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# All-Optical Sequence Matching (AOSM) Enabled All-Optical Switching for Optical Data Center Networking

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**Abstract.** To realize fast, energy-efficient and large-capacity data communications among servers while accommodating different kinds of applications in data centers, various optical networking architectures such as OPTUNS, OPSquare, ROTOS, etc., have been proposed. These architectures require electric control which is used to realize optical channel establishment or optical packet routing. However, electric control has high implementation complexity and cost. It is expected to realize all-optical switching without any electric control. All-optical sequence matching (AOSM) technique which directly conducts the matching operation between target sequence and data sequence at the optical layer provides a new implementation idea for all-optical switch in data centers. In this letter, we design an AOSM enabled all-optical switch. It contains the function modules of optical packet recognition, optical packet filtering, optical packet aggregation, etc. The AOSM is realized by all-optical logic gates and is used to realize optical packet recognition. The proposed all-optical switch can help to realize all-optical switching without any electric control for optical data center networks. The feasibility of the proposed switch is verified by the software of VPItransmissionMaker.

**Keywords.** Data Center, High Nonlinear Fiber (HNLF), All-Optical Sequence Matching (AOSM), All-Optical Switching

## 1. Introduction

Data centers which support various kinds of applications such as big data, cloud computing, Internet of things, 5G, etc., have become important infrastructures. A data center is composed of tens of thousands of generic servers which maintain massive computing and storage resources. To realize large-capacity data communications among servers in data centers, optical networking which has the advantages of large-capacity and low energy consumption has been widely adopted [1-2]. Besides, various optical networking architectures including optical circuit switching (OCS) architectures such as optical tunnel network system(OPTUNS) [3], optical switching architecture (OSA) [4],

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optical pyramid data center network (OPMDC)[5], etc., and optical packet switching (OPS) architectures such as low-latency interconnect optical network switch (LIONS) [6], hierarchical large-scale interconect optical network(Hi-LION) [7], optical parallel intra/inter-cluster switching networks (OPSquare)[8], the hybrid fast opitcal switches and modified top-of-the-rack switches (HiFOST)[9], reconfigurable opitcal top of rack and fast optical switches(ROTOS) [10], etc., have been proposed. However, these architectures require electric control which is used to realize optical channel establishment or optical packet switching. For the OCS architecture, electric control is realized by distributed generalized multiprotocol label switching (GMPLS) protocol or centralized software defined network (SDN) controller [11]. However, the optical channel setup delay is very long by using electric control and the implementation complexity is very high. For the OPS architecture, electric control is implemented by high-speed FPGA, SDN controller, fast optical switch, etc. However, there exist technical difficulties including control synchronization, optical packet synchronization, etc., to be addressed [8, 9]. The implementation complexity and cost are also very high. It is expected to realize all-optical switching without any electric control for data center optical networking.

The OPS architecture which adopts the statistical multiplexing technology is more suitable for both elephant flow and mouse flow. If optical packet recognition and optical packet routing are directly achieved in the optical layer, all-optical switching can be expected. All-optical sequence matching (AOSM) which directly recognizes the specific target sequence in an input data sequence at the optical layer provides a new implementation idea for all-optical packet recognition. It was firstly proposed for photonic firewall which identifies a specific target pattern in the transmitted optical signal to provide primary optical packet filtering [12, 13]. In [12], a pattern recognition system that can recognize and locate M-bits target pattern in the N-bits data segment is introduced. It comprises a XNOR gate and a recirculating AND gate loop which are both realized by semiconductor optical amplifier (SOA). Compared with the SOA, high nonlinear fiber (HNLF) has an extremely high response rate and is more suitable for dealing with the high-speed optical signal. In [13], a matching system for the on-off keying (OOK) modulated optical signal by using the effects of cross-phase modulation (XPM) and four-wave mixing (FWM) in HNLF is proposed. In this system, the data rate can reach 160Gbps.

In this letter, we design an AOSM enabled all-optical switch. It recognizes and forwards optical packets to the designated out port without any electric control. The rest of this letter is organized as follows. Section II elaborates the principles of AOSM and optical packet filtering (OPF). Section III elaborates the structure of the proposed all-optical switch. The simulation platform and results are presented in Section IV. Finally, Section V concludes this letter.

## 2. Optical Packet Recognition and Filtering

This section first elaborates the principle of the AOSM. Then, the principle of OPF which is achieved by an AOSM module, a switching signal generation (SSG) module, and an AND gate is elaborated. Moreover, the principle of SSG which generates on-off optical signal for controlling the AND gate is also elaborated.

