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Quantum Communication for 5G-6G Qubit-Driven Massive MIMO-OFDM Performance Analysis

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Abstract -- Communication frameworks that are extremely effective, intelligent, and secure are required due to the rapid shift from 5G to 6G networks. Through a performance analysis of qubit-driven Massive MIMO-OFDM, this paper investigates the integration of quantum communication concepts into conventional wireless systems. It provides a detailed comparison of quantum bit (qubit) representations and traditional binary bit processing. The study evaluates key performance measures across different channel models, such as Rayleigh and Nakagami-m fading, including Bit Error Rate (BER), spectral efficiency, Peak-to-Average Power Ratio (PAPR), and computational complexity. We demonstrate the potential for better robustness, reduced BER, and increased reliability in difficult wireless situations by incorporating qubit-based modulation, quantum channel estimation, and quantum error correction techniques into the OFDM and Massive MIMO framework. MATLAB simulation results show that qubit-based systems outperform classical binary systems, particularly in scenarios with high user density and mobility, making them a viable choice for upcoming 6G applications. Important information about the benefits and trade-offs of switching from classical to quantum-enhanced wireless communication systems is provided by the comparative study.

Keywords: Quantum Communication, Qubits and Binary Bits, Massive MIMO-OFDM, 5G and 6G Networks, Bit Error Rate, Channel Estimation.

I. INTRODUCTION

The rapid transition from 5G to 6G has been made possible by the continuous development of wireless communication technologies, which calls for improved data rates, lower latency, more spectrum efficiency, and extremely dependable connection. Conventional communication systems struggle to meet these demands as the number of linked devices increases exponentially [1]. In modern wireless networks, Massive Multiple-Input Multiple-Output (Massive MIMO) combined with Orthogonal Frequency Division Multiplexing (OFDM) has shown to be an essential solution that improves spectrum efficiency, network capacity, and interference reduction. However, growing computing complexity, higher power consumption, and overhead in channel prediction pose problems for conventional binary-based communication techniques [2].

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For reliable data transmission in conventional Massive MIMO-OFDM systems, the channel estimation method is essential. Least Squares (LS) and Minimum Mean Square Error (MMSE) are two examples of standard estimate procedures that are hampered by high pilot overhead, substantial computational costs, and interference vulnerability. Qubit-driven systems can significantly improve channel estimate accuracy while reducing pilot overhead and processing time by using quantum-assisted machine learning and quantum-enhanced compressed sensing. This study compares the effectiveness of qubits with traditional binary-based communication by examining their impact on Bit Error Rate (BER) in relation to Signal-to-Noise Ratio (SNR) within Massive MIMO-OFDM.

Additionally, Rayleigh fading, which depicts multipath propagation in which signals experience random amplitude variations, is a widely used model for describing wireless channels. In contrast to conventional systems, this study evaluates the role of qubits in Massive MIMO-OFDM systems operating under Rayleigh fading circumstances. To find out how qubit-driven communication adjusts to growing network density, different antenna topologies (such as 8x8, 16x16, and 32x32 arrays) are examined. Beamforming, spectral efficiency, and interference reduction may all benefit from qubits' special ability to encode and handle data differently from binary bits. The use of quantum-assisted error correction in MATLAB simulations is a key component of this study. Against ascertain their impact on Bit

Error Rate (BER) performance, conventional forward error correction (FEC) codes, such as Low-Density Parity-Check (LDPC) and Turbo codes, are compared against quantum-inspired approaches[6-8].

The role of quantum Fourier transformations, quantum state tomography, and quantum machine learning algorithms in improving BER performance in Massive MIMO-OFDM is further examined. This work aims to provide a comprehensive performance comparison between classical and quantum-based communication systems by integrating quantum computing concepts into Massive MIMO-OFDM.

The outcomes will highlight key advantages such higher spectrum efficiency, lower error rates, less pilot overhead, and enhanced resistance to interference and fading. In order to provide the groundwork for future developments in quantum wireless communication, the research will also address the difficulties and viability of incorporating qubit-based communication within 5G/6G networks. The results of the MATLAB simulations will offer crucial information about how qubits can revolutionise traditional wireless systems, improving future communication networks' dependability, effectiveness, and security. This study highlights the potential of qubit-driven Massive MIMO-OFDM in practical 5G/6G implementations, adding to the growing body of knowledge in quantum-assisted wireless technology.

II. RELATED WORK

Recent years have seen a significant increase in research interest in the integration of quantum communication concepts with classical wireless systems, particularly Massive MIMO-OFDM. According to recent research, qubit-based representations can greatly enhance system performance, outperforming traditional binary signalling. In particular, quantum-enabled OFDM systems that use Quantum Fourier Transform-like operations have demonstrated improved data transmission reliability and decreased error probabilities.

