Separation and insertion of optical bit-serial label in optical packet switching

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The bipolar phase-shift-keying (BPSK) optical orthogonal codes (OOCs) are inserted into the optical packet format of bit-serial label. The ultra-fast separation of the label and payload is performed through the auto-correlation pulses indicating the time position at which the optical switch changes the state. The insertion of the new label can also be realized by detecting the auto-correlation pulse at the line rate. Especially, the scheme can be adapted to the asynchronous separation and insertion and realize the variable-length packet switching. The results of simulation verify the feasibility of the scheme.

OCIS codes: 060.2330, 060.5060.

For dealing with the electronic bottleneck in current router based on optical-electronic-optical (O-E-O) conversion, optical packet switching (OPS) is a potential resolution. It realizes the packet switching in optical domain and provides the smallest packet switching granularity and the transparency to upper protocols. In optical packet switching, generalized multi-protocol label switching (GMPLS) is adopted and a label carrying on the switching information is attached to the payload. For lack of optical logical devices and optical random-access memories (ORAMs), it is very difficult to realize all-optical packet switching that processes the label information, to control optical switch matrix and resolve the output contentions in optical domain. Even though some schemes of all-optical packet switching were demonstrated, it is still far away from the application due to the finite functions and the small scale. The current available approach is the mixture of electronic processing and optical switch, i.e., to process the label information in electronic domain and switch the payload in optical domain. When the packet enters in the optical switching node, the label is separated from the payload and detected through optical-electronic conversion at first. The control unit looks up the routing table according to the label information and configures the optical switch matrix in electronic domain. The payload is switched to the proper output channel or the contention resolution module in optical domain. For realizing the switching in the next node, the new label is required to be inserted to the optical packet again before the payload leaves the switching node. There are many approaches to optical packet switching, including serial-bit labels[1,2], optical subcarrier labels[3,4], superimposed amplitude shift keying (ASK) labels[5], frequency shift keying (FSK) labels[6], differencial phase shift keying (DPSK) labels[7], and optical-code labels (OC-labels)[8,9]. There is very low crosstalk between the label and the payload in the bit-serial label coding method because the label and the payload are separated in the time domain. But it has tight timing requirement that needs the synchronization control of the label and the payload[10]. Thus it is difficult to separate the label and the payload before the switching and it is hard to insert the new label into the exact position after the switching by the strict timing and control. In this paper, we propose a new approach to optical bit-serial label switching using optical orthogonal code to recognize the bound of optical packet. The method simplifies the separation of the label and the payload and the insertion of the new label. Moreover, the method can be used in the asynchronous optical packet switching where the packets have variable lengths and the arriving time of the packet is random.

Optical orthogonal code is the key technology of optical code division multiple access (OCDMA). OCDMA allows many users to access the same optical fiber channel asynchronously through the assignment of unique signature codes[11]. Recently, a photonic add/drop multiplexer (PADM) based on optical orthogonal codes is proposed in Ref. [12], which allows the packet-by-packet cut-through and add/drop on a wavelength path in optical domain by attaching an optical orthogonal code label to the packet. In the proposed scheme of PADM, the two OOCs are located in the head and the tail of the packet and the auto-correlation pulses are generated only when the OOCs pass the matched decoders. By detecting the auto-correlation pulses, the time positions of the beginning and end of the packet are easy to be found. It is possible to control the optical switch and realize the packet add/drop function. In this paper, we modify the bit-serial label format and add the OOCs into the optical packet as shown in Fig. 1. The pulse series encoded according to OOC1 and OOC2 are inserted before and after the label. The OOC pulses are separated from the label and the payload with the guard times in time domain. Similar to PADM, the auto-correlation

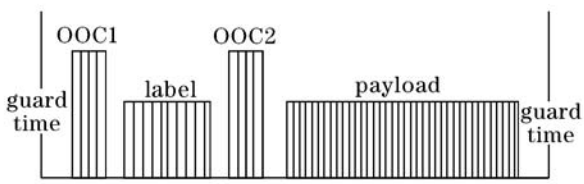

Fig. 1. Optical packet format.

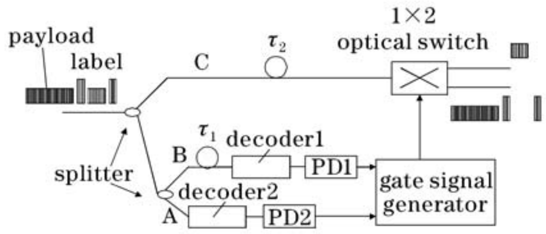

Fig. 2. Separation of the label and the payload.

pulses generated by the OOCs can indicate the arriving and the passing of the label. The auto-correlation pulses by the OOCs will make it easy to separate and insert the label. For the advantage of coherent OCDMA over incoherent OCDMA, the bipolar phase-shift-keying (BPSK) OOCs are adopted in this paper. The OOC encoders and decoders based on planer lightwave circuit (PLC) consist of variable tapped delay-lines with optical phase shifters[8,12].

