All-Optical Packet Switching Network based on Optical Code Processing

Wang-Hsai Yang and Cheng-Shong Wu

Department of Electrical Engineering, National Chung Cheng University, Taiwan.
160 San-Hsing, Min-Hsiung, Chia-Yi 621, Taiwan.

Abstract: - This work introduces a significant improvement for optical packet switching network based on OC processing. The key point of this method is the generalization of the optical label switching concept to forward optical packet without label swapping and O/E/O procedure. Our proposed method simplifies the design of switch devices in optical domain and packet forwarding process which speeds up packet forwarding and increases throughput significantly. As label swapping is eliminated in this method, the upper layer (label switching layer) can operate on optical networks transparently.

Key-Words: - optical packet switching, optical label switching, optical code, MPLS.

1 Introduction

Internet network is mainly based nowadays on IP technology. But large demand of bandwidth can only be met by Wavelength-Division Multiplexing (WDM) technology which has in turn its weaknesses. WDM is only used as transmission line, switching is still accomplished by electronic switching technology; hence each switching node has to process E/O and O/E conversion. As these factors limited the switching speed when adopting WDM optical fiber networks, a complete improved optical switching network that based on IP technology should be developed. This can be achieved by utilizing optical signal transmission during transmission process, and adopting optical processing while handling the switching process at every switching node. As some basic optical component technologies are well established, OPS are becoming a practical architecture for the next-generation all-optical networks. The optical packet switching (OPS) network enables the enhancement of switching speed and network efficiency. To achieve this goal adequately, we have to develop a new switching technology that is suitable to apply on all-optical network (instead of replacing the electronic switching technology with optical switching technology).

This work introduces a significant extension to the method of optical CDM for optical packet switching. The main advance is the generalization of the optical CDM (OCDM) concept to forward optical packets based on source routing, while avoiding either header modification or any label swapping techniques. Our proposed method simplifies the design of switching devices in the optical domain to simplify the packet forwarding process and speeds up packet forwarding and increases throughput significantly.

The remainder of this paper is organized as follows: The second section is related works. The third section describes OC-label switching system architecture and how to encode labels. In section 4, the preface difference code is applied to our OC system and briefly the performance is discussed. And in the last section, we conclude this study.

2 Related Works

The optical packet switching (OPS) is promising technologies for controlling the huge bandwidth of WDM optical fiber networks in a highly flexible and efficient manner. There are many researches focus on routing technologies that are suitable to adopt on IP over WDM networks at present. In [1], the author proposed the all-optical code division multiplexing switching network based on self-routing principles. It utilizes the variable length tag to include all routing information including the output port information at nodes that passed through by routing. It uses a bit to correspond every output channel that connects to the switch as to simplify the design. For instance, if the corresponding bit of the output channel is set as “1”, then other bit should be set as “0”. Before the packet is being transmitted out, the information that has been used in the front of the tag will be discarded.

In [2], the author indicated the photonic label switching method; it can be named as photonic

MPLS to indicate that operation principle is based on MPLS. However, the label is indicated by optical code. The label is processed by optical code correlation. Hence optical code will be released, processed and replaced from every switching node. That is, this photonic label must be exchanged at every switching node.

In [3], the author has pointed out an innovative method called KIS. Chinese Remainder Theorem has been used in this method for labeling in optical domain as to eliminate both changing the label during the transmission process, and label distribution protocol. This leads to simplify the design of switching equipment in optical domain, and enhance the speed of packet transmission. However, it converts the label from optical signal to electronic signal to carry out division calculation to process the output port, and again converts it back to optical signal (that is the O/E/O process). The O/E/O process is complicated and expensive in optical area.

In [4], we have proposed a new method which utilizes the existing Optical CDM coding method, such as PC, EPC, QC and EQC, to encode the label as optical label, and achieve the same goal as [3]. It excludes label swapping and O/E/O process by every core node. When an optical packet reaches the core node of the optical network, its label will be taken out and inserted in the optical correlator. Then, the correlator uses this label to carry out the correlation process with the code sequence which is set by this core node. This will lead the control signal that controls this optical packet to approach the correct output port. Despite the length of label is too long, we have raised new technologies that are based on the existing technologies, and it is the discussion focuses of this paper.

