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Record-high secret key rate for joint classical and quantum transmission over a 37-core fiber

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***Abstract*— We overcome the low secret key rates of current quantum communication systems using space division multiplexing in a heterogeneous 37-core fiber. We demonstrate record-high rates of 107 Mb/s for the quantum channel alone and of 65 Mb/s when co-propagating with 370 Gb/s classical data.**

INTRODUCTION

Quantum key distribution (QKD) is being intensely studied as a means to securely share encryption keys for future absolute secure communication links [1]. The current critical limitations of QKD schemes are related to the short achievable propagation distances of single photon systems, the low obtainable key rates and the challenge of co-existence with classical data channels. In classical communication systems, we have recently seen great enhancements in total data capacity using space-division multiplexing (SDM) [2]. Uncoupled heterogeneous multicore fibers (MCFs) use single-mode cores with low cross-talk between the spatial channels, enabling multiple-input/multiple-output (MIMO)-free ultra-high capacity classical communication demonstrations [3-4]. The high isolation between the cores in these MCFs also renders them very useful for quantum applications, such as for enhancing the secret key rates in QKD systems either by creating high-dimensional keys (qudits) or by multiplexing keys to higher rates [5-7]. In this paper, we propose to use independent cores of a recently developed MCF counting the highest number of cores achieved to date, 37 [8], to transmit parallel QKD keys to reach a record-high secret key rate. With all 37 cores fully lit by quantum signals, we achieve a joint secret key rate of 107 Mb/s, more than 4 times higher than the previous record of 26 Mb/s [9]. Moreover, we demonstrate the robustness of our scheme by transmitting quantum channels together with classical channels: 10 Gb/s through all 37 cores for a total co-propagating classical data rate of 370 Gb/s. With all 37 cores loaded with a classical and a quantum channel, the achieved secure key rate becomes 65 Mb/s. This rate is higher than any other QKD-only reports to date, and 30 times higher than the current record for QKD-classical co-transmission [10-12]. The record-high rates achieved in this work are summarized in Fig. 1 a), showing the significant improvement compared to state of the art.

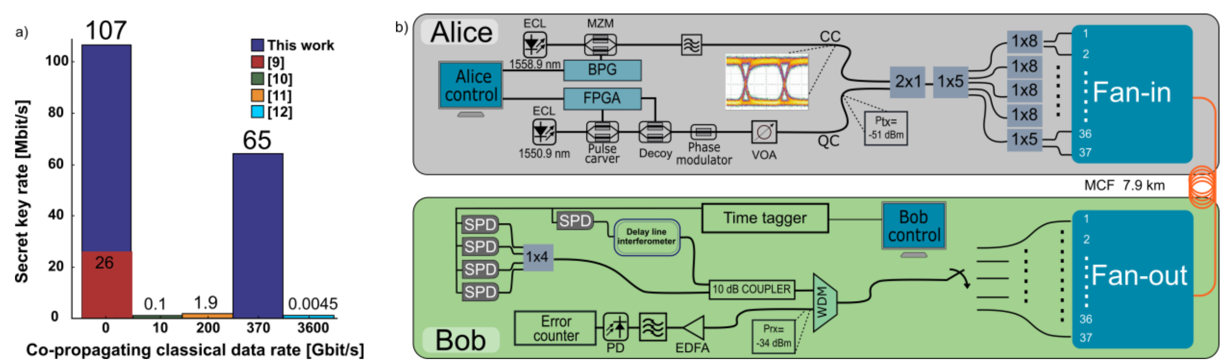

Fig. 1: a) Secret key rate as a function of co-propagating classical data rates achieved in the state of the art. b) Experimental setup. Top: Alice, the transmitter. Bottom: Bob, the receiver. FPGA: field programmable gate array; MZM: Mach-Zehnder modulator; OBPF: optical band-pass filter; CC: classical channel; QC: quantum channel.

