A High Dimensional Entanglement-based Fully Connected Quantum Key Distribution Network over 100 Users

Xu Liu[1], Rong Xue[1], Xin Yao[1], Heqing Wang[3], Hao Li[3], Lixing You[3], Yidong Huang[1,2], and Wei Zhang[1,2,*]
[1]Frontier Science Center for Quantum Information, Beijing National Research Center for Information Science and Technology (BNRist), Beijing Innovation Center for Future Chips, Electronic Engineering Department, Tsinghua University, Beijing 100084, China
[2]Beijing Academy of Quantum Information Sciences, Beijing 100193, China
[3]State Key Laboratory of Functional Materials for Informatics, Shanghai Institute of Microsystem and Information Technology, Chinese Academy of Sciences, Shanghai 200050, China
** zwei@tsinghua.edu.cn*

Abstract: A high-dimensional entanglement-based fully connected quantum key distribution network is proposed and demonstrated experimentally over 100 users, where a broadband entanglement photon pair source is shared by end users via wavelength and space division multiplexing.

1. Introduction

Many field tests of quantum key distribution (QKD) [1, 2] have been implemented, which proves it to be a reliable technology. However, most of the implementations are limited to two parties. The ability to efficiently build cryptographic keys among multiple users can significantly extend the applications of QKD. Hence, how to achieve and build practical quantum network gradually becomes the focus of research, which can bring QKD to become a widespread technology. Herein, a highly efficient entanglement-based QKD network architecture is proposed, in which more than 100 users can be fully connected based on one quantum light source. In this architecture, a broadband entanglement photon pair source at telecom band is shared by end users via wavelength and space division multiplexing. The spectrum of entangled photon pairs is divided into 16 pairs of frequency-conjugate channels and each pair supports a subnet with 8 users by a passive beam splitter. What's more, high-dimensional encoding is applied in QKD network to utilize the entanglement resource efficiently. Eventually, we show that one entangled photon source can be shared over 100 users, and high-dimensional entanglement-based QKD could be realized between any two users.

2. The Experiment and Results

The illustration of the proposed QKD network is shown in Fig. 1.

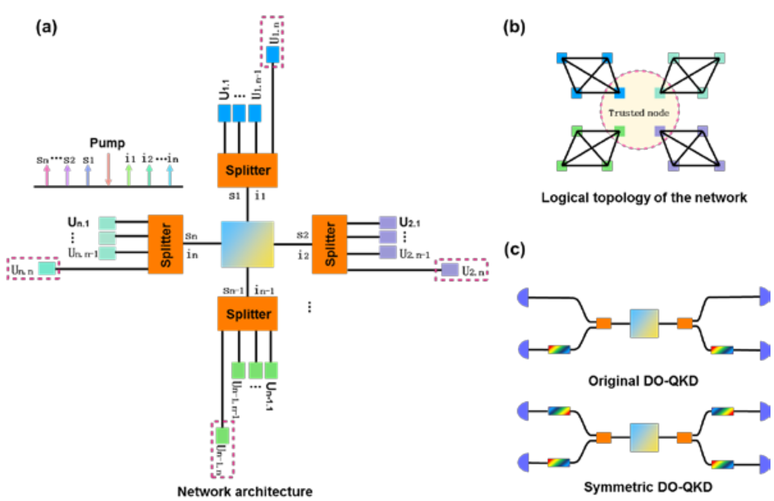

Fig. 1. (a) The sketch of the network architecture; (b) The logical topology structure of the network; (c) The sketches of the original DO-QKD and the symmetric DO-QKD.