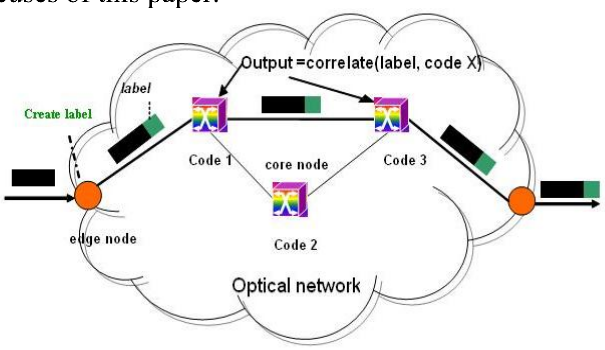


Fig. 1. Optical Code label switching system

3 System Architecture

In this section we will introduce optical code label switching system. Fig. 1 shows the optical network: ingress edge node connecting an optical network and a traditional network. Each edge node is responsible to figure out the shortest path for the packet that is going to access optical network, and to generate an optical label to place at the front position of this packet. Every core node setting has a code sequence, when a packet reaches certain core node; this code sequence is used to process correlation procedure with the label. The outcome is the output port for this packet to access next node. The subsequent code nodes reiterate the operation with the same label.

Besides, the correlation process is operating in optical domain, and label has not been modified or changed during the packet transmission process. Therefore, there is no need to process the O/E/O procedure or label swapping operation in such system.

3.1 Optical Packet Format

Fig. 7 in [3] indicates that when there are 50 core nodes, the utility rate of 8 route length (that is passing through 8 nodes) is around 2%, while the route length of higher utility rate are higher (3, 4, 5, 6) in average. Therefore, when the number of core node is below 50, the route length of higher utility rate in average is located at 3, 4, 5, and 6 nodes. Hence, under such situation, we assume that 8 is the highest limit of reasonably supported route length. When an edge node is resolving the route for a packet and discovers that its route length is longer than 8, we can then use two stages routing [4], that is routing passes the third place, and then goes to destination. For instance, when one packet is transmitting from A to C and has been parsed that it will pass the ninth core node, then we may divide the route into two parts AB and BC. The subject is route to the third place B first, then access C from B. This routing regulation can be added to the routing protocol, enabling users to implement this protocol when the route length is too long. This can solve the problem that we are going to mention below: packet construction may have the problem that the label is too long or has unstable length.

Fig. 2 shows the optical packet architecture used by this system, it converts the original electronic packet to an optical form, then an optical code label is directly packed in the front of it, and a detection bit is added as the detective signal. Optical signal can be indicated by On-OFF keying (OOK) data format at this point, that means that bit 1 will generate 1 pulse, and bit 0 will not generate any pulse. As mentioned above, the label length can be set to the length of 8 optical code sequences. This optical code sequence can offer the route data that is needed by any core node. When route exceeds 8 core nodes, we should adopt the two stages routing methods to handle the situation. When the route does not exceed

8 core nodes, the places that have not been used by the label can be replaced by no pulse.

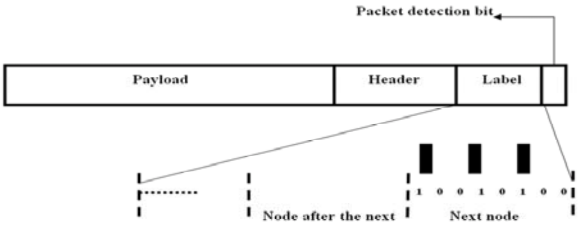
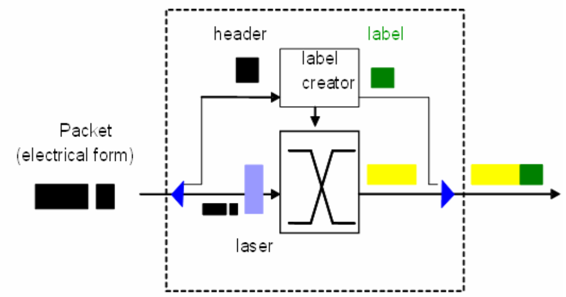


Fig. 2. The optical packet format

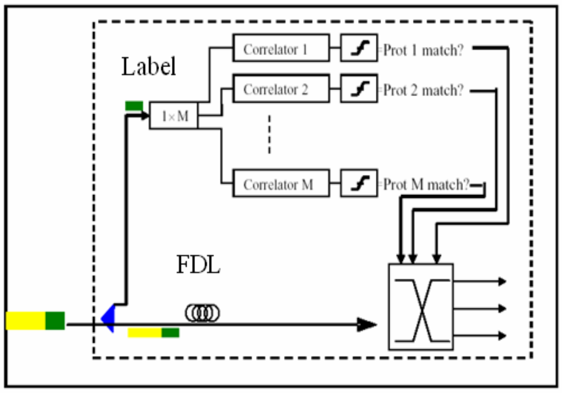
3.2 Node Construction of Optical Label Switching

