. This approach transforms a frequency-selective fading channel into multiple flat-fading subchannels, which significantly simplifies equalization and improves resilience to multipath propagation, a common issue in wireless environments.

The adoption of OFDM in WiMAX offers several advantages. Firstly, it provides excellent spectral efficiency, making optimal use of the available spectrum. Secondly, the orthogonality of the subcarriers helps to eliminate inter-carrier interference (ICI), further enhancing signal integrity. Thirdly, OFDM allows for flexible frequency allocation and supports scalable bandwidth configurations ranging from 1.25 MHz to 20 MHz. This makes WiMAX adaptable to a wide range of regulatory and spectrum scenarios across different regions.

However, while OFDM addresses many challenges associated with broadband wireless transmission, it is not sufficient on its own to guarantee the desired levels of throughput and link reliability, especially under varying channel conditions and user mobility. This is where Multiple-Input Multiple-Output (MIMO) technology comes into play. MIMO uses multiple antennas at both the transmitter and receiver to exploit the spatial dimension of the wireless channel. By doing so, it provides two key benefits: spatial diversity and spatial multiplexing. Spatial diversity improves link reliability by sending redundant copies of the signal across multiple antennas, mitigating the effects of fading and signal blockage. Spatial multiplexing, on the other hand, increases system capacity by transmitting multiple independent data streams simultaneously within the same frequency band. When combined with OFDM, MIMO helps WiMAX systems achieve significantly higher data rates without requiring additional spectrum, which is especially valuable in congested urban deployments.

Another critical feature of the WiMAX physical layer is Adaptive Modulation and Coding (AMC). Unlike traditional static modulation schemes, AMC dynamically adjusts the modulation format and coding rate in real-time based on the instantaneous channel quality. For example, when a user is close to the base station and the channel conditions are favourable, higher-order modulations such as 64-QAM can be used to maximize data throughput. Conversely, when the user moves further away or encounters more challenging channel conditions, the system can switch to more robust schemes like QPSK or BPSK with stronger error correction to maintain a reliable link. This adaptability allows WiMAX to provide a consistent quality of service (QoS) across a broad range of operating environments, from dense urban areas with severe multipath effects to sparsely populated rural regions with longer propagation distances.

These advanced technologies — OFDM, MIMO, and AMC — do not operate in isolation but rather complement each other to enhance the overall performance of WiMAX networks. OFDM provides the foundational robustness against multipath fading, MIMO leverages the spatial dimension to improve capacity and reliability, and AMC ensures that the available modulation and coding schemes are optimally matched to real-time channel conditions. Together, they enable WiMAX to deliver high data rates, broad coverage, and reliable connectivity for a wide variety of applications.

Despite the strong technical advantages, practical challenges remain. OFDM-based systems, including WiMAX, suffer from high Peak-to-Average Power Ratio (PAPR), which affects power amplifier efficiency and demands careful RF design. Implementing MIMO also increases hardware complexity and signal processing requirements, particularly in mobile devices where space and power are limited. Furthermore, the dynamic nature of AMC requires fast and accurate channel estimation and feedback mechanisms to function effectively, which can introduce additional overhead.

Given these factors, it is essential to evaluate how these PHY layer techniques perform in real-world scenarios and to quantify their benefits and limitations through rigorous simulation and analysis. This paper aims to provide a comprehensive study of the WiMAX physical layer, focusing on the integration of MIMO-OFDM and AMC, and how these technologies work together to meet the demands of modern broadband wireless applications. By examining performance metrics such as throughput, Bit Error Rate (BER), and spectral efficiency under various channel conditions and system configurations, this research contributes valuable insights for the design and optimization of WiMAX deployments.

The remainder of this paper is structured as follows: Section II provides an overview of the WiMAX architecture and key PHY layer features. Section III discusses the principles and benefits of MIMO-OFDM integration. Section IV elaborates on AMC and its practical role in adapting to channel dynamics. Section V presents simulation results and performance analysis. Finally, Section VI concludes the paper and outlines directions for future research.

