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Analysis of SNR of Physical Layer of 802.16e WiMAX under AWGN Channel and Doppler impact for Rician Blurring Channel with various Digital Modulation Techniques

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Abstract: The drive to provide high-speed, cost-effective, and broadly accessible broadband wireless access (BWA) technologies has been a cornerstone in the evolution of the 802.16 standards, known as WiMAX. This standard outlines the air interface specifications for fixed BWA systems, operating within the 10-66 GHz frequency range. A significant body of research, including the model discussed in this context, has been devoted to evaluating the performance of the WiMAX Physical Layer (PHY) across various channel conditions, employing different digital modulation techniques. This analytical approach specifically focuses on measuring the system's efficacy by observing the impact on packet and bit loss rates under the IEEE 802.16 standard. Through such in-depth analysis, the model aims to shed light on the potential and limitations of WiMAX technology in delivering robust and efficient wireless broadband services.

Keywords: WiMAX, OFDM, AWGN, Rician Blurring Channel.

1. Introduction

The increasing preference for remote internet access for communication, radio, and television services, whether in stationary or mobile settings, underscores the rapid evolution of wireless internet technologies. This evolution has prompted an urgent need for swift and reliable access to the World Wide Web, leading to the development of WiMAX (Worldwide Interoperability for Microwave Access), a cutting-edge broadband wireless access technology introduced by the IEEE 802.16 working group. WiMAX stands out for its ability to deliver high data throughput over long distances, supporting both line-of-sight (LOS) and non-line-of-sight (NLOS) deployments.

The potential for WiMAX to improve WMANs is highlighted by its ability to provide services up to 20 or 30 miles from a base station, in accordance with the standards developed by the IEEE 802.16 group. The WiMAX Forum has further enhanced this technology by creating two system profiles: the fixed system profile based on IEEE 802.16-2004 OFDM PHY and the mobile system profile based on IEEE 802.16e-2005 mobile OFDMA PHY. One notable feature of WiMAX technology, especially at the physical layer, is its resilience and adaptability to different operational scenarios. This is backed by a number of mathematical models that can predict the behaviour of radio channels.

This document delves into the essential and optional characteristics of the WiMAX PHY layer, especially focusing on performance in fading environments. It outlines the structural framework of the paper, including the description of the fixed WiMAX PHY layer's primary attributes, the application of SUI-based channel conditions with path loss and delay spread for theoretical transmitter/receiver setups, and the implementation of SUI channels in the 802.16e system. The paper also discusses the foundational aspects of path loss and delay spread, followed by a detailed examination of simulation models, their parameters, and the analysis of simulation outcomes and empirical tests. The concluding sections provide a summary of findings and propose directions for future research, alongside a brief overview of the WiMAX PHY model and OFDM transformation techniques, offering a comprehensive exploration of channel characteristics and simulation results, culminating in the final observations of the study.

2. WiMAX Cost and Usage

The concept of citywide coverage for wireless Internet access through WiMAX is indeed ambitious, yet it is not driven by altruism from companies; rather, it stems from a calculated business interest. The question of who will invest in WiMAX infrastructure hinges on its application and deployment strategy. WiMAX can be implemented in two main ways: as a form of super WiFi to provide non-line-of-sight wireless connections for users needing to access the internet on a mobile or portable device, or as a line-of-sight service designed to offer multiple users a stable, always-on, high-speed wireless Internet connection.

Using radio waves to transfer data between computers, WiMAX functions similarly to WiFi. In order to safeguard the connection and prevent unauthorised access, a device that is equipped with WiMAX technology may receive data from a WiMAX station. In comparison to WiMAX's 70 Mbps maximum speed, the fastest WiFi connections can only manage 54 Mbps under ideal circumstances. Each user may still get speeds similar to cable modem services while using WiMAX, even when these 70 megabits are shared across several corporate connections and hundreds of home customers. Because of this capabilities, WiMAX is seen as a good choice for both business and individual users who need fast and dependable internet service in large cities.