When a packet in traditional network is accessing an optical network, it features electronic signal by itself, and will approach the edge node located on the edge of the optical network. Edge node includes label creator and optical cross-connect (OXC). As shown in Fig. 3(a), the header of the traditional network's packet will be resolved by label creator in order to find a path to route the packet, and generate a label that contains routing information. On the other hand, the packet goes through the switch and converts the signal into optical type, and then it is carried to the next core node. When the header is being resolved, the label creator will also send control signal to configure the optical cross-connect (OXC), and choose the correct output port to transmit optical packet.

The core nodes are shown in Fig. 3(b), including optical correlators, OXC and FDL. When the optical packet approaches the first core node, its front label will access the optical correlator and the code sequence (set by this core node) to process the correlation procedure. The outcome is the control signal that controls this optical packet to approach the correct output port. Note that the core node has to possess fiber delay lines (FDLs), and to use it as a temporary storage device for optical signal, and then wait for completing the correlation procedure. The turns needed by FDL is related to the length of label.



(a)



(b)

Fig. 3. (a) The Configuration of Optical Network's Edge Node. (b) The Core Node Construction of an Optical Network.

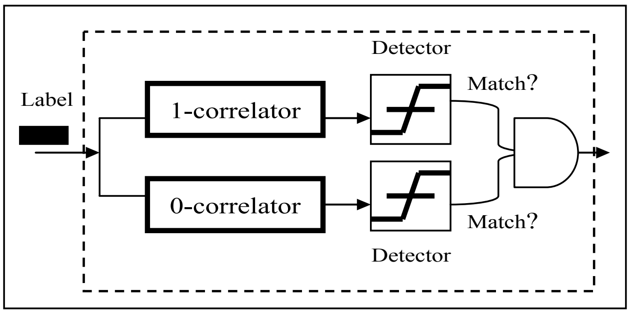


Fig. 4. Correlator Architecture

3.3 Architecture of Optical Correlator

We are going now to introduce the architecture of optical correlator, as it is shown in Fig. 4. The purpose of a correlator is to examine whether the input signal is matching with the required signal or not. Fig. 5 shows the architecture of Tapped-Delay-Line Correlator [5]. For instance, if we input an optical signal "10101" and there are 5 slots, and there is a pulse at slots 1, 3, and 5 (and no pulse at other slots). Such correlator needs 5 taps, and has to set the weight for each tap. While weight=1, it represents that the switch on the delay-line is off, and on the opposite is on. Such optical signal will be divided by power splitter into three parts, and passes 3 groups FDLs ($\tau = 0$, $\tau = 2$, and $\tau = 4\ T_{bit}$) separately. The three parts will be reorganized at the power combiner, as shown in the diagram. Signal power detection will be done at suitable sampled time T_S, to determine whether it has passed the threshold set on the detector or not. Notice the pulse with the greatest power in the middle, which is the only pulse who can make the photo diode generates a higher current. This high current is required to start the threshold detector and send out a "match" signal.

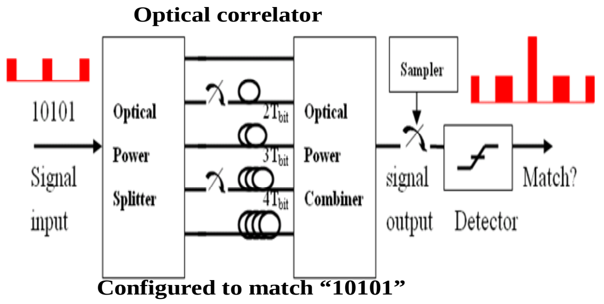


Fig.5. Architecture of Fiber Tapped-Delay-Line correlator

The correlator shown in Fig. 5 is named as 1-correlator; we also need 0-correlator because if the optical signal we input in Fig. 5 is "11111", the signal may still passes the detector's threshold at suitable sampled time. So, we need another 0-correlator to detect whether the inputted optical signal is the required optical signal or not. Take Fig. 5 as an example, the signal we want to detect is "10101", then the 0-correlator have to be set as "01010", and to implement detection of signal energy at suitable time T_S, to determine whether the energy is "0" or not. In other words, the purpose of 1-correlator is to detect the signal at certain slots is "1" or not, while 0-correlator is to detect whether the signal is "0" in the reminding slots or not. Therefore, when one optical signal is matching when it passed the 1-correlator and 0-correlator, then the result stands for this signal is matching.