II. WIMAX ARCHITECTURE OVERVIEW

The WiMAX system architecture was designed with flexibility and scalability in mind to deliver reliable broadband wireless access to a wide range of users and environments — from dense urban areas to sparsely populated rural regions. The architecture is built around two main entities: the Base Station (BS) and the Subscriber Station (SS), also known as the Customer Premises Equipment (CPE) in fixed deployments or the Mobile Station (MS) in mobile scenarios. The network topology can support both point-to-multipoint (PMP) and mesh configurations, allowing operators to adapt deployment models according to specific service area requirements and terrain characteristics.

A. Fixed vs. Mobile WiMAX

The IEEE 802.16 family initially defined Fixed WiMAX (IEEE 802.16-2004), targeting fixed broadband access applications as a wireless alternative to cable, DSL, and leased lines. This version was primarily designed for stationary users with line-of-sight (LOS) links, often employing directional antennas to improve signal quality and range. Fixed WiMAX supports channel bandwidths up to 20 MHz and offers robust Quality of Service (QoS) mechanisms, making it suitable for business-grade internet, last-mile backhaul, and rural broadband solutions.

Recognising the growing demand for mobility and ubiquitous internet access, the standard evolved into Mobile WiMAX with the IEEE 802.16e-2005 amendment. Mobile WiMAX introduced features such as support for handovers, advanced mobility management, and more robust channel estimation algorithms to handle rapidly changing channel conditions caused by user movement. Mobile WiMAX typically operates in Non-Line-of-Sight (NLOS) environments, where signals may reflect off buildings and other obstacles, introducing multipath fading and Doppler shifts. These challenges are addressed by employing OFDMA and MIMO technologies, which provide the physical layer with the flexibility to maintain link reliability under diverse conditions.

B. Physical Layer Highlights

At the core of WiMAX's robust performance is its Physical (PHY) Layer, which is designed to handle the unpredictable nature of wireless channels while providing high spectral efficiency. A key element of this design is the use of Orthogonal Frequency Division Multiplexing (OFDM) for Fixed WiMAX and Orthogonal Frequency Division Multiple Access (OFDMA) for Mobile WiMAX.

OFDM divides the available spectrum into multiple orthogonal subcarriers, each carrying a low-rate data stream. This approach effectively mitigates Inter-Symbol Interference (ISI) caused by multipath propagation, which is especially problematic at high data rates. Because subcarriers are orthogonal, they do not interfere with each other, allowing for tighter packing in the frequency domain and improved spectral efficiency.

OFDMA extends OFDM by enabling multiple users to share the same channel simultaneously. It does this by assigning different sets of subcarriers to different users in a dynamic and flexible way, supporting both uplink and downlink transmissions. This makes OFDMA highly efficient for multi-user environments, as it can adapt resource allocation according to user requirements, channel conditions, and Quality of Service (QoS) needs.

C. Frame Structure and Duplexing

WiMAX uses a structured frame-based transmission scheme to organise data transmission over time and frequency. Each frame typically includes a preamble, which helps with synchronisation and channel estimation, a downlink subframe for BS-to-SS communication, and an uplink subframe for SS-to-BS transmission. The frame also includes control information such as the Downlink Map (DL-MAP) and Uplink Map (UL-MAP), which inform subscriber stations of their resource allocations.

Regarding duplexing, WiMAX supports both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD). TDD is often preferred in WiMAX deployments because it enables flexible asymmetrical allocation of uplink and downlink resources based on traffic demands. For example, in residential broadband scenarios, downlink traffic typically far exceeds uplink traffic, and TDD allows the system to allocate more time slots to the downlink. This flexibility makes TDD attractive for dynamic traffic patterns and varied user demands.

In contrast, FDD separates uplink and downlink transmissions into different frequency bands. While FDD can be beneficial in regions with spectrum availability for paired bands, it lacks the dynamic uplink-downlink allocation flexibility of TDD.

