Quantum Communication Based Image Transmission with Transmit and Receive Diversity in MIMO Communication Systems

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***Abstract*—Quantum communication systems have the potential to revolutionize media transmission technologies with unparalleled efficiency and reliability. However, practical and scalable implementations are challenged by issues such as channel fading and interference. To address these, we propose a novel approach combining quantum superposition with transmit and receive diversity schemes in Multiple-Input Multiple-Output (MIMO) systems, designed to mitigate the effects of fading for enhanced image transmission. In our simulations, images in JPEG and HEIF formats are channel encoded with rate 1/2 polar coding, converted into qubit superposition states, and transmitted through a 2x2 MIMO system with varied diversity schemes. At the receiver, a quantum decoder reconstructs the classical information, followed by polar decoding to retrieve the original image data. Our approach achieves notable improvements in image quality, with Peak Signal-to-Noise Ratio (PSNR) up to 58.27 dB for JPEG and 64.72 dB for HEIF, and Structural Similarity Index Measure (SSIM) up to 0.9994 for JPEG and 0.9999 for HEIF, outperforming classical systems, especially under low Signal-to-Noise Ratio (SNR) conditions, demonstrating the system's enhanced ability to maintain image quality in noisy channels. These findings highlight the promise of quantum superposition-based media transmission to set new standards in reliable, high-fidelity communication for next-generation systems.**

***Index Terms*—Image Transmission, MIMO, MISO, Quantum Communication, SIMO**

I. Introduction

In the modern era of consumer electronics [1], high-quality image transmission is essential for a wide range of applications, including mobile video streaming, real-time video calls, online gaming, virtual reality [2], extended reality [3], and smart home devices. As these applications demand higher-resolution images and faster data transmission, maintaining image quality has become crucial. Poor image quality can significantly impact the user experience, resulting in pixelation, blurring, and delays. These problems are especially pronounced in real-time applications, where users anticipate a seamless and visually engaging experience.

Image data, especially in compressed formats like Joint Photographic Experts Group (JPEG) and High Efficiency Image Format (HEIF), are highly correlated, meaning that pixels within an image are interdependent. Compression algorithms exploit these correlations to reduce the size of image files while maintaining visual quality. However, this interdependence makes the image data more vulnerable to errors and data loss during transmission. Even small amounts of lost or corrupted data can disrupt the decoding process and cause noticeable degradation in the quality of the received image.

As the demand for high-resolution image transmission grows, maintaining image quality becomes essential. A key challenge in real-world communication is fading, which causes signal fluctuations due to multipath interference and environmental factors, leading to data loss and image degradation. Classical communication systems use error correction, modulation, and signal processing to mitigate noise and interference. However, their performance is limited by bandwidth, channel capacity, and dynamic conditions, making them less effective for modern high-resolution image transmission in variable environments.

Quantum communication [4] offers a promising solution to address challenges in image transmission by leveraging quantum mechanical principles such as superposition [5] and entanglement [6]. These properties enable more efficient and resilient data transmission, enhancing noise resistance, reliability, and channel capacity, which can significantly improve image quality even under adverse conditions. Quantum superposition allows qubits to hold multiple states simultaneously, increasing data throughput and optimizing encoding processes, thereby reducing transmission errors. However, quantum communication systems remain susceptible to channel impairments like fading, which can degrade performance. To mitigate these effects, established techniques from classical communication can be adapted to enhance quantum communication systems.

One such technique is Multi-Input Multi-Output (MIMO) communication system [7], which uses multiple antennas at both the transmitter and the receiver to mitigate the effects of multipath fading and interference by leveraging spatial diversity [8]. There are four broad MIMO transmission schemes that can be defined: single-input single-output (SISO), which uses no spatial diversity, multi-input single-output (MISO), which uses transmit diversity, single-input multi-output (SIMO), which uses receive diversity, and MIMO, which uses both transmit and receive diversity. They have been shown to be effective in increasing data rates, reliability,

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and efficiency in classical communication systems, and their application in quantum communication could offer similar benefits, potentially improving performance under complex channel conditions.

