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Original Article

Optimization Scheme Design of Quantum Satellite Starship Communication under Complex Marine Meteorological Conditions

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Abstract *- In the atmospheric boundary layer far from the mainland, the complex climate environment, strong sea winds, and intermediate currents pose challenges to ocean satellite and starship communication. Especially in quantum communication, the interference of ionosphere, space plasma, and ice crystal particles can affect the stability and security of communication, which has become a research hotspot in the current field of starship communication. This article proposes an innovative method to optimize starship communication based on Quantum Entanglement Adaptive Control (QEAC). This article establishes the relationship between environmental factors and fidelity, bit error rate, and adaptive adjustment strategies. It compares the system performance parameters before and after the introduction of QEAC. This innovative method can improve the fidelity of quantum satellite communication systems under natural environmental interference through quantum entanglement adaptive control. Especially in the amplitude damping and depolarisation channels, the application of QEAC has significantly improved the stability of quantum starship communication. To verify the effectiveness of the proposed method, this paper conducted performance simulation experiments and achieved satisfactory results. Therefore, the optimization strategy based on quantum entanglement adaptive control proposed in this article is innovative and practical, providing a novel solution for solving the problems faced by ocean satellite communication. This study is of great significance for improving the stability and security of quantum starship communication under complex oceanic and meteorological conditions*.

Keywords *- Quantum communication, Quantum optics, Satellite communications, Ocean optics, Starship communications.*

1. Introduction

With the rapid development and application of quantum communication technology, quantum communication technology has been widely used in the military field. However, in naval warship security communication [1], due to the impact of the complex marine climate environment of naval warship navigation, the use of quantum communication cannot achieve good communication results, usually due to the impact of the climate-environment, leading to the instability of quantum communication between starships.

From the perspective of the principle of quantum communication, the most direct way of quantum communication systems can be transmitted through near-Earth free space channels and optical fibres, among which free-space quantum communication has high research value. Geographical conditions and fibre optic facilities do not limit free-space quantum communication, and quantum communication can be achieved over longer distances and even global coverage.

As an essential component of constructing the integrated network of heaven and earth, free-space quantum communication has become a research hotspot in quantum information. China has made significant progress in this regard, successfully launching the quantum science experimental satellite “Mozi” in 2016 [2] and completing multiple satellite ground quantum communication experiments, including satellite ground quantum teleportation, quantum entanglement distribution over 1200 kilometres, and high-speed quantum key distribution between satellite and ground. These experiments have made breakthroughs in entanglement-based secure quantum encryption at the 1000-kilometre level and provided an experimental foundation for constructing wireless quantum communication systems. At present, China has established optical ground stations in Lijiang, Yunnan [3], Nanshan, Xinjiang, Delingha, Qinghai, and Ali, Xizang, which, together with the Mozi satellite constitute an integrated space and ground experimental system [4]. However, free space quantum communication faces challenges from the influence of the external natural environment on channels and the complexity of channels. Optical ground stations are only established in areas with suitable environmental conditions, and the Mozi satellite can only conduct experiments in ideal atmospheric environments at night. Therefore, it is necessary to address these issues to build an integrated quantum communication network between heaven and earth. To address the impact of the natural environment on free-space quantum communication, this paper proposes an innovative optimization strategy based on the Quantum Entanglement Adaptive Control (QEAC) model.

This strategy aims to improve the anti-interference ability of the quantum satellite ground link under natural interference and lay a theoretical foundation for establishing an integrated quantum communication network. Compared with existing research, the method proposed in this article focuses on the specific impact of the natural environment on free-space quantum communication and provides solutions. By introducing a quantum entanglement adaptive control model, we can effectively improve the performance of quantum satellite communication systems in complex environments, thereby promoting the development of integrated quantum communication networks.

Under the above background, this paper will study based on the QEAC model, combine the characteristics of the interference of quantum communication in the complex marine climate environment, optimize the quantum communication scheme of the starship communication, and improve the stability and reliability of the quantum communication between the starship communications by constructing a communication control strategy based on QEAC, provide a basis for further developing the application of quantum communication in the starship communication..

2. Principle of Quantum Satellite Starship Communication Technology

Quantum satellite starship communication, in essence, is the application of quantum communication technology in the communication between satellites and ships. The communication interaction between artificial satellites using “quantum communication” as the information transmission mode and ships with quantum communication reception devices deployed in the ocean is shown in Figure 1. The communication forms of quantum communication technology mainly include quantum teleportation and cryptography. Quantum cryptography communication technology has entered into practical use [5].

This transmission principle does not require the participation of the transmission medium but only transfers the communication information by transferring the particle state. First, prepare the quantum with the quantum entanglement effect, which is recorded as A and B, respectively. When data is stored in A and B, quantum particle C containing relevant information is measured together with A, thus changing the state of A and B [6]. The inverse measurement method measures quantum D and B, and all the communication information in the quantum is obtained. However, quantum teleportation technology has not been thoroughly studied because a single quantum state is too elementary to lose a fibre channel and is expensive.