4 Network Implementation

In order to implement this optical code label switching system, we first describe how to encode the optical code label (OC-label). OC-label is an optical code, which means it is a sequence of optical pulses. An OC-label can be viewed as an identification mark that is attached to the packet. When core node is traveling by, packet uses this OC-label to process correlation, it produces routing information. First of all, assume there are N nodes in the optical network. In order to get the optical code that is needed for encoding, we have to figure out an integer M, and makes $M > \log_2 N$. Making use of this integer M, we can generate 2^M (0, 1) sequence, and distribute them to the only M+1-bits code sequence at each node, and named as node-code sequence. That is, we assume at least 2^M code size. Generally , we can assume that there are 8 output ports at each core node, then we need three bits to represent the binary 0~7, which is named as port-sequence. Using C_{node} to represent the node-code sequence at certain node, and P^{node} to represent the port-code sequence at certain code. When a packet approaches the ingress edge node of the optical network, the ingress edge node will parse its header to figure out a route to access its destination. When the route has been parsed via the optical network, we can obtain two arrays and the OC-label is made based on these two arrays. These two arrays include the output information that is contained in all the core nodes that pass through this route.

These two arrays are noted as $\overline{C}$ and $\overline{P}$ separately. Just assume a route passed n nodes, these two arrays are shown as the following:

$$\overline{C} = (C_i,\ C_j,\ \cdots,\ C_n) \quad \text{and} \quad \overline{P} = (P^i,\ P^j,\ \cdots,\ P^n) \tag{1}$$

Hence we can make use of the arrays in (1) to create OC-label, array L is used to represent the OC-label; the result generated from L is shown in the following formula:

$$L = (C_i P^i,\ C_j P^j, \cdots,\ C_n P^n) \tag{2}$$

After arranging the route value of each core node and the port-code sequence to the node-code sequence, we can generate a new code sequence. For instance, if a node-code sequence is "1001" and port-code sequence is "101", then the new code sequence is "1001101". Use the following correlation relationship to obtain the information needed by route at every node that being passed through.

$$\textit{output port(node)=correlator(L)}, \quad \text{for all traversed node} \tag{3}$$

4.1 An Example

To make it more clearly, we take the following example: assume there are 30 nodes in the core network, and then we need 30 node-code sequences. Take M=5. We first describe how to encode label. Assume there are 8 output ports at each core node, hence we need 3 bits to represent the binary 0~7. Each node-code sequence is represented by 6 bits, thus we use 9 bits (chips) to represent the output port information needed by the route at certain node. Assume there is a packet traveling from point A to point B in the core network and it has to pass through 3 core nodes. Each node has been set as code1=100001, code2=100010 and code3=100011. The output ports (passed through) are in order 2, 3 and 4, respectively. Then at A node, this packet's OC-label used $\overline{C} = (100001,\ 100010,\ 100011)$ and $\overline{P} = (010,\ 011\ \ 100)$ to encode. At this time, OC-label is $L = (100001010,\ 100010011,\ 100011100)$.

When the labeled packet has been transmitted to the code node, OC-label will be taken out, split and amplified, and then delivered to the 1-correlator and 0-correlator of each port. Only when the correlator of the matching port implements signal power detection at the appropriate sampled time T_S =9 bit time can pass the threshold that have been set on the detector.

Fig. 7 shows the correlators' processing result of the outport port2 located at node 1. We can see that 1-correlator and 0-correlator match the threshold only when at the first sampled time T_S , they are not able to match threshold at the same time at other sampled times.

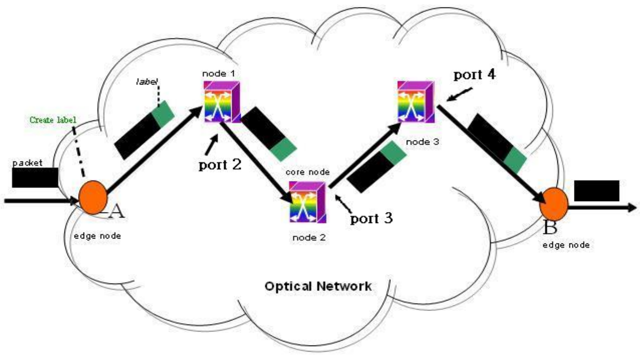


Fig. 6. A Transmission Example and Indication of Port Number of the Optical Packet Passed By.