This study examines a quantum communication framework that employs superposition principles to enhance image transmission over MIMO communication channels with two transmit and receive antennas. By leveraging the unique properties of quantum superposition, we aim to mitigate the effects of signal fading, thereby improving the overall reliability and performance of MIMO communication systems. Specifically, we examine this system under various diversity schemes: transmit diversity using a 2×1 MISO configuration, receive diversity with a 1×2 SIMO configuration, and a no-diversity 1×1 SISO setup. For comparison, we implement a classical communication system with equivalent bandwidth and test both systems using the same diversity schemes on a flat-fading Rayleigh channel [9]. In our simulations, images are first source-coded using Joint Photographic Experts Group (JPEG) and High Efficiency Image Format(HEIF) formats. Then, a polar code with a rate of 1/2 is applied as the channel coding method for both quantum and classical communication. Simulations are conducted across a range of channel signal-to-noise ratio (SNR) values, and our findings show that quantum communication outperforms classical communication in all scenarios in terms of peak signal-to-noise ratio (PSNR) and structural similarity index measure (SSIM). This analysis explores MIMO diversity techniques in quantum communication to improve the reliability and robustness of media transmission in consumer technology.

In summary, the key novel contributions of this study are as follows:

- Investigate the performance of superposition based quantum communication systems utilizing transmit and receive diversity techniques in MIMO to mitigate fading effects over the communication process for image transmission.
- Compare its performance with that of an equivalent classical communication system using the same diversity techniques.
- Propose a more robust end-to-end image transmission system that provides a solution to fading in real-world communication processes.

The paper is structured as follows: we first review related work and its limitations, then describe the simulation methodology. Next, we present and discuss the experimental results. Finally, we summarize the key findings and their significance.

II. Related Works

Quantum communication is based on the fundamental principles of quantum mechanics [10], which have led to the emergence of quantum computing [11] and significant advancements in communication technologies. By utilizing fundamental quantum phenomena like superposition and entanglement, quantum communication systems are capable of processing and transmitting information in more efficient, reliable, and secure ways than classical methods. Entanglement, in particular, plays a critical role in enabling secure communication, with key applications such as quantum key distribution (QKD) and quantum teleportation demonstrating its potential to safeguard data during transmission. Many research studies have investigated QKD capability, highlighting its potential for secure communication [12], [13]. Quantum teleportation, on the other hand, has been extensively studied, with numerous investigations exploring its potential applications in secure and efficient communication [14], [15].

Furthermore, recent studies have explored the application of entanglement for secure image transmission [16], [17], addressing the growing concerns around privacy and data integrity in the digital media landscape. In this context, quantum communication offers a robust framework for ensuring the secure transmission of sensitive data, such as personal images or confidential medical records, across potentially insecure networks. This opens up new avenues for protecting user privacy in industries like healthcare, finance, and government, where data security is paramount.

Despite the well-established theoretical foundations of quantum superposition in quantum mechanics, its direct application in quantum communication systems remains relatively underexplored. This principle is one of the cornerstones of quantum computing and quantum communication, as it offers an exponential increase in processing power and communication capabilities compared to classical systems. Although the influence of quantum superposition on communication complexity has been investigated [18], [19], it offers valuable insights into how this quantum phenomenon can improve the efficiency and effectiveness of information transmission. However, despite these advances, a fully realized approach utilizing the superposition principle to develop an end-to-end quantum communication system, particularly for media transmission, remains unachieved. Also, current research in this area has not fully addressed the impact of channel fading effects, which are crucial for realistic transmission environments. Given the significance of fading in practical communication systems, further exploration of how quantum superposition can be utilized to mitigate fading effects in image transmission is essential for achieving optimal performance in real-world applications.

MIMO communication systems which use multiple antennas at both the transmitter and receiver improve communication performance, particularly in terms of data rate and reliability, by exploiting spatial diversity and multiplexing to mitigate the effects of fading, interference, and signal degradation. While the performance of MIMO communication systems has been well-studied in the context of classical communication [20]–[23], despite these advancements, classical MIMO systems are ultimately limited by the inherent constraints such as noise, interference, and the finite capacity of communication channels. However, research on MIMO systems in the realm of quantum communication is still limited. Most existing studies focus on entanglement based quantum MIMO communication methods, such as MIMO based quantum teleportation [24], [25] and MIMO based quantum key distribution (QKD) [26], which leverage quantum entanglement for secure communication. These studies have provided valuable insights into how MIMO techniques can be applied to quantum communication systems, but the specific effects of MIMO techniques on media transmission, particularly in quantum superposition-based communication systems, have not been explored.

