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Design and Evaluation of Quantum OFDMA Under Depolarization Conditions

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ABSTRACT

Orthogonal frequency division multiple access (OFDMA) is a key technology scheme to enhance the resource utilization efficiency in modern wireless communication systems including LTE and 5G. On the other hand, OFDMA encounters noise, channel interferences, scalability, and spectral efficiency problems. To overcome these drawbacks, this work presents a novel communication scheme that combines quantum communication methods as a novel resource adaptive for OFDMA systems called Q-OFDMA. The Quantum Fourier Transform (QFT) is applied as a core module to enhance the robustness and efficiency of OFDMA in the presence of a noisy quantum channel. Model performance assessment was carried out via full simulations using the Qiskit quantum simulator, with two simulated use cases: the variation of the depolarizing parameter and the increase in the number of users. The results confirm that the Q-OFDMA model is significantly better than the reference quantum communication model, maintaining a lower Bit Error Rate (BER) under different depolarization and user densities.

Keywords

Quantum Communication, Orthogonal Frequency Division Multiple Access, Quantum Fourier Transform, Depolarizing Channel, Bit Error Rate.

1 INTRODUCTION

Classical communication theory is fundamentally rooted in classical physics and currently faces significant challenges due to the growing demand and increased user density. In this context, integrating quantum techniques has appeared as a potential solution[Che21, Mit20]. Quantum mechanics provides the essential theoretical framework for the development of quantum computing (QC) and quantum information processing (QIP). This framework is based on specific mathematical formulations and comprehensive scientific models, ensuring the clarity, consistency, and predictive accuracy inherent to quantum theory[NC10].

As a result, phenomena that were once regarded as abstract in quantum mechanics are now becoming accessible through experiments, paving the way for significant advancements in communication and information technology. These innovations could transform the methods of data transmission, processing, and security in our increasingly interconnected world[IG12].

Integrating quantum technologies into communication systems has emerged as a prominent research direction in contemporary communication theory, promising significant advancements over classical systems. In general, communication systems are comprised of three stages of encoding information, sending it through a communication channel, and decoding at the receiver to recover the original information[ZWR^{+}24]. Figure 1 is a schematic of the difference between classical and quantum communication systems[Car15].

In the classical communication systems, data is initially mapped into a physical signal through a classical to classical ($C \rightarrow C$) mapping by the encoding stage. Then these signals get transmitted through the chan-

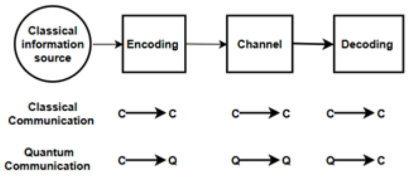

Figure 1: Classical/Quantum communication model

nel, in which some distortion as well as noise effects take place. Corrupted signals are then classically decoded to recover the original information. Quantum communication, however, uses quantum encoding techniques to encode classical symbols into quantum states. These quantum states are sent through the quantum channels, in which quantum noises, such as decoherence, will corrupt the quality[Zur03]. At the receiving station, quantum decoding decodes the quantum states back to classical symbols. At each sampling period, the receiver conducts quantum measurements and infers, based on the observed outcome, the most likely transmitted quantum state. In general, quantum communication exploits quantum mechanics effects, and the important features include a higher level of security, improved noise immunity, and higher information transmission efficiency than the classical case.

Multiple Access Techniques

Classical wireless communications use several multiple access types like Time Division Multiple Access (TDMA), Orthogonal Frequency Division Multiple Access (OFDMA), Code Division Multiple Access (CDMA), and Non-Orthogonal Multiple Access (NOMA). All these schemes are meant to enable congestion tolerant use of spectrum-limited resources[MD21]. TDMA assigns dedicated time slots to each user, minimizing the chance of collision within the medium. OFDMA allocates subcarriers of the frequency to users, which improves the robustness against multipath fading and interference[FF19]. CDMA distinguishes users with unique spreading codes, which may receive simultaneous transmission over their entire bandwidth[GAI+21]. NOMA, on the other hand, allows multiple users to utilize partially overlapping resources from each other, utilizing power differences and advanced signal processing[LYD+22]. Benefits of utilizing these types of methods are to mitigate interference, using the channel more efficiently to maintain maximum spectrum efficiency, and preserving QoS to attain a high level of service. These methods help to improve the performance, reliability, and scalability of recent wireless communications systems.

