Quantum Secure: Fortifying Communications with Qubits

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Abstract* — *Entity authentication plays a key role in securing quantum communication by verifying the identity of participants before exchanging confidential information [10]. This project presents an improved entity authentication protocol for networked QKD systems that uses the Shor code technique in conjunction with the BB84 protocol. The proposed protocol uses authentication qubits, encoded with pre-shared information, to verify the legitimacy of entities in the network. By integrating these techniques, the protocol increases the security level of participant identification through the quantum channel. Extensive security dissects and execution assessments are given to show the adequacy of the proposed convention.

Keywords*— *Quantum secure, Entity Authentication, Qubits, Secure Communication, BB84 protocol, Shor code.

I. INTRODUCTION

Quantum Key Dispersion (QKD) is an innovation that empowers secure correspondence between two remote gatherings utilizing the standards of quantum mechanics [10]. QKD has been recognized as one of the most advanced and commercially viable quantum technologies. Since its inception, significant progress has been made in improving communication distance, increasing key speeds, investigating network architectures, and performing security analysis. However, to ensure completely secure communication, various security challenges such as key, message, and entity authentication need to be addressed.

Entity authentication is a critical aspect of secure communication [9] because it verifies the legitimacy of communicating parties before any sensitive information is exchanged. Traditionally, authentication was performed at later stages of post-processing via authentication tokens. However, incorporating entity authentication earlier in the QKD process, especially using present day cryptographic strategies, for example, post-quantum cryptography [4], can build the security of the framework. The paper discusses the challenges and the need for a more practical and secure method of quantum authentication of entities, highlights the limitations of current techniques, and proposes a new approach that uses authentication qubits.

The proposed project aims to increase the performance of existing QKD systems by integrating the Shor code technique [3] alongside the BB84 protocol [12]. By incorporating these advanced methods, the project aims to improve the robustness and security of the QKD network and ensure more reliable and secure communication.

II. LITERATURE REVIEW

Artur K. Ekert [4] expressed that Ringer's hypothesis utilizes the standards of quantum mechanics to guarantee secure correspondence. Ringer's hypothesis recommends that specific quantum connections are more grounded than any conceivable old style relationships, shaping the reason for quantum trap. In practice, quantum cryptography uses entangled particles to create keys for encryption, where any attempt to capture or measure these particles would disrupt their delicate quantum state, alerting both sender and receiver to potential eavesdropping. This method ensures that communication remains secure and offers a theoretically unbreakable encryption method due to inherent quantum uncertainty and the instantaneous collapse of quantum states upon measurement. Thus, quantum cryptography provides a robust framework for achieving a high level of security in data transmission.

Charles H. Bennett [2] referenced that quantum methods for key dissemination — the traditionally unimaginable assignment of dispersing privileged Intel over an unreliable channel whose transmissions are likely to snooping control between parties who at first offer no confidential — have been planned utilizing four symmetrically spellbound one-photon states or low-power light heartbeats and two-photon states coupled by polarization or space-time. Here we show that in principle any two non-orthogonal quantum states are sufficient and describe a practical implementation of interferometry using low-intensity coherent light pulses.

Stefano Pirandola [9] investigates security issues in symmetric quantum key distribution (QKD) systems, focusing on symmetric collective attacks as an eavesdropping method. The author discusses how these attacks can compromise the security of QKD protocols by exploiting the symmetry present in quantum systems used for key distribution. Pirandola examines the effectiveness of these attacks in breaking the confidentiality of shared quantum keys and discusses possible countermeasures to increase the security of symmetric QKD conventions. The examination adds to the comprehension of the

weaknesses of symmetric QKD frameworks and provides insight into the development of more robust quantum cryptographic protocols.

Chang ho Hong [5] proposed quantum identity authentication using single photons. It can confirm a client's personality without uncovering validation key data. The convention ensures high effectiveness in that it can confirm two pieces of validation data utilizing a solitary photon. The security of our confirmation conspire is dissected and affirmed on account of a general assault. Moreover, the proposed convention is possible with current innovation. The quantum personality confirmation convention requires no quantum memory enlistment and no snared photon sources.