When an optical packet arrives at the switching node, the label needs to be extracted to the label processing unit and the payload is directed to the optical switch matrix. The function of separating the label and the payload is demonstrated in Fig. 2. A portion of optical power of incoming packet is divided by the splitters and sent to the decoders. The decoder1 matches the OOC1 and generates an auto-correlation pulse in the end position of the OOC1 pulse series. The OOC2 pulse series, the label, and the payload have cross-correlation output like the noise in the decoder1. The decoder2 matches the OOC2 and generates an auto-correlation pulse in the end position of the OOC2 pulse series. The outputs of decoders are converted into electronic signals through photodetectors (PDs). By using the decision unites to eliminate the effect of cross-correlation outputs, only the auto-correlation pulses can drive the gate signal generator that controls the state of 1×2 optical switch[12]. The transition of the state of 1×2 optical switch can switch the label to one port and the payload to another port. It realizes the separation of the label and the payload.

For separating the label from the optical packet, the transition of the state of 1×2 optical switch will happen in the two guard times between the label and the OOC pulse series. The auto-correlation pulses will be generated in the end position of the OOC pulse series. So the duration between the two auto-correlation pulses is larger than the duration of the label. For adjusting the interval time between the two auto-correlation pulses to equal to the duration of the label, the delay time, τ_1 and τ_2, are involved as shown in Fig. 2. The relation of the delays of the optical packets is demonstrated in Fig. 3. The optical packet in the branch B is delayed with τ_1 and the decoder1 generates an auto-correlation pulse in the position p_1 of the optical packet in the branch C. The optical packet in the branch C is delayed with τ_2 and the decoder2 generates an auto-correlation pulse in the position p_2 of the optical packet in the branch C.

After the payload is outputted from the optical switch matrix, a new label is inserted into the corresponding position of the optical packet as shown in Fig. 4. At first, the payload is amplified to compensate the power loss in the transmission and switching by an optical amplifier.

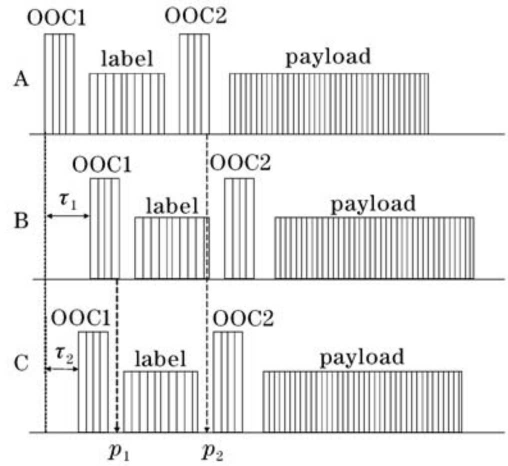

Fig. 3. Timing relation of the three packets in branches A, B and C.

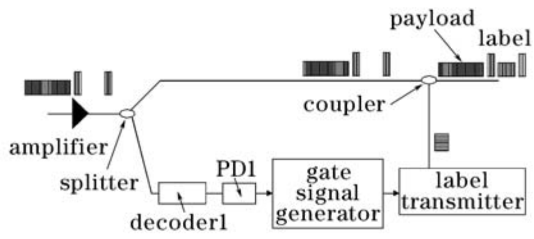

Fig. 4. Insertion of the new label.

The splitter extracts a part of the power of the payload and sends it into the decoder1. An auto-correlation pulse is generated in the end position of the OOC1 pulse series. It indicates the arrival of the payload and the position where a new label will be inserted. The auto-correlation pulse is detected by the PD1 and the gate signal is generated to enable the transmission of the new label. The optical packet with the new label will be sent to the next switching node.

