Quantum transceiver for secure global communications

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We report on the development of a photonic transceiver for secure space communications in space. The device, including an entangled photon source and a faint pulse source, needs to meet unprecedented requirements in terms of performance, size, weight, energy consumption and environmental constraints.

Introduction

Quantum key distribution (QKD) enables two (or more) partners to exchange an encrypted key over a completely secure communication channel. It is used before classical information is transmitted over conventional non-secure channels (RF links, optical fibre networks…). It is based on quantum physics laws that allow encoding information into the correlation of two or more particles, and state that a single particle like a photon cannot be split or cloned, thus ensuring the absolute security of the communication. Whereas optical fibre link losses and current photon-detector technology limits quantum communication channels on Earth [1, 2] to 200 km, those problems are almost discarded in space. Previous experiments have shown the feasibility of communication over long distances [3, 4].

In this paper we present a photonic subsystem able to generate and detect entangled photons as well as faint laser pulses, called Quantum Transceiver (QTxRx). The QTxRx has to fulfill highly demanding specifications for space applications, i.e. a total size < 200 x 150 x 100 mm^3, a mass < 3 kg and a peak total power consumption (including electronics) < 15 W as well as all the severe environmental requirements (vibrations, shock, temperature, radiation).

Quantum communication terminal for space

The purpose of this project is to embed a quantum communication terminal aboard a LEO satellite, such as the International Space Station. This terminal contains a transmitter and receiver module. In the following we will focus on the former that is subject to the requirements. The transmitter gather two different experiences of quantum cryptography relying on single photons emission: a) an entangled photon source (EPS) and b) two faint pulse sources (FPS) for Decoy transmission. The EPS generates entangled photons pairs and each FPS generates pulses containing a small number of photons.

Each output of the EPS is coupled with the one of a FPS with an optical combiner. Then a two-telescope system sends photons through space to Optical Ground Support Equipment (OGSE), where they are analyzed. The EPS is used in a simultaneous key transmission scheme: each station receives one photon of each pair. After transmission both stations compare the received key: one reveals publicly to the other some random elements of the received key. If the elements match, the key is secure.

The FPS is used for a consecutive key transmission scheme, where each station receives two keys from the terminal. After the transmission, one station sends a logical combination (XOR) of both keys to the other one. Out of that exchange, one unconditionally secure key is computed.

Space environment adds constraints such as temperature range, vibrations, radiation. All the components to be used in the quantum transceiver should be selected and tested for space qualification. This point is even more critical for sensitive components like laser diodes and non-linear crystals.

Embedded Single Photon Sources

Since past decades, entanglement has been extensively studied. As entangled particles are correlated, if one is modified the other one is also affected. This property can be used to reveal an eavesdropper on a transmission: when comparing transmission results, received pairs would differ if an eavesdropper is here. The entangled particles are generated by spontaneous parametric down-conversion. The goal of this project is to develop one of the existing sources [5-7] into an integrated product compliant with space requirements, including physical dimensions, weight and power consumption. Selection criteria include optical performances, pump requirements, optomechanics.

The decoy state protocol provides full security of transmission through the use of weak pulses [8]. Signal and decoy states are pulses containing a fixed average number of photons, for example 0.1, 1 and 10 photons. Decoy and signals states should be indistinguishable in time, spectrum and amplitude from the signal states. In such manner, an eavesdropper using a photon number splitting attack will not be able to make a difference between pulses and can be detected with high probability when carefully analyzing the transmission. It has been shown that transmission is secure with three pulse levels and four different polarization states. The FPS of the QTxRx will send random levels at random polarization to both distant ground stations with a repetition rate of 10 MHz and a timing resolution better than 1 ns.

Conclusions

This project is part of the SPACE-QUEST proposal, and will be focused on the development of an integrated QTxRx, a subsystem essential to achieve global secure communications. At the conference, we will dissert on how the design, material procurement and fabrication are driven by the demanding specifications and environmental constraints. This development is funded by the European Space Agency under the ARTES-5 telecom programme, contract number 21460/08/NL/IA.

References

[1] Z.L. Yuan, A. R. Dixon, J. F. Dynes, A. W. Sharpe and A.J. Shields. *Practical gigahertz quantum key distribution based on avalanche photodiodes*, New J. of Physics, 11, 045019, 2009

[2] H. Takesue, E. Diamanti, T. Honjo, C. Langrock, M. M. Fejer, K. Inoue, and Y. Yamamoto. *Differential phase shift quantum key distribution experiment over 105 km fibre.* New J. of Physics, 7, 232 (2005)

[3] A. Fedrizzi, R. Ursin, T. Herbst, M. Nespoli, R. Prevedel, T. Scheidl, F. Tiefenbacher, T. Jennewein and Anton Zeilinger, *High-fidelity transmission of entanglement over a high-loss free-space channel*, Nature Physics (2009)

[4] C. Bonato, R. Ursin, C. Pernechele, V. Luceri, G. Bianco, P. Villoresi, T. Jennewein, F. Tam-Burini, M. Aspelmeyer, A. Zeilinger, and C. Barbieri. *Experimental verification of the feasibility of a quantum channel between space and earth*, New Journal of Physics, 10:033038 (2008)

[5] P. Trojek and H. Weinfurter, *Collinear source of polarization-entangled photon pairs at non-degenerate wavelengths*, Applied Physics Letters, 92, 211103 (2008)

[6] O. Kuzucu and F. N. C. Wong, "Pulsed Sagnac source of narrow-band polarization-entangled photons", Physical Review A 77, 032314 (2008)

[7] A. Fedrizzi, T. Herbst, A. Poppe, T. Jennewein and A. Zeilinger, *A wavelength-tunable fiber-coupled source of narrowband entangled photons*, Optics Express, 15, 23 (2007)

[8] H.-K. Lo, X. Ma, and K. Chen, *Decoy state quantum key distribution*. Physical Review Letters 94, 230504 (2005)