Experimental Study of Co-propagation of Quantum and Optical Signals with Flattened and Spectrum-flexible Switching Node

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Abstract: We demonstrate an experiment about co-propagation of quantum and optical signals with flattened and spectrum-flexible switching node that could integrate quantum-key-communication(QKD) network with optical network and show the ability of supporting two kinds of communications and the flexibility of spectrum and bandwidth allocation.

OCIS codes: (060.5565) Quantum communications, (060.1810)Co-switching devices

1. Introduction

Quantum key distribution provides an unconditional physical layer for secure communication and uses non-orthogonal coded single photon states, such as single photon polarization, phase or angular momentum, to provide secure information. These all can be transmitted and switched as same as optical signal in the fiber. So far, the study on point-to-point co-fiber transmission for QKD communication has been quite mature. More and more researchers have turned into studying large-scale and multi-user QKD network based on optical network. In 2003, [1] made an experiment of an optical switching system for QKD communication based on the 4x4 2-D MEMS switch array and reached a transmission distance more than 10 km. But this system couldn't support the case of the co-switching of multiple wavelengths that have different destination. In 2016, [2] proposes a unequal frequency spacing (UFS-iWDM) frequency allocation to to reduce four-wave mixing(FWM) noise that falls at the quantum channels that improve the performance of co-propagation. The schemes above neither considered to integrate the quantum network into the existing optical network. This paper will present an flattened switching node scheme supporting the co-propagation of quantum signal and optical signal, the node is based on WSS and coupler and could provide abilities of flexible spectrum allocation and non-blocking switching.

2. Flattened and spectrum-flexible switching node based on WSS

To integrate QKD with optical communication, we should know features of both quantum signal and classic signal. The quantum signal can't be amplified, it needs the link loss to be extremely low, while the classic signal is not sensitive to the link loss. When passing through the beam splitter, quantum signal only appear in one branch of the beam splitter at a specific probability, while classic signal appear in all branch of the beam splitter at a specific ratio of the input power. In the process of QKD, the delay time between quantum signal and synchronization signal has an important effect on key generate rates. The synchronization signal is needed to have the same path with quantum signal on the link layer to keep the signal synchronized. Meanwhile,quantum signal is extremely weak and is very easy to be disturbed by classic signals of other channels, so it's very important to consider the effects of classic signals on quantum signals when they are co-propagated. Luckly, WSS could meet all these requirements and the switching node structure based WSS and coupler is showed in figure 1.

Switch node has characteristics of flexible grid, multi-granularity, low loss, non-blocking. So it could switch signal with variety of bandwidth simultaneously and could achieve 'Packet Routing' that the signals who have same destination but different center wavelength and bandwidth could always passing through the same classic fiber path. Based on this switching node, we could also design a wavelength allocation algorithm to reduce the impairment on the quantum channels induced by four-wave mixing (FWM). When expanding node's degree, it doesn't increase the device cascade, Since it's attenuation remains stable, approximately 3.5 dB under current technical conditions.

For classic signal, There is only one constraint that the signals couldn't overlap in the spectrum when switched to the same port. In figure 1, wave 2 and wave 6 have different center wavelength, but their spectrum have a little

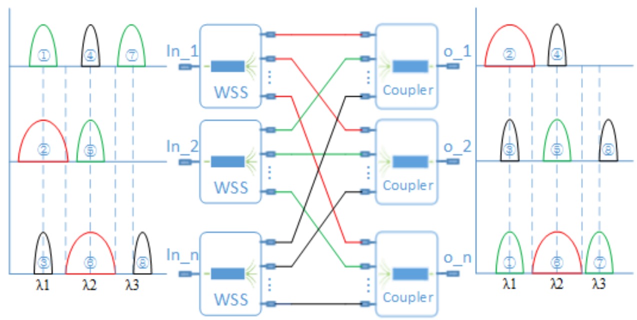

Fig. 1. Switching Node Structure.

intersection, so they can't be switched to the same port. For quantum signal, we could compute the channels that FWM sit on according to the current classic signal passing the node, and make quantum signal stay away from these channels to reduce the interference induced by FWM when allocating the quantum signal channel. In the past studies, someone have proposed switching node based on WDM and OXC, and multi-granularity switching node of three-layers based on DWDM, CWDM and OXC. The comparisons of these three structures in figure 2 and 3 show that the flattened switching node we build has lower loss and more transmission distance.