In the previous bit-serial label processing[1,2], a portion of optical packet power is detected and the total packet including the label and payload is received. The label information is extracted to control the gain of a semiconductor optical amplifier (SOA) gate to absorb the label and pass the payload. After the payload is switched to the proper output, the new label is inserted before the payload. The biggest problem in the previous scheme is difficult to confirm the time positions to switch the gain of the SOA gate and transmit the new label without any indication. In our scheme, the OOCs play the role of the indications, and the precision of separation and insertion can be enhanced. Furthermore, the auto-correlations of the OOCs are performed in the optical domain and only the simple judge function is realized in electronic domain. So the processing speed is ultrafast and the scheme can satisfy the demand of optical packet switching. The third advantage of our scheme is to adapt to the asynchronization optical packet switching where the packets have variable length and arrive in the switching node at random. In our scheme, no packet-level timing is required and the auto-correlation pulses of the OOCs indicate the separation and insertion of the label separately. It has no concern with the time slot and the packets are independent of each other. So this scheme can support the optical packet switching of IP traffic without segment and assembling.

The simulation is performed for using the photonic transmission design suite (PTDS), a famous photonic design automation tool made by Virtual Photonic Inc. The optical packets, 10-Gb/s payload and 2.5-Gb/s label, are generated according to the packet format in Fig. 1 and transmitted on a 50-km fiber. The 8-bit BPSK OOCs [0 π π 0 0 π π 0] and [0 0 0 π π π π π] in Ref. [12] are adopted for OOC1 and OOC2. The auto-correlation of OOC1 and OOC2 is 8 and the cross-correlation of them is no more than 2. Other optimal OOCs can also be adopted to reduce the cross-correlation value in this scheme. Figure 5(a) shows the optical packet generated in the simulation. The full-width at half-maximum (FWHM) of the OOC pulse is 0.1 ns. The outputs of decoder1 and decoder2 are shown in Figs. 5(b) and (c), respectively. The auto-correlation pulses are generated in the end positions of the OOC1 and OOC2. Due to the cross-correlation processing in the decoders, the label, the payload, and the unmatched OOC are suppressed. The state of optical switch can be changed from one output to another output by the control signal from auto-correlation pulses.

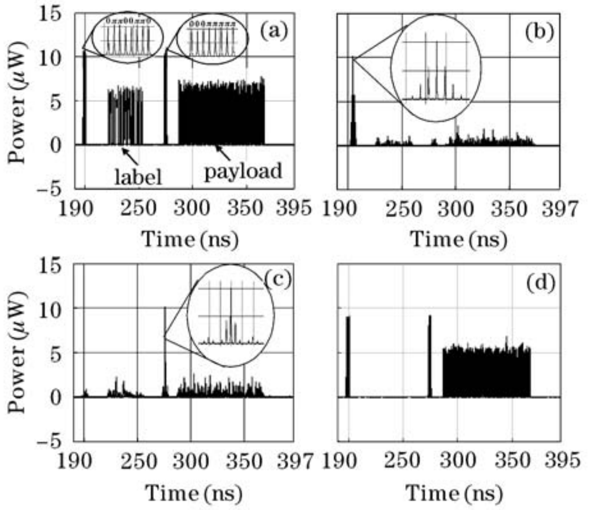

Fig. 5. (a) Generated optical packet, (b) output of the decoder1, (c) output of the decoder2, (d) the payload after separating the label.

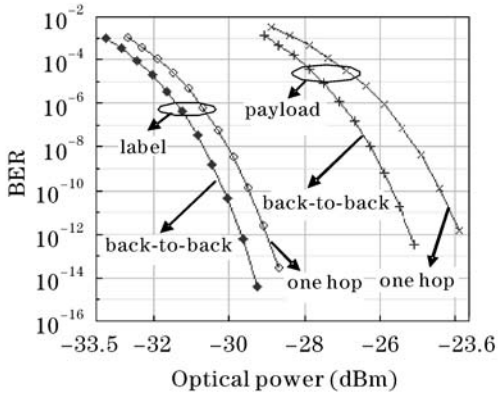

Fig. 6. BER of the label and the payload.

Figure 5(d) shows the payload, which will be directed to the optical switch matrix, after separating the label. The bit error rates (BERs) of the label and the payload are shown in Fig. 6. The power penalties of the label and the payload are 0.65 and 1.03 dB respectively at a BER of 10^{-9}. It is caused mainly due to the infection of the optical packet transmission.

In conclusion, a new scheme is proposed to deal with the ultra-fast separation of the label and the payload and the insertion of the new label in the optical packet switching based on bit-serial label. The two BPSK OOC pulse series are inserted into the optical packet format. The auto-correlation pulse generated from the OOC pulse series can indicate the time position of the change of the optical switch state. It will realize the online separation of the label and the payload. When the new label is to be inserted into the switched packet, the OOC pulse series will generate the auto-correlation pulse to indicate the insertion time of the new label. The scheme can realize asynchronous optical packet switching. The results of the simulation are demonstrated to verify the feasibility of the scheme.

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