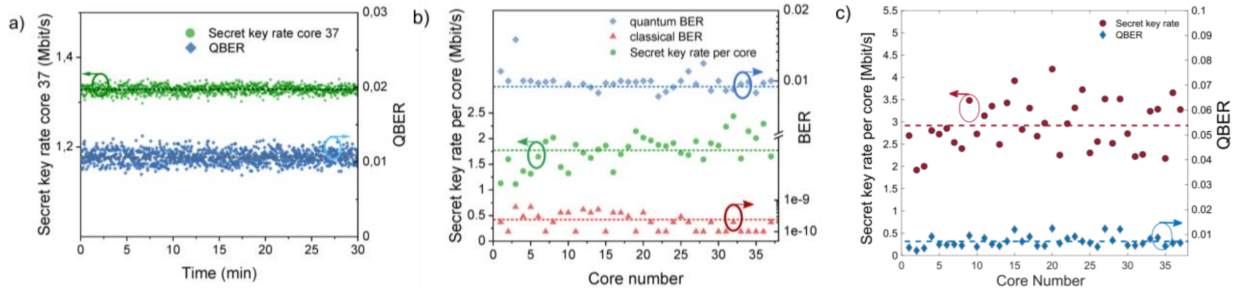

Fig. 2: a) Longterm stability of secret key rate and quantum bit error rate in core 37, in the QKD-classical co-propagation case. b) Generated secret key rate and measured quantum and classical bit error rates per core, in the QKD-classical co-propagation case. c) Generated secret key rate and measured quantum bit error rate per core, for QKD-only transmission scenario.

Experimental Setup and Results

The experimental setup is shown in Fig. 1 b). A 7.9 km 37-core uncoupled heterogeneous MCF [8] is used to enhance the secret key rate through SDM. As QKD protocol, we implement the three states time bin BB84 1-decoy state protocol with finite key analysis [13-14]. A train of pulses is generated by carving a continuous wave laser at 1550.9 nm by an intensity modulator (IM) controlled by an FPGA board. A second IM is used to randomly prepare the quantum states (595 MHz repetition rate, adding data according to the chosen QKD protocol). A variable optical attenuator (VOA) and cascaded beam splitter are used to reduce the power to the quantum regime (-74 dBm, *i.e.* an average of 0.1 photons per pulse) and to split into 37 different paths. 10 Gb/s classical on-off keying signals at 1558.9 nm are simultaneously injected into all cores of the MCF. At the receiver, a wavelength division multiplexing (WDM) filter is used to separate classical from quantum channels. The classical channel is detected using a pre-amplifier and a photodetector, and the bit error rate (BER) is measured for all channels. A free-space delay line interferometer (visibility V=0.98) is used for eavesdropping-checking in the quantum channel. We use superconductive nanowire single photon detectors (SN-SPDs) with around 60% efficiency, dark counts of 30 Hz, connected to a time tagger unit acquiring the time of arrival of the photons. The measured bit error rate for the quantum channel (QBER) and achieved secret key rate for core 37 is shown in Fig. 2 a) when measured over 30 minutes and with co-transmission of a classical channel. An average secret key rate of 1.32 Mb/s and an average QBER of 1E-2 is achieved, which is well below the requirements for the used QKD protocol. Fig. 2 b) shows results for all 37 cores in terms of secret key rate and quantum and classical BER with simultaneous co-propagation of a classical 10-Gb/s channel (with BER < 1E-9). The average secret key rate per core is 1.77 Mb/s yielding a total rate of 65 Mb/s. The measured BER for both classical and quantum channels are on average 2.4E-10 BER and 9.5E-3 QBER, respectively, being lower than standard requirements in both cases. When the classical channels are switched off, we achieve a successful transmission of a secret key rate of 2.9 Mb/s per core on average, resulting in a total rate of 107 Mb/s, with average QBER of 7.2E-3, as shown in Fig. 2 c).

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Conclusions

We demonstrated record-high secret key rates (65 Mb/s for 37 classical and quantum channels co-transmitted, and 107 Mb/s for QKD-only) enabled by parallel transmission of quantum keys in a 37-core fiber.

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