‘Circular type’ quantum key distribution

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March 31, 2022

Abstract

‘Circular type’ interferometric system for quantum key distribution is proposed. The system has naturally self-alignment and compensation of birefringence and also has enough efficiency against polarization dependence. Moreover it is easily applicable to multi-party. Key creation with 0.1 photon per pulse at a rate of 1.2KHz with a 5.4% QBER over a 200m fiber was realized.

Quantum key distribution is expected as one of the most important technology on information security in the near future and provides two remote parties, Alice and Bob, with a common key in private manner. Many groups have reported its realization on optical fibers or others[1]-[5]. Almost all reports based on interferometric system have a problem on alignment and compensation of birefringence. Geneva group has solved this problem using Faraday mirror excellently[6, 7]. Their solution is self-alignment and compensation, that is, the two optical paths constituting its interferometric system are the same physical path and therefore the difference between the two paths is compensated automatically.

But the solution has a flaw that it is sensitive to the polarization dependent loss because the first and second paths are discriminated each other by polarization states with the polarisation beam splitter[7]. Our proposal depicted in Fig.1 adopts circular-type optics instead of a Faraday mirror and a polarisation beam splitter.

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But the optics maintains self-alignment and compensation of birefringence because the light pulses circulate the same physical path each counterclockwise and clockwise. The optics, then, minimizes polarization dependent loss because the two paths are naturally discriminated. Our system is, in addition, simpler than the Geneva group’s system and therefore has excellent performance on transfer efficiency. Though the system requires two fibers as communication channel, the installation of two fibers is not critical because multi-core-fiber cables are currently used in the real world.

In Fig.1, Bob, as well as the Geneva’s system, has a photon source and sends a photon pulse through a circulator into the system. The pulse splits at a coupler. The first half circulates the whole optics counterclockwise, where the pulse is named CCW pulse, and the second half circulates clockwise, where the pulse is named CW pulse. The CCW pulse propagates to Alice through an optical fiber (the upper fiber) and goes back to Bob through another optical fiber (the lower fiber). After passing a delay line fiber, the CCW pulse is applied a phase shift $\phi_B$ with a phase modulator in Bob (PMB) and returns the coupler. Polarisation controllers, PCA in Alice, PCB in Bob, PCC at the coupler tune the pulse to a phase modulator in Alice (PMA), PMB, and the coupler respectively. The CW pulse passes the PCC, PMB, PCB, and the delay line in the order and propagates to Alice through the lower fiber. Alice does not have the two pulses simultaneously because the delay line staggers their transit timings. Alice, then, applies to the CW pulse only a phase shift $\phi_A$ with PMA. After passing PMA, the shifted CW pulse is attenuated to the average photon number $\mu = 0.1$ per pulse with the variable attenuator A and
goes back to Bob through the upper fiber. The returned CW pulse reaches the coupler at the same time as the arrival of the CCW pulse because they travel the same optical path reversely and the two pluses give rise to interference. As the results of interference, the photon is detected at either avalanche photo diodes APD1 or APD2 according to its phase difference \( \Delta \phi(=\phi_A - \phi_B) \).

In practice, we have implemented the BB84 protocol\(^8\) using a SCIENTEX OPG-2000B-830 LASER with wavelength \( \lambda = 830nm \) and the repetition rate 100\(KH\)z. The photon source is composed of the LASER, a polarisation controller (PCL) and an isolator. We used EG&G SPCM-AQR-14-FCs, which are Peltier cooled Si-APD, as APD1 and APD2. The transmission distance between Alice and Bob was set 200m and 800m fiber was used as the delay line. We, then, obtained the high performance of 1.2Kbps as the raw creation rate and 5.4% as the quantum bit error rate (QBER).

Although almost all reports of quantum key distribution have targeted point to point link architecture, our system can, further, target one to many link architecture\(^9\). The system can naturally extend to multi-party quantum key distribution on looped networks in Fig.2, where key distribution between Bob and anyone of Alice, David, Fox, George, and so on is feasible.

Figure 2: Schematic Diagram of quantum key distribution on looped network: Cyclopastry
For example, Bob selects one entity from the four entities. The selected entity and Bob, then, perform the BB84 protocol and the other entities allow light pulses through their modules without disturbance. If they disturb the pulses, Bob and his partner notice the disturbance as eavesdropping. The proposed system requires only one quantum key distribution system though Bob can commute many entities.

In conclusion, we have presented a new simple and efficient interferometric system for quantum key distribution. Our one-to-one system was tested with a raw creation key rate 1.2KHz over a distance 200m. Our looped network system for more than two parties would be tested soon.

References

[1] Bennett, C.H., Bessette, F., Brassard, G., Salvail, L., and Smolin, J.: ‘Experimental Quantum Cryptography,’ J. of Cryptol., 1992, 5, pp.3-28.

[2] Townsend, P.D., Rarity, J. G., and Tapster, P.R.: ‘SINGLE PHOTON INTERFERENCE IN 10km LONG OPTICAL FIBER INTERFEROMETER,’ Electron. Lett., 1993, 29, (7), pp.634-635.

[3] Franson, J.D., and Ilves H.: ‘Quantum cryptography using optical fibers,’ Appl. Opt., 1994, 33 (14), pp.2949-2954.

[4] Townsend, P.D.: ‘Secure key distribution system based on quantum cryptography,’ Electron. Lett., 1994, 30, (10), pp.809-810.

[5] Marand, C., and Townsend, P.D.: ‘Quantum key distribution over distances as long as 30 km Opt. Lett., 1995, 20, (16), pp.1695-1697.

[6] Zbinden, H., Gautier, J.-D., Gisin, N., Huttner, B., Muller, A., and Tittel, W.: ‘Interferometry with Faraday mirrors for quantum cryptography,’ Electron. Lett., 1997, 33, (7), pp.586-588.

[7] Ribordy, G., Gautier, J.-D., Gisin, N., Guinnard, O., and Zbinden, H.: ‘Automated ‘plug & play’ quantum key distribution,’ Electron. Lett., 1998, 34, (29), pp.2116-2117.

[8] Bennett, C.H. and Brassard, G.: ‘Quantum cryptography: Public key distribution and coin tossing,’ in Proc. of IEEE Int. Conf. Computers, Systems and Signal Processing, Bangalore, India, 1984, pp.175-179.

[9] Townsend, P.D., Phoenix, S.J.D., Blow, K.J., and Barnett, S.M.: ‘Design of quantum cryptography systems for passive optical networks,’ Electron. Lett., 1994, 30, (22), pp.1875-1877.