Therefore, this study is novel in investigating how MIMO techniques, when applied to superposition based quantum communication systems, can enhance the performance of media transmission in real-world communication channels. By combining the benefits of MIMO with the power of quantum superposition, this research aims to bridge the gap between the current limitations of quantum communication and its future potential for highly efficient and reliable media transmission in practical scenarios. This integration could lead to the development of more robust and high-quality quantum communication systems capable of transmitting complex media, such as high-resolution images and videos, with greater efficiency and fewer errors, even in the presence of real-world channel impairments.

III. Methodology

To implement our proposed system as represented in Fig.1, we start by selecting a set of images from the Microsoft COCO data set [27]. This data set includes a diverse array of images that are ideal for evaluating communication systems due to their varied content and complexity. After selecting the images, we apply either JPEG or HEIF compression for source encoding to optimize images for transmission by reducing their data requirements. JPEG offers good compression rates, while HEIF achieves higher compression with less image degradation, delivering better quality at low bitrates. HEIF files are typically 50% smaller than JPEGs with minimal quality loss, making it ideal for bandwidth-sensitive applications. This choice of encoding format allows us to evaluate the impact of different compression standards on system performance, especially image fidelity after transmission.

Following source encoding, the compressed bitstream undergoes channel encoding using a rate $1/2$ polar code [28]. Channel coding is essential in any communication system, as it adds redundancy to enable error correction during transmission. Polar codes are chosen because they are the most advanced and low-complexity channel coding method in the classical domain, effectively reducing errors in noisy channels. In this research, we use polar codes for quantum-domain error correction instead of quantum error correction codes [29], as existing quantum error correction methods are more complex. Integrating them into the proposed MIMO system would introduce additional complexity, making polar codes a more practical choice.

Once the bitstream is channel encoded, it is then input into the quantum encoder. In this process, each classical bit is translated into its corresponding qubit. Specifically, a classical bit of 0 is represented by the qubit $|0\rangle$, and a classical bit of 1 is represented by the qubit $|1\rangle$. This mapping allows the classical information to be prepared for quantum transmission, leveraging quantum states to facilitate efficient and reliable communication.

These qubit basis states can be represented according to the following matrices as represented in (1) and (2).

$$|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \tag{1}$$

$$|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{2}$$

After qubit mapping, the quantum encoder utilizes the Hadamard gate, which is represented in (3), to convert the qubits into superposition states.

$$H = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \tag{3}$$

If the Hadamard gate is applied to $|0\rangle$, it results in the following vector, as represented in (4). It can also be represented in matrix form, as shown in (5).

$$H|0\rangle = \frac{1}{\sqrt{2}} (|0\rangle + |1\rangle) \tag{4}$$

$$H \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 1 \\ 0 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ 1 \end{pmatrix} \tag{5}$$

Similarly, when the Hadamard gate is applied to $|1\rangle$, it results in a superposition state, as represented in (6). This can also be represented in matrix form, as shown in (7).

$$H|1\rangle = \frac{1}{\sqrt{2}} (|0\rangle - |1\rangle) \tag{6}$$

$$H \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} 0 \\ 1 \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 \\ -1 \end{pmatrix} \tag{7}$$

In this MIMO communication system, complex baseband modulation is required. Therefore, the generated superposition states need to be processed using an additional phase gate S, as shown in (8).

$$S = \begin{bmatrix} 1 & 0 \\ 0 & i \end{bmatrix} \tag{8}$$

Applying the S gate to $H|0\rangle$ and $H|1\rangle$ results in (9) and (10).

$$SH|0\rangle = \frac{1}{\sqrt{2}}(|0\rangle + i|1\rangle) \tag{9}$$

$$SH|1\rangle = \frac{1}{\sqrt{2}}(|0\rangle - i|1\rangle) \tag{10}$$

These qubit superpositions with additional phase states are then fed into the transmitter for transmission over a channel under 1×1 SISO, 2×1 MISO and 1×2 SIMO diversity schemes, as shown in Fig. 2.

In the proposed system, the communication channel is modeled as a flat-fading Rayleigh channel to simulate real-world wireless transmission conditions where signal fading occurs due to multipath propagation. A Rayleigh fading model is particularly suitable in environments with no direct line-of-sight, as it assumes that the magnitude of the signal fades according to a Rayleigh distribution.

This setup includes multiple transmitter antennas operating under MIMO principles, where each transmit-receive antenna

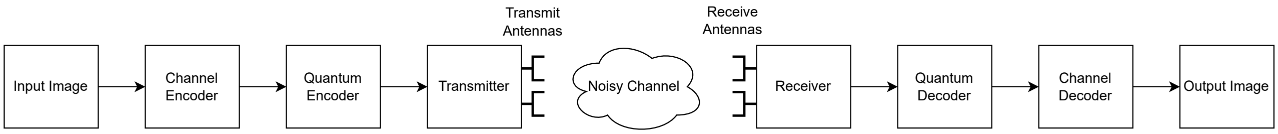


Fig. 1. End-to-end quantum communication system using MIMO technology.

