Towards high-dimensional QKD in deployed multicore fiber

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Abstract:

The demand for higher secret key rates, in conjunction with the need for extending the reach of quantum-key distribution has led to the devising of multiple novel protocols. Most of these protocols make use of qubits, owing to the simplicity with which they can be encoded in quantum communication systems that are available today. On the other hand, high-dimensional quantum states, yet more challenging to generate and transmit, enable higher secret-key rates and are more robust against errors in the process of quantum key distribution. A promising implementation of high-dimensional QKD is the one based on path encoding in optical-fiber quantum channels [1], where the most straightforward choice would be the use of multiple fibers. This choice, however, is challenged by the intrinsic non-homogeneity of different fibers. A more practical alternative is the one offered by multi-core fiber (MCF) technology, which has matured in recent years in the context of space-division multiplexed classical optical communications. In both cases, a key-requirement is that the relative phase between spatial paths is preserved, which requires some phase-stabilization procedure in the presence of propagation-induced random phase drift. High-dimensional QKD in MCFs has been recently investigated in [1], where 4-dimensional QKD on a 2-km-long MCF was demonstrated. This was possible thanks to a phase stabilization scheme in which the phase fluctuations of a co-propagating classical continuous-wave laser signal were monitored in order to compensate for the phase drift. The same stabilization system was successfully tested more recently in the unique SDM test-bed in L'Aquila [2], in Italy, on various strands of deployed MCFs, up to a total length of 26 km [3].In this work, we aim at developing a real-time high-dimensional QKD system based on joint path and time-bin encoding in MCFs. By using two fiber cores and two time bins, we generate 4-dimensional states.

Key achievements:

- **Stabilizing Channel with Phase Lock Loop**
- **QBER as low as 1% in key generation base**

High-Dimensional QKD vs. qubit-base QKD

- **Higher key generation per state transmission**
- **Higher Noise Tolerance**
- **Bounds Eve's information based on the dimension of Hilbert space, in some protocols**

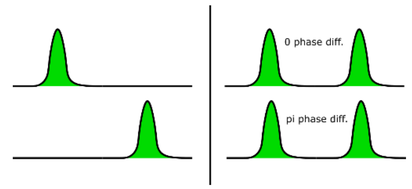
Protocol (Time-Bin + 2 Cores)

Z-basis

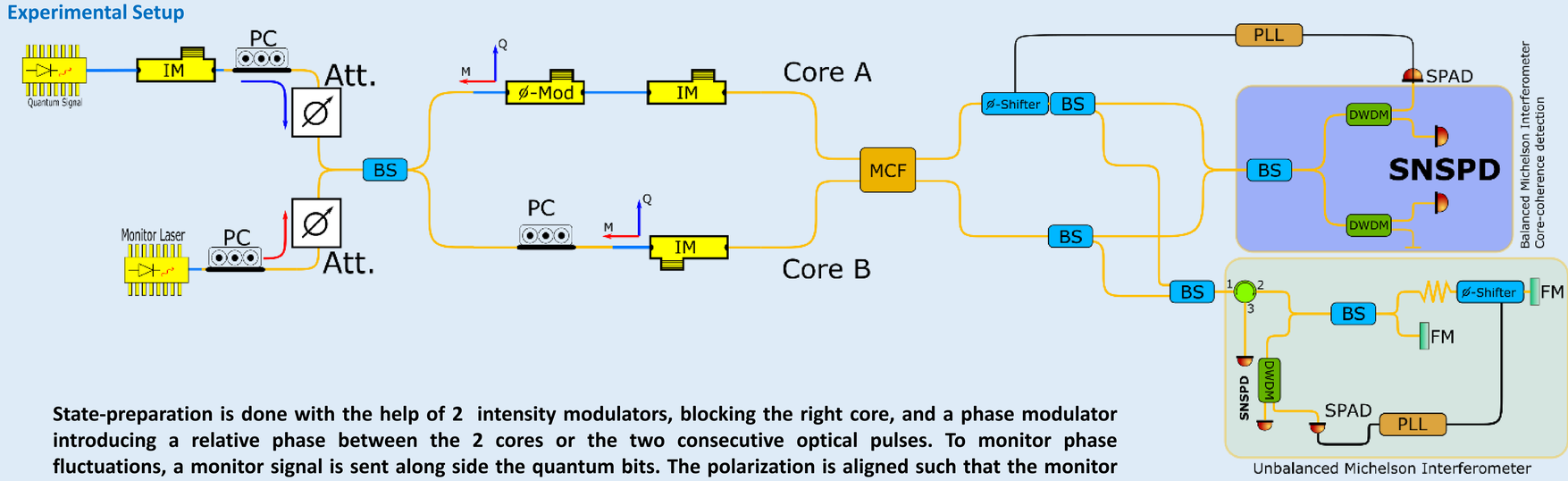
$$A + B \otimes \cap\_$$
$$A + B \otimes \_\cap$$
$$A - B \otimes \cap\_$$
$$A - B \otimes \_\cap$$