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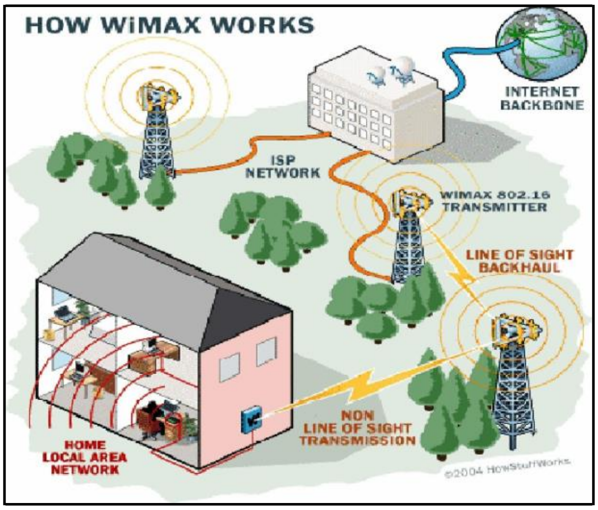

Fig. 1. Working Principle of WiMAX

The distinguishing feature of WiMAX, compared to WiFi, is not its speed but its remarkable range. While WiFi typically covers an area within approximately 100 feet (30 meters), WiMAX significantly extends this reach, capable of providing wireless access over distances of up to 30 miles (50 kilometers). This extended coverage is made possible by the use of specific frequencies and the power of the WiMAX transmitters. Although obstacles such as terrain, weather conditions, and large structures can impact the signal quality and reduce coverage in certain scenarios, WiMAX has the inherent potential to span vast areas, making it an ideal solution for widespread internet access.

This expansive coverage capability of WiMAX makes it particularly valuable in emergency situations, where reliable communication is critical for public safety officials. During crises, such as gas line explosions or terrorist attacks, traditional communication infrastructures, including cables and phone lines, can be compromised or completely severed. WiMAX, with its wide coverage area, can play a crucial role in ensuring uninterrupted communication. It enables authorities to quickly ascertain the situation, identify potential casualties, and coordinate rescue or cleanup efforts. The technology's resilience and ability to cover large geographic areas without the need for extensive physical infrastructure make it a key asset in disaster response and management, providing a robust platform for critical communication when it's most needed.

WiMAX technology offers a resilient solution for establishing a backup or even a primary communication network that is highly resistant to disruption from targeted attacks. The strategic placement of multiple WiMAX transmitters within and around a critical control center, spaced as far apart as feasible, significantly enhances the network's durability and reliability. By housing each transmitter in a fortified, bomb-resistant structure, the network ensures that no single attack can incapacitate the entire communication system. This distributed architecture not only mitigates the risk of total network failure but also guarantees that authorities and emergency responders within the command center maintain uninterrupted communication capabilities under all circumstances. Such a system is invaluable for maintaining operational continuity and effective response in the face of emergencies, thereby enhancing the resilience of critical infrastructure against both natural and man-made disasters.

3. OFDM System Implementation

IEEE 802.11a, HIPERLAN/2, and MMAC Systems are just a few of the new wireless local area network standards that are based on the foundational technique of orthogonal frequency division multiplexing (OFDM), which has enthralled researchers and technology labs around the world owing to efficiency in handling high data rates. Its use goes far beyond the UHF band and into the world of wireless broadband telecommunications, where capacity to handle the high data rates of broadband and the need for speed need large bandwidth.

Old Field Deployment (OFDM) is based on a multi-carrier modulation (MCM) method that was developed in the '50s and '60s. However, technical constraints made its actual implementation difficult, especially when it came to effectively executing the Fast Fourier Transform (FFT) and its inverse (IFFT). The FFT method, developed by Cooley and Tukey in 1965, was a game-changer that allowed OFDM to be used in digital systems. The digital implementation of OFDM is based on the mathematical processes known as Discrete Fourier Transform (DFT) and its inverse (IDFT), which allow for the transformation of data from the time domain to the frequency domain.

