QUANTIFICATION OF INFORMATION LOSS AND RECOVERY IN NONLOCAL PMD COMPENSATION

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We propose a new treatment of polarization-mode dispersion (PMD) nonlocal compensation in the framework of quantum information theory, and we quantify its beneficial effect in terms of restoration of concurrence and quantum mutual information.

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The development of robust and efficient quantum channels is an essential requirement in the realization of quantum protocols, most of which rely on the generation and distribution of quantum entanglement among different nodes of a network [1]. A better understanding of the decoherence processes that affect the communication over the existing fiber-optic infrastructure is thus of paramount importance, as well as devising new methods to preserve the entanglement quality.
One of the most relevant decoherence mechanisms that affect fiber-optic communications is polarization-mode dispersion (PMD), which originates from the presence of random birefringence in the fiber, as a result of manufacturing- and deployment-related issues [2]. In the framework of the first-order approximation, its effect is that of pure birefringence: it causes an incident pulse to split into two orthogonally polarized replicas, which propagate undistorted. The parameters that characterize PMD vary stochastically in time, but since the characteristic time constants of buried fiber-optic cables can be as long as days, or even months [3], they can be measured and monitored at the network nodes.
The effect of PMD on polarization-entangled photons has been thoroughly investigated in recent studies [4,5], and the possibility of nonlocal PMD compensation has been demonstrated [6]. Attention has never been paid, though, to how PMD affects the information content carried by the entangled photons. We quantify this by using the quantum mutual information I(A : B) [7-9], whose definition relies on another key quantity, the von Neumann entropy.
We focus on the case where the two photons of a polarization-entangled pair generated by a pulsed-pump source transverse two different fiber-optic channels impaired by PMD in the process of reaching their parties.
After reviewing the description of photon-pair propagation in the presence of PMD, we then extend this analysis to study the dependence of the von Neumann entropy and mutual information on the PMD parameters; for a special case, we find a one-to-one analytical relation between concurrence and mutual information, and we characterize their relation in the general case. Finally, we discuss the possibility for one of the parties involved to perform nonlocal PMD compensation, by introducing a PMD element of which both magnitude and direction can be controlled. In Fig. 1 we show how this ranslates into concurrence and mutual information restoration, the quality of the compensation being affected by some system parameters (such as Alice's PMD magnitude and the pump bandwidth).

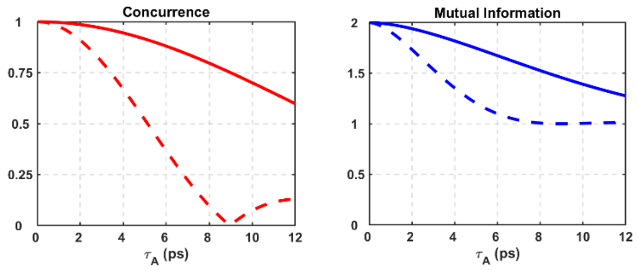

Fig. 1 Concurrence (left) and quantum mutual information (right) as functions of Alice's PMD magnitude; dashed lines are for the uncompensated case, while solid ones are for the case of nonlocal compensation performed by Bob.

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