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Optical Code Division Multiplexing for Packet Labeling in Optical Switching Networks

Wang-Hsai YANG[†a)], Cheng-Shong WU[†b)], *Nonmembers*, *and* Hui-Kai SU[††c)], *Member*

SUMMARY In this paper, we proposed a photonic packet switching control method by used optical correlator for optical packet label packet-switched networks for next Generation networks. The main advance is rely on using the Optical Code Division Multiplexing (OCDM) code to labeling optical packets based on source routing. Based on OCDM labeling either header modification or any label swapping techniques can be avoids. With advantage of existing OCDM coding called OCDM-labels schemes to encapsulate the packets, together with optical correlator to decode the label in optical domain, which can achieve optical packet switching without header modification/label swapping techniques. The O/E/O conversion procedure at each switching device can also be eliminated. This method not only simplifies the design of switch devices in the optical domain to simplify the packet forwarding process, but also speeds up packet forwarding and increases throughput significantly.
key words: *optical packet switching, header modification, label switching, OCDM*

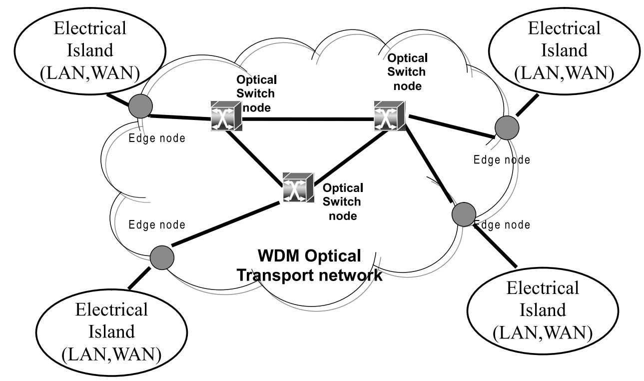

Fig. 1 Optical/electronic mixed network.

1. Introduction

As users generate a huge amount of traffic, network switching devices, which process the data in electronic signals, can end up in a performance bottleneck. All-optical technologies that rapidly deliver an enormous bandwidth, called Wavelength Division Multiplexing (WDM) networks, are needed to meet the challenges of the bandwidth demands. In the future, all-optical packet forwarding techniques and optical signaling based core switching nodes in the networks will become the dominant technology in high speed networks [1]. Because the WDM technique provides multiple network capacity, optical forwarding technologies allow a larger bandwidth and lower latency. Figure 1 shows a hybrid optical/electronic network, that is, IP over photonic WDM network. The electrical islands are the existing IP networks with electrical switches and routers. The IP packets pass through the middle optical networks, by way of an optical-label path which is set up between the edge nodes by optical-label to carry the IP packet transparently.

Some switching technologies [2]–[5] support the optical switch node in Fig. 1. For all switching schemes, photonic packet switching appears to be a powerful candidate because of the high-speed data rate transparency it offers. Photonic packet switching was first studied and experimentally tested in the 1980s. From the early 1990s, many projects were tried to further explore the feasibility of photonic packet switching [6]–[11]. The Optical label switching (OLS) technology offers seamless integration of data and optical networking while supporting packet switching using the optical labels. The OLS technology has been proposed to simplify packet forwarding by processing labels such that optical packets can be routed with low latency to their destinations [1]. Optical label switching simplifies the design of switching devices in the optical domain and speeds up packet forwarding significantly.

This work introduces a significant extension to the method of optical label for optical packet switching. The main advance is the use of the optical CDM (OCDM) to label the optical packet and to forward optical packets based on source routing encoded in the label, while avoiding either header modification or any label swapping techniques. This method simplifies the control of switching devices in the optical domain and the forwarding process to speeds up packet forwarding and increases throughput significantly. Our proposal also takes advantage of the existing OCDM coding schemes to labeling the packets, called OCDM-labels. An OCDM-label can be easily processed at the optical network by an optical correlator in the optical domain; that is, without conversion to label and payload into the electronics form. With the help of optical correlator to decode the header in optical domain, this technology not only without header modification/label swapping techniques, but also avoids the O/E/O procedure.

The remainder of this paper is organized as follows.