In orthogonal frequency division multiplexing (OFDM), these transformations play a crucial role in allocating the frequency spectrum by translating data onto orthogonal subcarriers. The IDFT operation may transform data from the frequency domain into the time domain by comparing the input from the frequency domain with its sinusoidal orthogonal basis functions at certain frequencies. Like projecting the data onto these sinusoidal basis functions, this procedure does the same thing. An efficient and theoretically similar method to DFT and IDFT is provided by modern OFDM systems, which use FFT and IFFT blocks to accomplish these computations. By splitting the wide frequency spectrum into several smaller bands, OFDM boosts the system's resilience to multipath interference and improves its capacity to offer broadband speeds efficiently, allowing it to efficiently manage huge data rates.

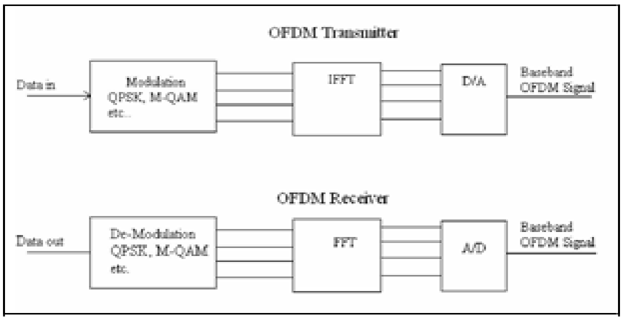

Fig. 2. Basic OFDM Transmitter and Receiver

IEEE 802.11a, HIPERLAN/2, and MMAC Systems are just a few of the new wireless local area network standards that are based on the foundational technique of orthogonal frequency division multiplexing (OFDM), which has enthralled researchers and technology labs around the world owing to efficiency in handling high data rates. Its use goes far beyond the UHF band and into the world of wireless broadband telecommunications, where capacity to handle the high data rates of broadband and the need for speed need large bandwidth.

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4. Rician Fading Channel

Rician fading is a model used to describe the effect of multipath propagation of a radio signal, which includes a strong line-of-sight component in addition to numerous reflected and scattered signals. This model is an extension of Rayleigh fading, which only accounts for the multipath components without a direct line of sight between the transmitter and receiver. In Rician fading, the dominant line-of-sight signal, such as a direct path from the transmitter or a significant reflection (e.g., off the ground or nearby structures), plays a crucial role in the signal's overall strength and quality.

The key differentiator in Rician fading is the presence of this dominant component, which can be a single line-of-sight path or a composite signal formed from several strong signals, such as a combination of a direct path and a ground reflection. This dominant signal is typically treated as a deterministic element, meaning its behavior can be predicted with a high degree of accuracy, in contrast to the random nature of the multipath components. This deterministic component can also contribute to shadow fading, affecting the signal's propagation and reception over various terrains and environments.

Rician fading models are particularly relevant in scenarios where there is a clear, unobstructed path between the transmitter and receiver, making them suitable for modeling satellite communication channels and other environments with a significant line-of-sight component. These models take into account the complex interplay between the dominant signal and the multitude of other signals received, providing a more accurate representation of signal behavior in environments where both line-of-sight and multipath components are present.

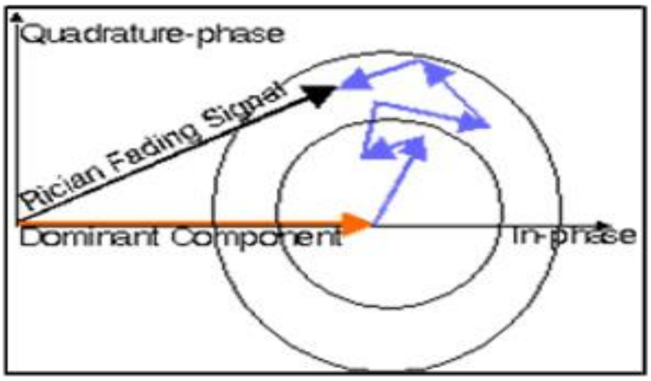

Fig. 3. Phasor Diagram of Rician fading signal [7]

4.1 Rician Factor

The Rician *K*-factor is a crucial parameter in the modeling of Rician fading, representing the ratio of power in the dominant (line-of-sight) component to the average power of the scattered (non-line-of-sight) components. It quantifies the relative strength of the direct path in comparison to the cumulative effect of multiple indirect paths that contribute to the signal's overall reception. The expression for the received signal's power in the line-of-sight component is denoted as $C^2/2$, where C represents the amplitude of the direct signal.