Researchers have investigated a range of signal processing methods in the context of 5G communication systems with the goal of maximising Massive MIMO-OFDM performance for high-quality data and image transmission. These programs ensure robustness in the face of channel impairments while showcasing the effective use of spectral resources. Quantum technologies are expected to be crucial in enabling ultra-high data rates, enhanced security, and sophisticated communication capabilities in 6G networks.

The importance of advanced beamforming and interference mitigation techniques to address real-world problems like intercarrier interference is highlighted by recent research on terahertz-band Massive MIMO systems. Simultaneously, quantum-assisted channel estimation techniques have proven to significantly improve estimation accuracy while reducing computational requirements. Similarly, improved resistance to noise and fading effects is provided by qubit-based modulation and error correction techniques.

Additionally, quantum-inspired beamforming and resource allocation methods have shown improvements in system fairness and spectrum efficiency in multiuser environments. The reliability of wireless communication systems is greatly increased by the integration of quantum security mechanisms, such as entanglement-based techniques and secure key generation. Innovative approaches that combine machine learning and quantum concepts are also producing promising results in adaptive channel estimation and signal recovery.

Modern wireless communication frameworks for Massive MIMO-OFDM in 5G/6G mostly rely on conventional binary-based techniques to improve data transmission efficiency and reliability. Standard Massive MIMO-OFDM systems use OFDM modulation, large antenna arrays, pilot-assisted channel estimation, and error correction methods like LDPC and Turbo codes to increase spectral efficiency and system capacity. However, these systems suffer from poor performance in fading environments, more computational complexity, higher power consumption, and inadequate defence against attacks and interference.

Machine learning-based approaches[8-9] for error correction, resource allocation, and channel estimation have been developed to address these issues. Deep learning frameworks improve signal recovery, while reinforcement learning makes adaptive resource management easier. Despite these advancements, ML-based systems may have significant processing demands, require enormous training datasets, and suffer in extremely dynamic contexts. By facilitating safe key exchange based on quantum principles, Quantum Key Distribution (QKD) has been studied [10] to improve communication security. Reversible logic has also been proposed for LDPC encoders in order to reduce power consumption in hardware applications. Nevertheless, these techniques mainly focus on energy efficiency and only slightly improve the system's overall performance, particularly in terms of channel estimation and error rate reduction.

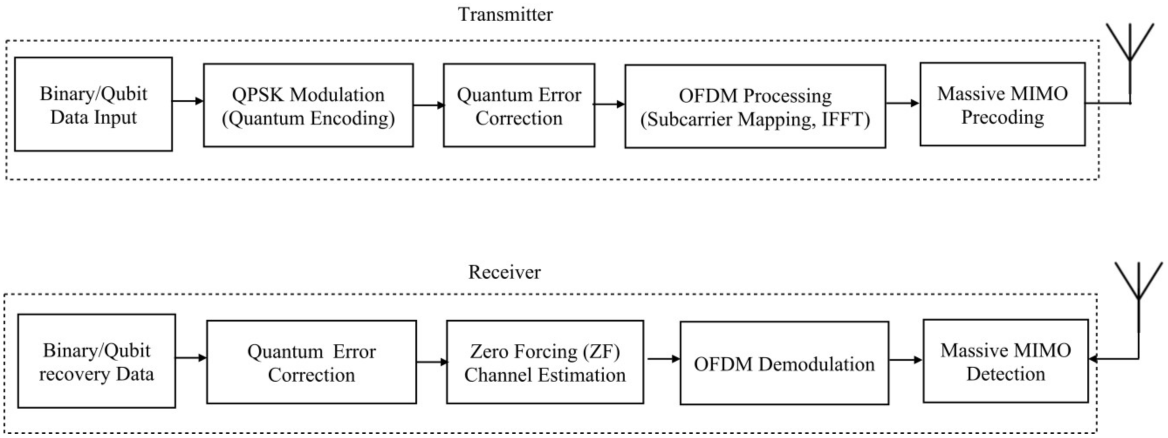

Figure 1: Block diagram of Binary/Qubit based Massive MIMO-OFDM

III. PROPOSED METHODOLOGY

In quantum encoding, data is processed using quantum states (qubits) [12] rather than classical bits. Instead of discrete 0s and 1s, a quantum state can be in a superposition of both:

$$|\psi\rangle=\alpha|0\rangle+\beta|1\rangle \qquad (1)$$

where α and β are probability amplitudes. Quantum QPSK extends this by encoding symbols into quantum states:

$$|\psi0\rangle=|00\rangle,\ |\psi1\rangle=|01\rangle,\ |\psi2\rangle=|10\rangle,\ |\psi3\rangle=|11\rangle| \qquad (2)$$

Through quantum superposition and entanglement, multiple symbols can be processed simultaneously, improving data transmission efficiency. Additionally, Quantum Error Correction (QEC) techniques, such as Shor, Steane, or Surface codes, can be applied to protect the transmitted quantum states against de-coherence and noise.