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[†]The authors are with the Department of Electrical Engineering, National Chung-Cheng University, Chia-Yi 621, Taiwan.
[††]The author is with the Department of Computer Science and Information Engineering, Nanhua University, Chia-Yi 622, Taiwan.
a) E-mail: yangwh@mail.hit.edu.tw
b) E-mail: ieecsw@ccu.edu.tw
c) E-mail: pat@ee.ccu.edu.tw
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The second section introduces the related works. The third section describes for exit OCDM code are inspected and the OCDM-label switching systems, i.e. how to encode labels. In Sect. 4, we test whether the four kinds of applied to our proposed switch system. We also give a briefly discuss about the scalability. In the last section, we conclude this paper.

2. Related Works

There are many switching paradigms that have been proposed for use over WDM optical networks as mentioned above. For all the switching schemes, photonic packet switching appears to be the best candidate because of its high-speed data rate transparency. The optical packet switches are capable of routing and switching an optical packet by processing the packet header in optical or electronic forms. When the packet header is processed for header recognition, the payload needs to wait in fiber delay lines and then be forwarded later to the next node. Photonic packet switching techniques can be divided into two categories: synchronous and asynchronous. For packet header recognition and packet delineation in both these categories, bit-level synchronization and fast clock recovery are required [12]. On the other hand, to resolve header and packet header modification is very time-consuming and expensive.

Recently, optical label switching has been proposed as an alternative approach to improve the packet forwarding process [13]–[16]. Optical label switching offers packet switching using the optical-labels. It assigns a short fixed-length optical label containing routing information to packets for transport across networks. Based on the label-operated method, it can be subdivided into three classe [13]. In the first approach, each path through the optical core network is allocated by a globally unique label. That is, each path is mapped onto a globally unique label. The switching devices forward a packet by routing table lookup. The drawback is that distributing these labels will be time consuming and very complicated. The second approach is to tag all the forwarding information in the header; this method can avoid lookup tables in each core node [14]. This "tagging approach" carries all routing information in the labels, which are a set of output port numbers of all passing nodes to the destination, in a stack in the header and rotates the stack for each traversed core node. These techniques still require header modification. The third approach is photonic MPLS label switching [15], [16]. The label is suitable for expressing routing information for each label switching device. The fundamental idea of MPLS label switching is to use interior routing protocols (e.g. OSPF) to calculate the shortest paths to all possible destinations, and then assign a sequence of labels along each path. This requires the label distribution protocol to allocate the label information between switches. As packets enter the optical label switching network, they are prefixed a label that contains routing information at the ingress edge node. When a labeled packet arrives at the first core node, the incoming label identifies the packet's trajectory through the network. The incoming label is removed and replaced by the appropriate outgoing label. When the packet arrives at the edge switch of the optical label switching network, the label of the packet is removed and routed normally. The drawback is that label swapping is needed at each switching device.

Table 1 Comparing four architectures.

	KIS	OC-MPLS	SCM	OCDM-Label
O/E/O procedure	Yes	No	No	No
Label swapping	No	Yes	Yes	No

Recently, some studies based on the photonic MPLS technique have been proposed to simplify the packet forwarding process [13], [15], [16]. These methods simplify the design of switch devices in the optical domain and speed up packet forwarding significantly. However, in [13], the key identification scheme (KIS) is not an all-optical technology. Instead, KIS need an "optical-electronic-optical" (O/E/O) process that requires the network switching devices to convert the labels from optical signals to electrical signals, make the division operations to decide the output port, and then convert the electrical signals back to optical signals. The O/E and E/O conversions are inevitable at each optical switch node; hence, the electronic circuits limit the data forwarding speed. In [15], the author proposed a photonic label switching scheme, based on optical code routing, called OC-MPLS. The label processing is based on optical code correlation. The author used the optical code with a specially devised optical encoder and decoder pair to deploy the photonic label processor. But the optical code is extracted, processed, and replaced at every intermediate switching node. That is, this photonic label switching scheme requires label swapping at each switching node.

