

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

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**Abstract:** Quantum key distribution provides an unconditional physical layer for secure communication. Study on switching and large-scale Networking problems in Quantum Communication could promote QKD communication to industrialization and practical. The current quantum switching nodes can only handle the wavelength of a specific bandwidth and have a strong constraint on the path of the transmission. And the spectrum reuse rate is very low. So it can't meet the demands of build large-scale network. This paper will present a WSS-based flattened flexible and non-blocking switching node that could support quantum communication and classic optical communication at the same time with multi-granularity.

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## 1. Introduction

QKD uses non-orthogonal coded single photon states, such as single photon polarization, phase or angular momentum, to provide secure information exchange for two remote users. These all can be transmitted and switched same as classic optic signal in the fiber. So far, the study on point-to-point QKD communication based on fiber-optic links has been quite mature. More and more researchers have turned to large-scale and multi-user QKD communication network systems based on existing optical devices, and strive to make QKD communication network and existing optical network one integration. In 2003, Paul Tolver experimented with the optical switching system of the QKD communication based on the 4x4-based 2-D MEMS switch array under the B92 protocol and reached a transmission distance of more than 10 km at the time of the device attenuation of 5.9 dB. But this system can not achieve the signals with the existence of multiple wavelengths in one fiber are transmitted and switched, only can provide signal switching services for the fiber that only contains one signal. 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 loopier and wavelength division multiplexer, and this scheme has lower power loss and higher stability than using active device. However this scheme also adopted the real-time full connection, increased the complexity of the network, and is difficult to expand. Although the wavelength can be reused, but the reuse rate is relatively low. the scheme above two have a certain routing path compared with the using of beam splitter, but neither considered to integrate the quantum network with the existing classical optical network. This paper presents an quantum switching node scheme supporting the coexistence of quantum signals and classical optical signals based on WSS and coupler and providing more flexible spectrum allocation and non-blocking switching for any wavelength with any bandwidth in any input port.

## 2. Difference between quantum communication and classical optical communication

To integrate quantum communication with classical optical communication, we should consider the same point and difference between quantum communication and classical optical communication. The quantum signal can't be amplified, it needs the transmission link loss to be extremely low, while the classic optical signal is not sensitive to the link loss due to the signal power is very large. The quantum signal will show in one branch of the beam splitter at a specific probability when passing through the beam splitter, while the classical optical signal is transmitted to the branch of the beam splitter at a specific ratio of the input optical power. In the process of quantum communication, the delay time between quantum signal and synchronization signal has an important effect on secret key generate rate. the synchronization signal is needed to transport in the same way 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 the classic optical signals of other channels, so it is very important to consider the effects of classical signals on quantum signals when this two kind of signals are transported at the same time in the same fiber or switching node.

### 3. Flattened switching node based on WSS

This article 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 quantum signal switching and classical optical signal switching, Which can be used to simultaneously transmit quantum signal and classical signal. the switching node scheme is show as figure 1. The

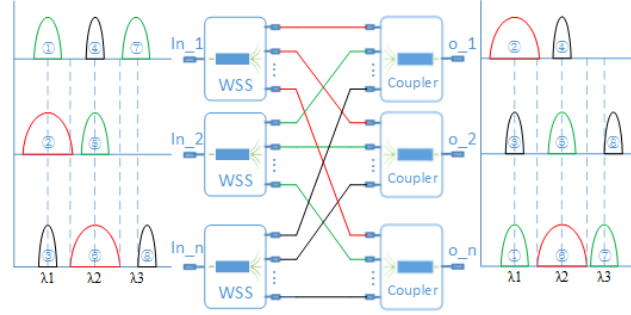


Fig. 1. Switching Node Structure.

switch node only have two kinds of optical devices, WSS and coupler and have the characteristics of flexible grid, multi-granularity, low loss, non-blocking. it has the flexibility to switch a variety of bandwidth signals Simultaneously and it can achieve "Packet Routing" that the signals that have same destination but have different center wavelength and bandwidth could always keep in the same fiber. 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 the degree, it doesn't increase the device cascade, and it's attenuation remains the same, 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*4DWDM	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

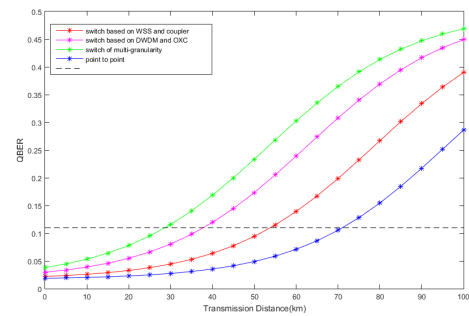


Fig. 3. Transmission Distance vs QBER

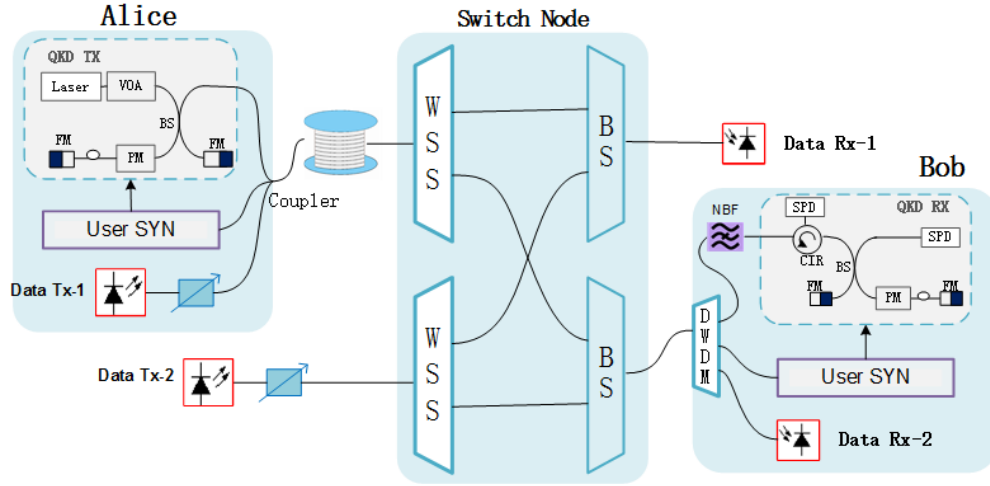


Fig. 4. experiment setup of coexistence switching node

#### 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 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 it's 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.

co-propagation co-propagate

#### 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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