The starship communication link constructed by quantum communication has higher security. This encryption method based on quantum communication can theoretically provide a way that cannot be cracked or eavesdropped. In the technology based on quantum communication, data communication is limited to two parties, namely the sender and the receiver. Entangled photons encrypted with a specific polarization as the security layer are sent to two sites. Satellites use polarization measurement to create security keys, and stations can use polarization measurement to encrypt and decrypt data. This is technically “unbreakable” because users can quickly discover the existence of third parties: no eavesdropper can see these photons without changing or even destroying them [7].

Applying quantum communication technology to warships can improve the security of warship communication, especially in the military application field; it will significantly enhance the confidentiality of warships and play a vital role in the protection and privacy of communications in future wars. However, from the perspective of existing technology applications, how to apply quantum communication to warship communication is limited by the impact of the marine climate environment. The stability of direct starship communication is still a considerable challenge, and the stability of quantum communication in the complex marine climate environment must be solved.

3. Influence of Complex Ocean Meteorological Conditions on Quantum Satellite Starship Communication

When quantum signals are transmitted in free space, environmental factors inevitably affect them. When quantum signals are sent to the marine environment, such as sand and dust weather, haze weather, rainfall environment, etc., they are inevitably affected by objective factors caused by the marine climate environment, as follows:

Surge motion, sea fog and ocean tide are common natural phenomena caused by ocean climate change. Under the action of swell movement, wave height and swell period change will destroy quantum state coherence, called quantum decoherence. Decoherence leads to the loss of information carried by the quantum state and the decrease of quantum entanglement, which affects quantum communication. Previous studies have shown that the period change impacts the entanglement. With the increase of the propagation period, the swell is affected by the reverse flow, and the entanglement of the quantum channel increases, mainly because the wave energy transmission rate increases, the wave energy increases, and the entanglement of the quantum channel decreases with the increase of wavelength. At the same time [10], the wave motion will destroy the coherence of the quantum state, and the quantum channel noise will cause a change in the channel capacity. Under the wave motion's diffraction effect, with the wavelength increasing, the wave energy transmission rate will accelerate, the wave energy will increase, and the quantum channel will increase.

Capacity will decline. In the case of a large wavelength, the period change will make the channel capacity decline more obvious. As the propagation period increases, the surge is affected by the reverse current, and the capacity of the quantum channel decreases [11]. Sea fog is a weather phenomenon formed by tiny water droplets or ice crystals suspended at sea level, with horizontal visibility typically less than one kilometre. The thickness of sea fog is generally about 200-400 meters [8]. The process of forming sea fog is mainly affected by the response of atmospheric haze particles to changes in meteorological factors such as wind speed and humidity, and they absorb or release water along with these changes, thereby forming fog droplets. The radius range of fog droplets ranges from 1 micrometre to 60 micrometres, and fog droplets in sea fog may even reach 100 micrometres [9].

Research has shown that when the visibility of sea fog varies between 1-10km, as visibility increases, droplet particles gradually disperse, and droplet size gradually increases. In the process of quantum satellite communication and quantum key distribution, when the optical quantum signal passes through sea fog and comes into contact with fog droplet particles, it will cause the intensity attenuation of the optical quantum signal. This attenuation is influenced by the concentration of fog droplets and the transmission distance.

Therefore, it is necessary to adaptively adjust the system parameters according to the degree of sea fog during quantum communication to ensure the quality of communication. To cope with the impact of sea fog on quantum communication, we can choose the appropriate communication time based on accurate ocean climate forecasts to avoid the negative impact of link attenuation on communication quality. In addition, the reliability and stability of communication can be improved by adaptively adjusting system parameters and using appropriate compensation techniques [12].

Due to the influence of the tide-generating force of the sun, moon and other celestial bodies, the ocean will generate tides. Tide is a natural phenomenon in space. When carrying out Xinghai quantum communication, the atmospheric space environment inevitably affects the quantum state. When carrying out Xinghai quantum communication later, the light quantum will attenuate in a certain periodic environment due to the change of ocean tide and tide. The energy loss of quantum signal in channel transmission is inevitable.

Take optical quantum as an example. Due to the ocean tide phenomenon, Channel loss will cause visual quantum loss when the optical quantum is transmitted to the sea near the sea. It has been found that, with the increase in wind speed, the intensity of ocean tides becomes larger. When the sea tide height gradually increases, it causes the rise in seawater refractive index and the enhancement of seawater attenuation, reducing the channel capacity of amplitude damping channel to varying degrees [13]. From the quantum communication principle perspective, the sea tide height significantly impacts the performance of Xinghai quantum communication. Therefore, in the actual Xinghai quantum communication system, communication should be carried out according to the changing characteristics of sea tides in different periods to ensure that the Xinghai quantum communication will not be affected by large ocean tides and ensure the reliability of the communication link [15].

Based on the above analysis, due to the impact of various marine environments, the communication between satellite ships based on quantum communication will inevitably be affected by the marine environment, especially in terms of the impact of the climate environment. Climate change will lead to the generation of sea fog and the change of particles in the marine area [16], which will be the primary consideration in this study. To improve the stability and reliability of quantum satellite communication, the QFME control model is built to optimize and reduce the impact of quantum satellite communication caused by such marine meteorological conditions.

