

Flattened Switching Node with Flexible Co-propagation of Quantum and Optical Signals

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Abstract: We propose a flattened switching node with flexible co-propagation of quantum and classical optical signal that could combine the quantum key distribution network and Optical network into one. and we exhibit a stable experimental platform that could show the value of the use of this structure.

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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, Paul Toliver made an experiment of an optical switching system for QKD communication based on the 4x4 2-D MEMS switch array under the B92 protocol and reached a transmission distance more than 10 km while the device attenuation is 5.9 dB. But this system can't support the case of the co-propagation with multiple wavelengths that have different destination. In 2010, Shuang Wang et al. Of China University of Science and Technology proposed a wavelength-saving quantum signal switching device composed of a three-port loop and wavelength division multiplexer, and this scheme has lower power loss and higher stability than using active device. However this scheme adopted the real-time full connection and increased the complexity of the network. without using beam splitter, the scheme above two have a certain routing path for quantum signal, but 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. Difference between quantum communication and classical optical communication

To integrate quantum communication with optical communication, we should consider similarities and differences between quantum signal and optical signal. The quantum signal can't be amplified, it needs the link loss to be extremely low, while the optical 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 optical 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. However, the classical optical signal doesn't require additional synchronization signal. Meanwhile, quantum signal is extremely weak and is very easy to be disturbed by optical signals of other channels, so it is very important to consider the effects of optical signals on quantum signals when they are co-propagated.

3. Flattened switching node based on WSS

We makes full use of the characteristics of WSS: (a)Flexgrid Dynamic Channel Width Control; (b)Flexgrid Dynamic Attenuation Control; (c)Channel plans are configurable 'on-the-fly'. These three features simultaneously meet the needs of co-propagation switching of quantum signal with optical signal. the switching node structure is showed

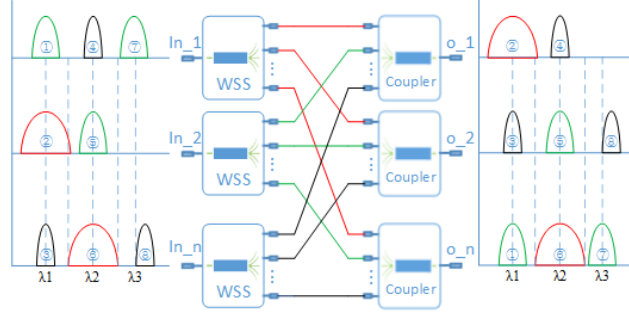


Fig. 1. Switching Node Structure.

as figure 3. The switch node only have two kinds of optical devices, WSS and coupler. It has the 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 optical 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 optical signal, this switching node only have one constraint that the signals switched to the same port can't overlap in the spectrum. For example, in fig.1. wave 2 and wave 6 have different center wavelength, but their spectrum have a little 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 optical signal in the fiber, let the quantum signal stay away from these channels to reduce the interference induced by FWM when allocating the quantum signal channel. In the past studies, some have proposed switching node based on WDM and OXC, and the three-layers multi-granularity switching node based on DWDM, CWDM and OXC. There are some comparisons to these three structures below.

	device of passing through		Insertion loss	Node total insertion loss
switch based on DWDM and OXC	1*4 DWDM		1.8dB	8.3dB
	16*16 OXC		6.5dB(Max)	
switch 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*4 DWDM	1.8dB	
switch based on WSS and Coupler	8*8 OXC		3dB(Max)	4.4dB
	1*4 WSS		4.2dB(Max)	
	Coupler		0.2dB	

Fig. 2. Comparison of Insertion Loss

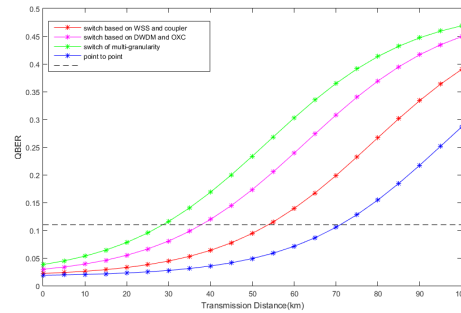


Fig. 3. Transmission Distance vs QBER

4. Experiment setup

Our experimental implementation is composed of QKD transmitter/receiver, classic optic transmitter/receiver and quantum/optic coexistence switch node. Alice have abilities of sending the quantum signal, quantum sync signal and classic optical signal. Bob could receive and parse these three kind of signal. QKD transmitter node consists of a pulsed light source (LS), a Faraday-Michelson interferences(FM) containing a phase modulator (PM) and a variable optical attenuator(VOA). QKD receiver node has one more 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 500MHz repetition rate is followed by variable optical attenuator to approximate single photon generation. In this case, the photon number will follow a Poisson statistical distribution and, to limit eavesdropping, the power of the signal exiting Alice is set to a value lower

