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QKD and QDC via optical–wireless link for quantum mobile telephone network application

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Abstract

We propose a novel system of the simultaneous continuous variable quantum key distribution (QKD) and quantum dense coding (QDC) using a soliton pulse within the nonlinear micro-ring resonator devices. By using the appropriate soliton input power and nonlinear micro-ring parameters, the continuous signals are generated spreading over the spectrum. The polarized photons are formed by using the polarization control unit incorporating into the micro-ring system, which is allowed the different time slot entangled photon pair randomly formed. Results obtained have shown that the application of such a system for the simultaneous continuous variable quantum cryptography and dense coding within a single system is plausible, which is can be implemented within the mobile telephone hand set and networks.

Keywords: Quantum dense coding; Quantum key distribution; Optical–wireless link; Quantum telephone

1. Introduction

Mobile telephone has been brought to the world for two decades, where some technologies nave been involved in many areas of research. To date, the searching for new devices and technologies are still needed. Quantum key has become an interesting tool for communication security, especially, when the possibility of using quantum cryptography in a mobile telephone network is reported by Yupapin [1]. Suchat et al. [2] have also reported the use of a hybrid system to form the quantum key distribution (QKD), where they have shown that quantum cryptography could be performed via the optical–wireless link. They have also shown that the entangled photon states can be recovered in the link by using the quantum repeater [3]. In practice, the continuous quantum codes (keys) are required in the realistic application. Some research works have shown that there are some techniques of continuous variable quantum cryptography proposed, however, the systems are still complicated. Yuan and Shields [4] have demonstrated a robust, compact and automated QKD system, based upon a one-way Mach–Zehnder interferometer, which is actively compensated for temporal drifts in the photon phase and polarization. The system gives a superior performance to passive compensation schemes with an average quantum bit error rate. Qi [5]

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has proposed a new QKD protocol in which information is encoded on continuous variables of a single photon. In this protocol, Alice randomly encodes her information on either the central frequency of a narrowband single-photon pulse or the time delay of a broadband single-photon pulse. Ma et al. [6] have demonstrated a one-way QKD scheme based on phase encoding and polarization measurement of single photons with intrinsically stable Faraday-mirror-type Michelson interferometers that can compensate for birefringence effects automatically. Liu and Goan [7] have studied two continuous variable systems or two harmonic oscillators and investigate their entanglement evolution under the influence of non-Markovian thermal environments. The continuous variable systems could be two modes of electromagnetic fields or two nano-mechanical oscillators in the quantum domain, where there is no such a system that can be performed within a single system. In this work, we have proposed the simultaneously continuous variable QKD and quantum dense coding (QDC) system that can be implemented within the simple system, where the continuous variable quantum codes can be generated by using the different time slot entangled photon pairs. The initial codes can be generated by Alice, and finally, the retrieval codes by Bob can be performed. The simultaneous up–down link is also available via optical–wireless link.

2. Continuous variable QKD generation

To generate the broad spectrum of light over the range, an optical soliton pulse is recommended as a powerful laser pulse which can be used to generate the chaotic filter characteristics when propagates within the nonlinear micro-ring resonators [8]. When the soliton pulse is introduced into the multi-stage micro-ring resonators as shown in Fig. 1, the input optical field (E_{in}) in the form of soliton pulse is expressed

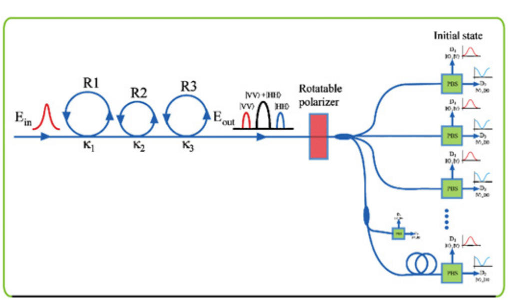

Fig. 1. A schematic diagram of a continuous variable quantum key distribution with the different time slot entangled photon encoding; PBS: polarizing beamsplitter, Ds: detectors, Rs: ring radii, and κs: coupling coefficients.

by an Eq. (1).

$$E_{in} = A\,\mathrm{sech}\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right)\right], \tag{1}$$

where A and z are the optical field amplitude and propagation direction, respectively. $L_D = T_0^2/|\beta_2|i$ is the dispersion length of the soliton pulse. This solution describes a pulse that keeps its temporal width invariant as it propagates and thus is called a temporal soliton. T_0 is known, once we can find the proper peak intensity ($|\beta_2|/\gamma T_0^2$) that will make this pulse a soliton. For example, when the micro-ring resonator at the 1550 nm wavelength, with a 12 W peak power, then $T_0 = 5$ ns long, which is a pulse of about 2 mm length (in z). For the soliton pulse in the micro-ring device, a balance should be achieved between the dispersion lengths $L_D = T_0^2/|\beta_2|$ and the nonlinear length $L_{NL} = 1/\gamma\psi_0$, which are the length scales over which dispersive or nonlinear effects make the beam become wider or narrower. For a soliton pulse, there is balance between the two and hence $L_D = L_{NL}$.

$$n = n_0 + n_2 I = n_0 + \left(\frac{n_2}{A_{eff}}\right)P, \tag{2}$$

where n_0 and n_2 are the linear and nonlinear refractive indexes, respectively. I and P are the optical intensity and optical field power, respectively. The effective mode core area of the device is A_{eff}.

Thus, the normalized output of the light field can be expressed as

$$\left|\frac{E_{out}}{E_{in}}\right|^2 = (1-\gamma)^2 \times \left[1 - \frac{\kappa[1-(1-\gamma)^2\tau^2]}{1+(1-\gamma)^2(1-\kappa)\tau - 2(1-\gamma)\sqrt{1-\kappa}\tau\cos\phi}\right]. \tag{3}$$

The close form of Eq. (3) indicates that a ring resonator in the particular case to very similar to a Fabry–Perot cavity, which has an input and output mirror with a field reflectivity, $1-\kappa$, and a fully reflecting mirror. Where n_0 and n_2 are the linear and nonlinear refractive indices, the coupling coefficient is κ. Where $\tau = \exp^{-\alpha L/2}$ represents the one round-trip losses coefficient, $\phi_0 = kLn_0$ and $\phi_{NL} = kLn_2|E_{in}|^2$ are the linear and nonlinear phase shifts, $k = 2\pi/\lambda$ is the wave propagation number in a vacuum, respectively.

In principle, to generate the continuous variable entangled photons, the chaotic signal is recommended to employ within the series micro-ring resonators. After the soliton pulse is input into the first micro-ring device as shown in Fig. 1, the continuous light modes (broad spectrum) are generated, i.e. with narrower spectral width than the input pulse, which is obtained by the chaotic signal generation. However, in practice, the evidence of such a device in realistic application is