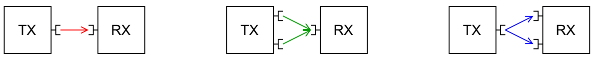


Fig. 2. MIMO based diversity schemes used in simulations: (a) Reference (no diversity), (b) transmit diversity, (c) receive diversity.

pair experiences independent fading. The independence of fading across these pairs is a crucial assumption, as it aligns with the benefits of spatial diversity in MIMO systems, enabling improved reliability and signal strength at the receiver. Additionally, the model assumes that the channel state information (CSI) is perfectly known to the receiver, allowing for optimal decoding and reducing errors due to channel uncertainty.

To adapt this classical channel model for quantum symbol transmission, the model is extended to include quantum noise effects within the fading channel. In quantum communication, noise sources differ fundamentally from classical noise and are represented by quantum states that interact with the transmitted signal. Quantum noise [30] in fading channels typically arises from quantum bit-flip, phase-flip, depolarization, phase damping, and amplitude damping, where the properties of transmitted qubits can be altered or lost due to interactions with the environment. The Rayleigh model is thus modified to capture these additional quantum decoherence effects, representing the unique challenges of maintaining quantum state integrity over noisy, fluctuating channels.

After the qubit superposition states pass through the communication channel, they are received and processed by the quantum decoder, which is responsible for converting the superposition states of the qubits back into classical bits. The process begins by removing the additional phase information of the received qubit states. To achieve this, we apply the inverse of the S gate, denoted as $S^\dagger$, which is defined in (11).

$$S^\dagger = \begin{bmatrix} 1 & 0 \\ 0 & -i \end{bmatrix} \tag{11}$$

After that, decoding process involves quantum measurements, which are essential for extracting classical information from the qubit superposition states. These measurements are performed using quantum measurement operators that correspond to specific quantum observables, leading to outcomes that are probabilistic in nature due to the inherent uncertainty of quantum mechanics.

When a measurement is conducted, the quantum superposition state collapses, and the resulting post-measurement state, denoted as $|\psi'\rangle$, depends on the measurement. To maintain consistency with quantum mechanics, the state is normalized, as shown in (12).

$$|\psi'\rangle = \frac{M_m|\psi\rangle}{\sqrt{\langle\psi|M_m^\dagger M_m|\psi\rangle}} \tag{12}$$

Here, M_m represents a measurement operator applied to the quantum state $|\psi\rangle$. The operator $M_m^\dagger$ is the adjoint (Hermitian conjugate) of the measurement operator M_m, and it ensures the measurement process is consistent with the principles of quantum mechanics. The key measurement operators used in this process are typically $M_0 = |0\rangle\langle 0|$ and $M_1 = |1\rangle\langle 1|$, which project the quantum superposition state onto the basis states $|0\rangle$ and $|1\rangle$, corresponding to classical bit values.

As an example, consider the M_0 operator, which projects a superposition state onto the $|0\rangle$ state. This process is illustrated in the following steps from (13) to (14).

$$|\psi'\rangle = \frac{|0\rangle\langle 0|\left(\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle\right)}{\sqrt{\left(\frac{1}{\sqrt{2}}\langle 0| + \frac{1}{\sqrt{2}}\langle 1|\right)(|0\rangle\langle 0|)\left(\frac{1}{\sqrt{2}}|0\rangle + \frac{1}{\sqrt{2}}|1\rangle\right)}} \tag{13}$$

$$= |0\rangle \tag{14}$$

From this, it is evident that applying the M_0 operator collapses the superposition state to $|0\rangle$, which corresponds to the classical bit 0. However, the M_0 operator alone is insufficient to differentiate between received qubit states, as it lacks sensitivity to the phase information inherent in the superposition. Conversely, the M_1 operator performs a projection onto the $|1\rangle$ state. This not only allows the state to collapse to the classical bit 1 but also enables the extraction of critical phase information. The phase information embedded in the superposition states is instrumental in distinguishing between different received qubit states, making M_1 essential for accurate decoding in scenarios where phase plays a role in encoding information. The ability to decode phase-dependent information ensures that the quantum decoder can accurately reconstruct transmitted classical data, even in complex or noisy transmission scenarios.