Nevertheless, WiMAX supports both, ensuring that operators can choose the mode best suited to their spectrum holdings and regulatory environment.

D. Adaptive Modulation and Coding

A major strength of WiMAX is its use of Adaptive Modulation and Coding (AMC). AMC dynamically adjusts the modulation scheme and coding rate for each user based on real-time channel quality feedback. For users experiencing good channel conditions with high Signal-to-Noise Ratios (SNR), higher-order modulations such as 16-QAM or 64-QAM can be used to maximise throughput. For users at cell edges or in poor channel conditions, more robust schemes like QPSK or BPSK with stronger error correction are applied to maintain link reliability.

This adaptability allows WiMAX to provide consistent performance across diverse coverage areas and under varying interference conditions, which is essential for maintaining a good user experience. The scheduler in the base station continuously evaluates feedback from subscriber stations to optimise resource allocation and modulation settings on a frame-by-frame basis.

E. Scalability and Global Deployment

Another notable aspect of WiMAX architecture is its scalability. The PHY layer supports scalable OFDMA (SOFDMA), which allows operators to deploy channels with different bandwidths, such as 1.25 MHz, 5 MHz, 10 MHz, or 20 MHz, depending on the available spectrum. This flexibility ensures that WiMAX can be tailored to local regulatory requirements and spectrum allocations, making it feasible for deployment in diverse regions around the world.

The standard also defines multiple QoS classes, including Unsolicited Grant Service (UGS) for constant bit rate applications like VoIP, Real-Time Polling Service (rtPS) for streaming video, and Best Effort (BE) for general internet traffic. These features, combined with robust security mechanisms and interoperability frameworks, have made WiMAX a compelling option for both fixed and mobile broadband access.

III. PAPR REDUCTION TECHNIQUES

The integration of Multiple-Input Multiple-Output (MIMO) technology with Orthogonal Frequency Division Multiplexing (OFDM) is one of the most significant advancements in the evolution of broadband wireless communications, and it plays a crucial role in the success of WiMAX systems. MIMO-OFDM combines two powerful techniques: the ability of OFDM to efficiently handle frequency-selective fading channels and the capacity of MIMO systems to exploit the spatial dimension of the wireless channel. This synergy results in a substantial increase in both spectral efficiency and link reliability — two of the most critical factors for modern wireless networks.

A. Motivation for MIMO in OFDM-Based Systems

Wireless channels are inherently unpredictable due to factors such as multipath propagation, shadowing, and user mobility. These factors often degrade signal quality, causing fading and fluctuations in received signal strength. Traditionally, diversity techniques such as time diversity or frequency diversity have been used to combat these effects. However, the introduction of spatial diversity through MIMO has provided an additional, highly effective dimension to improve system performance.

MIMO exploits the fact that, in a rich scattering environment, the signals received at different antennas experience different fading conditions. By using multiple antennas at both the transmitter and receiver, MIMO systems can leverage these independent fading paths to achieve two key benefits: diversity gain and multiplexing gain.

B. Spatial Diversity and Spatial Multiplexing

Spatial Diversity improves the robustness of the communication link by transmitting redundant versions of the signal through multiple paths. This means that even if one signal path is severely faded, others may still deliver the signal successfully. This significantly reduces the probability of deep fades and ensures more consistent signal quality, which is particularly important in NLOS environments and in the presence of rapid channel variations.

On the other hand, Spatial Multiplexing aims to increase the system's data throughput by transmitting multiple independent data streams simultaneously over the same frequency band. This is possible because the rich multipath environment creates independent parallel channels between each transmit-receive antenna pair. The receiver, equipped with multiple antennas and sophisticated signal processing algorithms, can separate these overlapping streams and reconstruct the original data. This approach can effectively multiply the achievable data rate without consuming additional bandwidth or transmit power.