4. Optimization Strategy and Method Design Based on Quantum Entanglement Adaptive Control

4.1. Quantum Entanglement Adaptive Control Strategy and Model Construction

In quantum communication, an intense laser beam is injected into the cavity, which interacts with the atoms in the cavity [14]. At this time, the photons leaked from the cavity carry part of the information of the atoms in the cavity. The measured signal light ES and the strong local light EL enter from the optical Beam Splitter (BS) channels, respectively, and there is a specific optical phase difference between them. After coupling on the beam splitter, the emitted light field is two coherent superposition light fields, E1 and E2, and then the two photodetectors detect the light fields E1 and E2, respectively, generating photocurrent signals I1 and I2, and the obtained signals become photocurrent difference signals after passing through the subtracter. Under the specific phase difference between the local light EL and the measured signal light ES, the current difference signal carries the phase and amplitude information of the input signal, which can be used to predict the atom's state. Finally [17], the controller adjusts the atomic spin in the cavity by reading the predicted nuclear state. The QEAC model is shown in Figure 1.

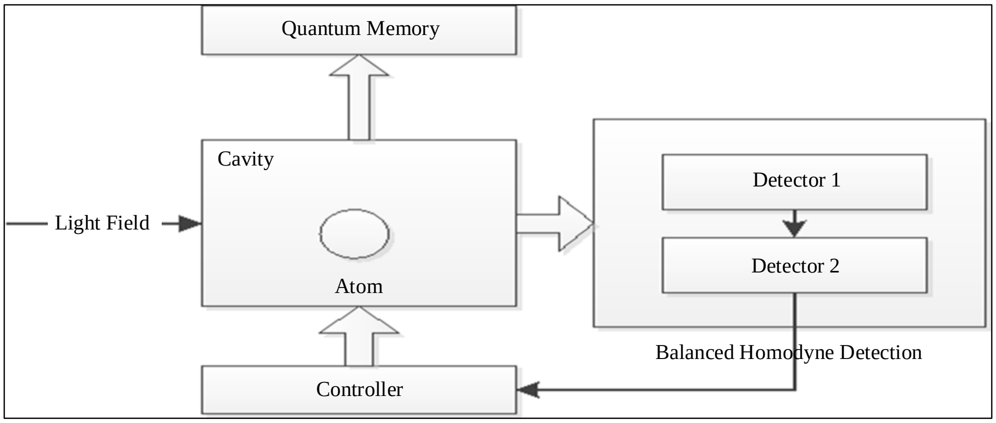

Fig. 1 QEAC model

In the QEAC system, because the feedback time is shorter than the relaxation time of the cavity, the feedback time can be ignored, so the measured results will be immediately fed back to the system, forming an adaptive control loop. Under this operation, the controller changes the state of the atoms in the cavity and then forgets the results. The stochastic equation based on balanced zero beat measurement is:

$$d\rho(t) = \left\{-i[H,\rho(t)] + a^{+}\rho(t)a - \frac{1}{2}a^{+}a\rho(t) - \frac{1}{2}\rho(t)a^{+}a\right\}dt \quad (1)$$

Where: H is the hamiltonian of the optical cavity system; A and a † are photon generation and annihilation operators, respectively; Is the density matrix of the optical cavity system; T is the time. ρ(t) photocurrent measured by quantum zero beat is,

$$I(t) = Tr[(L + L^{+})\rho(t)]\Delta t \quad (2)$$

In the formula, κκρ indicates trace acquisition; The operator is the photon generation operator measurement channel, which can be expressed as i[F,ρ(t)], F is the variance, dρ(t) is the mode matching visibility, I(t) is the total quantum efficiency of the balanced zero beat measurement device (including detector efficiency, optical element loss, etc.) $(L+L^{+})$ is the photon annihilation operator measurement channel; It is a minimal time interval. In the QFFC system, the control quantity is determined by the photocurrent measured at zero beats, that is

$$Tr(\cdot)LL = \eta\xi^{2}S_{1-2}^{ideal} + 1 - \eta\xi^{2}S\xi\eta; L^{\dagger}\Delta t$$

$$\rho_{f} = -i[F,\rho(t)]I(t) \quad (3)$$

Formula 3 is the density matrix after receiving the photoelectric current difference signal; It is the Hermitian Communist operator. Using Formulas 1 and 2, the random term is eliminated, and the master equation of the optical cavity under feedback control is obtained as follows: ρ_i F

$$\frac{d\rho}{dt} = -i[H,\rho(t)] + a^{\dagger}\rho(t)a - \frac{1}{2}a^{\dagger}a\rho(t) - \frac{1}{2}\rho(t)a^{\dagger}a + \kappa[a\rho(t) + \rho(t)a^{\dagger}] + \frac{1}{2}\eta\kappa^{2}\rho(t) \quad (4)$$

Tr $[(L+L^{+})\rho(t)]$ is a super operator. The Hermitian conjugate operator is determined so that the system is stable now. Assuming that the system state is consistent with the measurement operator in the free evolution direction, the master equation of the system is

$$\kappa\kappa\rho(t) = i[F,\rho(t)]Fd\rho(t) = 0\ QEAC$$

$$\rho_{1} = -i[H_{1},\rho] - \frac{J}{2}[q,[q,\rho]] \quad (5)$$

Formula 5 is the density matrix after quantum entanglement adaptive control; ρ_1 is the attenuation rate of the cavity mode; H_1 it is the feedback Hamiltonian of the quantum system;q Is a measurement operator. The formula 5's first term is the system's free evolution process, and the second term represents the influence generated after measurement. Both are time-varying operators and satisfy Formula 5 at any time.

