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Exploration of the Practical Development of Quantum Communication

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Abstract: *With the development of technology, quantum technology with enormous military value has become a key technology related to national information security in the application and development of communication systems. The application of quantum communication technology in military and civilian research is of great significance for China's future information network construction, as well as the safety of people's lives and property. One need to increase investment in technology, increase investment in technology, and establish a sound policy system and institutional mechanisms. Only by increasing the promotion of this project can one further promote the development of military civilian integration of quantum communication technology in China and gradually establish a strong quantum communication information network. This article introduced the principles and development of quantum communication, and verified through simulation experiments that quantum technology communication has a lower bit error rate and better performance compared to traditional communication systems.*

Keywords: *Quantum Communication, Practicality, Quantum Cryptography, Future Development*

1. Introduction

Quantum communication is a new communication method based on quantum entanglement, characterized by high efficiency and high security. The most exciting feature of this communication technology is its "never leak" function, which uses special password technology, making the key neither replicable nor stolen. If stolen, the entire communication would automatically "self-destruct" and notify the user.

A large number of scholars have conducted relevant research on quantum technology. Rivero-Angeles M E believed that significant progress has been made in research in fields such as quantum computing, quantum algorithms, and quantum networks. However, there is still little research on the application of quantum technology to WSN (wireless sensor network). On the one hand, this is due to the large, expensive, and high energy consuming equipment required by existing quantum computers. On the other hand, wireless sensor networks require small nodes, low prices, and extremely low energy consumption. In the next decade, quantum computing is expected to become a miniaturized and commercialized quantum computing, laying the foundation for its application in sensor networks [1]. Koziy A A studied several important single photon detection technologies represented by quantum key distribution. The two most promising types of single photon detectors have been proposed in experiments. The most efficient SPD (Supplier Performance Development) scheme was proposed, and their advantages and disadvantages were analyzed based on their potential application in quantum key distribution devices. This makes it possible for research to track the global technological development trends of the industry over the past five years [2]. Manzalini A proposed that in recent years, with the widespread application of ultra wideband and low latency network technologies such as 5G, many industries have achieved digitization. This trend of technological and economic development is expected to continue and accelerate in the next 10 years, with the emergence of 6G and intelligent networks and services. Among numerous research achievements, quantum optical communication is considered as a new type of communication with great development potential [3]. Although the above research has conducted relevant research on quantum communication in different fields, there is little literature summarizing the practical development of quantum communication.

Quantum information has the advantages of high efficiency, high security, etc. It is regarded as an important support for the new generation of information technology, and has become the hottest research

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direction in the world. Some scientists predict that quantum communication would be realized globally in the next 10 years. This paper discusses the practical development of quantum communication, and describes the progressiveness and future development of quantum communication technology.

2. Practical Development of Quantum Communication

2.1 Concept of Quantum Communication

Principles of quantum communication technology:

Quantum communication is a technology based on quantum entanglement that transmits information through invisible quantum transfer (transmission). Through experiments, it has been confirmed that regardless of the distance between two entangled particles, when one particle changes, the other also changes accordingly. Based on this, the communication process is as follows:

(1) It is necessary to construct a pair of particles with entangled states and place the two particles on both sides of the communication.

(2) A particle with an unknown quantum state is measured together with an emitted (running) particle, and the receiving particle immediately collapses (changes), collapsing (changes) to a state symmetrical to the collapsed (changes) state of the emitted particle.

(3) The information of the joint measurement is transmitted to the receiver through a classical channel, and the receiver performs a Mississippi transformation (equivalent to an inverse transformation) on the collapsed particle based on the received information, generating an unknown quantum state that is the same as the emitter.

Theoretical principles of quantum cryptography:

(1) The “non replicable” theory refers to a chaotic quantum with any auxiliary state, and experts are unable to construct a symmetric or unweighted quantum state that can replicate the chaotic quantum state. The existence of a chaotic quantum state is currently unclear.