Among these methods, OFDMA has gained considerable attention due to its robustness against multipath fading, efficient spectrum allocation, and strong performance in high-data-rate environments. Despite its benefits, classical OFDMA still faces limitations, particularly regarding spectral efficiency, noise resilience, and scalability. To address these limitations, this paper explores the potential integration of quantum communication principles with OFDMA.

In the development of a scalable quantum multiple access scheme, several core challenges must be considered to ensure reliable performance. A primary concern involves supporting the simultaneous transmission of quantum data across multiple users while preserving the integrity of each quantum state. Additionally, quantum channels are inherently vulnerable to various forms of noise such as decoherence, phase shifts, and quantum errors, which can severely impact the quality and reliability of communication. Overcoming these noise-induced degradations is crucial for maintaining system performance. Another significant issue is the design of quantum encoding and decoding strategies that can effectively separate user data while preserving orthogonality among quantum states.

In this paper, we address the aforementioned challenges by proposing and analyzing a novel model that integrates quantum communication techniques with OFDMA. The quantum OFDMA framework leverages core quantum principles, including quantum encoding, the QFT, and quantum channel modeling, to enhance the performance of conventional OFDMA systems. By incorporating these quantum techniques, the model aims to significantly improve transmission efficiency, reduce susceptibility to quantum noise, and support more scalable multi-user communication. This integration not only enhances system robustness under depolarizing noise conditions but also lays the groundwork for future developments in quantum-assisted wireless communication.

The rest of this paper is organized as follows: Related Work in section 2, we review related work and discuss notable developments for quantum computing techniques to be used in communication systems and in multiple access scenarios. In Section 3 we present the classical OFDMA model and also we describe its structure as well as its drawbacks. In Section 4 we present the Q-OFDMA system which includes its quantum encoding, QFT and quantum channel model. Section 5 describes the simulation setup and gives quantitative results in terms of bit error rate for different depolarizing noise regimes. Section 6 concludes the paper and provides insight on the future work that can be done to extend the Q-OFDMA model and investigating its practical application.

2 RELATED WORK

Over the past few years, the research community has widely investigated quantum computing and quantum information technology to improve classical communication systems. Several studies have explored the integration of quantum techniques to enhance data security, reliability, and overall performance. For example, in[Mit20] researchers have investigated how the advent of quantum computing affects the security of communication systems. Specifically, a study of the 5G system revealed that quantum computing could compromise current security methods, and many researchers emphasized the urgent need to use encryption methods that can resist quantum attacks in communication systems.The article[WR22] offers an exciting view of how quantum information technology (QIT) can be used in future 6G systems, looking at how quantum computing, quantum communication, and quantum sensing can work together to enhance 6G performance. Their work lays the foundation for utilizing QIT to facilitate secure quantum communication techniques such as quantum key distribution (QKD), improve resource management in wireless environments using quantum computing, and propose innovative concepts for quantum-assisted radio access networks (qRAN) and quantum non-terrestrial networks (qNTN).

Another prominent approach focuses on enhancing the reliability of quantum communication through the development of error correction codes tailored to certain noise models. In the present framework, the authors in[LLPS23] developed a code designed to correct errors in quantum systems specifically for a fully correlated noise channel where all qubits experience the same unitary error. Their method involves a recursive design and a new form of decomposition for encoding and decoding operators into quantum gates that can be effectively implemented on IBM quantum computers. This improvement could lead to better ways to keep quantum data safe, highlighting the importance of optimizing gates for using real quantum computers. In[FP14], the authors developed a formal equivalence between the QEC decoding and the contraction of tensor networks, providing a single framework to analyze quantum codes.

