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Proposition of Optimization of the MeetInTheMiddle Protocol for Quantum Repeaters

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ABSTRACT

Quantum computing relies on concepts derived from classical information theory and quantum physics. In order for quantum communications to be a reality, it is essential to have the most advanced infrastructures in place. In this paper, we explore the significance of quantum communication and the utilization of quantum repeaters, which rely on the phenomenon of quantum entanglement. We present the MeetInTheMiddle protocol for quantum repeaters and its total transmission probability, and then propose an improvement of this protocol based on the comparison of the total transmission probability.

INTRODUCTION

Quantum communication gives secure communication possibilities, its principles are the important bases of the quantum internet, which makes it possible to transmit quantum entanglement over long distances (Barbeau, 2019). The distribution of long-distance entanglement is challenging due to the exponential light losses in optical fibers. To address this issue, researchers have been exploring the use of quantum repeaters, which are able to amplify and regenerate entanglement over long distances. A potential solution is to use quantum repeaters based on the exchange of entanglement(Liorni *et al.*, 2021). In a quantum networks, the utilization of quantum repeaters is imagined for the start to finish move of quantum states. Quantum repeaters influence entrapment swapping, conceivably together with error rectification, to accomplish multi-jump communications (Azuma *et al.*, 2015).

The degradation of photons in optical fibers grows exponentially with widening of the distance (Yoshida *et al.*, 2020). The fidelity of the communication is lost in a very large way with the length of the channel. Thus, the big problem in quantum communication remains to find the best methods to generate entangled pairs of high fidelity over long distances. Quantum repeaters attempt to overcome this obstacle in a temporal polynomial based on the use of quantum memory and local quantum operations to purify and connect pairs (Duan *et al.*, 2001; Jiang *et al.*, 2007).

LITERATURE REVIEW

1-BSA (Bell State Analyser)

Among other applications, it is used in linear optics and quantum computation, as well as in quantum communication protocols like quantum repeaters, quantum teleportation, dense coding, and quantum key distribution. (Valivarthi *et al.*, 2014) .

Any two-photon state can be projected deterministically and unambiguously onto the four maximally-entangled Bell states if the BSA is complete, i.e. (Valivarthi *et al.*, 2014).

$$|\phi^{\pm}\rangle = \frac{1}{\sqrt{2}}(|00\rangle \pm |11\rangle)$$

And (1)

$$|\Psi^{\pm}\rangle = \frac{1}{\sqrt{2}}(|01\rangle \pm |10\rangle)$$

The MeetInTheMiddle Protocol

This protocol was presented in (Duan & Kimble, 2003; Feng *et al.*, 2003; Jones *et al.*, 2016; Simon & Irvine,

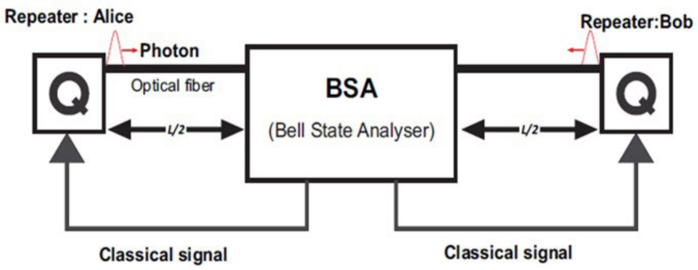

Figure 1: Principle of the MeetInTheMiddle protocol

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2003), it is a very simple protocol for the entanglement distribution, which serves to realize the quantum entanglement between distant nodes in a quantum network (Browne *et al.*, 2003; Cirac *et al.*, 1997; Duan & Kimble, 2003; Jones *et al.*, 2016; Liu *et al.*, 2020), and which plays an indispensable role for the realization of the quantum cryptography (Briegel *et al.*, 1998; Ekert, 1991) and quantum teleportation (Bennett *et al.*, 1993).

