Multiplexing QKD systems in Conventional Optical Networks

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Current QKD designs try to keep the quantum channel as error free as possible by using a separate physical medium for this purpose. In the most common case, this means the exclusive use of an optical fiber for the quantum channel, precluding its use for any other purpose. In current optical networks, the fiber is the single most expensive element and this poses a major problem from a cost and availability point of view. Sharing the fiber is thus mandatory for the widespread adoption of QKD. The objective of this communication is to propose a general scheme and present some preliminary measurements of a metropolitan area network (MAN) designed to multiplex of the order of 64 addressable quantum channels and the associated QKD classical service signals on a single dark fibre. It uses as much existing components and infraestructure as possible in an attempt to simultaneously lower most of the practical barriers for the adoption of QKD.

Introduction

Modern telecom networks are using passive components and WDM as the multiplexing technology [1]. Therefore, a direct optical path between two points can be established, and thus a quantum channel. Ideally, QKD systems would simply use one of these wavelengths in the WDM ITU grid, but the power difference between quantum and classical signals (70-100 dB) would limit the number of QKD systems to just a few [2]. Instead, in our WDM scheme, we multiplex only the quantum channels and the classical service signals needed to stabilize each quantum channel. Quantum signals use wavelengths around the O band of the spectrum (1260-1360 nm), and the classical ones use the C band (1530-1565 nm). This allows to: (i) use standard telecom components for the classical signals; (ii) strongly reduce the noise due to the 200 nm separation; and (iii) ease their manipulation by keeping them in separated groups, thus allowing for wavelength-addressing schemes. Fibre absorption in the O band increases ≈ 0.1 dB/km over C band, but this is a minor concern in MANs, since losses stem primarily from wavelength independent components and splices.

QKD Metropolitan Area Network

Fig. 1 shows the design of a QKD-MAN using our QKD network model. The network is divided into WDM-PON access networks, where QKD systems are connected, and a DWDM backbone network, which connects all access networks. Each access network has assigned a quantum O-subband and the corresponding, AWG-periodic, C-subband for the associated service channels. The structure matches a real telecom MAN, allowing the use of as much existing commercial components as possible. Dotted rectangles mark the network devices that we have modified according to our WDM scheme. In particular, backbone nodes route quantum and classical subbands to the corresponding access network using band-pass filters and circulators, and access networks use optical switches and the periodicity of the AWGs to ensure all-to-all connectivity in the network. QKD devices select the destination by just choosing the wavelength and setting the port in the switch connected to the nearest AWG. The losses of each path are kept within the loss budget of modern QKD systems (approx. 30 dB) [3].

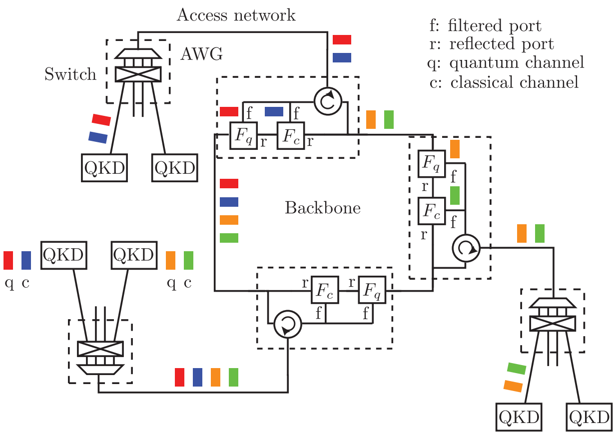

Fig. 1. QKD-MAN: DWDM-PON access networks are linked through a simplified ring core. Any pair of QKD devices is capable to establish a QKD channel (quantum+classical) no matter their access neworks. The colors (pairs) represent the wavelengths of the channels of each QKD (one pair, e.g., red-blue, represents the QKD link). Simultaneous connections are possible sharing all the components. Note that the network depicted is a general one; a real one, with more fixed connections, can bypass some of the devices and have less losses.

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Results

To estimate the maximum number of simultaneous QKD conections of this network, we have started with the scenario represented in Fig. 2. As the figure shows, it is a simplification of the QKD-MAN in which only AWGs are used. Although the rest of the components are bypassed (e.g., filters), the result is valid. In fact, this is a worst-case scenario from the noise perspective, since the effect of the bypassed components mainly amounts to either, a further filtering of the signal or extra losses, thus reducing the noise in the detectors.

The powerful classical signals are simulated using a standard telecom SFP transceiver at 1510 nm with a peak power of +2 dBm. The SFP is connected to one of the inputs of the AWG. Then, after 9.5 km of single-mode fiber, the optical spectrum at a non-adjacent port of the output AWG is analyzed. The total loss is approx. 12 dB at 1310 nm. The original spectrum of the SFP transceiver (marked LD in Fig. 2) and the resulting one after crossing the network (measured at the end point marked OSA in Fig. 2), are shown in Fig. 3.

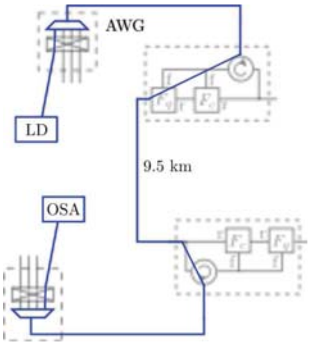

Fig. 2. QKD-MAN overlapped with the experiment's scenario (blue line). Legend: LD, laser diode (in particular, a SFP transceiver), and OSA, optical spectrum analyzer.

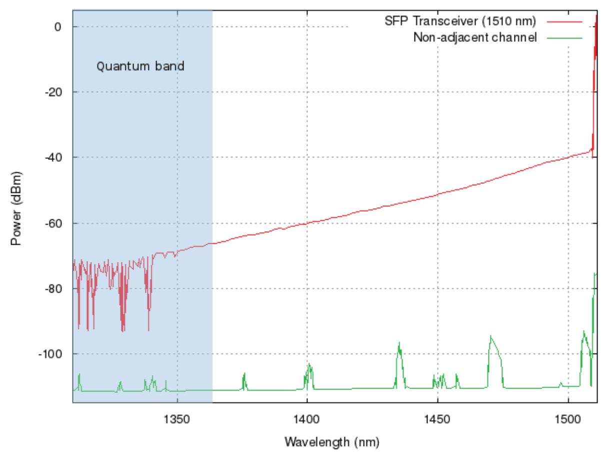

Fig. 3. Power spectrum of the classical test signal (launch +2 dBm, 1510 nm, red line) and the unfiltered (other than the AWGs and devices shown in Fig. 2) output (green) through the network.

In the 1510-1350 nm range, the spectrum presents several peaks due to crosstalk and the periodicity of the AWG. The noise level in the quantum band (blue region) is below -110 dBm ($<$ 60 KHz). If we take into account the insertion losses of all the bypassed components in the network (a total path loss of approx. 30 dB, although in many circumstances could be reduced to 20 dB), the noise level is reduced to $<$-130 dBm ($<$0.47 KHz). Now, considering that a modern SPD has a darkcount probability between 10^{-4} and 10^{-5} (with a freq. of 100 MHz, equivalent to a darkcount rate of 10 KHz and 1 KHz), this would allow for a network using a standard 64 channels AWG at the same time without affecting the performance of the QKD systems. Therefore, the performance of the QKD systems is not expected to change. Further filtering, pulse shaping and optimization of the classical signals used to stabilize the quantum channel would reduce still more the noise. The limiting factor would become then the network losses.