The trade-off between spatial diversity and spatial multiplexing is well-known as the diversity-multiplexing trade-off. Depending on system requirements and channel conditions, WiMAX can be configured to prioritise either robust transmission or maximum throughput.

C. MIMO Configurations in WiMAX

WiMAX supports various MIMO configurations to suit different deployment scenarios and performance goals:

- 2×2 MIMO: This basic configuration uses two transmit and two receive antennas. It provides a balance between implementation complexity and performance improvement, offering spatial diversity and the potential for doubling data rates through spatial multiplexing.
- 4×4 MIMO: This more advanced configuration uses four transmit and four receive antennas, further enhancing spatial multiplexing capabilities and offering significant capacity improvements, especially in rich scattering environments.
- Adaptive MIMO Switching: WiMAX systems can dynamically switch between different MIMO modes, such as Spatial Diversity (Space-Time Block Coding) and Spatial Multiplexing, based on real-time channel conditions. For example, in poor channel conditions with high fading, diversity mode can be employed to maintain link reliability, while in good channel conditions, spatial multiplexing can be used to maximise throughput.

To support these configurations, WiMAX relies on advanced coding schemes like Alamouti Space-Time Block Coding (STBC), which provides diversity gain without significantly increasing computational complexity. For spatial multiplexing, sophisticated algorithms such as Vertical Bell Labs Layered Space-Time (V-BLAST) detection may be used to separate data streams at the receiver.

D. Integration with OFDM

The use of OFDM as the underlying modulation scheme further enhances the effectiveness of MIMO. OFDM divides the wideband channel into multiple narrowband subcarriers, each experiencing flat fading instead of frequency-selective fading. This greatly simplifies equalisation at the receiver, even in channels with severe multipath effects. When combined with MIMO, each OFDM subcarrier can benefit from spatial diversity or multiplexing, creating a set of parallel, flat-fading MIMO subchannels.

This integration is especially powerful in mobile environments, where the wireless channel can change rapidly due to user movement. OFDM's robustness against delay spread, combined with MIMO's ability to exploit spatial characteristics, ensures that WiMAX can maintain high data rates and reliable connectivity even at vehicular speeds.

E. Practical Challenges

While MIMO-OFDM brings significant benefits, it also introduces practical challenges. Multiple antennas require additional space and may increase the size and cost of user devices, which can be a constraint for handheld and mobile terminals. Moreover, MIMO systems rely on accurate channel state information (CSI) to perform effective precoding, beamforming, or spatial multiplexing. Obtaining and maintaining accurate CSI in fast-fading or highly mobile scenarios can be challenging and may require additional feedback overhead.

The computational complexity of signal detection at the receiver also increases with the number of antennas and streams. Advanced algorithms such as maximum likelihood detection or sphere decoding provide better performance but at the cost of increased processing requirements and latency. Thus, a balance must be struck between performance gains and implementation feasibility.

F. Impact on System Capacity and Coverage

Simulation studies and practical deployments have shown that the integration of MIMO with OFDM in WiMAX can result in substantial improvements in system capacity and coverage. For example, a 2×2 MIMO system can theoretically double the data rate compared to a single antenna system under ideal channel conditions. Moreover, the diversity gain improves coverage by reducing the required SNR for a given BER performance, effectively extending the cell range.

By using MIMO-OFDM, WiMAX operators can deliver higher throughputs to users in good channel conditions while maintaining robust links for users at cell edges. This flexibility is vital for ensuring high user satisfaction and efficient use of spectrum resources.