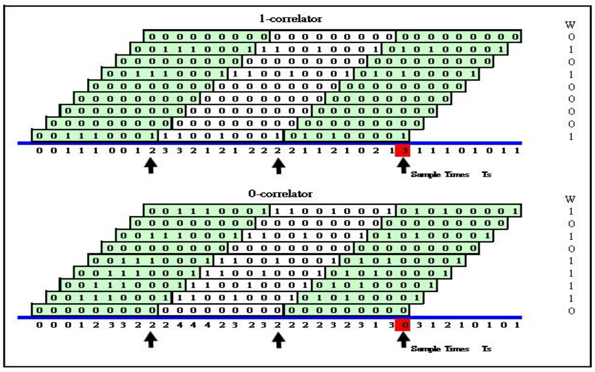


Fig. 7. The Operation Result of the "1-correlator" and "0-correlator" located on Port 2 of Node 1.

4.2 Performance analysis

Number of concurrences occurs when function of label correlates with some certain node-code sequence. Each coincidence is defined as an event which occurs when two (ones) from two sequences occupy the same chip. In this system, the optical reception is based on power detection. We define the "recognizing margin" as the difference between code weight and the maximum number of coincidences in correlation of the label with node-code sequences of core switching node (that is not visited by a packet). The above-mentioned optical code encoding is a simple example showing an insufficient recognized margin and recognizing interference.

For implementation to be feasible, when encoding optical code, in order to enable the receiver recognizes the correct signal easily, we have to follow the following rules [6]:

1. The autocorrelation of any code sequence has to be as big as possible, that means the locations of chip =1 should be as many as possible.
2. The cross-correlation of any two code sequences has to be as small as possible, that means the overlapping location of chip=1 of any two code sequences should be as few as possible.

If we adopted the four kinds of encoding system in [4] to encode the optical code sequences we want, then, the selection of prime number P will be bigger while the length of core sequence will be longer at the same time. Therefore, if we use the above-mentioned four kinds of encoding scheme to encode the label, when core network has 30 nodes, then we need 30 code sequences. Take $P=31$, the lengths of code N_{PC} and N_{QC} = *961* chips, N_{EPC} and N_{EQC} = *1891* chips. In this case, the length of code sequence seems to be too long.

To overcome this, we adapt the perfect difference code (PDC) to encode the code sequences that we require [7]. The PDC is employed as a signature code in the (synchronous optical code) division multiplexing system. A $(v,k,1)$ -PDC is a member of a cyclic (v,k,λ) difference set which has code size v and code weight k. The code length of PDC is equal to its code size. Once the core network grows to include more nodes, it will not increase the label length dramatically. Therefore, the code length of node-code sequence obtained by PDC is not too long under reasonable code size. The PDCs have the following characteristic: the cross-correlation between any two distinct codes is exactly one.

As indicated in [8], a core network with 10~30 core switching nodes is quite sufficient. In [9] European ACTS Optical Pan-European Network project, these numbers are discussed too. We compare the performance between OCDM and OC systems shown in Table 1. For example, if the core network contains 30 core switching nodes, it requires 30 node-code sequences. Take the prime number p = 31, that is, there are 31 code sequences for prime sequence codes/quadratic congruence codes, and code weights v=31, that is, there are 31 code sequences for perfect difference codes.

Hence, if the core network has 30 nodes, it requires 30 code-node sequences. In OCDM system [4], given that $p = 31$, N_{PC}/N_{QC} is *961* chips. Assuming that the optical pulse generator is 10G Hz, then a chip time τ= 1/10G, and it takes 3*1k/10G = 0.3μs to complete a label correlation. In this article, the label length of OC system is 8 times the length of node-code sequence. Hence it takes 8*35/10G= 0.03μs to complete a label correlation.

Table 1. The performance of OCDM system and OC system.

	weight	code length	label length	process time of label
OCDM	31	961 chips	2883 chips	0.3 μs
OC	6	31 chips	280 chips	0.03 μs

5 Conclusions

We have presented an optical code based routing scheme in this paper using optical code to encode the required label. This transmission method requires no O/E/O procedure at all nodes during the transmission process. There are also no needs for label distribution protocol, and will not be related to the header modification/label swapping issues. We have adopted correlation in optical domain and determined that we have to replace the output port by route lookups; it improves the method that we have presented in [4] as well, that is shortening the length of the label.

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