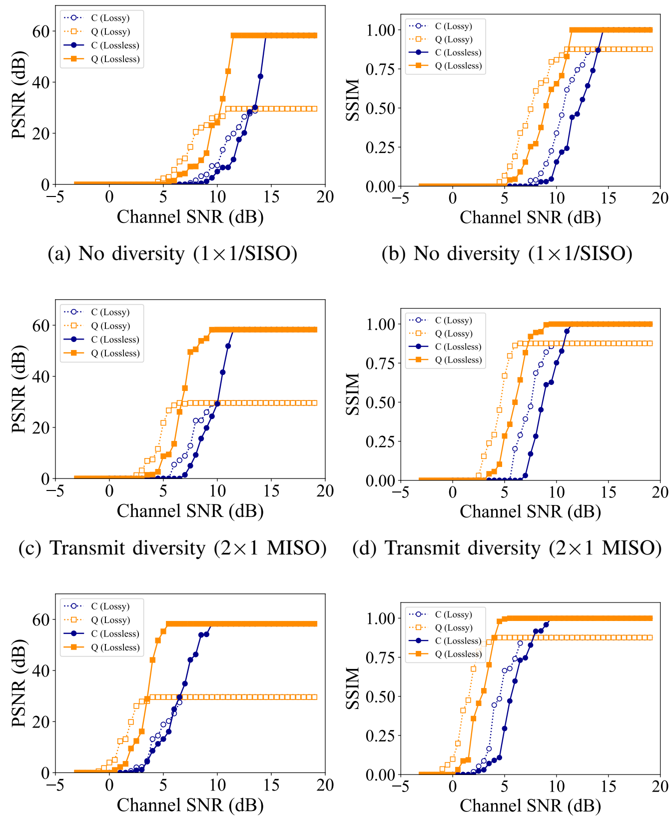
After quantum decoding, the output bitstreams undergo polar decoding to recover the original data. The polar decoder corrects transmission errors and determines the most likely transmitted bit sequence, ensuring reliable data recovery. Once the bitstreams are channel decoded, the final step involves reconstructing the original image. The appropriate source decoder, either JPEG or HEIF, is used depending on the encoding format of the images. This source decoder reverses the compression process, converting the decoded bitstreams back into the reconstructed image, which is then available for display or further processing.

To evaluate the diversity gains of MIMO schemes in the proposed quantum communication system, we compare it with a classical MIMO system employing complex baseband binary phase shift keying (BPSK) modulation and rate 1/2 polar codes, ensuring similar bandwidth utilization in both cases. In classical communication, BPSK represents bit 0 with $(1 + 0i)$ and bit 1 with $(-1 + 0i)$, while in quantum communication, the Hadamard and phase gates generate states such as $\frac{1}{\sqrt{2}}(|0\rangle + |1\rangle i)$ for bit 0 and $\frac{1}{\sqrt{2}}(|0\rangle - |1\rangle i)$ for bit 1. Simulations are performed for the proposed system over an SNR range of -3 dB to 19 dB in a low-mobility urban environment. The evaluation considers multipath fading, dynamic interference, and specific channel parameters. The system operates with a sample rate of 1000 Hz. The path delays are set to $(0, 3\times10^{-6}, 8\times10^{-6}, 20\times10^{-6})$ seconds, while the average path gains are $(0, -3, -6, -9)$ dB. Additionally, a maximum Doppler shift of 10 Hz is considered. This system can process and transmit any image, including high-resolution images, ensuring accurate reconstruction. Performance is evaluated using 20 images with varying spatial information content, and the results are averaged for comparison. Image quality is assessed using PSNR, SSIM, and bit error rate (BER) variation, which are standard metrics for objective image quality evaluation.

IV. Results and Discussion

This study analyzes the performance of a superposition based quantum communication for image transmission system with 1×1 SISO, 2×1 MISO, and 1×2 SIMO schemes and compares it with an equivalent classical communication based image transmission system. Fig. 3 illustrates how the PSNR and SSIM of the decoded images vary with different channel SNR for JPEG images with lossy compression (quantization parameter (QP) = 25) and near lossless compression (QP = 100) for the three MIMO diversity scenarios. The results show that the quantum communications based system (Q) is able to reconstruct images with significantly higher PSNR and SSIM metrics compared to the classical communications based system (C), especially under low channel SNR across all three diversity schemes. It should also be noted that 2×1 MISO incurs a 3 dB disadvantage compared to 1×2 SIMO in both quantum and classical scenarios. This is due to setting the experiments so that the total transmitted power is identical in all schemes.