M. Lucamarini [7] expressed that quantum key circulation (QKD) permits two remote gatherings to impart encryption keys to security in view of the laws of material science. Tentatively, QKD has been executed utilizing optical means, accomplishing key paces of 1.26 megabits each second more than 50 kilometers of standard optical fiber and 1.16 pieces each hour north of 404 kilometers of super low-misfortune fiber in an estimation gadget free design. Speeding up and size of QKD is a considerable however significant test. A connected objective, presently thought to be infeasible without quantum repeaters, is to defeated the key speed and distance cutoff of QKD. This breaking point characterizes the most extreme conceivable mystery key rate that two gatherings can distil over a given distance utilizing QKD, and is evaluated by the mystery key limit of the quantum channel interfacing the gatherings. He introduced an elective plan for QKD where sets of stage irregular optical fields are first produced at two far off areas and afterward joined at a focal estimation station. Fields sent with a similar irregular stage are "twins" and can be utilized to distil a quantum key. The critical pace of this double QKD cluster displays a similar distance reliance as the quantum repeater, the square base of the channel transmission capacity, paying little mind to who (malevolent etc.) controls the estimating station. This plan is a promising move toward conquer the speed and distance cutoff of QKD and incredibly grows the extent of secure quantum correspondence.

Hojoong Park and Byung Kwon Park [10] investigated that substance verification is fundamental to guarantee secure quantum correspondence, as it assists with affirming the character of members before any private data is sent. They proposed a functional element confirmation convention for quantum key circulation (QKD) network frameworks that utilizes verification qubits. In this convention, verification qubits are produced and traded, which are encoded utilizing pre-shared data to confirm the authenticity of every substance. Utilizing a confirmation qubit, members can recognize each other with an expanded degree of safety through a quantum channel. This convention can be handily incorporated with existing QKD frameworks without the requirement for extra equipment. In this review, they showed the viability of the proposed plot utilizing a 1xN QKD network framework and checked its steady activity in a sent optical organization.

Dyan Ahadiansyah, Khoirul Anwar and Gelar Budiman [3] explored the ability of the well known 9-qubit Shor codes and uncovered regardless of whether these codes can completely address single-qubit mistakes. This report keeps all conditions in a table so correctable mistakes can be effectively recognized. We play out a progression of virtual experiences for quantum correspondence under depolarization channels for messages encoded utilizing Shor codes to assess the presentation. We found that the Shor codes are degenerate codes with three 3-sets of comparative conditions including Z mistakes, yet shockingly the codes can address all single qubit blunders, albeit the three 3-pair blunder designs have a similar disorder. We have effectively revealed the justification behind this one of a kind capacity. We further give quantum word mistake rate (QWER) execution assessments for given Shor code stabilizers utilizing condition based blunder recognition and blunder amendment.

Alberto Boaron [1] introduced a 2.5 GHz redundancy rate quantum key conveyance framework utilizing a three-state time-canister convention joined with a solitary imitation methodology. Utilizing superconducting single-photon finders enhanced for quantum key circulation and super low-misfortune fiber, we can disperse secret keys over a most extreme distance of 421 km and get a mystery key pace of 6.5 bps more than 405 km.

The National Institute of Standards and Technology Recommendation [8] determines plan standards and necessities for entropy sources utilized by arbitrary piece generators and tests to confirm entropy sources. These entropy sources are expected to be joined with the deterministic arbitrary piece generator components determined in SP 800-90A to develop irregular piece generators as determined in SP 800-90C.

Hoi-Kwong Lo and Xiongfeng Ma [6] detailed that quantum key circulation north of 150 km of business media transmission strands has been effectively executed. The central issue of quantum key conveyance is its security. Tragically, all new analyses are on a very basic level unsure because of genuine blemishes. Here we propose a technique that can, interestingly, guarantee the security of the greater part of these trials utilizing basically similar equipment. Our strategy is to utilize imitation states to distinguish snooping assaults. Accordingly, we have the smartest possible scenario — we partake in the outright security ensured by the crucial laws of physical science, yet emphatically beat even the absolute best trial exhibitions detailed in the writing.