ρ_1 JH_1 q-i$[H_1,\rho]$qρtρ(t)

Based on the above models, to realize the simulation of communication interference between quantum communication starships under complex marine meteorological conditions, this paper simulates two kinds of environmental simulation models, as follows:

4.1.1. Sea Fog Simulation Analysis

The visibility of sea fog is affected by the scattering of light by fog droplet particles. The fog droplets with a radius smaller than have strong scattering compared with short waves and weak scattering for long waves. The visibility formula of fog can be expressed as 0.5μm.

$$V = C \cdot \frac{r_{ef}}{W} \quad (6)$$

Where,r_{ef} is the effective radius of droplet particles, unit: liquid water content, unit: 2.5. V Indicates sea fog visibility, W stands for water content， and C stands for refractive index. According to Formula 6, the visibility is proportional to the droplet radius when the water content is constant. Under different ocean conditions, if the water content of fog is the same, its visibility will be different.

Because the droplets of sea fog are larger and have lower density than land fog, the visibility of sea fog is greater than that of land fog. According to different geographical locations and fog generation conditions, fog is mainly divided into advection fog and radiation fog [18]. The discussion in this paper is based on the conditions of advection fog. W. According to data statistics and mapping, H. Radford obtained the relationship between fog water content and visibility as follows:

$\mathrm{r_{ef}\mu mWg/m^3CV}$

$$W = (18.35\,V)^{-1.43} = 0.0156\,V^{-1.43} \quad (7)$$

Because the process of sea fog from generation to dissipation is very complex, the common distribution model is the droplet distribution proposed by Deirmendian, the generalized gamma distribution.

$$n(r) = a \cdot r^{\alpha} exp\left(-b \cdot r^{\beta}\right) \quad (8)$$

In Formula 8, r^{α} the droplet radius represents the number of droplet particles within the unit volume and unit radius interval. The macroscopic parameters of the physical properties of fog can be obtained from the equation, namely rn

$$r_0 = \left(\frac{\alpha}{b\beta}\right)^{1/\beta}$$

$$N_0 = \Gamma\left(\frac{\alpha+1}{\beta}\right)\frac{\alpha}{\beta^{(\alpha+1)/\beta}} \quad (9)$$

$$W = \frac{4\pi}{3}\left(\frac{\alpha}{\beta}\right)^{1/\beta} r_0^3 \rho N_0 \frac{\Gamma\left(\frac{\alpha+4}{\beta}\right)}{\Gamma\left(\frac{\alpha+1}{\beta}\right)}$$

In Formula 9, is the mode radius of the fog droplet, in Formula 9, is the number of fog droplet particles contained in the unit volume, and in Formula 9, is the water content of the sea fog and the density of water Among them, the gamma model of time (KhragianMazin distribution model) is widely used, namely,

$$\mathrm{r_0 N_0 W\rho\alpha} = 2, \beta = 1$$

$$n(r) = a \cdot r^2 exp(-b \cdot r)$$

$$a = \frac{9.781}{V^6 W^5} \times 10^{33}$$

$$b = \frac{1.304}{VW} \times 10^7$$

Init represents the droplet radius and the number of droplet particles within the unit volume and unit radius interval.rn

In the case of gamma distribution, the expression of droplet concentration can be obtained as,

$$N = \int_0^{\infty} n(r)dr = 2a/b^3 = \frac{8.222}{V^3 W^2} \times 10^3$$

The spectrum of sea fog droplets is analyzed. According to the relationship between fog water content and visibility, the relationship between different droplet size distribution and water content can be obtained, which can be expressed as [4],

$$n(r) = 3.73 \times 10^{23} W^{-0.804} r^2 exp(-2.392 \times 10^5 W^{-0.301} r) \quad (10)$$

and get the relationship between different droplet size distribution and visibility as follows:

$$n(r) = 1.059 \times 10^{25} V^{1.15} r^2 exp(-8.359 \times 10^5 V^{0.43} r) \quad (11)$$

The droplet size is usually of the order of magnitude. The droplet radius in Formula 11 is, where the droplet size distribution can be expressed as μmμmr = $2.93 \cdot V^{(-0.43)}$

$$n(r) = 9.091 \times 10^7 V^{-0.21} exp(-2.449 V^{-0.18})$$

When the light quantum passes through the droplet particles, the droplet will produce extinction, scattering and other effects. The extinction coefficient of droplet particles can be expressed as,

$$\sigma_{fog} = 1.5\pi \cdot C\frac{W}{\lambda} \quad (12)$$

Where, σ_{fog} is the extinction coefficient of the sea fog, and the unit is water content, λ indicating the incident light wavelength.σ_{jog} km^{-1},Wλ