As proven by the results of PSNR and SSIM, decoded JPEG images (with lossy compression) for the quantum and classical communication systems when the channel SNR is 10 dB under the 1×1 SISO diversity scheme and when the channel SNR is 7 dB under the 2×1 MISO and 1×2 SIMO schemes are shown in Fig. 4, which clearly demonstrates that the proposed quantum communication based system enables better quality image reconstructions at the receiver compared to the classical communication. The improved performance at a lower SNR level of 7 dB under the 2×1 MISO and 1×2 SIMO diversity schemes demonstrates that quantum communication with transmit and receive diversity provides enhanced robustness to noise. This results in superior image quality, even in challenging network conditions, making it ideal for consumer technology applications that require reliable, high-quality media transmission. This advantage is particularly noticeable when compared to the 1×1 SISO scheme, which operates without diversity, where the decoded image quality at 10 dB SNR is comparable to the decoded image quality under the diversity schemes at 7 dB SNR.



(a) No diversity (1×1/SISO) (b) No diversity (1×1/SISO)
(c) Transmit diversity (2×1 MISO) (d) Transmit diversity (2×1 MISO)
(e) Receive diversity (1×2 SIMO) (f) Receive diversity (1×2 SIMO)

Fig. 3. Comparison of average PSNR (left) and average SSIM (right) for classical (C) and quantum (Q) systems under: (a), (b) 1×1 SISO, (c), (d) 2×1 MISO and (e), (f) 1×2 SIMO diversity schemes with lossy (QP = 25) and lossless (QP = 100) JPEG source encoded images.

The performance analysis of quantum and classical communication systems with lossy (QP = 25) and near-lossless (QP = 100) HEIF source-coded images under the same diversity schemes, shown in Fig. 5. The results align with those obtained for JPEG source coding, with the quantum communication (Q) based MIMO system consistently outperforming the classical system (C) in terms of both PSNR and SSIM for a given channel SNR level. This superior performance is due to the inherent noise resilience and error-correction capabilities of quantum communication, which allows for more accurate image reconstruction even in challenging conditions. Furthermore, HEIF encoding achieves higher PSNR and SSIM values compared to JPEG due to its more efficient compression techniques, resulting in better preservation of image quality and fewer compression artifacts. This demonstrates that while quantum communication systems enhance performance regardless of the source coding method, HEIF's advanced compression provides additional benefits by further improving image quality compared to JPEG, similar to trends observed in classical communication systems.

Additionally, BER variation for quantum (Q) and classical

(a) Classical (1×1 SISO)

(b) Quantum (1×1 SISO)

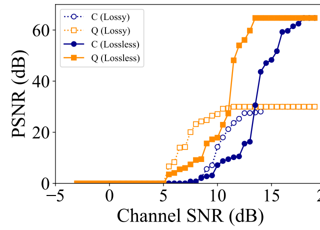
(c) Classical (2×1 MISO)

(d) Quantum (2×1 MISO)

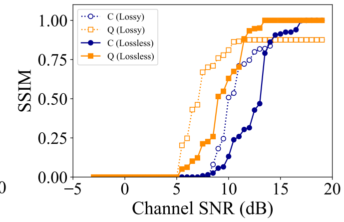
(e) Classical (1×2 SIMO)

(f) Quantum (1×2 SIMO)

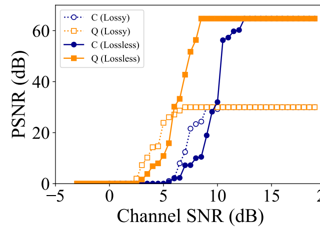
Fig. 4. Examples of received (lossy) JPEG encoded images for classical and quantum systems under each scheme. (a), (b): 1×1 SISO with channel SNR of 10 dB; (c), (d): 2×1 MISO with channel SNR of 7 dB; (e),(f): 1×2 SIMO with channel SNR of 7 dB.