In environments such as indoor channels where there is a clear, unobstructed line-of-sight path between the transmit and receive antennas, the *K*-factor typically ranges between 4 and 12 dB. These values indicate a relatively strong direct signal component compared to the scattered signals, common in scenarios where transmission paths are less obstructed, and the direct signal can significantly influence the received signal quality.

When the *K*-factor is 0, which corresponds to $-\infty$ dB, the scenario degenerates to Rayleigh fading. This situation arises in environments devoid of a line-of-sight component, where the signal's propagation is characterized solely by its interaction with multiple obstacles, leading to a multitude of scattered signals reaching the receiver without any dominant path. Rayleigh fading is thus considered a special case of Rician fading, applicable when the direct signal component is absent, and the signal propagation is dominated by multipath effects.[7]

4.2 Rician Channels

Occasions of Rician obscuring are found in

- Microcellular channels
- Vehicle to Vehicle correspondence, e.g., for AVCS
- Indoor inciting
- Satellite stations

5. Reed Solomon Encoding

Applying the Reed-Solomon coding to the figures is based on adding abundance to the data evolution. If a block error occurs while the signal is being sent, this redundancy increase may fix it. After the randomizer produces its output, the data is sent to the Reed Solomon Encoder.

The RS encoder's encoding communication relies on Galois Field Computations to perform the abundance component assessments. The formula GF(2m) suggests the Galois Field, which is often used to address data in botch control coding.

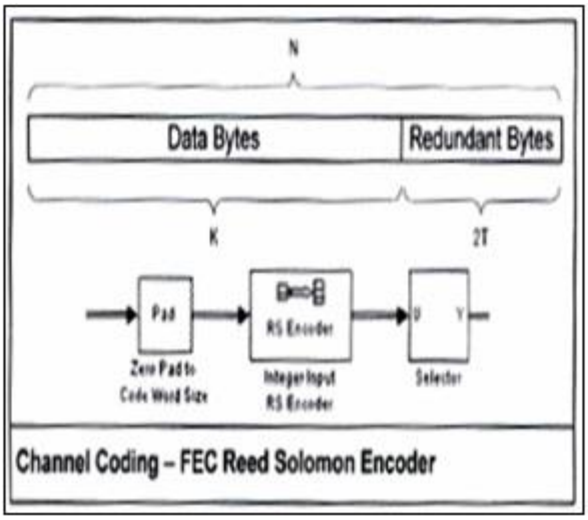

Fig. 4. FEC Reed Solomon Encoder

Before data is processed by the Reed-Solomon (RS) Encoder, The efficient operation of the encoder is guaranteed by the addition of eight tail pieces. Data transmission burst faults may be effectively corrected using the Reed-Solomon encoding procedure, a kind of error correction coding. This encoding method augments the data stream with redundant information by manipulating polynomial algebra inside a finite field, which is also called a Galois Field (GF). Because of this redundancy, the receiver may identify and fix mistakes without retransmission being necessary.
Two polynomials are required for the Reed-Solomon Encoder to function: g(x) for the code generator and p(x) for the field generator.

1. **Code Generator Polynomial ((*g*(*x*)):** This polynomial is instrumental in constructing the Galois Field Array. It defines the rules for generating codewords in the RS code. Specifically, $g(x)$ is used to produce the parity check symbols that are appended to the data to form codewords that have error-correcting capabilities. The degree of $g(x)$ determines the error-correcting capability of the code.
2. **Field Generator Polynomial (*p*(*x*)):** This polynomial is used to establish the finite field (Galois Field) over which the RS code operates. The choice of $p(x)$ determines the size of the Galois Field, which in turn affects the number of symbols that can be represented and the error correction capabilities of the RS code. The polynomial $p(x)$ is critical in defining the operations of addition, subtraction, multiplication, and division within the field.