In quantum satellite communication and quantum key distribution, the light quantum signal will contact the fog droplet particles when passing through the sea fog, which will inevitably attenuate the light quantum signal strength. The transmission distance in the sea fog environment is, with the unit of, and the light quantum strength is dkm.

$$I_d = I_0 exp(\sigma_{ext} \cdot d) \quad (13)$$

Where, I_0 is the initial energy of optical quantum, σ_{ext} is the extinction section and the radius distribution range of droplet particles is 0-15 μ When m, the total extinction section can be expressed as I_0 σ_{ext}.

$$\sigma_{ext} = \int_0^{15} Y(r)\sigma_{fog}\, dr \tag{14}$$

Where is the distribution function of droplet particles Y(r).

$$Y(r) = \frac{N}{\sqrt{2\pi} r ln\,\delta} exp\left(-\frac{ln^2(r/r_{ave})}{2ln^2\,\delta}\right) \tag{15}$$

Where, N represents the droplet concentration, r_{ave} represents the geometric mean radius of droplet particles, and δ represents the geometric mean deviation. When the quantum signal is transmitted in the sea fog, the link attenuation caused by droplet particles can be expressed as $Nr_{ave}\ \delta$

$$A_{laf} = 10 \cdot \sigma_{ext} \cdot log\, e \cdot d \tag{16}$$

At the same time, from the fidelity perspective, the link channel fidelity is a parameter reflecting the transmission capacity of quantum signalling.

When quantum satellite communication is affected by sea fog, the average fidelity of the quantum link channel is.

$$F\left(\sum_i P_i\psi_i, \varepsilon\left(\sum_i P_i\psi_i\right)\right) = tr\left(\left(\sum_i P_i\psi_i\right)\varepsilon\left(\sum_i P_i\psi_i\right)\right)^{\frac{1}{2}} \tag{17}$$

Wherein the depolarization channel state after superposition is,

$$\varepsilon\left(\sum_i P_i\psi_i\right) = \begin{bmatrix} \frac{P' + 2(1-P')P_1}{2}, & 0 \\ 0, & \frac{P' + 2(1-P')(1-P_1)}{2} \end{bmatrix}$$

Wherein,

Pi is the quantum state probability after superposition and evolution,

P' is the quantum character timing probability of the information source,

P_1 is the Quantum state timing probability.

$$P' P_i \psi_i$$

$$P_1|0\rangle 1 - P_1|1\rangle$$

$$F_t = \sqrt{\frac{P' + 2(1-P')P_1P_1}{2}} + \sqrt{\frac{P' + 2(1-P')(1-P_1)(1-P_1)}{2}}$$

The above is the analysis model of the impact of marine meteorological conditions on satellites and starships in the complex climate. Based on the above model, this paper will optimize its control of it from the perspective of communication fidelity.

4.2. Optimization Method Based on Quantum Entanglement Adaptive Control

Based on the above analysis model, the stability of the starship communication will be directly affected by the complex marine climate environment in the quantum communication, which is mainly reflected in the impact on the amplitude damping channel and depolarization channel of the starship communication, as follows:

In the amplitude damping channel, let the initial state in the free space environment be φ A. The excited state is 1, and the ground state of the quantum system is 0. A quantum bit attenuates excited state 1 to ground state 0 with probability p, transitioning the free space environmental state to φ B. The unitary evolution of the composite system after the interaction of qubit and free space environment is expressed as:

$$\begin{cases} |0\rangle|\varphi_A\rangle \to |0\rangle|\varphi_A\rangle \\ |1\rangle|\varphi_A\rangle \to \sqrt{1-p}|1\rangle|\varphi_A\rangle + \sqrt{p}|0\rangle|\varphi_B\rangle \end{cases} \tag{18}$$

Formula 18, p is the error probability of quantum bits affected by the free space environment. Using two Kraus operator operators, the initialization density matrix of the quantum system can be evolved at the top.

$$\rho_A = \begin{pmatrix} \rho_{00} & \rho_{01} \\ \rho_{10} & \rho_{11} \end{pmatrix}$$

$$\rho_A \to \rho_A' = \begin{pmatrix} \rho_{00} + p\rho_{11} & \sqrt{1-p}\rho_{01} \\ \sqrt{1-p}\rho_{10} & (1-p)\rho_{11} \end{pmatrix}。 \tag{19}$$

Let the information source be, p is the probability of quantum character timing of the information source, ρ is the character number. If the input character is, the state of the quantum system after passing through the free space environment is,

$$\{p_i, \rho_i\} p_i \rho_i \sum p_i = 1 i \rho_0 = |0\rangle\langle 0|, \rho_1 = |1\rangle\langle 1|$$

$$\rho_A \to \sigma = \begin{pmatrix} 1 + pp_1 - p_1 & 0 \\ 0 & p_1 - pp_1 \end{pmatrix} \tag{20}$$