Recent studies propose novel quantum measurement techniques that aim to minimize the probability of error in distinguishing non-orthogonal quantum states. The work in[SR22] evidences the importance of the quantum nature of the noise and of the real measurement procedures in assessing the real decoding results. Moreover, in[CW24] the authors have studied the BER performance of the considered quantum receiver as a function of the signal power and for different detection strategies. These results indicate the enormous potential for quantum detection schemes to improve the communication reliability of quantum-limited environments. Efforts have been made to deploy QC methods in the context of classical multiple access systems to improve the performance in terms of signal processing. For example, Grover quantum search algorithm[CKS17] has been used for signal detection in OFDMA and SC-FDMA systems, which achieves low-complexity and maximum-likelihood detection schemes but still works well in terms of accuracy performance under multiple user scenarios with minor computational complexity overhead[MZK24]. Additionally, a method called quantum key distribution using orthogonal frequency-division multiplexing (OFDM-QKD) has been proposed to secure communication at high speeds while using less bandwidth in trusted-node quantum networks. The method in[BRS15] uses all-optical OFDM encoders and decoders to parallelize key generation and cope with issues such as time misalignment and crosstalk noise by designing active decoding techniques to improve throughput and scalability.

In addition, recent literature has studied new quantum communication concepts that exploit classical multiple access and quantum communication mechanisms. In[AK21], the authors presented a quantum communication method that uses Code Division Multiple Access (CDMA) and QFT to extend the short timing of the source signals. They showed that their scheme was superior to the corresponding classical multiple access methods for quantum communications tasks, both in its noise robustness and ability to accommodate multiple users, showing the potential of quantum transformations in the search for new improvements on classical multiple access methods for quantum communications. Additionally, they developed a new scheme for QCDMA, drawing inspiration from various works, including[RS21, ASI24]. Their method enables numerous users to utilize a quantum communication channel by encoding quantum light pulses with pseudorandom spectral phase patterns. While such encoded pulses are sent to all users using a quantum star coupler, only the legitimate user can perform the correct decoding, recovering the original signal. The model can explain different types of input states, like coherent and number states, and its findings show the significance of other key quantum effects, such as entanglement and Heisenberg uncertainty principle.

While previous studies have demonstrated the benefits of quantum techniques in classical communication contexts, they often overlook scalable integration within orthogonal multi-user frameworks. To address this, the present paper investigates integrating quantum technologies into OFDMA to overcome classical OFDMA limitations. We propose a quantum-enhanced OFDMA (Q-OFDMA) system using quantum encoding and QFT techniques. Our goal is to improve system robustness, spectral efficiency, and BER performance under noisy quantum channel conditions. The study specifically evaluates how BER varies with different numbers of users and depolarizing noise levels. Particular emphasis is placed on analyzing channels characterized by varying depolarization parameters. This approach aims to advance multi-user communication and guide future developments in quantum-assisted wireless communication systems.

3 CLASSICAL OFDMA MODEL

Orthogonal frequency division multiple access (OFDMA) is an advanced version of OFDM[WLZL08]. It works by dividing the available subcarriers among multiple users, enabling the exploitation of multiuser diversity[SQB+21]. This characteristic makes OFDMA particularly suitable for cellular broadband wireless networks such as LTE, 5G networks, and Wi-Fi technologies[FCR24]. However, efficiently utilizing OFDMA in wireless broadband systems involves significant challenges. One critical challenge is jointly allocating subcarriers and transmission power among users in both uplink and downlink scenarios[ZZDS21]. This allocation must fulfill specific Quality of Service (QoS) criteria like target bit rate, acceptable latency, and fairness constraints[YHN+23]. The classical OFDMA transmission scheme illustrated in Figure 2 consists of multiple stages designed to enable efficient multi-user communication over a shared frequency channel. At the transmitter side, each of the N users first apply an encoding operation to their digital input stream. Following the encoding stage, in order to perform an

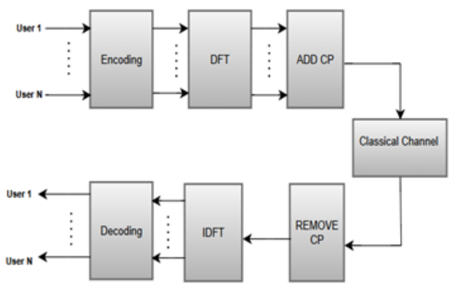

Figure 2: Classical OFDMA system

efficient multicarrier modulation, the discrete Fourier transform (DFT) is then applied by the system. The orthogonality of the subcarriers is required for the distinction of signals and for the suppression of intercarrier interference. The DFT further simplifies the channel equalization as frequency-domain operations are possible, which is a particularly important property under frequency-selective fading channels. At the transmitter, DFT is employed to transform a group of modulated frequency-domain data symbols into an aggregate time-domain signal. This time-domain signal is the OFDMA waveform, which is able to transmit simultaneously across the space and over orthogonal subcarriers and realizing dynamic resource allocation among users.The transformation for the n-th user's data is mathematically represented as:

$$X_n(k) = \sum_{t=0}^{B-1} x_n(t) \cdot e^{-j\frac{2\pi kt}{B}}, \quad k = 0, 1, \ldots, B-1 \quad (1)$$

where x_n is the encoded time-domain signal for user n, B is the total number of subcarriers (equal to the OFDM symbol size), and $X_n(k)$ is the frequency-domain representation.To mitigate inter-symbol interference (ISI) caused by multipath fading, a Cyclic Prefix (CP) of length L is appended to each OFDMA symbol before transmission. The signal is then transmitted over a classical wireless channel. On the receiver side, the cyclic prefix is removed to restore the orthogonality of the subcarriers. The received time-domain signals are then passed through the Inverse Discrete Fourier Transform (IDFT) to revert to the original domain:

$$\hat{x}_n(t) = \frac{1}{B} \sum_{k=0}^{B-1} \hat{X}_n(k) \cdot e^{j\frac{2\pi kt}{B}}, \quad t = 0, 1, \ldots, B-1 \quad (2)$$

Where $\hat{X}_n(k)$ represents the received frequency-domain signal, possibly affected by channel noise and distortion. Finally, the demodulated data is passed through a decoding stage to recover the transmitted information. The overall received signal after CP removal and before DFT can be expressed as:

$$y(i,t) = \sum_{n=1}^{N} x_n(i,t) * h(t) + v(i,t) \quad (3)$$

where h(t) denotes the channel impulse response, * represents the convolution operation, and v(i,t) is the additive white Gaussian noise. This structured framework enables the dynamic and efficient allocation of subcarriers to multiple users, achieving robustness and scalability in varying channel environments. However, classical OFDMA still faces limitations in noise resilience, spectral efficiency, and security, particularly in dense multi-user environments. Incorporating quantum information processing into this scenario, quantum encoding and QFT techniques can further enhance system performance. Specifically, quantum-based methods improve resistance to noise, enabling more robust communication. Thus, quantum approaches significantly benefit channel estimation accuracy, reliability, and scalability of the uplink OFDMA system.

4 QUANTUM OFDMA MODEL

The proposed quantum multiple access model, which is an analog of the classical OFDMA present in section 3, consists of several segments including quantum encoding, QFT for the transmitting side, then the quantum data is processed to the quantum version of the channel. On the receiver side, the IQFT and measurement

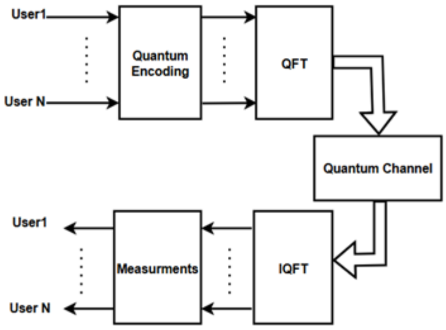

Figure 3: Quantum OFDMA system

are implemented to get user data back. The architecture of Q-OFDMA is illustrated in Figure 3. One of the most remarkable advantages of quantum systems is their ability to support smooth transitions between classical and quantum domains. In our Q-OFDMA model, this property enables a seamless exchange of information without relying on mechanisms such as the cyclic prefix, which is essential in traditional OFDMA systems. The absence of a cyclic prefix is made possible by the continuous-state propagation inherent in quantum mechanics. This scheme simplifies the process of quantum transmission and promotes the efficiency of transmitting and the reliability of receiving the quantum state. Thus, the Q-OFDMA model represents a considerable improvement for next-generation quantum communication systems.