Another proposal is for optical label switching that uses subcarrier multiplexing label swapping technology. The label information is carried by a low bit rate subcarrier multiplexed signal (SCM) while the baseband signal carries the payload data. Although header recovery of the SCM can be performed in the optical domain by using a very precise optical filter, this is a difficult and expensive technology and also requires label swapping [15], [17]. Table 1 briefly compares the architectures mentioned above. We can see that only OCDM-labeling transmit optical packet without costly label swapping and time consuming O/E/O procedure.

3. Optical CDM Label Switching System

In this section, we introduce our optical CDM labeled switching system. As shown in Fig. 2, the optical network consists of ingress edge nodes that connect optical networks and conventional networks and the core switching nodes. Every edge node first finds the best path for an optical packet that enters the optical networks, and then the edge node generates an OCDM-label and prefixes it to the packet. We assume that the edge node knows about the topology and other traffic information of the optical core network and can calculate the best path of the packet. The best path may be the

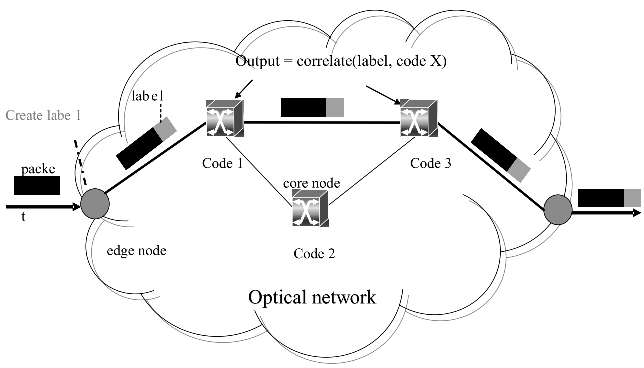

Fig. 2 An optical CDM label switching system.

shortest path from ingress node to the egress node or may be determined according to the results of traffic engineering. This routing method acts like source routing. Source routing is a way of forwarding a packet through a network in which the path is predetermined by the source, and the path information is placed in the label. In our scheme, the routing information is coded using CDM method in the label. The details of the CDM code will be described in Sect. 3.2.2. A core switching node is an optical label switching router. Each core switching node is assigned a code sequence with chips. When a packet reaches a core switching node, the code sequence is used to correlate with the label of the packet. The result of this correlation represents the output port of this packet to the next node that this packet is going to reach.

In addition, a switch decides the output port for a packet by way of correlating its optical sequence to the label in the optical domain. The label is not changed during its transmission process. Hence, such a system the time consuming O/E/O procedure and label swapping/header modification can be eliminated.

3.1 Edge and Core Node Architecture

The edge and core node architecture is depicted in Fig. 3. A packet entering from a conventional network into an optical network is itself an electrical signal. At first, it comes to the ingress edge node of the optical network, where the header for the conventional network is parsed by the label creator, in order to find the best path and generate an optical-label for the packet. The packet is converted into an optical signal by laser, by assuming that the data type is on-off keying, i.e., bit 1 generates a pulse, bit 0, no pulse. Before forwarding to the next core switching node, the label creator prefixes the OCDM-label to the packet and sends it out to the next node, as shown in Fig. 3. While the header is being processed, the label creator sends a control signal to set the optical cross connect (OXC) to select the right output port to deliver the optical packet. The source routing information is encoded in the label by using optical CDM. So that each core switching can determined the output port of the packet by correlated its own optical sequence with the label.