The density matrix of the quantum state emitted during the satellite ground communication is the density matrix after the quantum entanglement feedback control. During the quantum measurement, the density matrix will shrink to the state with the probability of and shrink to the | 1 state with the likelihood of, where the sum is a complex number called the probability amplitude of the quantum state. Then, for the amplitude damping channel, the average fidelity can be expressed as:

$$|\varphi\rangle\rho = \begin{pmatrix} |\alpha|^2 & \alpha\beta \\ \alpha\beta & |\beta|^2 \end{pmatrix} |\alpha|^2|0\rangle|\beta|^2\alpha\beta|\alpha|^2 + |\beta|^2 = 1$$

$$F(\rho_1,\sigma) = Tr\sqrt{\begin{pmatrix} 1+pp_1-p_1 & 0 \\ 0 & p_1-pp_1 \end{pmatrix}^{\frac{1}{2}} \times \begin{pmatrix} |\alpha|^2 & \alpha\beta \\ \alpha\beta & |\beta|^2 \end{pmatrix} \times \begin{pmatrix} 1+pp_1-p_1 & 0 \\ 0 & p_1-pp_1 \end{pmatrix}^{\frac{1}{2}}}$$

Further, if the general state of the quantum state is, and the quantum state of the free space environment is, then the joint evolution of the quantum state and free space environment can be expressed as$\alpha|0\rangle+\beta|1\rangle|e\rangle$

$$|e\rangle(\alpha|0\rangle+\beta|1\rangle) \rightarrow \alpha(|e_0\rangle|0\rangle+|e_0'\rangle|1\rangle)+\beta(|e_1\rangle|0\rangle+|e_1'\rangle|1\rangle) \quad (21)$$

Formaula 21 is the dual quantum states of the quantum states in the evolution state and is an entangled states. A qubit generally evolves into

$$|\ \langle e_0'\rangle|e_1\rangle|e_1'\rangle|e_0\rangle|0\rangle+|e_0'\rangle|1\rangle|e_1\rangle|0\rangle+|e_1'\rangle|1\rangle$$

$$|e\rangle(\alpha|0\rangle+\beta|1\rangle) \rightarrow (|e_+\rangle I+|e_-\rangle Z+|e_+'\rangle X + |e_-'\rangle Y)\otimes(\alpha|0\rangle+\beta|1\rangle),$$

Where, I, X, Y and Z are mechanical quantity operators; Are four particular quantum states of free space environment;

Represent tensor product. It is stipulated that it is the initial state of the free space environment and is the quantum state of three accessible space environments with equal probability. Then, the unitary evolution of the composite system composed of qubit and free space environment is expressed as:

$$Z|e_+\rangle,|e_-\rangle|e_+'\rangle,|e_-'\rangle\otimes|e_+\rangle=|e_-\rangle,|e_+'\rangle = |e_X\rangle,|e_-'\rangle=|e_Y\rangle,|e_-\rangle = |e_z\rangle|e_I\rangle|e_X\rangle,|e_Y\rangle,|e_Z\rangle$$

$$|\varphi\rangle|e_1\rangle \rightarrow \sqrt{1-p'I}|\varphi\rangle\otimes+\sqrt{\frac{p'}{3}}X|\varphi\rangle\otimes|e_X\rangle\sqrt{\frac{p'}{3}}[Y|\varphi\rangle\otimes |e_Y\rangle+Z|\varphi\rangle\otimes|e_Z\rangle], \quad (22)$$

Formula 22 is the quantum bit; Is the depolarization probability of the qubit. The four Kraus operator operators are: $|\varphi\rangle p'$.

$$\begin{cases} K_0=\sqrt{1-p'}I \\ K_1=\sqrt{\frac{p'}{3}}X \\ K_2=\sqrt{\frac{p'}{3}}Y \\ K_3=\sqrt{\frac{p'}{3}}Z \end{cases} \quad (23)$$

Suppose that the initial density matrix of the quantum system evolves into,

$$\rho_A=\begin{pmatrix} \rho_{00} & \rho_{01} \\ \rho_{10} & \rho_{11} \end{pmatrix}$$

$$\rho_A \rightarrow \rho_A' = \begin{bmatrix} \left(1-\frac{2}{3}p\right)\rho_{00} & \left(1-\frac{2}{3}p\right)\rho_{01} \\ \left(1-\frac{2}{3}p\right)\rho_{10} & \left(1-\frac{2}{3}p\right)\rho_{11} \end{bmatrix}, \quad (24)$$

Then, the state of the quantum system after passing through the free space environment is:

$$\rho_A \rightarrow \sigma = \begin{pmatrix} \frac{p}{2}+(1-p)p_1 & 0 \\ 0 & \frac{p}{2}+(1-p)(1-p_1) \end{pmatrix} \quad (25)$$

Based on the above methods, it can effectively ensure the high fidelity of quantum communication under depolarization signal and phase damping channel. Combined with the analysis above, this channel is the most easily interfered in the formal marine environment, which is greatly affected by the marine environment.