(2) The quantum entangled states A and B have finite Hilbert space dimensions, and only when the Schmidt number is greater than 1, the density matrix of the two state system of the two body mixed state can meet the following conditions:

$$\rho_{\mathrm{AB}} = \sum_i P_i \rho_A^{(i)} \otimes \rho_B^i \tag{1}$$

$$\sum_i P_i = 1 \tag{2}$$

In various situations, the chaotic entanglement states are A and B, and any phase factor is added. This state would not change. Assuming that x_1 and x_2 are the coordinates of the two particles, the wave function of the two particles have an entangled state, which cannot be decomposed in the following way:

$$\Psi(x_1, x_2) = \int_{-\infty}^{+\infty} \exp\left[\frac{i}{\hbar(x_1 - x_2 + x_0)P} dp\right] = \Phi(x_1)\Phi(x_2) \tag{3}$$

(3) The uncertainty principles A and B in quantum mechanics cannot have deterministic values at the same time, and the Heisenberg generalized uncertainty relationship is:

$$\Delta\mathrm{A}\Delta\mathrm{B} \geq \frac{1}{2}[\mathrm{A},\ \mathrm{B}] \tag{4}$$

The basic scheme of quantum communication:

Currently, there are two main options for quantum communication. One type is direct communication, commonly known as the “Bing protocol”, where information is transmitted directly through quantum media, also known as invisible quantum transmission. The unknown quantum state of a particle in A is instantly transmitted to another particle in B [4]. However, another type is invisible quantum transmission, where the unknown quantum state of one particle in B is instantly transmitted to another particle in A [5].

However, invisible quantum transmission is still in the laboratory stage and has not been successfully implemented in actual quantum communication [6]. The next most commonly used and developed method is indirect communication, also known as quantum key distribution. In this method, there are two channels: classical channel and quantum channel. Classical channel uses traditional wired or wireless methods to transmit encrypted information, while quantum channel is used to generate keys [7]. Each time a message is sent, both parties must generate a new key, so the encryption key is different each time, thus achieving the method of encrypting the information one by one [8]. Quantum communication includes two aspects: hardware for generating, transmitting, and detecting unique photon sequences, as well as communication protocols, the most common of which is the BB84 protocol and its variants.

In 1993, American physicist Charles-Bennett proposed the theoretical idea of “quantum communication” based on quantum entanglement. Quantum communication refers to the use of the principle of indivisibility of a single photon and the characteristic of quantum non-cloning to achieve information transmission through quantum as a transmission channel. It is a new and absolutely safe communication method [9].

2.2 Advantages of Quantum Communication Technology

Quantum communication, as a new communication method, has the following characteristics:

First, in quantum communication, it is not necessary to rely on complex mathematical operations. In the case of quantum state changes caused by interception, tampering, copying or other operations, quantum cryptography technology is used to use quantum state as the key to ensure the security of communication, achieve the purpose of non-interference and non-repetition, ensure the “full security” of communication, and break through the limitations of traditional cryptography [10].

The second is efficiency. Using the principle of quantum stacking, there may be multiple quantum states or multiple quantum states in a quantum system. Quantum parallelism can provide powerful computing power for the mathematical operations of two types of information. By combining quantum communication with quantum computing, it is expected to achieve efficient transmission of n-dimensional quantum states, greatly improving their transmission capacity and efficiency.

Thirdly, it has strong anti-interference ability. Quantum communication uses quantum long-distance communication as the carrier and has the ability to pass through obstacles and the atmosphere. At the same time, the line has zero delay and electromagnetic pollution quality characteristics, which can greatly improve transmission speed and fully ensure the environmental protection of the communication channel [11].

2.3 Development History of Quantum Communication

In 1993, the fundamental theory of quantum communication was first proposed, and in the same year, six internationally renowned scientists jointly proposed the quantum invisibility scheme [12-13]. This process involves transferring an unknown quantum state as a particle to another location, and then replacing other particles with that particle [14]. Its basic idea is to decompose particle information into two states and transfer them between them [15]. Classical information refers to the information that particles are detected by the emitter in some way, while quantum information is the information that the emitter cannot recover through detection. The receiver receives these two kinds of information and reappears the original quantum state [16]. Therefore, the principle of quantum communication only transmits the quantum state of the original object, rather than the original object itself. The quantum invisibility in quantum technology has significant significance and influence in understanding and revealing a series of unknown natural laws [17]. Quantum states, due to their unbreakable confidentiality and the ability to transmit large amounts of information, have also received worldwide attention and become carriers of information [18].

Development trends:

① Lightweight and miniaturization of communication payloads: Laser and quantum communication payloads have narrow signal beams and small aperture, which are characterized by light weight, low power, and small volume compared to microwave communication [19]. However, when it comes to engineering and commercial applications, platforms have higher requirements for the weight, power consumption, and payload size of laser and quantum communication. Therefore, lightweight and miniaturization are the application needs and development trends of laser and quantum communication payloads.