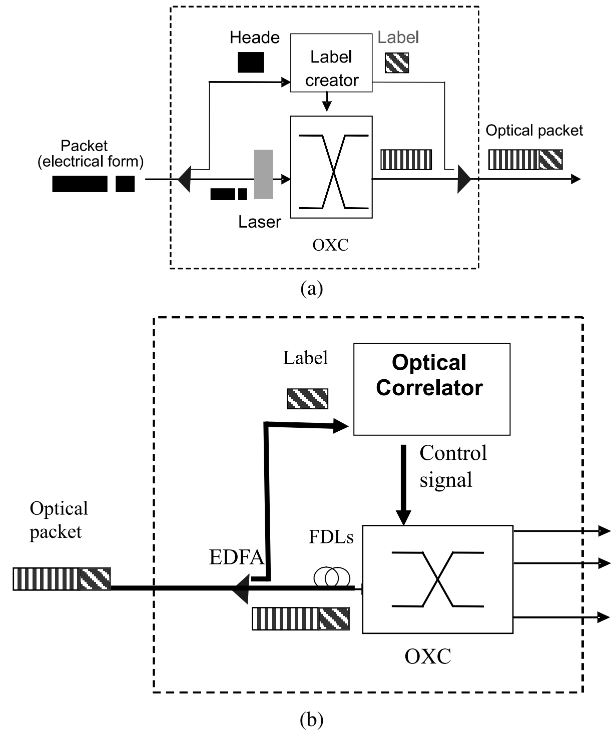

Fig. 3 (a) Ingress edge node architecture. (b) Optical switch (core) node architecture.

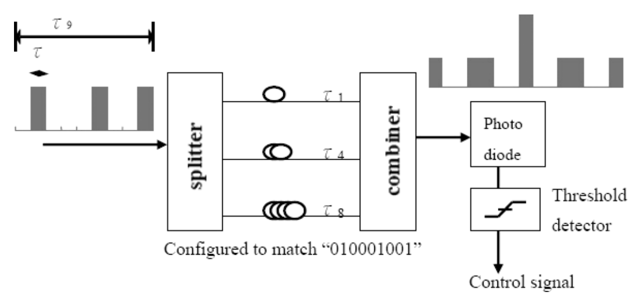

Fig. 4 Simplified optical correlator architecture.

The core node contains a tunable optical correlator for each input port. The correlator in Fig. 3(b) compares an incoming optical code sequence with the desired optical code that is configured in the correlator. We can use a common implementation of an optical correlator as the tapped delay line. An example of an optical tapped delay line correlator is illustrated in Fig. 4. At the input side, the optical signal represents one of the bits of the label with nine slots. In slots 2, 6, 9, there is one pulse for each slot. The other slots get no pulse. This one-bit optical signal will be split into three parts by a power splitter. Each part passes separately through FDLs of different delays, $\tau = 8$, $\tau = 4$, and $\tau = 1$, and is combined by a power combiner. The new signal will be revealed inside the diagram. The pulse of maximum energy can be found at the central spot. Only this pulse can push the photo diode to generate a powerful enough current to enable the threshold detector to send a signal of bit = 1.

When the optical packet reaches the core switching node, its front-end optical-label will be split out, optical amplified if needed and stuffed into the optical correlator module and correlates with the code sequence of this core switching node. The result of the correlator is the control signal that guides the optical packet to the correct output port, as shown in 3(b). In our OCDM-label system, the correlation result will be the output port of the optical packet. Note that the optical switch node must consist of fiber delay lines (FDLs) to be the register buffers for optical signals to wait for completion of correlation. The length loops that are required by the FDL are related to the length of the label and the time to set up the optical cross-connect. Assuming that N is the length of a code sequence and the core switching node contains 2^s ports, the length of the entire label becomes $s \times N$, where correlation time is $T = sN\tau$, and the required FDL loops are sN.

3.2 OCDM-Label

When the edge node finds the best path for an optical packet that enters the optical networks. The edge node generates an OCDM-label and prefixes it to the packet. An OCDM-label contains the source routing information according to the best path by using optical CDM. So that each core switching can determined the output port of the packet by correlated its own optical sequence with the OCDM-label.

3.2.1 Encode Optical Label

In this subsection, we are going to describe how to encode the OCDM-label. Assume the all-optical core switches have a unique node-specific code sequence, $C_{node} = \{C_{node}(i)\}_{i=1}^{N}$, which is $(0, 1)$ sequences of length N in the optical core network. Each 0 and 1 of a sequence is called a chip. The set of all code sequences satisfies certain autocorrelation and cross-correlation constraints. We assume that there are eight output ports for each core switching node, because nodes in a transport network typically have no more than five immediate neighbors. Thus, we need three bits to represent the values 0–7. Each value represents a port. Each code sequence stands for bit $=$ 1. bit $=$ 0 is indicated with no pulse. For example, Fig. 5(a) uses a code sequence, code1, to encode the port-code sequence, C^5_{node1}, of output port to be $5(101_2)$. Figure 5(b), instead, uses code2 to encode port-code sequence, C^3_{node2}, of port as $3(011_2)$. Where the port-code sequence for a port m of the core node n with $3N$ chips is $C^m_n = \{C^m_n(i)\}_{i=1}^{3N}$, where