The principle of MeetInTheMiddle protocol is explained in Figure 1 (Jones *et al.*, 2016):

Probability of transmission for MeetInTheMiddle Protocol

The total transmission probability for MeetInTheMiddle can be written as (Jones *et al.*, 2016):

$$P= P_{optical}\, P_{BSA}\, P_{optical} = P_{BSA}(P_{optical})^2 \quad (2)$$

Because the opticals fibers are identicals, knowing that:

$P_{optical}$

The product of probabilities for fruitful transmission through the memory/photon interface and transmission through optical fiber over separation L/2 to arrive at the BSA .

P_{BSA}

Probability of fruitful BSA outcome when two photons arrive .

Each round of entanglement has a duration

$$t_{round} = t_{link} + N_{tclock} \quad (3)$$

With

t_{link}

It is time for the light to pass through the link.

N

Number of photons sent by each repeater.

t_{clock}

Synced to it, the repeaters emit photons at regular intervals.

MATERIALS AND METHODS

1-Proposal for an Improvement of MeetInTheMiddle Protocol

Here we will leave the same principle of operation. The difference is that two BSA must be used. The number of photons N is divided into two parts N_1 and N_2 (Figure 2).

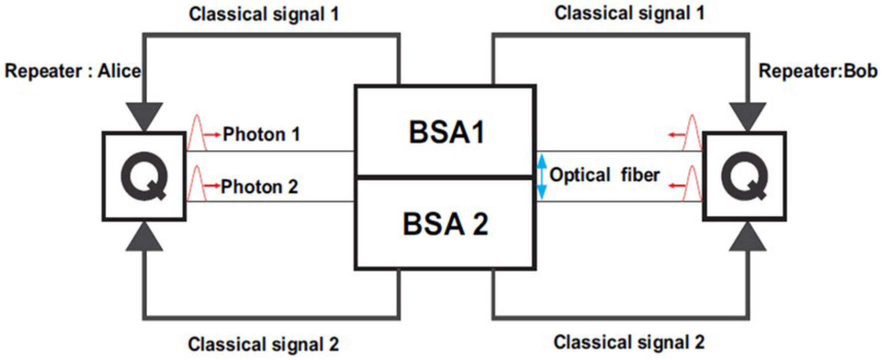

Figure 2: Proposed principle of the MeetInTheMiddle Protocol

In this case, we have $N = N_1 + N_2$

And

N_1

The number of photons that must be passed by BSA1.

N_2

The number of photons that must be passed by BSA2.

Each round has duration:

$$t_{round} = t_{link} + N_1 t_{clock} + N_2 t_{clock} = t_{link} + N t_{clock} \quad (4)$$

2-Probability of Transmission for the New MeetInTheMiddle Protocol

By the same demonstration, we can write the probability for the new MeetInTheMiddle :

$$P= P_{BSA1}\,(P_{optical})_2 + P_{BSA2}\,(Poptical\,)^2 \quad (5)$$

RESULTS AND DISCUSSION

The two BSAs are identical, so $P_{BSA1} = P_{BSA2}$

Finally

$$P= 2\, P_{BSA}(P_{optical})^2 \quad (6)$$

With the use of two BSAs, we find that the duration of the round has not changed, and that the probability of transmission is doubled, which means that there is an increase in the number of confirmation messages allowing to use entanglement. The transmission probability is fundamentally related to the success rate of the entanglement distribution and the efficiency of the quantum repetition protocol. This “heralding” of successful entanglement distribution is a key feature of quantum repeater protocols. It allows the repeaters to establish entanglement links between adjacent nodes, which are then combined through entanglement swapping to create long-distance entanglement. In summary, the classical confirmation messages are an essential part of quantum repeater protocols, allowing the repeaters to establish and use entanglement despite the probabilistic nature of transmitting qubits over lossy channels. The messages enable the repeaters to discard failed attempts and focus on the successful entanglement events.

Thus, the new form of the MeetInTheMiddle protocol is more secure than the original.

CONCLUSION

In this paper, we proposed an improvement of the MeetInTheMiddle protocol for quantum repeaters based on the increase of the probability of transmission and the number of confirmation messages.

The technology of developing repeaters based on entanglement distribution can revolutionize the telecommunications industry. It reduces latency and improves the overall quality and reliability of data transmission. However, he remains cautious about the near future.

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