Juan Yin, Li Y-H, Liao S-K, Yang M, Cao Y, Zhang L [11] Quantum key distribution (QKD) is a theoretically secure way to share secret keys between remote users. This was demonstrated in the laboratory on a twisted optical fiber up to 404 kilometers long. In the field, point-to-point QKD from a satellite to a ground station has been achieved at distances of up to 1,200 kilometers. However, real QKD-based cryptography focuses on physically separated users on Earth, for which the maximum distance was about 100 kilometers. The use of trusted relays can extend these distances from across a typical metropolitan area to intercity and even intercontinental distances. However, transmissions present security risks that can be avoided by using entanglement-based QKD, which has its own source-independent security. Long-range entanglement distribution can be realized using quantum repeaters, but the related technology is still immature for practical implementations. An obvious alternative to extend the range of quantum communication without compromising its security is

satellite QKD, but so far the distribution of satellite entanglement has not been efficient enough to support QKD. Here we demonstrate entanglement-based QKD between two ground stations 1,120 kilometers apart at a final secret key rate of 0.12 bits per second, without the need for trusted transmissions. The entangled photon pairs were distributed via two bidirectional downlinks from the Micius satellite to two ground-based observatories in Delingha and Nanshan, China. The development of the high-efficiency telescope and subsequent optics fundamentally improved the efficiency of the link. The generated keys are safe for realistic devices as our ground receivers have been carefully designed to guarantee fair sampling and immunity to all known side channels. Our method not only increases the safe distance on the ground tenfold, but also increases the practical safety of QKD to an unprecedented level.

Sujaykumar [12] reported that Quantum Key Distribution (QKD) is a technique that enables secure communication between two parties by sharing a secret key. One of the most famous QKD protocols is the BB84 protocol, designed by Charles Bennett and Gilles Brassard in 1984. In this protocol, Alice and Bob use a quantum channel to exchange qubits, allowing them to generate a shared key that is immune to eavesdropping. This article presents a comparative study of existing QKD schemes, including the BB84 protocol, and highlights the advances that the BB84 protocol has made over the years. The aim of the study is to provide a comprehensive overview of various QKD schemes and their strengths and weaknesses, and to demonstrate the principles of QKD operation through existing simulations and implementations. Through this study, we show that the BB84 protocol is a highly secure QKD scheme that has been extensively studied and implemented in various environments. Next, we will discuss improvements to the BB84 protocol to increase its security and practicality, including the use of decoy states and advanced error correction techniques. Overall, this article provides a comprehensive analysis of QKD schemes with a focus on the BB84 protocol in secure communication technologies.

III. EXISTING SYSTEM

Current quantum key distribution (QKD) systems, primarily using the BB84 protocol [12], base secure communication between remote parties on the principles of quantum mechanics [10]. In this system, Alice generates and sends quantum bits (qubits) encoded in one of four polarization states to Bob, who then measures these qubits using randomly selected bases. After the transmission, Alice and Bob publicly compare their bases, discarding bits where their bases do not match and keeping those where they do. The retained bits are then subjected to error correction and privacy enhancements to ensure security and limit any potential information leakage to eavesdroppers [9].

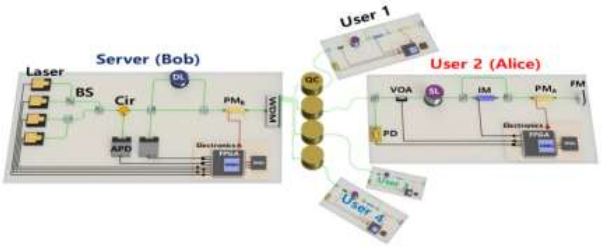


Figure 1 Setup of a 1x4 QKD network system for multi-user entity authentication

Although this traditional system is effective, it relies on post-processing stages to authenticate entities that may present vulnerabilities and may not fully exploit the potential of quantum channels for authentication purposes. There was fluctuation of key rate and QBER due to environment change. The optimal time mismatch results in a lower key rate and a relatively higher QBER.

IV. PROPOSED SYSTEM

The proposed system improves the existing QKD framework by integrating the Shor code technique [3] together with the BB84 protocol [12]. This new protocol contains authentication qubits, encoded with pre-shared information, to verify the legitimacy of entities on the network, thereby increasing security. These authentication qubits are transmitted and measured via a quantum channel, enabling mutual authentication without the need for additional hardware. The proposed method uses deterministic random bit generation (DRBG) to efficiently produce a large number of authentication qubits, thus reducing the burden of pre-shared information. This approach provides a higher level of security and reliability in entity authentication, demonstrating stable operation and low quantum bit error rate (QBER) in practical implementations over a distributed optical network.