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② Through the efforts of research institutes in recent years, the key technologies and basic devices of laser and quantum communication have rapidly developed and gradually matured, from scientific research to commercialization. Some domestic and foreign companies are injecting a large amount of funds and actively promoting the commercialization process of laser and quantum communication. It is believed that in the near future, commercial lasers and quantum communication would become a reality.

The European Union, the United States, and Japan are actively deploying space laser communication systems. With the establishment and operation of space laser communication system, the inevitable trend is to connect orbiting satellites, space stations, nearby space probe and mobile/fixed receiving terminals on the ground, at sea and in the air to form an integrated air laser communication network. At the same time, these countries also actively explore the use of satellite, aircraft and other platforms to establish space quantum communication networks, and connect with the ground quantum fiber internetworking to form a global integrated space quantum communication network [20].

Development suggestions:

Quantum communication is a communication technology that has only begun to receive attention in the past 30 years, and China has already established a scientific research foundation in this field and is also at the forefront of the world in this field. Therefore, promoting the industrialization of quantum communication is an urgent problem to be solved.

(1) Developing a special plan for the research and industrialization of quantum communication technology

Internationally, significant progress has been made in both theory and application, with mature technological development. In order to accelerate the practical application of quantum communication technology and achieve a high position in the field of information technology, it is necessary to include quantum communication technology in the national “13th Five Year Plan”, consider and formulate specific plans for the research and industrialization of quantum communication technology, and provide strong policy and financial support for promoting its practical application.

(2) Actively cultivating outstanding talents in the field of quantum communication

Regarding China’s quantum communication technology, from a holistic perspective, China maintains synchronization and leadership in both theoretical and experimental aspects, and even leads the world in some aspects. Experts should take advantage of China’s strong support for quantum communication technology to achieve breakthroughs in application, cooperate with well-known foreign research and development institutions, actively cultivate an excellent team of quantum communication talents, and improve the research and development capabilities of quantum communication technology.

(3) Demonstration project for constructing quantum communication network

Because the biggest advantage of quantum communication is “anti-eavesdropping”, “one-on-one”, and “absolute security”, it is very suitable for places that require highly confidential communication, such as governments, banks, finance, securities, large enterprises, and so on. Therefore, it is particularly suitable for occasions where high security communication is required, such as government, banking, finance, securities, large companies, and large groups. At present, Hefei and Jinan have regarded the construction of the quantum communication demonstration project as a starting point for realizing the industrialization of quantum communication technology. In order to ensure national information security and the development of financial service centers, experts should actively carry out the construction of the quantum communication demonstration project to ensure the security of national information security and financial service centers.

The financial field is one of the most developed applications of quantum communication technology. The main challenge is how to reasonably and effectively store, manage, transmit, and apply a large amount of financial information, and ensure the security, reliability, and confidentiality of data. Among the existing practical systems for secure communication, only secure quantum communication has passed strict security testing. The application of quantum secure communication technology principles to the physical level of quantum encrypted transmission and storage of financial data can serve as a backup technology for advanced communication security in the future financial and information fields. According to the People’s Bank of China and the China Banking Regulatory Commission, some banks and securities institutions in China have developed or are currently implementing demonstration applications. The People’s Bank of China has organized a project to test and demonstrate powerful quantum communication technology, targeting the People’s Bank of China and guiding some commercial banks to jointly promote it. In 2017, the People’s Bank of China organized a project to test and

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demonstrate powerful quantum communication technology. In addition, Guodun Quantum has also helped Industrial and Commercial Bank of China deploy 1000 kilometers of quantum encryption technology for data transmission outside the bank, creating a secure quantum communication application for enterprise internet finance for Bank of Communications, and establishing a ring network with Beijing Rural Commercial Bank for multilateral secure quantum communication protection in case of disasters.