### 2.1. The Principle of AOSM

Figure 1 presents the structure of the AOSM. It is composed of an XNOR gate followed by an AND gate and a regenerator, which are connected to form a recirculating loop with a (N+1) bits period delayed [11, 12]. When the data sequence enters the system, it is repeated M times through the storage loop. The repeated data sequence and the target sequence are compared by the XNOR gate. Here, N and M are the lengths of the input data sequence and the target sequence respectively.

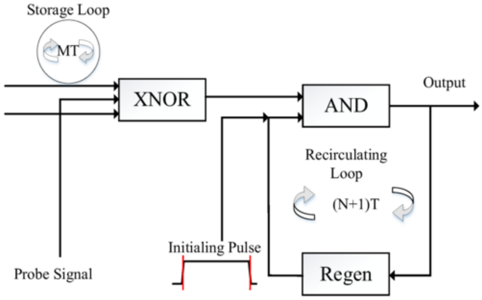



**Figure 1.** Structure of the AOSM.

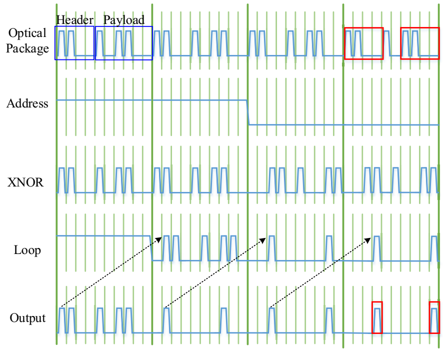



**Figure 2.** The waveforms of the AOSM.

In simulations, XNOR and AND gates are implemented by the HNLF-based Mach-Zehnder Interferometer (HNLF-MZI) structure. For the XNOR gate, the inputs of data sequence and target sequence are regarded as the pump light while the probe signal is the continuous light which is modulated by these two inputs. For the AND gate, one input signal is regarded as the pump light and another input signal is regarded as the probe light. When the target is found in the input data sequence, a light pulse will appear in the output and is aligned with the last bit of the recognized target sequence in the input data sequence. The output light pulse not only detects the target sequence but also locates where it is. For optical packet recognition, the optical packet is regarded as the data sequence and the address is regarded as the target sequence. An optical packet is composed of an optical packet header and the payload. The length of the address is equal to the length of optical packet header. Figure 2 presents the waveforms of the AOSM where the optical packet is “1100101100” and the address is “1100”. The first four bits of the optical packet are the optical packet header. In the last frame of the output signal, the first optical pulse indicates that the optical packet header matches the address. In Figure 2, if some pieces of the payload in the optical packet matches the address, there also will be an optical pulse appears in the output.

## 2.2. The Principle of OPF

The AOSM is used to recognize an optical packet. Then, the matched optical packet is allowed to pass through and the un-matched optical packet is blocked. The structure of the OPF is presented in Figure 3. An AOSM module, a SSG module, and an AND gate is used to achieve the OPF. The SSG is responsible for generating the on-off signal for the AND gate. The AND gate is used to allow all matched optical packets to pass through and block all un-matched optical packets.