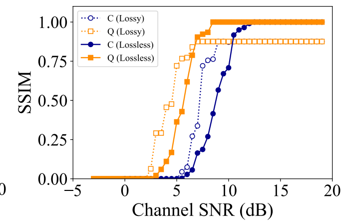
(a) No diversity (1×1/SISO)



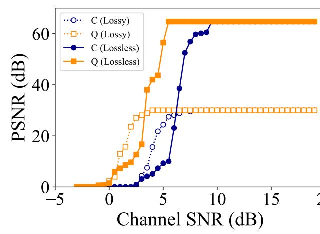
(b) No diversity (1×1/SISO)



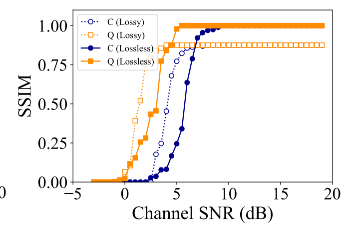
(c) Transmit diversity (2×1 MISO)



(d) Transmit diversity (2×1 MISO)



(e) Receive diversity (1×2 SIMO)



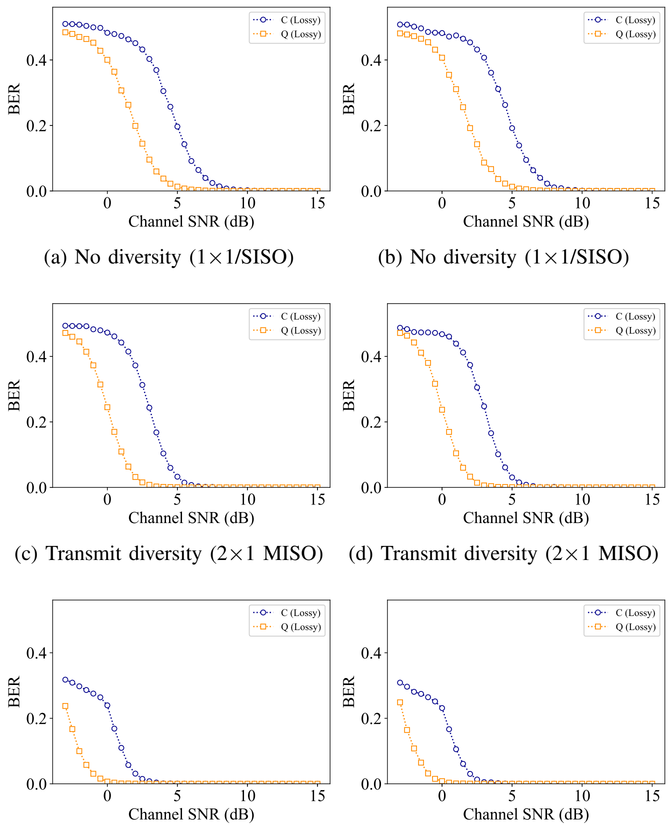
(f) Receive diversity (1×2 SIMO)

Fig. 5. Comparison of average PSNR (left) and average SSIM (right) for classical (C) and quantum (Q) systems under: (a), (b) 1×1 SISO, (c), (d) 2×1 MISO and (e), (f) 1×2 SIMO diversity schemes with lossy (QP = 25) and lossless (QP = 100) HEIF source encoded images.

(C) communication systems in JPEG and HEIF lossy formats provides an additional quality measurement of the proposed system as in Fig 6. This study demonstrates the superiority of quantum communication based image transmission systems over classical systems under transmit and receive diversity schemes (2×1 MISO and 1×2 SIMO). The quantum system achieves higher image quality through better noise resilience and error correction while maintaining low complexity and latency. Also, the system mitigates decoherence through single-qubit encoding to avoid fragile entangled states, classical polar codes for error correction, MIMO diversity to improve reliability, and low qubit dimensionality to reduce cumulative noise during transmission. The reason for using 2×2 MIMO system is that this is a testing setup, and low complexity is preferred over high-complexity systems. Although higher MIMO configurations could further enhance performance, they would increase system complexity. These findings hold great potential for consumer technology applications, including high-fidelity multimedia streaming, remote collaboration, and next-generation AR/VR experiences. Additionally, quantum communication provides secure and efficient solutions for industries like telemedicine and financial services, ensuring reliable and confidential data exchange. The system's strong noise resilience also supports stable live video broadcasting in challenging network conditions, enabling seamless, high-definition experiences for consumers.

Furthermore, we evaluate the performance of higher-order diversity schemes, including 4×1 and 2×2 schemes to evaluate performance, as shown in Fig. 7. The results demonstrate that increasing the diversity order enhances overall system performance but with increased complexity. Despite the system's promising scalability for higher order implementations and resilience to noise and fading, several practical challenges must be addressed, such as quantum hardware constraints, imperfect channel estimation, and increased decoherence, for successful deployment in larger network scenarios.