$$C^m_n(i) = \begin{cases} \left\lfloor \dfrac{m}{4} \right\rfloor \times C_n(i), & 1 \le i \le N \\ \left\lfloor \dfrac{m - \lfloor m/4 \rfloor \times 4}{2} \right\rfloor \times C_n(i-N), & N+1 \le i \le 2N \\ \left\lfloor \dfrac{m}{1} \right\rfloor \times C_n(i-2N), & 2N+1 \le i \le 3N \end{cases} \tag{1}$$

When an IP packet arrives at the ingress edge node of the optical core network, the ingress edge node for this packet finds the shortest path through the optical core network. When a path through the optical core network is resolved, a port-code sequence array is obtained. This array contains the port-code sequences when the port of the core node is on the path. The label is created based on the port-code sequence array. Thus, when a path through the network is desired, the array is formed by all the port-code sequences for the given path. Given this array it is possible to compute an OCDM-label.

In the following discussion, this array is denoted by for the port-code sequences on the path. Assuming the path through the core network comprises n core nodes, and then the n-dimension array is given as

$$\bar{C} = \left(C^i_{node1},\ C^j_{node2},\ \cdots,\ C^k_{noden} \right). \tag{2}$$

The array in (2) is used to create the OCDM-label, which is denoted as the OCDM-label L. First, we define a superposition sum operator, $\oplus$, for code sequence. A code sequence C_{n1} superposition sum of another code sequence C_{n2} is denoted by $C_{n1} \oplus C_{n2}$. The chip of code sequence $C_{n1} \oplus C_{n2}$ is 0 if the both chips are all 0 in the two sequences occupy at same chip, otherwise is 1. Then the OCDM-label L computes the following operations.

$$L = C^i_{node1} \oplus C^j_{node2} \oplus \cdots \oplus C^k_{noden} = \{L(i)\}_{i=1}^{3N} \tag{3}$$

For example, if the two port-code sequences are described in Figs. 5(a) and 5(b). Then the optical label is encoded by means of the $\oplus$operator, part (a)$\oplus$ part (b) to get its code sequence as shown in Fig. 5(c).

When a packet prefix of an OCDM-label L travels through the core network, each traversed core node uses the

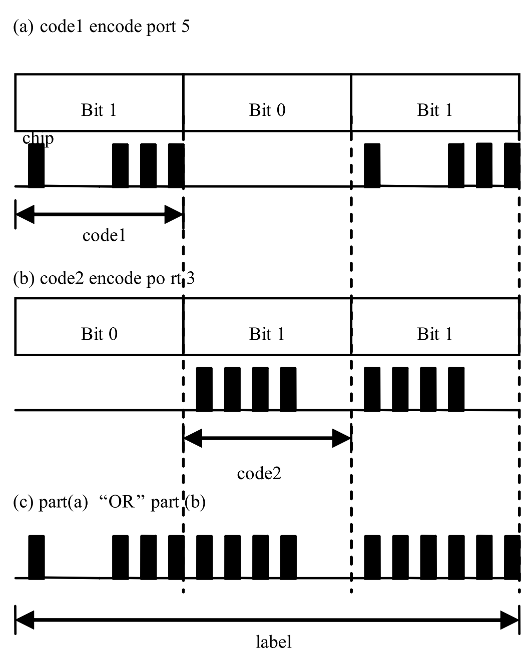

Fig. 5 Code description label.

OCDM-label L that correlates with a specific code that is configured in the correlator; the result is output port information that guides the core node how to forward the packet. The subsequent code nodes reiterate this operation with the same OCDM-label.