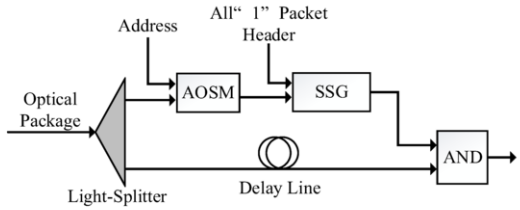



**Figure 3.** Structure of the OPF.

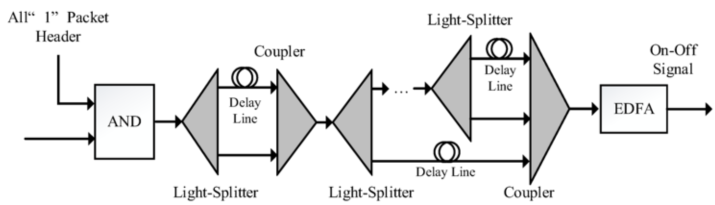



**Figure 4.** Structure of the SSG.

The structure of the SSG is presented in Figure 4. It is composed of multiple light-splitters, couplers, delay modules, and an EDFA. The input optical signal is first conducted the AND operation with a local sequence of which the header is all "1" and the payload is all "0". The waveform is presented in Figure 5 (a). This aims to clean all useless optical pulses in the output optical signal of the AOSM module. Then, the signal is split and delayed. Moreover, the delayed signal and the split signal are coupled together. After many times delay and light-splitting, the optical on-off signal is generated. The EDFA is used to amplify the attenuated optical signal. It makes the power of the signal to a sufficient size to perform the AND operation. The waveforms of the SSG are presented in Figure 5(b). The length of optical packet "1100101100" is 10. If the address matches the optical packet header, the optical on-off signal is "1111111111". This signal allows this optical packet to pass through. If the address does not match the optical packet header, the optical on-off signal is "0000000000". This signal will block this optical packet.

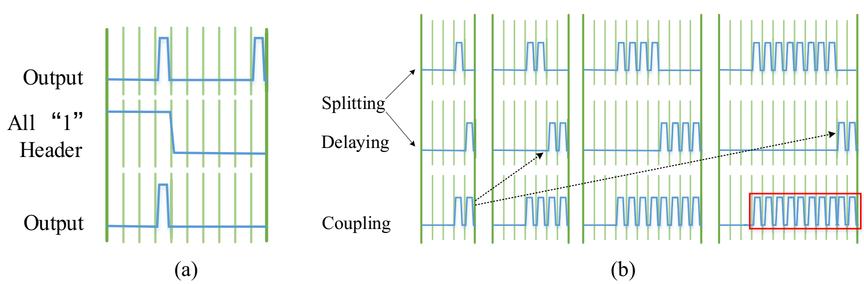



**Figure 5.** (a) The waveforms of useless optical pulse cleaning. (b) The waveforms of the SSG.

## 3. AOSM Enabled All-Optical Switch

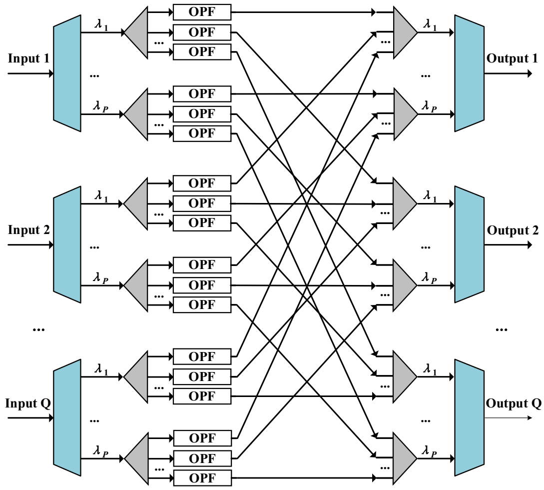



**Figure 6.** AOSM enabled all-optical switch.

Since the OPF has been directly implemented at the optical layer, all-optical switch can be achieved. The structure of all-optical switch is presented in Figure 6. It is composed of a group of de-multiplexers, OPF modules, light-splitters, couplers, multiplexers, etc. First, the input optical signal is de-multiplexed into multiple parallel wavelengths and then split into Q copies. Each copy passes through an OPF which is used to allow matched optical packets to pass through or block un-matched optical packets according to the input address. Next, all outputs of OPFs with the same wavelength in different input port are coupled together. At last, different wavelengths at a common output port will be multiplexed together. The number of used OPF modules is P*Q, where P is the total number of wavelengths in each fiber link and Q is the total number of output ports or input ports. A simulation platform is constructed by the software of VPItransmissionMaker to verify the feasibility of the proposed all-optical switch. To reduce the complexity, a 2*2 all-optical switch is implemented.

## 4. Simulation Platform and Results

VPItransmissionMaker is a graphical and simulation tool, with its user friendly interface, facilitates the implementation of a variety of networks including optical networks. It is easy to use but also proficient in simulating various types of networks and offering highly accurate results[14]. The simulation platform is presented in Figure 7. We assume each fiber link only contains two wavelengths and the data rate of each wavelength is 100 Gbps. The lengths of the optical packet and the address are 6 and 2 respectively. The XNOR gate, AND gate, and NOT gate is all realized by HNLF-MZI, which utilize the effects of FWM and XPM in the HNLF. The WDM signal is demultiplexed by the filter module. The XNOR gate is realized by a combination of a AND gate and a NOT gate. When the output of the XNOR gate passes through the AND gate, the laser generates a continuous wave (CW) as an input signal for the first AND operation. Afterward, one of the inputs to the AND gate is obtained by delaying the previous output signal. The delay module is designed to delay the result of the packet header judgment to the data location and control the output of the signal by the judgment result. EDFA modules are required between connected components, and the final output is demultiplexed and monitored by SignalAnalyzer.