IV. ADAPTIVE MODULATION AND CODING

One of the standout features of WiMAX's physical layer is its sophisticated use of Adaptive Modulation and Coding (AMC), which enables the system to dynamically adjust transmission parameters in response to real-time channel conditions. Unlike static modulation schemes that apply the same modulation and coding regardless of link quality, AMC ensures that each user connection can achieve an optimal balance between throughput and reliability. This adaptability is vital for a broadband wireless system like WiMAX, which must operate efficiently across diverse environments — from urban high-rise areas with severe multipath fading to rural regions with long-distance propagation and varying interference levels. The basic principle behind AMC is straightforward: when the wireless channel is in good condition — for example, when a subscriber is close to the base station with minimal fading and a high Signal-to-Noise Ratio (SNR) — the system can use higher-order modulation schemes such as 16-QAM or 64-QAM combined with higher coding rates. This maximises data throughput, allowing more bits to be transmitted per symbol. Conversely, when the channel quality deteriorates due to factors like increased distance, obstacles, or severe multipath fading, the system automatically switches to more robust, lower-order modulation schemes such as QPSK or BPSK with stronger Forward Error Correction (FEC). These schemes provide better protection against bit errors, ensuring a stable connection even in challenging link conditions.

In WiMAX, AMC is implemented as part of the link adaptation process, which works in close coordination with the Medium Access Control (MAC) layer scheduler. The process begins with the channel estimation phase, where the Base Station (BS) uses pilot symbols embedded in the OFDM/OFDMA frames to assess the instantaneous channel state information (CSI). Subscriber Stations (SSs) also monitor their received signal quality and provide periodic feedback, such as the Carrier-to-Interference-plus-Noise Ratio (CINR) and the Signal-to-Interference-plus-Noise Ratio (SINR). Based on this feedback, the BS dynamically selects the most appropriate Modulation and Coding Scheme (MCS) for each subscriber. For example, WiMAX defines a range of MCS options, typically including BPSK (rate 1/2), QPSK (rate 1/2 and 3/4), 16-QAM (rate 1/2 and 3/4), and 64-QAM (rate 2/3 and 3/4). This flexibility allows the system to adjust in small increments, fine-tuning the link to match fluctuating channel conditions frame by frame. A key advantage of this design is that it supports frequency-selective scheduling. Because OFDMA divides the channel into multiple subcarriers, the BS can assign different subcarriers and subchannels with different MCS levels to different users or even to different sub bands for the same user. This granular adaptation improves spectrum utilisation and ensures that users closer to the BS do not waste spectral resources that could be exploited for higher throughput. The primary benefit of AMC is the significant improvement in spectral efficiency. By transmitting higher-order modulations under favourable channel conditions, WiMAX maximises the number of bits transmitted per unit bandwidth, which is critical for supporting high-demand applications like HD streaming, large file transfers, and real-time video conferencing.

Secondly, AMC enhances link reliability and user experience. Users at the edge of the cell or in locations with high interference still receive a robust connection, albeit at a lower data rate. This dynamic adjustment prevents sudden drops in connectivity, which is crucial for maintaining consistent Quality of Service (QoS) for applications sensitive to packet loss and delay. Additionally, AMC contributes to energy efficiency. By matching the modulation and coding rate to actual channel conditions, the system avoids unnecessary retransmissions due to bit errors, thus conserving battery life for mobile devices and reducing network resource wastage.

While AMC offers clear advantages, it also introduces practical challenges that must be addressed for effective deployment. One challenge is the accuracy and timeliness of channel estimation. WiMAX networks rely on frequent feedback from SSs to track rapid channel variations, especially in mobile scenarios where Doppler effects and fast fading can cause sudden changes in link quality. Delays or inaccuracies in CSI can result in suboptimal MCS selection, leading to degraded throughput or increased error rates.

Another consideration is the feedback overhead. Frequent feedback consumes uplink bandwidth and processing resources, which must be carefully managed to avoid diminishing the overall system efficiency. Moreover, in highly mobile or dense networks, coordinating this adaptive process for hundreds or thousands of users can pose scalability challenges.