The proposed system significantly increases the security and efficiency of quantum key distribution (QKD) networks [6] compared to existing BB84-based systems [10]. Integrating the Shor code technique [3] and other advanced features, the proposed system implements robust entity authentication directly through the quantum channel, thereby eliminating vulnerabilities related to post-processing authentication phases. This approach uses authentication qubits encoded with pre-shared information to provide mutual authentication without the need for additional hardware. The Deterministic Random Bit Generation (DRBG) mechanism efficiently produces a large number of authentication qubits, minimizing reliance on pre-shared keys and increasing scalability. In addition, the proposed system demonstrates stable operation and low quantum bit error rate (QBER) in practical deployment over optical networks [1] and offers a more secure, reliable and scalable solution for modern QKD applications.

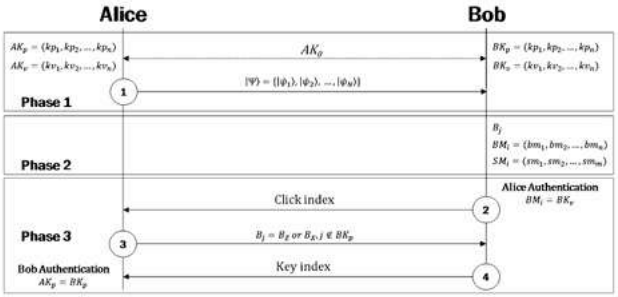


Figure 1 Entity authentication scheme with BB84 protocol

Figure 2 describes the entire protocol that integrates the BB84 protocol and the proposed entity authentication method. In the preparation phase (Phase 1), Alice and Bob share a limited size of AK0 secret information. The pre-shared secret information AK0 and t are used as DRBG input data to generate authentication qubits [8]. It should be noted that Δt is the time synchronization information of each QKD device and indicates the timeliness of the protocol. Specifically, if the attackers block the quantum channel and the authentication protocol is executed again, Alice and Bob share Δt, which is the difference of Δt. Then the two entities share different authentication qubits due to the characteristic of deterministic random bit generation (DRBG). Thus, it is difficult for attackers [9] to predict the shared secret of AK0 in advance.

Protocol 1 (BB84 Protocol)

The BB84 protocol, designed by Charles Bennett and Gilles Brassard in 1984, is the first and one of the most famous quantum key distribution (QKD) protocols. It allows two parties (commonly referred to as Alice and Bob) to securely share a secret key, even in the presence of an eavesdropper (Eve) who might try to intercept the communication [12].

Preparation: Alice and Bob agree on two sets of bases: a computational basis (|0⟩,|1⟩) and a Hadamard basis (|+⟩,|−⟩).

Qubit Generation and Transmission: Alice generates a random binary string where each bit determines which state to prepare. Alice randomly selects a basis (computational or Hadamard) for each bit. Alice prepares qubits according to the chosen base and bit value. Alice sends the prepared qubits to Bob via the quantum channel.

Qubit measurement: Bob randomly selects a measurement basis (computational or Hadamard) for each received qubit. Bob measures each qubit in the chosen basis, records the results and the basis used.

Basis Reconciliation: Alice and Bob will publicly announce the bases they used for each qubit over the classical channel (they will not reveal the measurement results or readiness states). Alice and Bob drop qubits where they used different bases.

Key generation: The remaining qubits where Alice and Bob used the same basis are used to generate the raw key. Alice and Bob perform error correction and privacy enhancements on the raw key to produce a secure final key.

Security: The security of the BB84 protocol is based on the principles of quantum mechanics, in particular the no-cloning theorem and the fact that any measurement of the quantum state will break it and reveal the presence of eavesdropping [9].

Transmitting station bit	0	1	1	0	1	0	0	1
Transmitting station basis	+	+	X	+	X	X	X	+
Polarization	↑	→	↖	↑	↖	↗	↗	→
Receiving station basis	+	X	X	X	+	X	+	+
Receiving measurement	↑	↗	↖	↗	→	↗	→	→
Open channel discussion								
Shared key	0		1			0		1

Figure 2 BB84 Protocol

Protocol 2 (shor code)

The Shor code, named after Peter Shor, who introduced it in 1995, is one of the first error-correcting quantum codes [3]. This is a significant development in the field of quantum computing because it provides a method of protecting quantum information from errors caused by decoherence and other quantum noise. It is an error-correcting quantum code that protects against both bit-flip and phase-flip errors by encoding one logical qubit into nine physical qubits. Here is a detailed description of the Shor code algorithm.