The process of Reed-Solomon encoding involves taking the input data, appending the tail bits, and then applying the encoding defined by the code generator polynomial to generate the parity bits. These parity bits are combined with the original data (and the tail bits) to form the encoded output, which includes both the original data and the added redundancy for error correction. The inclusion of tail bits ensures that the encoded data aligns properly with the RS encoding scheme, facilitating effective error correction at the receiver's end.

.5.1 Rician Fading Channel Simulation by using 16 QAM Model

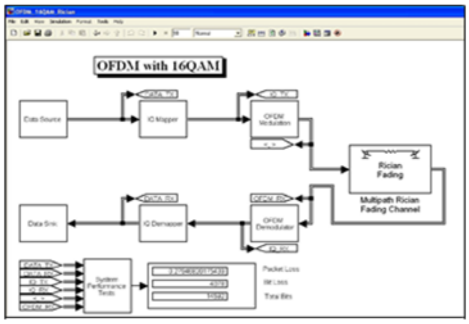

Fig. 5. QPSK Model for Rician Fading Channel

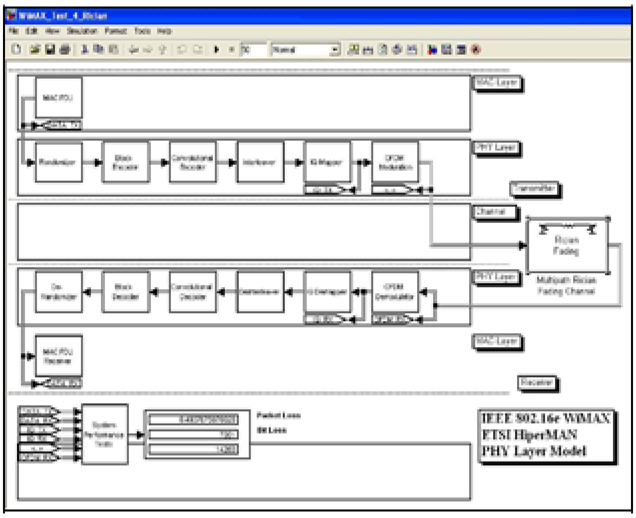