Quantum key distribution:

Usually, information is carried by an unknown quantum state, mediated by a quantum channel, and determined by a shared key jointly determined by two participants. Due to the existence of uncertainty and quantum uncertainty, the confidentiality and security of information are guaranteed. There are two ways to steal intelligence. The quantum states of the original information are measured and analyzed, and the required information is obtained through the measurement results. However, during the measurement process, the quantum state is interrupted, so this method would leave some traces that cannot be detected by legitimate users. By sending the quantum state of the original data to the recipient, the replicated data is measured to obtain the replicated data, thereby achieving encryption of the replicated data. However, based on Heisenberg’s theory of quantum entanglement and imprecision, it is not possible to accurately reproduce it. To theoretically solve the problem of quantum key distribution, it is necessary to use perfect single photon detectors and perfect single photon light sources. The laser emits about 10 x 10 photons in one second, and its carriage and transmission are made up of individual photons. Before 2005, due to sending only one message per thousand seconds within a 10 kilometer range, this method had almost no significance in practical applications. This is the first device independent quantum key allocation method that solves the most easily detected problem in this system by hackers, but its transmission range is only 50 kilometers. In 2014, the maximum safe range of this device reached 200 kilometers, setting a new world record. With the rapid development of quantum information technology, the dawn of quantum communication is gradually moving from laboratory to society.

3. Communication System Simulation Experiment Based on Quantum Technology

On this basis, the system was simulated using MATLAB and compared with the existing space-time packet code orthogonal frequency division multiplexing WLAN system. All simulations are based on WLAN (Wireless Local Area Networks), with multipath and white noise channels as the background. In the simulation, it is assumed that the channel in which the system is located is quasi-static, and channel estimation can accurately estimate channel parameters. The receiver can achieve complete synchronization. For the convenience of research, the relevant parameter settings are shown in Table 1.

Table 1: Relevant parameters for simulation experiments.

Item	Parameters
Capacity	5GHz
Multiway Channels	Gaussian White Noise
Number Of Subcarriers For Orthogonal Frequency Division Multiplexing	48
Inverse Fast Fourier Transform	64
Modulation Mode	16 QAM
Signal Source	1/2 Convolutional Code

The experiment would analyze the performance of pure OFDM (Orthogonal Frequency Division Multiplexing) and OFDM based on quantum communication in ideal Gaussian and fading channels. The comparison of their system error rate performance is shown in Figure 1.

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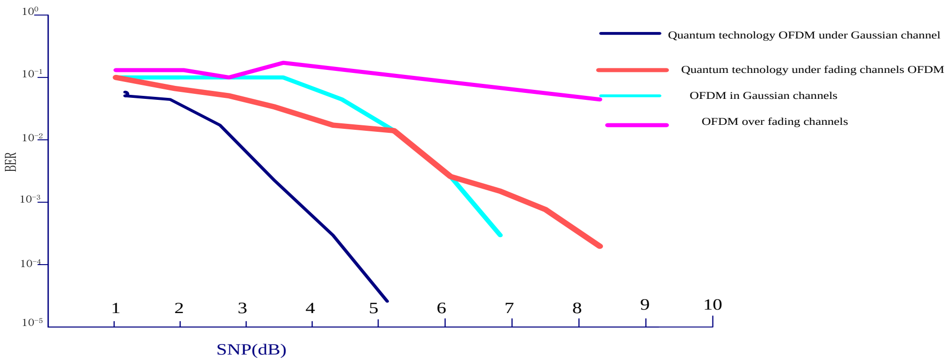

Figure 1: Comparison of bit error rates between single OFDM systems and OFDM systems based on quantum technology.

The simulation results show that under the same Gaussian channel conditions, the error performance of the quantum technology OFDM system is improved compared to the simple OFDM system in the range of 10 to 3 bit error rates. This means that in OFDM systems, the bit error rate would be greatly improved by adopting quantum technology.

The impact of modulation methods on system performance:

On this basis, the performance of OFDM systems with BPSK, QPSK, and 16 QAM was studied by simulating them under BPSK, QPSK, and 16 QAM conditions. The results are shown in Figure 2.