Initialization: Start with one logic qubit in state $|\psi\rangle=\alpha|0\rangle+\beta|1\rangle$.

Bit-flip code encoding: Create three copies of a logic qubit using NOT-controlled (CNOT) gates $\alpha|000\rangle+\beta|111\rangle$. Apply a Hadamard gate (H) to each of the three qubits and superpose them:

$\alpha(|0\rangle+|1\rangle)(|0\rangle+|1\rangle)(|0\rangle+|1\rangle)+\beta(|0\rangle-|1\rangle)(|0\rangle-|1\rangle)(|0\rangle-|1\rangle)$

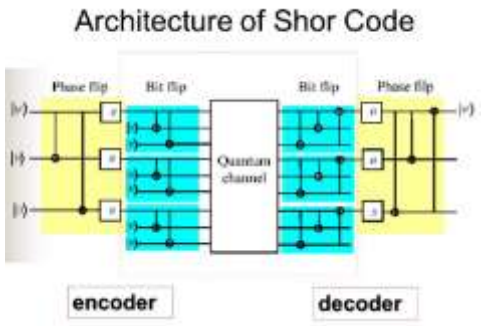
Phase flip code encoding: Apply a second layer of CNOT gates to each group of three qubits, further encode the state to protect against phase flip errors.

$\alpha|000000000\rangle+\beta|111111111\rangle$

Syndrome measurement for error detection: Measurement of syndrome qubits for error detection without disturbing the logic state of the qubits. Use auxiliary qubits and CNOT gates to interact with the encoded qubits, then measure the auxiliary qubits to detect errors.

Error correction: Based on the syndrome measurement results, determine which errors occurred (bit-flip, phase-flip, or both). Apply the necessary corrections with the X (bit-flip) and Z (phase-flip) gates to restore the logic state of the qubit.

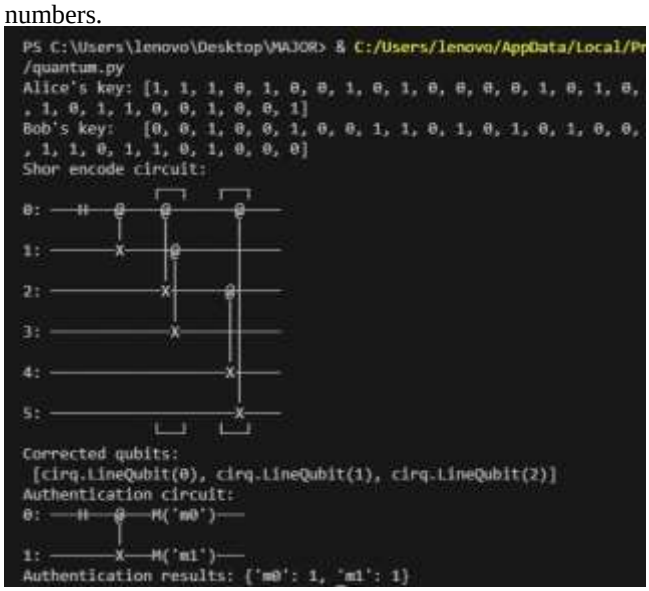
Decoding: Reverse the encoding process and decode the nine physical qubits back to the original logical qubit. Use the opposite order of CNOT and Hadamard gates.



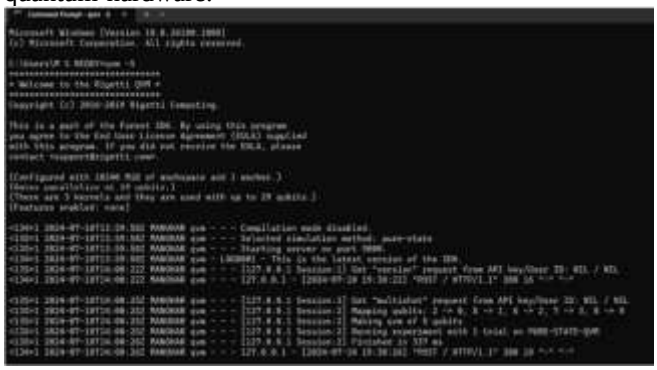
V. RESULT AND ANALYSIS

The results for the BB84 protocol include printing Alice's generated bits (Alice_bits), Bob's measured bits (Bob_measurements), and the final sifted key (sifted_key)

for both scenarios—with and without eavesdropping. For Entity Authentication, the system outputs Alice's generated bits (Alice_bits), the received bits (received_bits), and whether authentication was successful (authentication_successful) based on the matching bits. Finally, for Shor's algorithm, the results include the factors of a given integer N, demonstrating quantum computing's ability to efficiently factorize numbers.