Fig. 6. 16-QAM Model for Rician Fading Channel

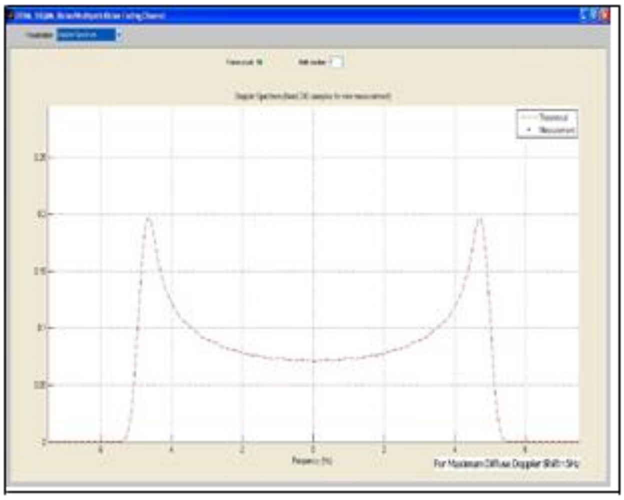

Fig. 7. Doppler Spectrum for Maximum Diffuse Doppler Shift=5Hz

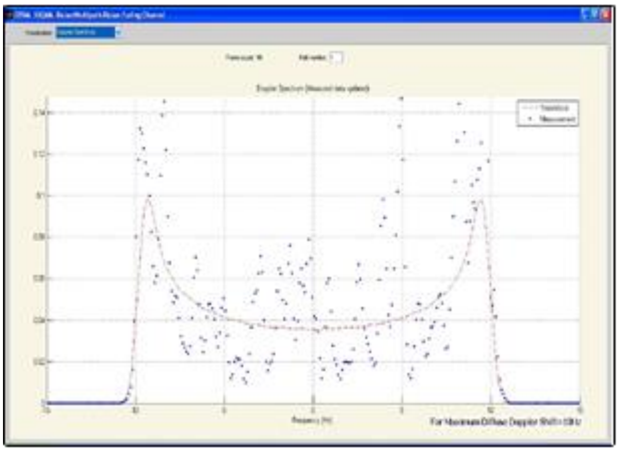

Fig. 8. Doppler Spectrum for Maximum Diffuse Doppler Shift=10Hz

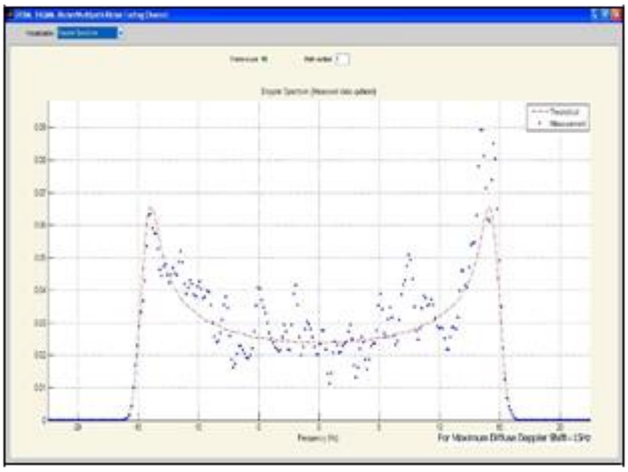

Fig. 9. Doppler Spectrum for Maximum Diffuse Doppler Shift=15Hz

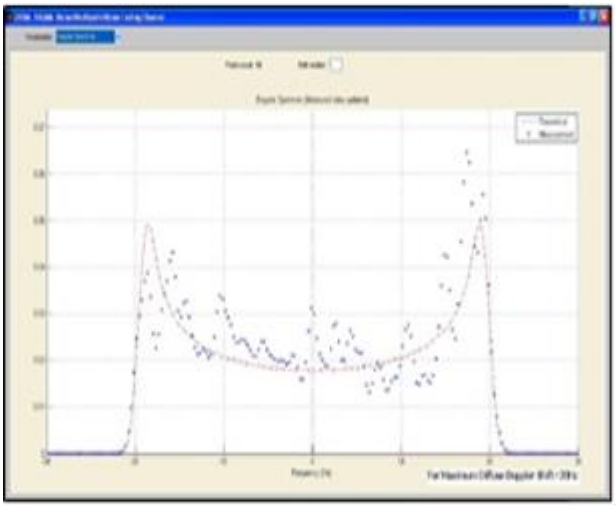

Fig. 10. Doppler Spectrum for Maximum Diffuse Doppler Shift=20Hz

6. Physical Layer Performance Results

This proposal's main objective is to use simulation results to evaluate the WiMAX OFDM physical layer's performance. The dispersion properties of QPSK and QAM, which use channel equalisation methods, were our primary focus when we set out to analyse this.