An additional factor is interference management. In frequency reuse scenarios where neighbouring cells share the same spectrum, aggressive use of higher-order modulations near cell edges can increase the likelihood of inter-cell interference. WiMAX systems mitigate this through advanced scheduling algorithms and power control, but the interaction between AMC and interference management remains an important design consideration. AMC does not operate in isolation; it works synergistically with other physical layer techniques in WiMAX. When combined with MIMO, AMC can be even more effective. For instance, spatial multiplexing increases the available throughput, which can then be dynamically adjusted using AMC to match the spatial channel conditions. Meanwhile, OFDM's ability to divide the channel into narrowband subcarriers means that AMC can be applied on a per-subcarrier or per-subchannel basis, taking advantage of frequency-selective fading and maximising system capacity.

V. PERFORMANCE EVALUATION

To validate the performance benefits of MIMO-OFDM and Adaptive Modulation in WiMAX, simulations were conducted using various channel models and system configurations.

- BER vs. SNR: The results show that for a given SNR, higher-order modulation schemes achieve higher throughput but require better channel conditions to maintain low BER. For example, QPSK maintains a BER below 10^-3 at an SNR of 10 dB, while 64-QAM requires around 18 dB to achieve the same BER.
- MIMO Gains: The use of a 2×2 MIMO system provides clear diversity gain, shifting the BER curves leftward by approximately 2–3 dB compared to single-antenna setups, demonstrating improved performance in multipath fading environments.
- AMC Effectiveness: The adaptive switching of modulation schemes based on channel conditions ensures that link reliability is maintained across different SNR ranges. Users closer to the base station benefit from higher data rates with 64-QAM, while users further away switch to QPSK to sustain reliable connections.
- Throughput vs. Distance: The throughput performance confirms that capacity declines with increased distance due to path loss and fading. However, the combined effect of OFDM, MIMO, and AMC ensures that the system delivers optimal data rates based on users' channel conditions.
- These results confirm that integrating MIMO-OFDM with AMC significantly enhances WiMAX's ability to deliver high data rates and robust performance in practical deployment scenarios.

Figure 1 shows the simulated BER vs. SNR curves for three modulation schemes: QPSK, 16-QAM, and 64-QAM. The results highlight the trade-off between data rate and reliability — higher-order modulation schemes achieve higher throughput but require better channel conditions to maintain acceptable BER levels.

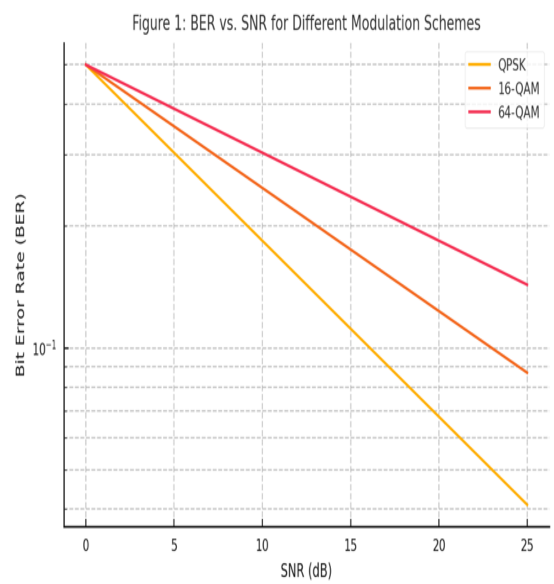

Figure 1. BER vs. SNR for different modulation schemes

Figure 2 compares the BER performance of a single antenna system with that of a 2×2 MIMO system using the same modulation scheme (e.g., QPSK). The results illustrate the diversity gain achieved by MIMO, with the BER curve shifting to the left by approximately 2–3 dB, indicating improved performance for the same SNR.