4.1 Quantum Encoding

Initially, we assume the presence of pure orthogonal quantum states. Under this assumption, the information transmitted over a quantum communication channel can be explained similarly to classical information theory[KPTŻ22]. The transmitter generates classical symbols a_i, which correspond directly to orthogonal quantum states. These symbols belong to a classical alphabet $A = \{\,|a_1\rangle, \dots, |a_N\rangle\,\}$ and are sent with corresponding probabilities $p_A = \{p_1, \dots, p_N\}$. At the receiver side, the receiver receives these symbols as quantum states from the alphabet $B = \{\,|b_1\rangle, \dots, |b_N\rangle\,\}$. These states are modified by the QFT, quantum channel, and IQFT. Importantly, orthogonality between quantum states ensures $\langle b_i \mid b_i\rangle = 0$ for all $i \neq j$. Consequently, the receiver can perform projective measurements to distinguish the received states. Hence, orthogonal states inherently prevent errors in decoding. Basis encoding is a straightforward method for converting classical information into quantum states. Specifically, it maps an n-bit classical binary string x onto an n-qubit quantum state $|x\rangle = |i_x\rangle$ where each $|i_x\rangle$ represents a computational basis state. For instance, if the classical binary input is 1101, then the resulting quantum state after applying basis encoding would be $|1101\rangle$.

4.2 Quantum Fourier Transform and its Inverse

One crucial transformation used in quantum computing is QFT which is analogous to the DFT used in classical signal processing[CVBY21, RPGE17]. DFT takes an input vector of complex numbers and produces an output vector, also composed of complex numbers. Mathematically, this transformation can be represented as:

$$y_k = \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} x_j \, e^{2\pi i jk/N}$$

The QFT uses a similar mathematical form, acting on quantum states rather than classical numbers. Specifically, the QFT operates on orthonormal quantum basis states $\{\,|0\rangle, |1\rangle, \dots, |N-1\rangle\,\}$ The transformation of a basis state $|j\rangle$ can be defined as:

$$|j\rangle \to \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} e^{2\pi i jk/N} \, |k\rangle$$

This transformation is unitary, making it appropriate for implementation on quantum computers. Moreover, the QFT can be represented using a product form, providing an efficient quantum circuit representation[SAI24]. For an n-qubit system with $N = 2^n$ the basis state $|j\rangle$ can be written using binary notation as $|j_1, j_2, \dots, j_n\rangle$

$$|j_1, j_2, \dots, j_n\rangle \to \frac{1}{2^{n/2}} \left(|0\rangle + e^{2\pi i \cdot 0.j_n}|1\rangle\right) \left(|0\rangle + e^{2\pi i \cdot 0.j_{n-1}j_n}|1\rangle\right) \cdots \left(|0\rangle + e^{2\pi i \cdot 0.j_1 j_2 \cdots j_n}|1\rangle\right) \tag{4}$$

This product formula helps construct efficient quantum circuits that implement the QFT. Such circuits use Hadamard gates and controlled-phase rotation gates, known as R_k, represented as:

$$R_k = \begin{bmatrix} 1 & 0 \\ 0 & e^{2\pi i/2^k} \end{bmatrix}$$

Applying Hadamard and controlled-phase gates sequentially on qubits transforms the input state according to the QFT definition. At the receiver side, IQFT serves as a foundational operation in quantum computing, particularly when recovering data from the frequency domain. After a quantum state has undergone a QFT, it exists in a superposition where amplitude components represent frequency information across computational basis states. To extract meaningful results and perform measurements in the standard basis, it becomes necessary to apply the IQFT. Mathematically, the IQFT on a basis state $|k\rangle$ in a Hilbert space of dimension N is defined as:

$$\text{IQFT}(|k\rangle) = \frac{1}{\sqrt{N}} \sum_{j=0}^{N-1} e^{-2\pi i jk/N} \, |j\rangle$$

This transformation effectively reverses the QFT operation, mapping the state back into the computational basis where each quantum amplitude corresponds to the likelihood of observing a specific classical outcome. The IQFT is essential for is necessary to bring the data back to a state ready for measurement at the end. Thus, in the Q-OFDMA framework, the IQFT not only completes the communication cycle but also ensures orthogonality preservation and efficient multi-user separation, contributing directly to the model's robustness and scalability in quantum multi-access environments.

