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Efficient Heralding of Passively Spatial-Multiplexed O-Band Photons for Noise-Tolerant Quantum Key Distribution

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Abstract: We demonstrate an O-band passively spatial-multiplexed heralded photon source with 74.5% heralding efficiency for noise-tolerant quantum key distribution. Relation between QBER and noise-degraded $g^{(2)}(0)$ of heralded photons transmitted over a 10-km-long fiber is observed.

OCIS codes: (270.5565) Quantum communications; (190.4410) Nonlinear optics, parametric processes

1. Introduction

Operating O-band quantum key distribution (QKD) on non-dedicated fibers has the advantage that no restrictions need to be imposed on existing C- or L-band Internet channels [1, 2]. However, presence of noise photons due to insufficient optical suppression of Internet channels or spontaneous Raman scattering coming from these channels may seriously affect the quantum bit-error rate (QBER). For greater noise-tolerance, one can consider transmitting O-band *heralded* photons for QKD [3]. The use of heralding signals to trigger photon detectors at the QKD receiver can reject uncorrelated noise photons. We have recently shown that using a heralded photon source (HPS) instead of a weak coherent source (WCS) for QKD enhances photon signal-to-noise ratio (PSNR) at the receiver by a factor of $\chi = \alpha_s(1+\mu) / \mu$, where α_s is approximately the heralding efficiency, and μ is the mean photon-pair number per time-slot at the source [3]. This relation indicates that higher heralding efficiency can lead to improvement on PSNR.

In this work, we demonstrate an O-band HPS based on two cascaded periodically-poled lithium niobate (PPLN) waveguides (HC Photonics). The O-band photon-pairs are produced via symmetric spontaneous parametric down-conversion (SPDC) [4–7]. Reduction of optical loss at the heralded arm has enabled a heralding efficiency of 74.5%. This is much higher than the 22.4% obtained in [3]. In the present case, $\chi = 6.95$ for a choice of $\mu = 0.12$. To further obtain a higher heralding rate which would increase the key rate, we have introduced a passive spatial-multiplexing (PSM) scheme to reduce the number of undetected heralding photons due to deadtime of the heralding detector. We transmitted the heralded photons over 10 km of noisy fiber to observe the relation between QBER calculated from measured PSNR and noise-degraded second-order correlation function, which is denoted by $g^{(2)}(0)$.

2. Experiment

Fig. 1. Experimental setup. The heralding arm uses two passively spatial-multiplexed detectors, SPCMs 1 and 2. At the receiver, SPCMs 3 and 4 implement a Hanbury-Brown–Twiss type measurement. APD: avalanche photodiode; AWG: arrayed waveguide grating; DDG: digital delay generator; DL: delay line; FBG: fiber Bragg grating; FC: fiber coupler; OBPF: optical band-pass filter; PDFA: praseodymium-doped fiber amplifier; PPLN: periodically-poled lithium niobate; SPCM: single-photon counter module; WDMC: wavelength-division-multiplexing coupler

Fig. 2. (a) Heralding rates and (b) heralded photon rates versus $g^{(2)}(0)$ values of the heralded photons. These were measured without transmission fiber for different pump powers. Filled squares: using just one heralding detector; empty circles: using two heralding detectors in PSM.

Figure 1 shows the transmission experiment setup. At the heralding arm, we use two single-photon counter modules (SPCMs, id Quantique) in PSM configuration. The XOR circuit serves to suppress multi-photon components. Differing from the active multiplexing scheme [8, 9], the purpose of introducing PSM in our experiment is to reduce the number of undetected heralding photons due to a long detector deadtime such that the heralded photon rate is increased. Figure 2 shows experimental results obtained without the transmission fiber, comparing the heralding rate and heralded photon rate of the proposed PSM configuration against typical single heralding detector scheme. We found that using two heralding detectors in PSM configuration gives higher photon heralding rate by 37% and higher heralded photon rate by 16% for $\mu = 0.12$, which corresponds to $g^{(2)}(0) = 0.2$. PSM would become more effective if we could use shorter photon detector deadtimes and a larger number of photon detectors.

Fig. 3. QBER versus noise-degraded $g^{(2)}(0)$ after transmission over 10 km of optical fiber. Solid curve is theoretical prediction. Error bars for QBER are smaller than the size of the markers.

We transmitted the O-band heralded photons over 10 km of optical fiber. In this experiment, we intentionally injected noise photons to study the noise-tolerant features of the scheme. The noise photons were produced from a tunable L-band laser and they leaked through a free-spectral range (FSR) mode of the arrayed waveguide grating (AWG), emulating a real-life situation. The observed relation between QBER and noise-degraded $g^{(2)}(0)$ is plotted in Fig. 3. QBER is calculated from $[2(1+\text{PSNR})]^{-1}$, where PSNR is measured after transmission [3]. When the noise source is switched off, we assume $\text{QBER} = 0$ since we have not considered other system imperfections such as detector dark counts or basis misalignments. We see that with increasing number of noise photons, QBER increases monotonically. It is known that for QBER values exceeding 11%, no secure key can be generated. Using WCS under these noisy conditions would not allow generation of secure keys due to lower PSNR by a factor of 6.95.

3. Conclusion

We have transmitted O-band heralded photons over 10 km of noisy fiber. The photons are produced using cascaded PPLN waveguides and the measured heralding efficiency is as high as 74.5%. PSNR is improved by a factor of 6.95 as compared to using WCS. We further introduced a PSM scheme to increase the heralding rate. This work is a step towards widespread non-disruptive deployment of QKD over metropolitan area networks carrying Internet traffic.

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