X-basis

$$A \otimes \cap \cap (0 - phase)$$
$$A \otimes \cap\cap\ (\pi - phase)$$
$$B \otimes \cap\cap (0 - phase)$$
$$B \otimes \cap\cap (\pi - phase)$$

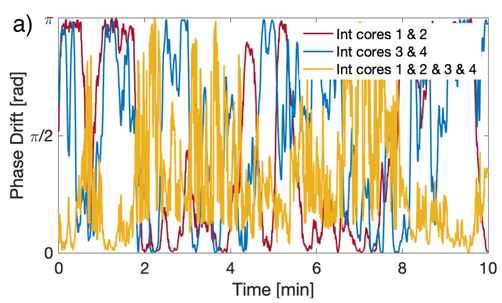


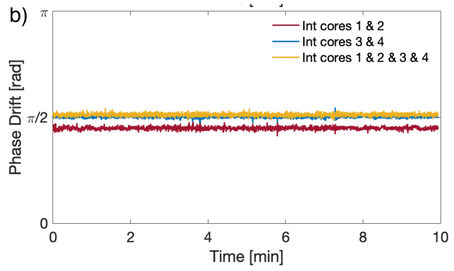
Experimental Setup



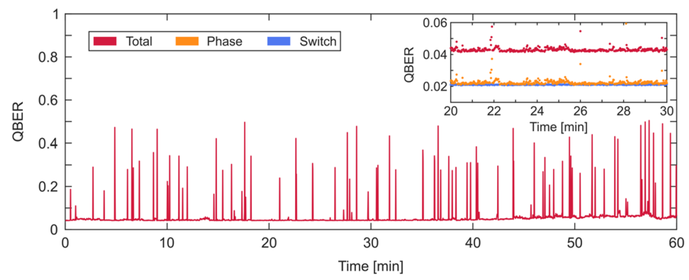
State-preparation is done with the help of 2 intensity modulators, blocking the right core, and a phase modulator introducing a relative phase between the 2 cores or the two consecutive optical pulses. To monitor phase fluctuations, a monitor signal is sent along side the quantum bits. The polarization is aligned such that the monitor signal is not modulated by intensity nor phase modulators.

Results





**Phase lock-loop performance over 10 Km of multicore fiber.
Top, relative phase drift between cores of MCF.
Bottom, relative phase when PLL is enabled.**



Measured QBER, after stabilizing phase drift between 2 cores, in 2Km Multi Core Fiber

References:

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[2] T. Hayashi, T. Nagashima, T. Nakanishi, T. Morishima, R. Kawawada, A. Mecozzi, and C. Antonelli, "Field-deployed multi-core fiber testbed," in2019 24th OptoElectronics and Communications Conference (OECC) and2019 International Conference on Photonics in Switching and Computing (PSC), Fukuoka, Japan, July 7-11,2019, pp. 1–3, IEEE, 2019.

[3] D. Bacco, N. Biagi, I. Vagniluca, T. Hayashi, A. Mecozzi, C. Antonelli, L. K. Oxenløwe, and A. Zavatta, "Char-acterization and stability measurement of deployed multicore fibers for quantum applications," 2021.