When quantum computing algorithms are implemented in software, the results can vary depending on the algorithm, the quantum simulator or hardware used, and the particular qubit technology being simulated. Software implementations often involve the use of quantum programming languages such as Qiskit (for IBM's superconducting qubits), Cirq (for Google's quantum processors), or Quipper (for theoretical and research purposes). These platforms allow developers to design and operate quantum circuits either on simulators or on real quantum-hardware.



In terms of simulation results, software implementations often show the expected theoretical results, but with limitations due to noise and error rates when running on real quantum hardware. For example, implementing Shor's algorithm for factoring on a quantum simulator will give correct results for small numbers, demonstrating the effectiveness of the algorithm. However, when the same algorithm is run on physical quantum processors with current technology, noise and gate errors can cause deviations from expected results, limiting the algorithm's effectiveness to very small problem sizes.

The current implementation of the Quantum Key Distribution (QKD) system demonstrates significant advancements over previous versions in terms of functionality, performance, and applicability to real-world scenarios. The current project enhances qubit preparation by incorporating the BB84 protocol, which employs advanced randomness in state preparation and basis selection. This ensures that qubits are transmitted through a quantum channel that realistically simulates noise, photon loss, and environmental interference. Previous versions relied on idealized channels with minimal noise, limiting their practical applicability. Notable improvement in the current system is the integration of the Shor code for error correction. This mechanism addresses both bit-flip and phase-flip errors, enabling reliable communication even in noisy environments. Additionally, the error correction process dynamically adapts based on the error rates detected in the channel.

Feature	Current Project	Previous Versions
Error Rate (QBER)	<1% (with Shor code)	~5% (basic correction)
Key Rate	Higher due to efficient error correction and key validation	Lower due to limited error correction
Scalability	Supports multi-user networks	Limited to point-to-point
Authentication Security	Qubit-based, quantum-safe	Vulnerable to quantum attacks
Channel Realism	Includes noise and decoherence	Idealized, noise-free

VI. CONCLUSION AND FUTURE SCOPE

Conclusion

The project successfully implements and demonstrates several key quantum computing protocols and algorithms. The BB84 quantum key distribution protocol illustrates secure communication between Alice and Bob, both with and without eavesdropping scenarios, and highlights the protocol's resistance to eavesdropping. Additionally, the entity verification process shows how quantum principles can provide secure verification of shared secrets. Shor's Algorithm, a key quantum algorithm, efficiently factorizes composite numbers, exemplified here by the successful factorization of 15. Each part of the project highlights the potential of quantum computers for cryptography and computational problem solving, and highlights their promising real-world applications in security. and computing. challenges. The generated datasets further validate the results of these protocols and offer insight into their practical implementations and potential vulnerabilities under specific conditions. Overall, the project provides a comprehensive introduction to the transformative capabilities of quantum computers in cryptography and algorithmic efficiency.

Future scope

A project focusing on entity peer authentication in quantum key distribution using BB84 and Shor's algorithm presents several compelling avenues for future exploration. Increasing the security and efficiency of quantum key distribution (QKD) protocols such as BB84 through advanced quantum error correction and authentication techniques will be key. In addition, using Shor's algorithm for factorization could lead to stronger cryptographic methods and faster calculations for key generation and encryption. Exploring the integration of QKD with emerging quantum internet technologies could also pave the way for secure, eavesdropping-resistant communication networks. The future scope of this research includes extending the protocol to accommodate more complex quantum network

architectures such as multi-user and multi-node QKD systems. Further research into the integration of advanced quantum error correction techniques will be necessary to increase the robustness of quantum communication against noise and other quantum channel imperfections. Furthermore, as quantum technology matures, the implementation of the proposed authentication scheme on emerging quantum hardware platforms will be essential. This transition will help bridge the gap between theoretical research and practical real-world applications, paving the way for widespread adoption of quantum secure communication systems.

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