Fig. 1(a) shows the sketch of the network architecture. The generated entangled signal and idler photons are frequency-conjugate over a wide spectrum, which are divided into different channels by wavelength division multiplexing. Each pair of these correlated wavelength channels is multiplexed into a single fiber and shared by multiple users by a 1×*N* passive beam splitter constituting a subnet of QKD. The end users in the subnet are fully connected due to the inherent correlation of the entangled photon pairs and the random routing by the passive beam splitter. The connections between subnets can be realized by a trusted node, which acts as a user marked in the dotted box in each subnet. The logical topology structure of this architecture is shown in Fig. 1(b). Every subnet is a fully connected mesh QKD network, and provides a user to the trusted node located in the center, which connects all the subnets. Obviously, the quality of coincidence events between two users in a subnet would reduce rapidly if the user number increases. To utilize the resource of coincidence events more efficiently, we introduce the dispersive optics QKD (DO-QKD) based on energy-time entanglement into the architecture. Normal and anomalous dispersion components are introduced at the two sides to carry out the security test which is guaranteed by the nonlocal dispersion cancellation effect of entangled photon pairs, which has been proven to be secure against collective attacks [3]. High dimensional time encoding can be utilized in this scheme, which supports multi-bit key generation per coincidence. However, the previous entanglement-based DO-QKD schemes cannot be introduced directly to the proposed architecture that realizes fully connected QKD network by 1×N beam splitters. Therefore, we introduce the "symmetric DO-QKD" into the network architecture as shown in Fig. 1(c), which is first proposed here to fully adapt the applications of network architecture.

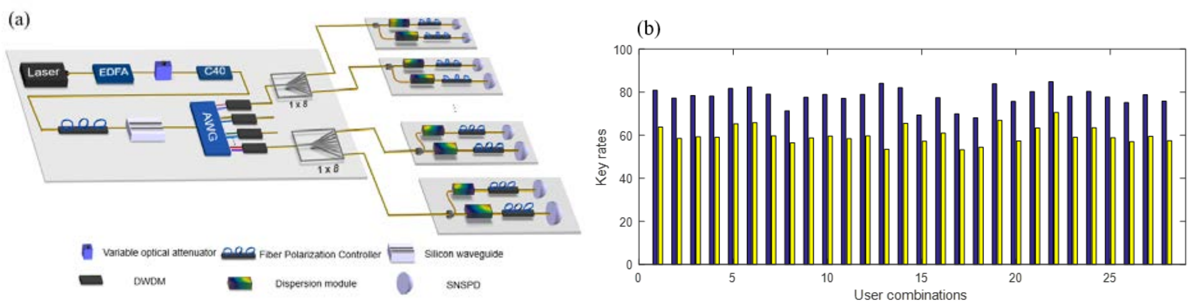

Fig.2 (a) Experimental system of the high-dimensional entanglement-based QKD network; (b) The QKD performances of all the user combinations in a specific subnet supported by photons with channels of 1552.52 nm and 1538.19 nm.

To demonstrate how many users can be supported by the proposed QKD network architecture, the detailed experimental system is established as shown in Fig. 2(a). The energy-time entangled photon pairs are generated in a broad telecom band through the SFWM effect in a piece of silicon waveguide. The wide spectrum of the signal and idler photons are divided into 32 different wavelength channels. Further, the photons of these correlated wavelength channels are multiplexed together by a dense wavelength division multiplexing (DWDM) component and then distributed randomly to 8 users by a passive 1×8 Planar Lightwave Circuit Splitter (PLCS), which constitutes 16 subnets. In each subnet, any two users can be fully connected for generating cryptographic keys based on the symmetric DO-QKD scheme. The QKD performances of all the user combinations in a specific subnet are shown in Fig. 2(b), in which the blue columns and yellow columns indicate the generation rates of raw keys and secure keys.

3. Conclusion

We successfully realized the demonstration of the high dimensional entanglement-based wavelength division multiplexing QKD network with 112 users based on only one quantum light source. It can be expected that the architecture has the potential to further scale up the number of users in a quantum communication network, such as by improving the bandwidth and brightness of the quantum light source.

4. Acknowledgments

This work was supported by the National Key R&D Program of China under Contract No. 2017YFA0303704, 2018YFB2200400 and 2017YFA0304000; the National Natural Science Foundation of China under Contract No. 61575102, 61875101, 91750206 and 61621064; Beijing National Science Foundation under Contract No. Z180012; Beijing Academy of Quantum Information Sciences under Contract No. Y18G26.

5. References

[1] Lee, Catherine, Bunandar, Darius, Zhang, Zheshen, et al., "Large-alphabet encoding for higher-rate quantum key distribution," Opt. Express **27,** 17539 (2019).

[2] Sasaki, M., Fujiwara, M., Ishizuka, H., et al., "Field test of quantum key distribution in the Tokyo QKD Network," Opt. Express **19,** 10387 (2011).

[3] Mower, Jacob, Zhang, Zheshen, Desjardins, Pierre, et al., "High-dimensional quantum key distribution using dispersive optics," Phys. Rev. A **87,** 062322 (2013).