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長距離量子通訊的解決方案：量子中繼站

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摘要

隨著世界各國在量子通訊領域的大力投入下，其發展也愈具規模。然而，隨著通訊距離的增長，巨大的損耗強烈的限制了通訊距離。在傳統光纖通訊中，中繼站放大被衰減的訊號得以延長傳輸距離，但基於不可複製原理所保護的量子通訊卻無法採用此傳統方案，為解決此難題，量子中繼站協定因而被提出。該協定利用糾纏交換使得從未交互作用過的節點分享量子關聯性，並連結遙遠的兩節點，達成長距離的量子通訊。本文將介紹量子中繼站的基本原理，探討記憶體型式和全光學型式的量子中繼站之物理原理及技術挑戰。另一方面我們也介紹能突破直接傳輸雙場量子密鑰分發之原理與現狀。我們相信本文之原理與現狀介紹將有助於讀者對長距離量子通訊有一個整體的認識。

關鍵詞：量子中繼站、量子通訊、量子密鑰分發、量子糾纏、量子科技

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Solutions for Long-Distance Quantum Communication: Quantum Repeater

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Abstract

With the large resources invested by many countries in the world, the networks of quantum communication have been developed. However, with the increase of communication distance, the losses on the communication line will greatly limit the distance of quantum communication. On the other hand, the no-cloning theorem that protects the security of quantum communication also restricts the application of classical repeater stations through amplifying the attenuated signal in quantum communication. To resolve this problem, the concept of quantum repeater (QR) protocol was proposed. The protocol uses the unique characteristics of quantum mechanics such as entanglement swapping (ES) to further distribute quantum correlations, entangle the nodes that have never interacted, and even resist losses caused by the transmission lines to achieve long-distance quantum communication. In this article, we discuss the difficulties encountered by quantum communications over long-distance transmissions and explain the solution: QR protocol. With the different architectures of QR protocol, their protocols can be divided into memory-based and all-optical types. We will introduce the physical principles of the two different types of QR and the process of the protocol. We also report on some recent progresses of QR. In addition, we also discuss the twin-field quantum key distribution (TF-QKD) scheme, recently proposed for long-distance quantum communication. We believe that this report will help the readers to understand the architecture of long-distance quantum communication and the technical challenges that it faces.

Keywords: quantum repeater, quantum communication, quantum key distribution, quantum entanglement, quantum science and technology

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