6.1 SCATTER PLOTS OF QPSK

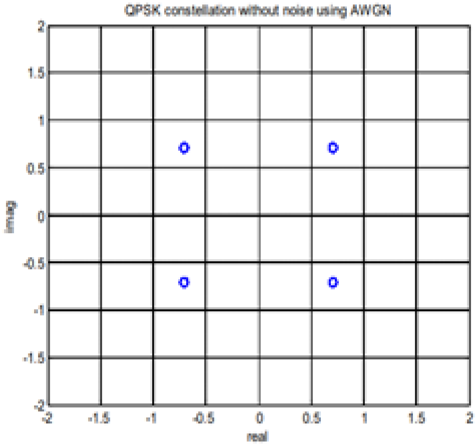

Fig. 11. QPSK constellation using ZERO force equalizer for FFT size 256

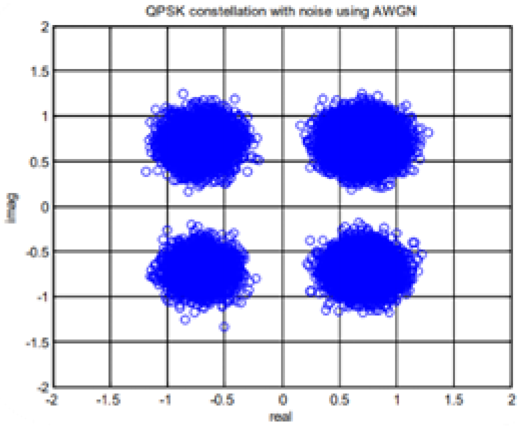

Fig. 12. QPSK constellation using ZERO force equalizer for FFT size 256

6.2 Scatter Plots oF 16 QAM

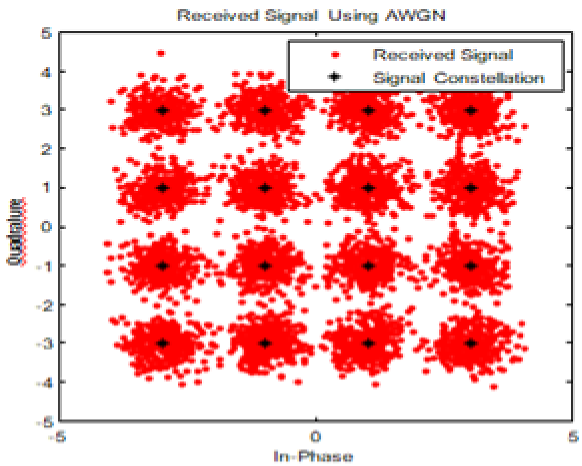

Fig 13: 16-QAM constellation using MMSE equalizer for FFT size 256

7. Conclusion

Conducting simulations for WiMAX technology presents a significant challenge due to the complexity of the IEEE 802.16

standard, which encompasses intricate wireless air interfaces and Media Access Control (MAC) protocols. The core difficulty in simulating WiMAX systems lies in integrating two distinct simulation methodologies: signal simulation and protocol simulation. Signal simulation is primarily utilized at the physical (PHY) layer to assess the performance of the air interface under various conditions, such as signal-to-noise ratio (SNR) variations in an Additive White Gaussian Noise (AWGN) channel and the impact of Maximum Diffuse Doppler in a Rician fading channel. On the other hand, protocol simulation is employed to evaluate the performance of higher-layer protocols, focusing on how data packets are managed, transmitted, and received across the network.

In this context, experiments were conducted using dual PHY layer models to gauge overall performance by altering SNR values for the AWGN channel and assessing the Maximum Diffuse Doppler effect for the Rician fading channel. The outcomes of these experiments were presented in graphical form, showcasing the relationship between the Maximum Diffuse Doppler effect (measured in Hz) and the observed Packet Loss and Bit Loss rates for frequencies of 5, 10, 15, 20, 25, and 30Hz within the Rician fading channel environment.

This approach underscores the intricate balance required to accurately simulate WiMAX systems, where both the physical attributes of the wireless channel and the operational nuances of network protocols must be meticulously considered. The objective is to achieve a comprehensive understanding of system performance, taking into account both the theoretical and practical aspects of WiMAX communication. By effectively merging signal and protocol simulation techniques, researchers can derive valuable insights into the resilience, efficiency, and scalability of WiMAX networks under a variety of real-world conditions.

Author contributions

Mahesh Pasari: Conceptualization, Methodology, Software, Field study, Data curation, Writing-Original draft preparation, Software, Validation., Field study. **Dr. Santosh Pawar:** Visualization, Investigation, Writing-Reviewing and Editing.

Conflicts of interest

The authors declare no conflicts of interest.

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