In BB84 protocol, two bases are used:
Rectilinear basis: $|0\rangle$, $|1\rangle$
Diagonal basis:

$$\begin{aligned} |+\rangle &= \frac{|0\rangle+|1\rangle}{\sqrt{2}} \\ |-\rangle &= \frac{|0\rangle-|1\rangle}{\sqrt{2}} \end{aligned} \qquad (3)$$

Each transmitted qubit randomly selects a basis.

The suggested framework incorporates principles of quantum communication into Massive MIMO-OFDM by substituting traditional bit representation with qubit-based processing, thereby enhancing reliability and spectral efficiency.

Quantum Error Correction (QEC) is an essential mechanism designed to preserve quantum information against disturbances such as noise, decoherence, and hardware imperfections. In contrast to classical error correction, which relies on adding redundant bits to identify and fix errors, QEC distributes the information of a single qubit across multiple correlated qubits. This encoding enables the system to detect and correct errors indirectly, without collapsing the quantum state through direct measurement, thereby maintaining the integrity of quantum information during processing and transmission.

A. OFDM System Model

Let the N is Number of subcarriers, Input symbol vector:

$$X=[X_0,X_1,\ldots,X_{N-1}] \qquad (4)$$

Time domain OFDM signal:

$$x(n)=\frac{1}{N}\sum_{k=0}^{N-1}X_k e^{j2\pi kn/N} \qquad (5)$$

After channel:

$$Y_k=H_kX_k+W_k \qquad (6)$$

Encrypted symbol:

$$X_k^{enc}=X_k\oplus K_k \qquad (7)$$

where K_k from QKD.
Total secure throughput can be expressed by

$$T_{secure}=R\cdot R_{OFDM} \qquad (8)$$

where

$$R_{OFDM}=B\log_2(1+SNR)$$

Therefore

$$T_{secure}(d,SNR)=\frac{1}{2}(\eta(d)+pd)[1-2H_2(Q(d))]\cdot B\log_2(1+SNR) \qquad (9)$$

The Error probability E_b and the noise variance σ^2 is related to $SNR=E_b/\sigma^2$, it can also be written by

$$P_e=Q\left(\sqrt{2SNR}\right) \qquad (10)$$

Where the Q-function can expressed by

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{\infty} e^{-t^2/2} dt \tag{11}$$

Thus

$$R(\sigma^2) = \frac{1}{2}(\eta + p_d)[1 - 2H_2(Q(\sigma^2))] \tag{12}$$

Quantum-assisted channel estimation and error correction techniques are utilized to enhance BER and SNR performance under fading wireless conditions. MATLAB-based simulations are carried out to compare the efficiency of the qubit-driven architecture with conventional binary MIMO-OFDM systems.

B. Nakagami-m Fading Model

The modeling of the 6G fading channel under Nakagami Fading can be expressed by

$$f(r) = \frac{2m^m r^{2m-1}}{\Gamma(m)\Omega^m} exp(-\frac{mr^2}{\Omega}) \tag{13}$$

where

m fading parameter and Ω is the $E[r^2]$

Instantaneous SNR:

$$\gamma = r^2 \frac{P_s}{N_0} \tag{14}$$

Average key rate under fading:

$$R_{avg} = \int_{0}^{\infty} R(\gamma) f(\gamma) d\gamma \tag{15}$$

Classical precoding methods in Massive MIMO include linear techniques like ZF, MMSE, and MF, as well as non-linear approaches such as DPC and THP, each offering different trade-offs between interference suppression and complexity. However, these methods become computationally intensive and less efficient as system dimensions increase. Quantum-assisted precoding provides an alternative by using advanced optimization algorithms to handle large-scale beamforming problems more efficiently. It also exploits quantum parallelism to process multiple signal paths simultaneously, improving spectral efficiency and system performance. Moreover, quantum-based learning and error correction techniques enhance adaptability and reliability, making them suitable for future wireless communication systems.