In this study, quantum superposition offers significant advantages for image transmission in MIMO communication systems, especially when employing low-complexity single-qubit encoding and decoding methods with classical error correction. This approach avoids quantum error correction codes, which would add unnecessary complexity to the system. Therefore, further development of optimized quantum error correction codes are needed. Additionally, multi-qubit encoding could enhance the quantum system's performance, although it introduces added complexity with an increased number of quantum gates. In conclusion, this study presents a quantum MIMO system that can reduce the need for computational and energy resources compared to classical communication systems, while also leveraging the inherent advantages of quantum hardware.

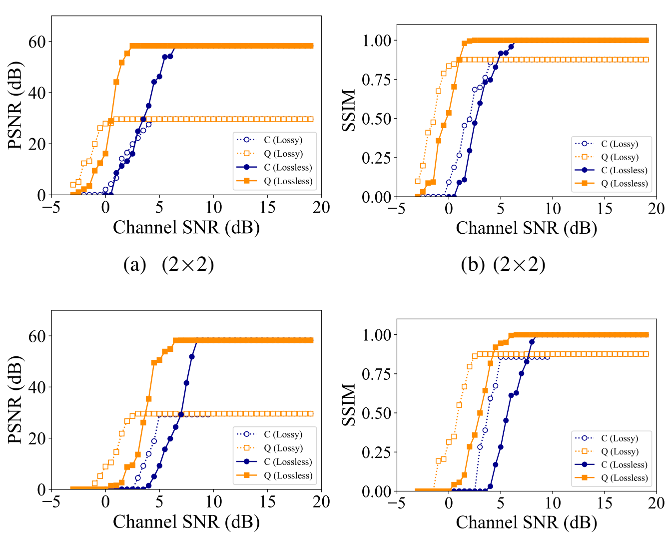


(a) No diversity (1×1/SISO) (b) No diversity (1×1/SISO)

(c) Transmit diversity (2×1 MISO) (d) Transmit diversity (2×1 MISO)

(e) Receive diversity (1×2 SIMO) (f) Receive diversity (1×2 SIMO)

Fig. 6. BER variation for JPEG format (left) and HEIF format (right) for classical (C) and quantum (Q) systems under: (a), (b) 1×1 SISO, (c), (d) 2×1 MISO and (e), (f) 1×2 SIMO diversity schemes with lossy (QP = 25) images.



(a) (2×2) (b) (2×2)

(c) (4×1) (d) (4×1)

Fig. 7. Comparison of average PSNR (left) and average SSIM (right) for classical (C) and quantum (Q) systems under: (a), (b) 2×2, (c), (d) 4×1 schemes with lossy (QP = 25) and lossless (QP = 100) JPEG source encoded images.

Although quantum MIMO hardware remains in its early stages of development, the simulation results presented in this study highlight the promising potential of quantum communication. These findings offer crucial theoretical validation and lay a strong foundation for future real-world implementation.

Future research should focus on low-complexity error correction and the integration of advanced quantum MIMO systems to further combat decoherence and transmission errors. Incorporating hybrid quantum-classical architectures, multi-qubit encoding, and adaptive methods like machine learning-based CSI prediction can significantly enhance performance and reliability in quantum communications.

V. Conclusions

This study highlights the superiority of quantum communication over all diversity systems, including no diversity (1 × 1 SISO), transmit diversity (2 × 1 MISO), and receive diversity (1 × 2 SIMO) in terms of image transmission quality. Notably, the transmit diversity (2 × 1 MISO) and receive diversity (1 × 2 SIMO) schemes demonstrate enhanced resilience to channel fading, offering more reliable and consistent performance under challenging channel conditions. Specifically, the quantum approach yields PSNR values of up to 58.27 dB for JPEG and 64.72 dB for HEIF and SSIM values of up to 0.9994 for JPEG and 0.9999 for HEIF, across various SNR levels and image quantization parameters (Q25 and Q100). Furthermore, HEIF image transmission consistently outperforms JPEG when using quantum communication based MIMO systems, underscoring the versatility and effectiveness of the quantum approach across different compression formats. These findings highlight the transformative potential of integrating MIMO diversity schemes with quantum communication, particularly for mitigating channel fading and enhancing media transmission fidelity. While this study presents a foundational quantum communication system with basic MIMO integration and demonstrates its potential through simulation, future work should focus on incorporating low-complexity error correction, advanced quantum MIMO architectures, and performance enhancement techniques to enable practical deployment.

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