Using the above methods, we can optimize the quantum satellite starships in the complex marine environment. In that case, It will help improve the stability of communication between starships in complex environments and provide a feasible scheme for applying quantum communication technology in starship communication.

5. Simulation Analysis of Quantum Entanglement Adaptive Control under Complex Marine Meteorological Conditions

5.1. Simulation Environment and Platform

In this study, we designed a theoretical model based on the previous construction and conducted simulation work using the MATLAB platform. MATLAB is a commercial mathematical software primarily designed for high-tech computing environments such as scientific computing, visualization, and interactive programming. It integrates many powerful functions, significantly improving work efficiency and user experience. In this study, we used MATLAB as a simulation platform to validate our theoretical model and design [19].

In this research, the model designed and constructed in this paper will be simulated and analyzed in the Matlab environment. According to the model, various quantum states and communication channel processes will be simulated in Matlab. Then, the algorithm model constructed in this paper will be observed under the simulated marine meteorological conditions to observe the impact of changes in meteorological conditions on communication, and the quantum communication simulation model constructed in this paper will be analyzed To observe its communication performance.

5.2. Simulation Results and Comparative Analysis

First of all, based on the quantum satellite starship communication model under complex ocean conditions constructed previously, this paper takes sea fog as an example to conduct simulation analysis, and the results are as follows:

5.2.1. Analysis of the Influence of Sea Fog Environment on Link Attenuation

Wavelength 1.51 is used in simulation μ M optical signal for quantum satellite communication, and the transmission distance of the signal in the sea fog is 0-40km, the simulation of the relationship between link attenuation droplet concentration and transmission distance is shown in Figure 2 below.

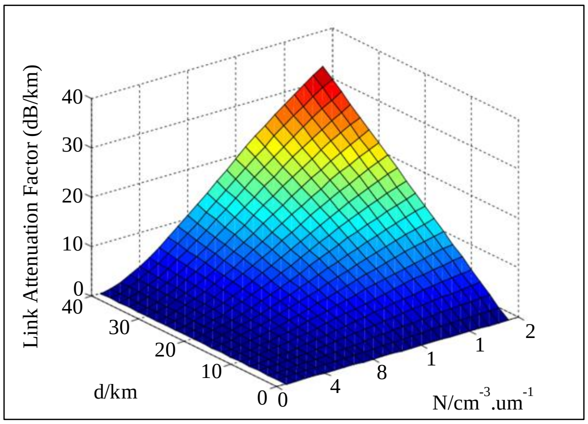

Fig. 2 Relationship between link attenuation and transmission distance and droplet concentration

In Figure 2, the axis represents the droplet concentration. The axis represents the distance of signal transmission in sea fog. The axis indicates the degree of link attenuation, and the unit is. It can be seen from the figure that when the concentration of droplet particles is at a specific value, there is no absorption between the droplets. When the transmission distance of the optical quantum signal gradually increases, the area size of the extinction section formed by the droplets in the sea fog increases, resulting in the gradual weakening of the optical quantum signal strength and the rising trend of chain attenuation; In the fixed light quantum transmission range, with the change of meteorological conditions, the concentration of droplet particles gradually increases, resulting in an increase in the number of droplet particles per unit volume and per unit radius interval. The extinction reaction gradually increases, leading to an increase in link attenuation. When the transmission distance is, and the droplet concentration increases from to, the link attenuation increases from to. When the droplet concentration and transmission distance increase from to, the link attenuation increases exponentially from to [20]. Therefore, the droplet concentration and transmission distance greatly impact the link attenuation. It is necessary to choose a suitable time for communication according to accurate marine climate prediction to avoid the impact of

$XYZdBd20\ km10\ cm^{-3}\mu m^{-1}20\ cm^{-3}\mu m^{-1}5.632\ dB23.86\ dBN = 12\ cm^{-3}\mu m^{-1}5\ km35\ km3.762\ dB28.62\ dB$

Secondly, this paper analyzes the influence of sea fog on the fidelity of the quantum link channel. Based on the fidelity model and algorithm optimization strategy constructed above, during the simulation process, when the optical quantum crosses the sea fog, the transmission distance in the sea fog is taken to simulate the droplet concentration, the size of the source character probability and the average fidelity of the channel. The simulation results are shown in the Figure 3.

d = 10km3

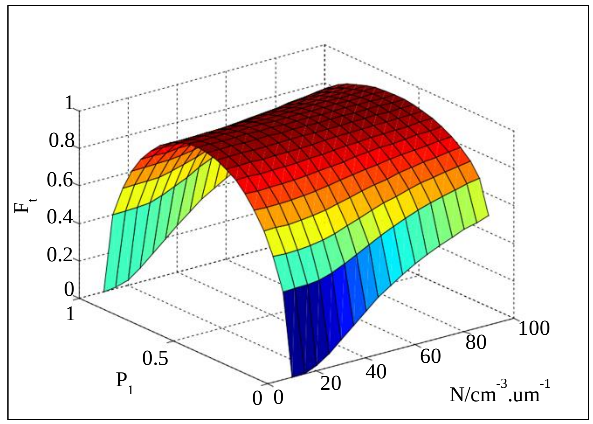

Fig. 3 The relationship between the average fidelity of the depolarization channel and the probability of source characters and droplet concentration

The axis in Figure 3 represents the probability that the source character is, the axis represents the droplet concentration, and the axis represents the average fidelity of the depolarization channel. It can be seen that when the droplet concentration is constant, the probability of the source characters is between 0 and 0.5, and the average fidelity of the depolarization channel shows an increasing trend. When the likelihood of the source characters is between 0.5 and 1, the average fidelity of the depolarization channel shows a decreasing trend.

