Integrating QKD into commercial optical transmission systems

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Abstract

Quantum Key Distribution (QKD) systems have evolved from pure research to first products. First demonstrations of QKD over deployed fiber have been reported, but so far, all these systems have employed dedicated dark fiber. QKD would be most useful if it could be added to existing optical transmission systems without requiring major changes in the network architecture. We discuss the conditions under which real optical transmission systems operate and how QKD could be incorporated into them.

Introduction

Commercialization of Quantum Key Distribution (QKD) systems has begun. However, currently available products are stand-alone systems. To realize the full potential of Quantum Cryptography (QC) for secure communications, it is necessary to integrate it into state-of-the-art communication systems. The main difficulty here is preventing the classical channels from causing decoherence of the quantum channel.

All state-of-the-art fiber-optic data transmission systems use the so called Wavelength Division Multiplex (WDM) technology to enhance the capacity of a single optical fiber. Up to 80 different optical wavelengths, each carrying its own data signals, are multiplexed onto a single optical fiber and transmitted to the receiving station. The wavelengths around 1540 nm are used and are standardized by the ITU [1]. A suitable QC system therefore has to work within this wavelength grid and ideally occupies only one wavelength. Typically, the signal powers of all WDM channels are comparable and the per-channel launch power exceeds 0 dBm. However, QKD relies on the detection of single photons or pairs of photons, leading to much lower channel powers. The detection of one photon every ns corresponds to an optical power of only -70 dBm. Therefore care has to be taken to spectrally isolate the QKD channel from the signal channels. Even then, nonlinear effects such as four-wave mixing (FWM) and stimulated Raman scattering lead to the generation of off-band photons which have to be prevented from interfering with the quantum channel.

Another concern, which is easily overlooked while developing the physical concepts, is the ease of management, installation, and maintenance required by commercial systems.

State of the Art: Quantum Cryptography in WDM System

QC channels have been shown to work within the standard ITU 100 GHz wavelength grid with the only restriction that no Erbium Doped Fiber Amplifier (EDFA) or other Amplified Spontaneous Emission (ASE) sources are included in the QC signal path [2,3]. QKD in single WDM links is possible due to the fact that the data rates in QKD are very low, thus the optical bandwidth which is covered by the QC signal is only a few MHz wide or even smaller. Therefore, by the use of cascaded, extremely sharp band- rejecting optical filters the influence of the 10-orders of magnitude more intense neighboring WDM signals can be filtered out. As the Quantum channel has only a bandwidth of a few 100 kHz, the spectral power density of the light generated by nonlinear processes from the WDM channels is sufficiently low. At the transmitter side of a WDM-QC mixed system the channels can be sufficiently separated by the use of high-quality optical filters.

Integrating a Quantum Channel

The following conditions for a QC channel in a WDM system are derived:

- As Raman generates more low energy photons, the QC Channel should lie in the highest optical frequency band of the system. If this is not possible the QC channel should be close to the higher channels to minimize the overlap with the Raman spectrum.
- Suppressed carrier modulation schemes in the WDM channels are minimizing the FWM products.
- In order to further minimize FWM products, the QC channel should be off-center from the WDM frequency grid, i.e. if the WDM channels are using the 100 GHz ITU grid, the QC channel should be ideally within the 50 GHz subgrid.
- In order to relax the requirement on the multiplexing filter which adds the WDM and the QC channels, a spectral distance of the QC and the WDM channel of two or more ITU grid spacings is recommended.
- All WDM transmission systems have an out of transmission band Optical Supervisory Channel (OSC) which is used to transmit administrative information with a low bitrate. This channel is usually spectrally located at shorter wavelengths

than the WDM data transmission channels. The OSC will generate Raman photons in the QC channel. If the number is too high, the QC channel could be either multiplexed with the OSC on a time division multiplex basis or, the QC channel sends only when the OSC sends a logical zero. The OSC bitrates are relatively low so that such a solution may be possible.

- Reach enhancement: The length of single spans of today's telecommunication transmission systems is up to 140 km. Most spans have a length of about 70 km, but also a significant part is longer. As current QKD systems have a realistic reach of about 50-70 km, their reach has to be extended to at least 100 km.
- Accurate wavelength stabilization of the filter and the QKD sources: The effective reduction of alien photons within the QKD channel works only if the transfer functions of the optical filters which eliminate the WDM channels are extremely sharp and additionally extremely stable against changes in the ambient conditions. Such elements can be built but their complexity and price have to be reduced.
- Key rate enhancement: The key rate for long reach spans is not sufficient yet and has to be increased.
- Shrinking of the systems: A viable QKD system has to consist of a printed circuit board (PCB) containing the electronics and mounted on the same PCB, the QKD optics which is all fiber-based. Such a PCB can then be used as a plug-in module of a bigger system.
- "Auto adjustment": Any QKD card has to work off the shelf. Necessary adjustments due to component drifts induced by temperature or aging have to be compensated for automatically
- "Hands off" installation and operation: Any technical service personal has to be able to install a QKD card after a short training. The up-time of a QKD system has to be enlarged to several years. The average availability has to be 99.xx%, xx depending on the Service Level Agreement.

Classification scheme for QC in WDM systems

To classify the expected performance of QKD in WDM systems, the authors propose a four quadrant scheme. Such a set of curves is shown in Figure 2 for a typical system as described in [4].

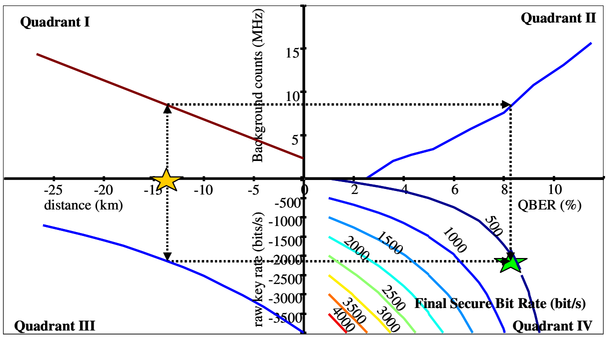

Figure 1: characteristic curves for a QKD in WDM system as described in [4]

Three independent curves, each characteristic for the respective QKD system, are plotted in the quadrants I, II and III. A simple rule connects the curves such that for any given parameter the resulting key rate can be read out from the fourth quadrant. The first quadrant plots the rate of background photons and dark clicks against the fibre length. This curve depends on the characteristics of the fibre (i.e. Raman, WDM filter characteristics and FWM). The second quadrant shows the quantum bit error rate (QBER) against the background rate derived from the first quadrant. This curve depends on the characteristics of the QKD system. The third quadrant contains the classical plot of the raw key rate against the transmission length which is again dependent of the used QKD system. From the resulting raw key rate of the third quadrant and the QBER from the second quadrant the final secure key rate can be read off the fourth quadrant. Such a presentation allows a quick estimation of the performance of a specific QKD system within an optical WDM network.

Conclusions

A number of constraints and requirements for the integration of QKD have been discussed and a classification scheme has been presented. The operation of QKD over WDM systems is feasible and first simplified links have been shown. Full integration in commercial WDM transmission systems still needs a lot of research, but their deployments should only be a matter of time.

References

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