IV. RESULTS AND DISCUSSIONS

The simulation framework considers an OFDM-based Massive MIMO system with a 64×64 antenna configuration, operating over a Rayleigh fading channel. Channel estimation is performed using the Least Squares (LS) method, followed by Zero-Forcing equalization for signal recovery. The system evaluates BER performance by comparing classical binary modulation with qubit-based transmission models under identical conditions.

In classical systems, binary bits are transmitted using conventional modulation schemes and are highly affected by noise, fading, and interference, leading to performance degradation at low Signal-to-Noise Ratio (SNR) levels. Although techniques like spatial diversity and error correction improve reliability, limitations still persist in harsh channel conditions.

On the other hand, qubit-based transmission utilizes quantum properties such as superposition, enabling more efficient representation and processing of information. When combined with quantum-inspired detection and error correction strategies, these systems demonstrate improved resilience to channel impairments. Simulation results typically show that qubit-based approaches achieve lower BER across a wide SNR range compared to classical methods.

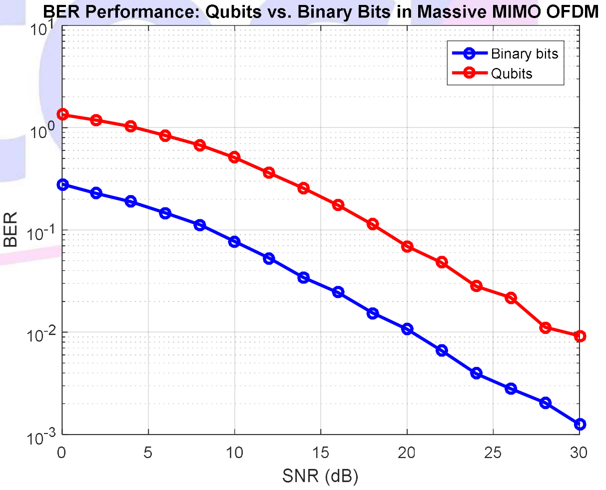

Figure 2: BER performance of Binary bits vs qubits in Massive MIMO

Figure 2 presents a comparative analysis of BER performance between qubit-based and classical binary transmission in a Massive MIMO-OFDM system, showing that quantum-assisted methods provide improved robustness and reduced error rates.

Figure 3 The spectral efficiency analysis of Massive MIMO-OFDM systems shows that classical binary modulation follows the Shannon capacity with performance improving gradually as SNR increases but remaining constrained by conventional limits. In contrast, qubit-based modulation leverages quantum properties such as superposition and entanglement, resulting in consistently higher spectral efficiency and faster growth across all SNR levels.

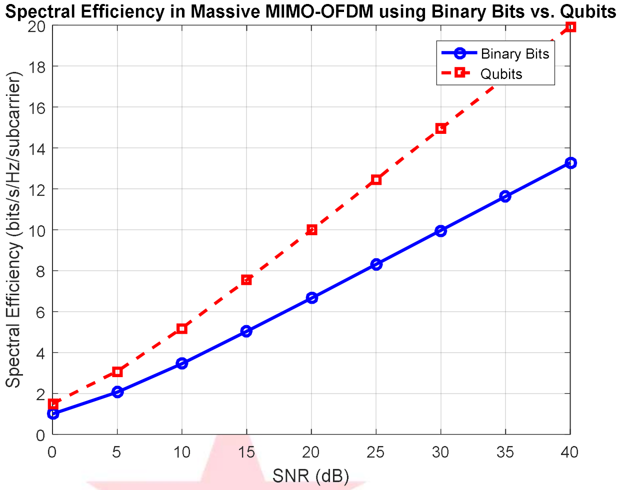

Figure 3: Spectral Efficiency Massive MIMO-OFDM using Qubits vs binary bits

The performance gap becomes more pronounced at medium to high SNR ranges, where quantum-assisted systems achieve significantly better bandwidth utilization while classical systems approach saturation.

V. CONCLUSION

The simulation results indicate that binary bit-based Massive MIMO-OFDM systems experience higher BER at low SNR due to fading, noise, and inter-symbol interference, despite improvements from LS channel estimation and Zero-Forcing equalization, which increase computational complexity. In contrast, qubit-based transmission achieves lower BER by utilizing quantum properties such as superposition and entanglement, along with quantum error correction techniques that enhance reliability under noisy channel conditions. Spectral efficiency in classical systems improves with spatial diversity but remains constrained, whereas qubit-assisted modulation and beamforming provide higher efficiency and better energy utilization. Channel estimation plays a critical role, where classical methods require higher pilot overhead under Rayleigh fading, while quantum-assisted approaches benefit from parallelism, reducing estimation errors.

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