	Device Passing Through		Insertion Loss	Node Total Insertion Loss
Switch of WDM and OXC	1*4 DWDM		1.8dB	8.3dB
	16*16 OXC		6.5dB(Max)	
Swith of Multi-granularity	Fiber Level	4*4 OXC	2.5dB(Max)	10.6dB
	Waveband Level	1*2 CWDM	0.8dB	
		4*4 OXC	2.5dB(Max)	
	Wavelength Level	1*4DWDM	1.8dB	
		8*8 OXC	3dB(Max)	
Switch of WSS and Coupler	1*4 WSS		4.2dB(Max)	4.4dB
	Coupler		0.2dB	

Fig. 2. Comparison of Insertion Loss

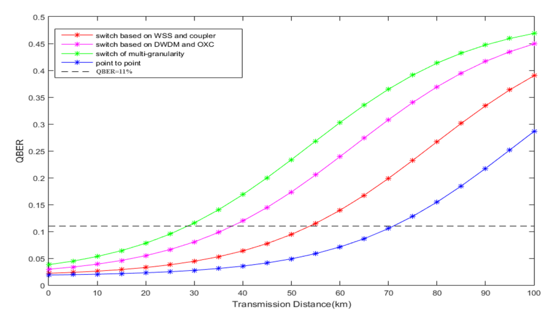

Fig. 3. Transmission Distance vs QBER

3. Experiment setup

Our experimental implementation is composed of quantum transmitter/receiver, optical transmitter/receiver and the switching node as figure 4 show. Alice have abilities of sending the quantum signal, quantum sync signal and classic signal. Bob could receive and demodulate these three kind of signals. QKD transmitter consists of a pulsed

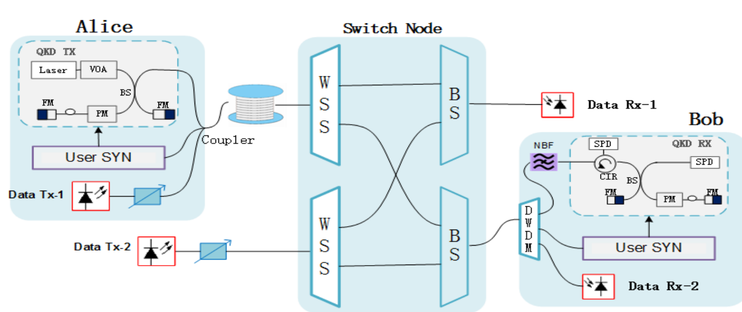

Fig. 4. Experiment setup based Coexistence Switching Node

light source (LS), a Faraday-Michelson interferences containing a phase modulator (PM), splitter and Faraday mirror(FM). QKD receiver has signal photon detector(SPD). Since it is difficult to create true single photon pulses, a pulsed 1553.73nm laser diode (1-ns pulse width) with 10MHz repetition rate is followed by variable optical attenuator(VOA) to approximate single photon generation. In order to detect the quantum signal within the appropriate time, we need a signal to synchronize the time of detection and set it's center wavelength 1529.99nm. There are two 1550nm Optical waves for sending large data as text, image, video etc. When performing quantum communication, there are a lot base selection information needed to be send on the public network. Since the switching node is unidirectional, if we make the public network through the quantum switching node and switched by switching node, we need to build two switch nodes. In cost consideration, we build another public network without switching that connect Alice and Bob directly. In this experiment, we set up three sets of contrast experiments. (a) Point-to-point quantum communication experiment; (b) Only quantum communication passes through the switching node; (c) Quantum communication and classic communication pass through the switching node at the same time.

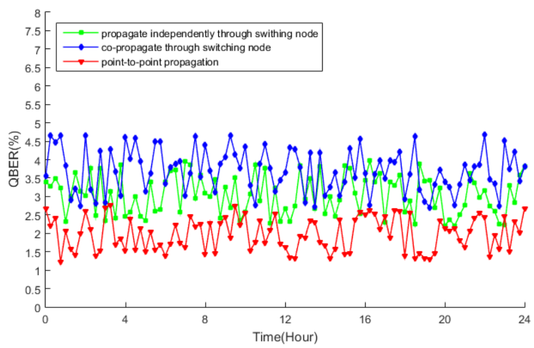

Fig. 5. QBER performance for 24 hours

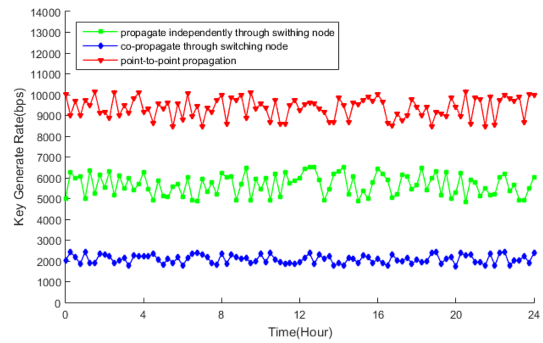

Fig. 6. Key Generation Rates performance for 24 hours

Figure 5 and 6 show the system performance of continuous 24 hours operation. the results show that the co-propagation switching could be realized by this switching node and the QBER and key generation rate is acceptable. In point-to-point situation, the average QBER is 1.7%, and average key generate rate(KGR) is 9000bps. In co-propagation situation, the average QBER is 3.7%, and average KGR is 2300bps. Although it has declined, but still acceptable.

4. Conclusions

We demonstrate an experiment on flattened and and Spectrum-flexible switching node with co-propagation of quantum and optical signal. This architecture support flexible spectrum and bandwidth allocation and has ability of switching signals mixed by quantum signal and optical signal.

5. Acknowledgements

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