4.3 Quantum Channel Model

In classical computing, the primary error type is the bit-flip, switching between states 0 and 1. Due to qubit superposition, quantum computing introduces additional error types. These quantum errors include bit-flip, phase flips, and combined bit-phase flips[Kin03, EMCGF19]. The phase flip error changes the quantum state phase, while the bit-phase flip error simultaneously changes both the bit and the phase. Mathematically, these errors can be described using specific Kraus operators[KSS10]:

$$\hat{K}_0 = \sqrt{1 - \frac{p}{2}}\,\hat{I}, \quad \hat{K}_1^j = \sqrt{\frac{p}{2}}\,\hat{\sigma}_j$$

In this formulation, $j = x$ represents a bit-flip, $j = z$ a phase flip, and $j = y$ a combined bit-phase flip. Each error has a probability $p/2$, while the probability of no error occurring is $1 - p/2$. These quantum errors are associated with the Pauli matrices $\hat{\sigma}_j$. Noise from the environment can be modeled using different quantum channels. A quantum channel describes the transformation of quantum states. Specifically, it maps an initial density operator ρ to a final density operator ρ_k . This transformation is known as a quantum operation or superoperator. Mathematically, the quantum channel can be expressed using an operator-sum representation[GIN18].

$$\rho_f = \sum_k E_k \rho E_k^\dagger$$

Where, the operators E_k represent the channel actions, referred to as Kraus operators. We consider a depolarizing channel, which acts on a qubit initially described by the density operator $\hat{\sigma}$. The depolarizing channel transforms this qubit into a new state, represented by Pauli operator description and density operator description, as shown in Figure 5.

This channel introduces unbiased noise, causing bit-flip and phase-flip errors with equal probability. Its action on a density operator $\hat{\sigma}$ is given by:

$$\mathscr{E}(\hat{\rho}) = (1-p)\hat{\rho} + \frac{p}{3}\left(\hat{\sigma}_x\hat{\rho}\hat{\sigma}_x + \hat{\sigma}_y\hat{\rho}\hat{\sigma}_y + \hat{\sigma}_z\hat{\rho}\hat{\sigma}_z\right)$$

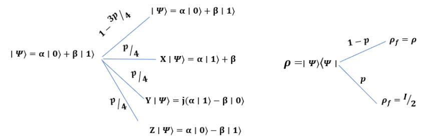

Figure 4: Depolarizing channel representations

However, combining these different error interactions incoherently might be conceptually questionable. This issue arises because bit-flip, phase-flip, and bit-phase flip errors do not commute. where the depolarizing parameter p lies between 0 and 1. The depolarizing channel is relevant for several reasons. First, it provides a standard model for noise processes commonly encountered in quantum systems. This type of noise model has wide-ranging applications in quantum information processing. Second, quantum parameter estimation demonstrates the advantages of quantum methods over classical techniques.

5 SIMULATION RESULTS

In this paper, the simulation mainly focused on analyzing the BER performance of a Q-OFDMA system and compare the results with the quantum reference model. The assessment was carried out using comprehensive simulations. These simulations were conducted utilizing the Qiskit platform and Python. The quantum simulator employed in the evaluation was the Qiskit Aer package. Qiskit Aer allows for accurate modeling of quantum computing processes. Through this simulation approach, the accuracy and reliability of the results were validated. Consequently, the obtained findings effectively demonstrated the BER characteristics within the Q-OFDMA framework under the depolarizing noise conditions.

We consider classical information represented by symbols. These symbols form a sequence of classical bits. Initially, these classical bits undergo encoding to transform them into quantum states by basic encoding. Thus, a classical-to-quantum (C $\rightarrow$ Q) mapping is performed. This mapping employs a comprehensive look-up table containing all possible n-bit binary sequences. Such a table is essential for verifying the accuracy of the received quantum states. Accordingly, the initial quantum state is prepared based on this mapping. This quantum state consists of four qubits. After preparation, the quantum state undergoes a QFT. The QFT is an essential step in the process. It transforms the encoded quantum information into the Fourier basis representation. This representation simplifies subsequent processing and analysis steps. Additionally, the simulation assumes that all possible codewords emitted from the source have an equal probability of occurrence. Such a uniform probability distribution assumption simplifies the modeling process. It enables easier initial analysis and helps interpret the simulation results.

In the Q-OFDMA channel scenario, once the QFT has been applied, each qubit is individually processed through a depolarizing quantum channel. This depolarizing channel has parameters defined within a specific and controlled range. This step effectively represents the inherent noise typically present in real quantum communication channels.