When the probability of the source character remains constant, the quantum channel's average fidelity decreases with the increase in droplet concentration. When the droplet particle concentration increases from to, the average fidelity of the depolarization channel decreases from to. It can be seen that when the droplet particle concentration is large, the average fidelity of the depolarization channel will be attenuated to a certain extent, resulting in a certain impact on the communication quality.

$X|0\rangle YZ|0\rangle|0\rangle|0\rangle P_1 = 0.320\ cm^{-3}\mu m^{-1}60\ cm^{-3}\mu m^{-1}0.83610.5892$

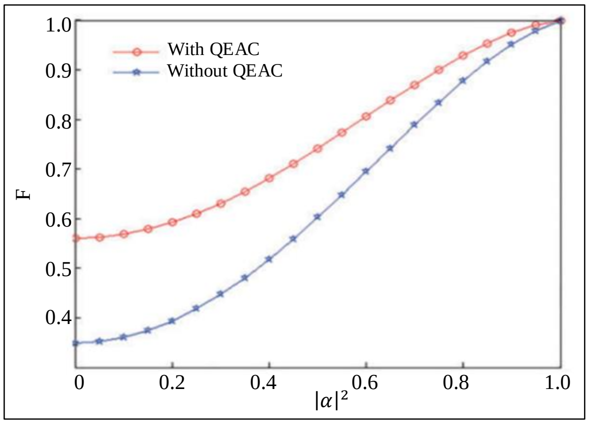

Fig. 4 The fidelity of the system before and after QEAC|α| 2 relationship

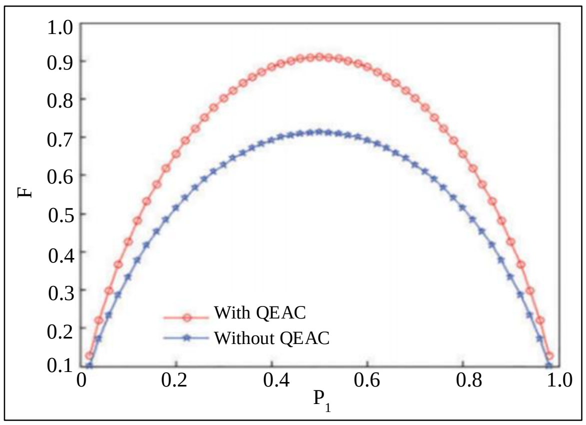

Fig. 5 The relationship between the fidelity of the system before and after QEAC and the character probability p1

Finally, according to the model constructed above, the average fidelity before and after using the entanglement feedback control system in the amplitude damping channel and depolarization is simulated, respectively. The results are shown in Figure 4.

As seen from Figure 4, the fidelity increases as the $|\alpha|^2$ value increases. With the entanglement feedback control system, the average fidelity of the channel is significantly improved. When $|\alpha|^2 = 0.2$, the fidelity was increased from 0.393 to 0.578. Therefore, QEAC can enhance the system's fidelity, which is significant in improving the system's anti-interference. According to the model built by Wen, it simulates the relationship between the fidelity and the probability of the source character in the depolarization channel. The results are shown in Figure 5. It can be seen from Figure 3 that the average fidelity of the channel has been significantly improved after using the entanglement feedback control system. When P_1=0.5, the channel fidelity increases from 0.712 to 0.909. It can be seen that using QEAC can improve the fidelity of the system. The maximum fidelity can be obtained by adjusting the state of the source quantum characters while using QEAC to obtain a better communication effect when quantum encryption communication is carried out.

6. Conclusion

Against the backdrop of increasingly mature quantum communication technology, this study innovatively applies quantum communication technology to the field of ships. By achieving high stability and high fidelity quantum communication, the confidentiality and security of ship communication can be improved.

An optimization strategy based on quantum entanglement feedback control is proposed in the design to address the interference caused by complex ocean meteorological conditions on quantum communication between ships and satellites. This strategy can establish the relationship between different environmental factors, fidelity, and error rate and compare and analyze the system performance parameters before and after introducing quantum entanglement feedback control. Through performance simulation verification, it has been found that the quantum entanglement feedback control strategy can improve the fidelity of quantum satellite communication systems under natural environmental interference in amplitude-damping channels and depolarization channels [21].

This will effectively enhance the stability of quantum communication between starships under complex marine and meteorological conditions, laying the foundation for promoting the application of quantum communication in the field of ships in the future.

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