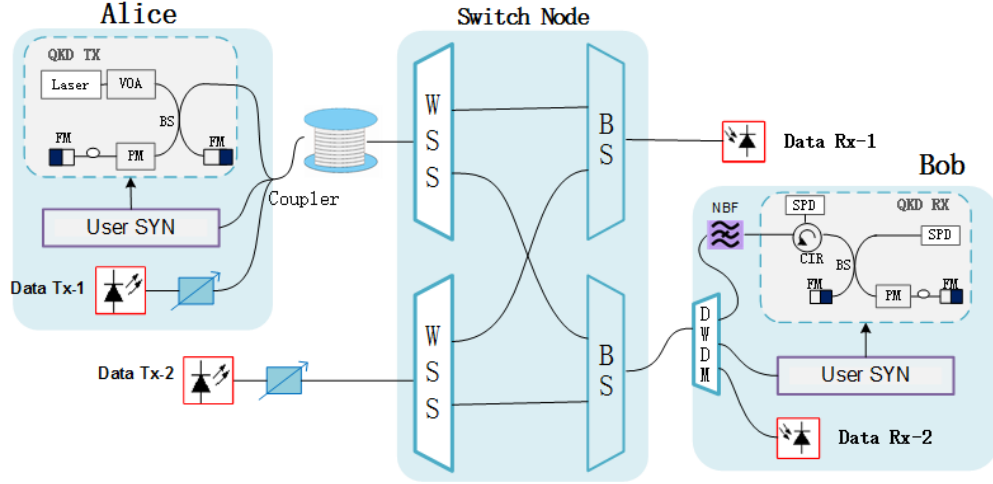


Fig. 4. experiment setup of coexistence switching node

than 1 photon per pulse on average (to reduce the probability of any given pulse contains more than one photon). In order to detect the quantum signal within the appropriate time, we need a signal to synchronize the time of detection and set its center wavelength 1529.99nm. There are two 1550nm Optical Netcard 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 let the public network through the quantum switching node and switched by node, we need to build two switch nodes. In account cost consideration, we build another public network without switching that connect Alice and Bob Directly. In the 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 classical optical communication pass through the switching node at the same time. The experimental results of the three experiments are shown in the following figure.

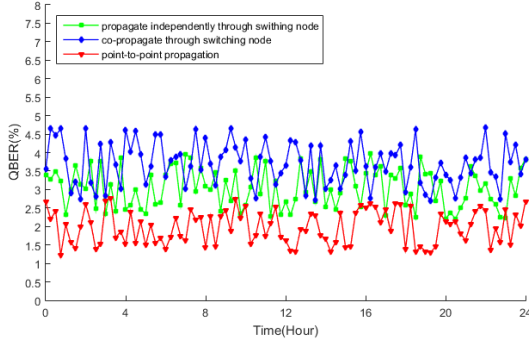


Fig. 5. QBER performance for 24 hours

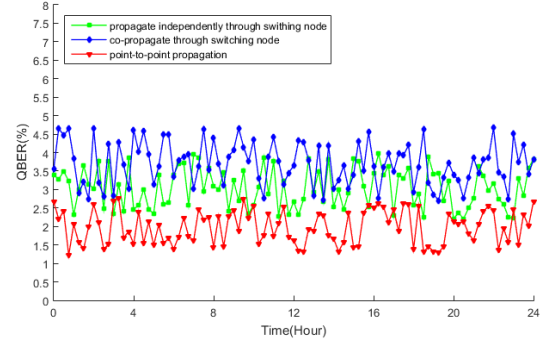


Fig. 6. Key generation rates performance for 24 hours

5. Conclusions

We proposed a flattened flexible non-blocking switching node with quantum and classic optic coexistence, this architecture could be compatible with the switch of quantum signals and classical optical signals, quantum communication optical network and the integration of the classic optical network to provide the basis, which provides the foundation for the integration of quantum communication optical network and classical optical network.

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