The introduction of such channel noise is crucial, as it realistically mimics environmental disturbances affecting quantum states during transmission. For a thorough and detailed investigation, the simulation systematically explores all possible combinations and sequences of channel operations on each quantum state. Such a comprehensive simulation strategy provides valuable insights by explicitly evaluating how channel-induced noise influences quantum system performance. It also ensures that the complexity and subtle interactions of noise effects within the Q-OFDMA system are thoroughly understood and accurately captured. Consequently, this approach significantly contributes to better identifying system vulnerabilities and performance limitations under realistic quantum channel conditions.

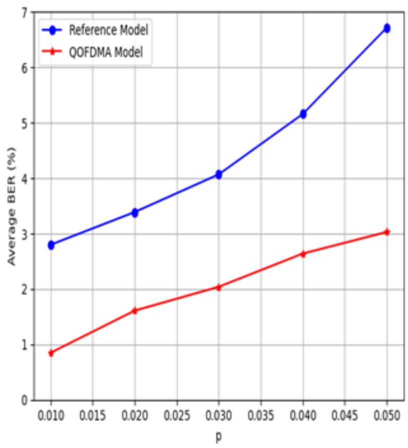

Figure 5: The Average BER With Different values of Depolarizing parameter

Figure 5 illustrates the simulation results comparing the average bit error rate (BER) performance between the reference quantum communication model and the proposed Q-OFDMA model. In this scenario, the depolarization parameter (p) is varied systematically from 0.01 to 0.05. As depicted clearly, the BER for both models increases gradually with higher values of the depolarization parameter. However, the Q-OFDMA model consistently exhibits significantly lower BER compared to the reference quantum model across the entire tested range. This enhanced BER performance in the Q-OFDMA model can be attributed to the effective integration of quantum encoding techniques and the application of QFT. Specifically, these quantum-enhanced approaches enable better mitigation of noise and interference introduced by the depolarizing quantum channel. Consequently, the Q-OFDMA model achieves greater resilience and stability, clearly illustrating its potential for improving the reliability and robustness of quantum-based wireless Q-OFDMA communication systems under noisy quantum channel conditions.

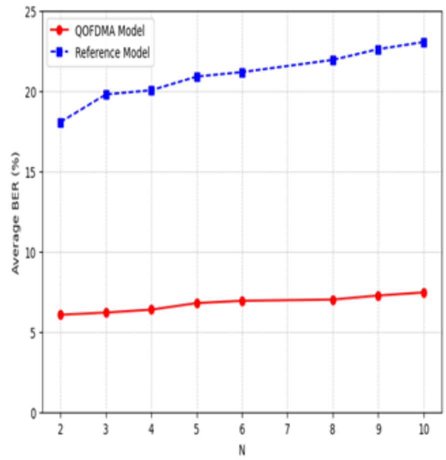

Figure 6: The Average BER with Increasing Number of Users

Figure 6 considers a scenario with a fixed depolarizing parameter, evaluating the impact of varying the number of users from 2 to 10 on the average BER performance. The results indicate that as the number of users increases, the average BER gradually rises for both the reference model and the Q-OFDMA model. This occurs due to the increased likelihood of errors introduced by the depolarization channel as more qubits (representing more users) simultaneously pass through the noisy quantum environment. Specifically, a larger number of users leads to a greater probability of quantum state corruption and interference between user signals, causing higher BER values. Despite this challenge, the Q-OFDMA model consistently achieves significantly lower BER compared to the reference model across the entire range.

6 CONCLUSION

This paper introduced and evaluated a novel Quantum OFDMA (Q-OFDMA) framework designed to enhance wireless communication performance under depolarizing quantum channel conditions. By integrating quantum encoding techniques and the QFT, the proposed Q-OFDMA system demonstrated significant improvements in BER performance compared to a reference quantum communication model. Through rigorous simulations using the Qiskit simulator, the model's robustness was verified under two scenarios: varying depolarization levels and increasing user density. In both cases, Q-OFDMA maintained a consistently lower

BER, affirming its capability to mitigate quantum noise and scale effectively with multiple users.

The results validate the feasibility of applying quantum principles in practical multiple-access scenarios. The Q-OFDMA model not only strengthens noise resilience but also highlights the potential of quantum communication paradigms to meet the growing demand for secure and efficient data transmission in future 6G and beyond networks.

7 ACKNOWLEDGMENTS

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