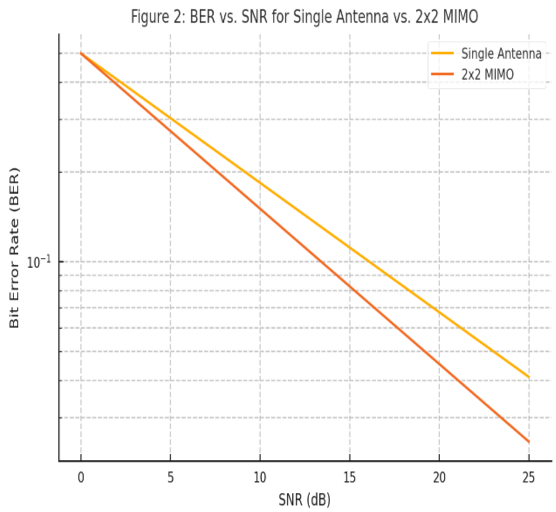

Figure 2. BER vs. SNR for Single Antenna vs. 2×2 MIMO

Figure 3 illustrates the concept of adaptive modulation switching, showing how the system dynamically selects the appropriate modulation and coding scheme based on real-time SNR levels. This adaptability helps maximise throughput when channel conditions are favourable and ensures link reliability when conditions degrade.

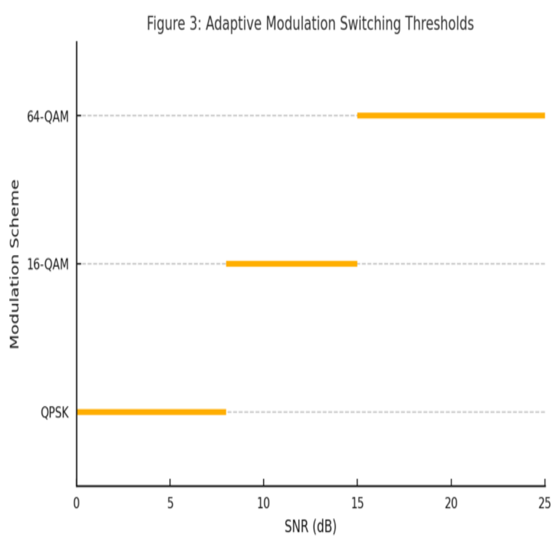

Figure 3. Adaptive Modulation Switching Concept

Figure 4 shows how system throughput changes with user distance from the base station. The plot confirms that throughput decreases with increasing distance due to path loss and lower SNR. However, the use of AMC helps maintain a robust link by dynamically switching to lower-order modulation schemes when needed.

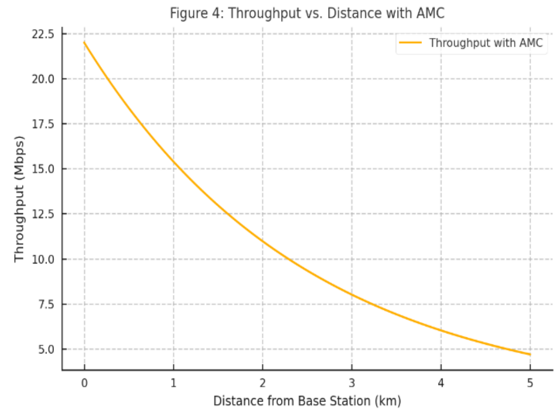

Figure 4. Throughput vs. Distance with AMC

The table 1 below summarises representative BER values for different modulation schemes at selected SNR levels, highlighting the performance trade-offs.

Table 1 summarises representative BER values for different modulation schemes at selected SNR levels

Modulation Scheme	SNR (dB)	Approx. BER
QPSK	10	$\sim 1 \times 10^{-3}$
16-QAM	15	$\sim 1 \times 10^{-3}$
64-QAM	18	$\sim 1 \times 10^{-3}$

VI. CONCLUSION AND FUTURE SCOPE

This paper highlights how the integration of OFDM, MIMO, and AMC in the WiMAX physical layer significantly improves spectral efficiency, link reliability, and overall system performance. Simulation results demonstrate that MIMO configurations and adaptive modulation can deliver robust broadband wireless access across various channel conditions. Future work should explore the integration of advanced PAPR reduction techniques with MIMO-OFDM in WiMAX, as well as the potential of massive MIMO and beamforming for further capacity enhancement in evolving broadband wireless standards.

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