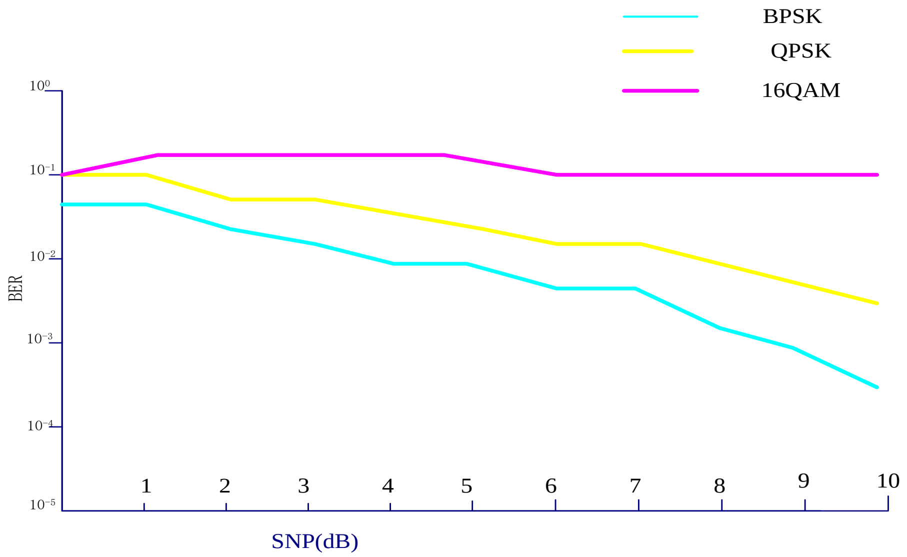

Figure 2: Comparison of bit error rate (ber) of systems under different modulation methods.

As shown in Figure 2, BPSK (Binary Phase Shift Keying) has the best bit error rate characteristics. Next is the QPSK (Quadriphase Shift Key) modulation method, followed by the 16 QAM (Quadrature Amplitude Modulation) modulation method. The results indicate that as the system throughput increases, its error rate performance also decreases.

The impact of the number of transmitting and receiving antennas (N, M) on system performance is examined. In a six path channel environment, the performance of quantum technology OFDM systems based on space-time block codes varies with the number of transmitting and receiving antennas. The results are shown in Figure 3. From Figure 3, it can be seen that under the same modulation method and the same ideal channel estimation, the performance of (2, 1) OFDM system is superior to (3, 1) and (4, 1) OFDM systems. This indicates that increasing the number of receiving antennas can improve system performance while maintaining the same number of transmitting antennas.

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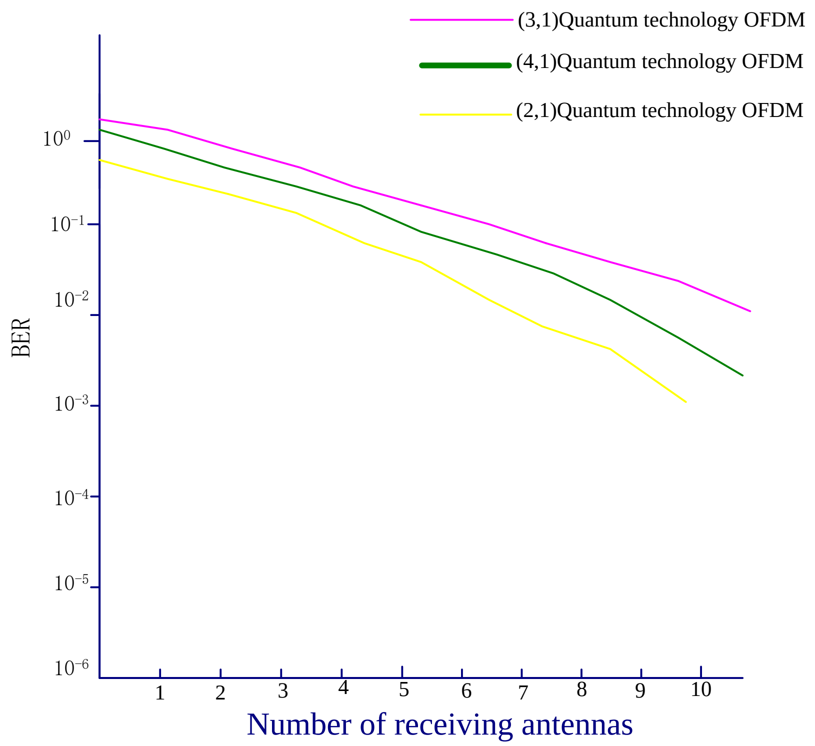

Figure 3: Comparison of system error rates when the number of receiving antennas changes.

4. Conclusions

Given the advantages and current development status of quantum communication, information security has high application value and broad development prospects in the fields of economic development and daily life, and would become an important means of information exchange between people in the future. At present, China has achieved some results in the field of quantum communication technology, laying a solid foundation for the further development of this technology. However, in order to further promote the development of information technology in China, relevant units must continue to conduct in-depth research and application, and increase investment in this field.

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