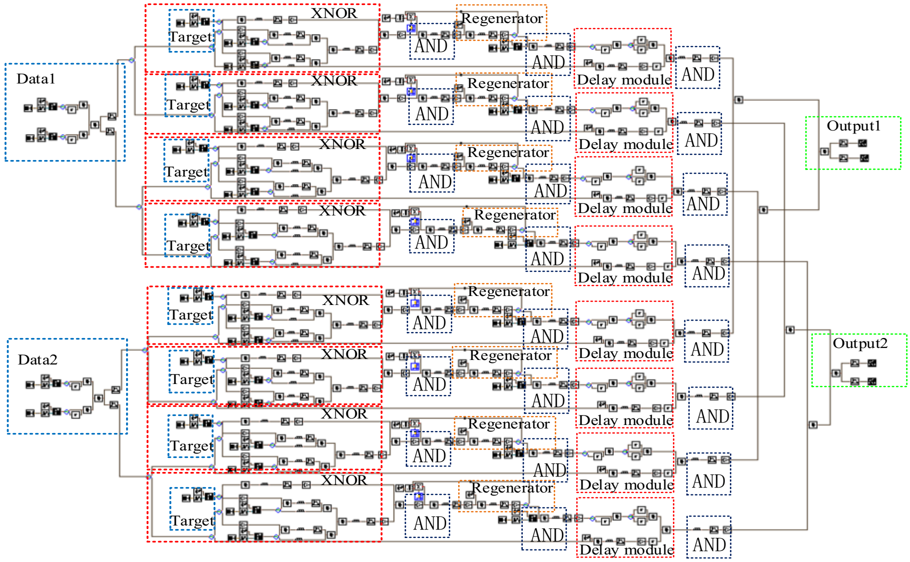
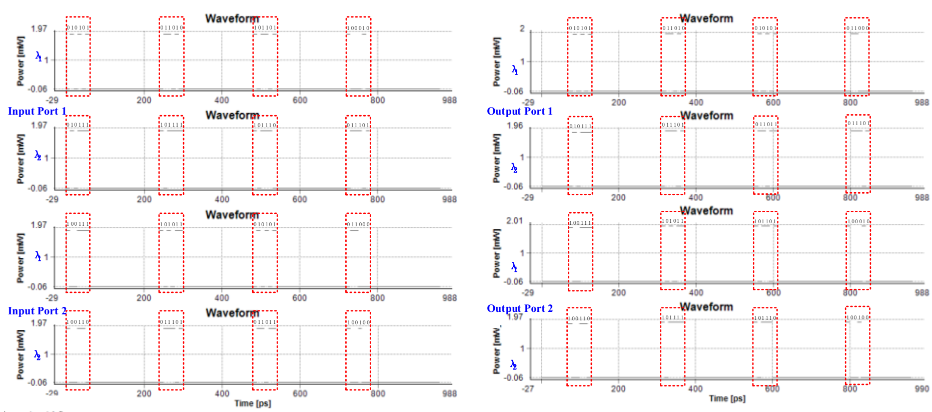



**Figure 7.** Simulation platform of all-optical switch based on VPItransmissionMaker.




(a) (b)

**Figure 8.** (a) Input optical packets. (b) Output optical packets.

Figure 8(a) presents all input optical packets. There are two wavelengths in each input port and four optical packets are loaded into each wavelength. Two addresses are "01" and "10", where "01" refers to the output port 1 and "10" refers to the output port 2. Figure 8(b) presents all output optical packets. The results show that each input optical packet can be correctly recognized and forwarded to the designated port. For the proposed all-optical switch, the processing delay of each optical packet is about (1/B)*(N+1)*(M-1), where B is the symbol rate of the input optical sequence, N is the length of the optical packet, and M is the length of the address. The processing delay is proportional to N and M. However, the proposed all-optical switch does not support optical packet contention avoidance. In the future, contention avoidance is our research focus and the priority strategy can be applied. Priority strategy means that only the optical packet with high priority can be forwarded to the output port. The priority strategy can also be implemented by all-optical logic gates.

## 5. Conclusion

An AOSM enabled all-optical switch is proposed. It achieves optical packet recognition and routing directly at the optical layer, and provides a promising method to realize all-optical packet switching in data centers.

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