3.2.2 Characteristics of OCDM-Label

While constructing OCDM codes, we need to obey the three rules in [18] to make the receiver recognize signals correctly and easily. When the rules are applied to our system, the above conditions translate into the following:

- The number of coincidences in correlation of code sequence C_n correlate with the label L, it is formed by one of port-code sequence C_n^m, zero-shift, $S = 0$, should be maximized.
- The number of coincidences in correlation of code sequence C_n correlate with the label L formed by one of port-code sequence C_n^m, for very shift, $S > 0$, should be minimized.
- The number of coincidences in correlation of code sequence C_n correlate with the label L does not formed by one of port-code sequence C_n^m, for very shift, $S \geq 0$, should be minimized.

The correlation function of OCDM-label L that correlates with code sequence $C_n = \{C_n(i)\}_{i=1}^{N}$ of some core node n is defined as follows:

$$A_{L,C_n}(s,l) = \sum_{i=1}^{N} L(i+l)C_n(i-s),$$
$$-N+1 \leq i \leq N-1,\ l = 0, N, \text{or } 2N. \quad (4)$$

The coincidence is defined as an event which occurs when two ones from two sequences occupy the same chip. There are two correlations here: one is a chip-by-chip shifting correlation ($S \geq 0$), and the other is a bit-by-bit shifting correlation (only $S = 0$). The chip-by-chip shifting correlation is operated at asynchronous circumstances and the bit-by-bit shifting correlation is operated at synchronous circumstances. When the code sequences hold good correlation properties, this also translates to corresponding real signals [18].

In our OCDM system, we also consider the four encoding methods-the Prime code, the Extended Prime code, the Quadratic Congruence code, and the Extended Quadratic Congruence code-introduced in [19]–[21]. The code characteristic is very important for us first to analyze and then to decide if it is applicable to label coding. Thus, we summarize the four coding schemes and quadruples mentioned previously, and add a new sequence S, as shown in Table 2. Each quadruple contains four parameters: N, length of code sequence; K, the decision weight; λa, the biggest value of auto-correlation set of a code sequence of chosen prime number p; and λc, the biggest value of cross correlation set of a code sequence of chosen prime number p.

Table 2 Code characteristic table.

	S (set number)	N chips (Code sequence length)	K (weight)	λa	λc
PC	p	p^2	p	p	2
EPC	p	$p(2p-1)$	p	p	1
QC	$p-1$	p^2	p	2	4
EQC	$p-1$	$p(2p-1)$	p	1	2

3.3 Label Processing

When a packet prefix of an OCDM-label L travels through the core network, each traversed core node uses the OCDM-label L that correlates with a specific code that is configured in the correlator; the result is output port information that guides the core switching node to forward the packet. The subsequent code nodes reiterate this operation with the same OCDM-label. Optical labeling processing is based on optical correlation. When the labeled optical reaches the core switching node, its front-end optical-label will be split out, optical amplified if needed and stuffed into the optical correlator module and correlates with the code sequence of this core switching node. In each bit time duration, if an autocorreltion peak is detected then the photo diode to generate a powerful enough current to enable the threshold detector to send a signal of bit=1, else bit=0. Once getting three bit values, this information will tell OXC to send out packets from the correct output port.

4. Program Simulation about Worst Cases of Encoding Labels

In this section, we run programs to figure out the worst cases encountered while using the four codes to encode labels, and we make a final decision about the label coding applicability of codes. The worst case of encoding a label is as follows:

- In an optical network, a packet must visit X nodes to reach its destination.
- For every visited core switching node, the packet is assigned to an output port where two consecutive bits are 1, for example, port 3 (011_2), port 6 (110_2), and port 7 (111_2).

As indicated by [22], a core network with 10–30 core switching nodes is quite enough. In [6] European ACTS Optical Pan-European Network project, these numbers are discussed, too. On the other hand, in Fig. 7 of [13], with 50 core switching nodes, the frequency of the used route length of 8 (i.e., visited 8 nodes) is about 2%. The higher usage-rate route lengths are 3, 4, 5, and 6. Hence, under such circumstances, we assume the maximum route length is 8 in our system. If the length of the route is larger than 8, the system can adopt two-step routing, that is, through third party forwarding. An example is illustrated in Fig. 6, where a route from edge node A to edge node C is resolved, with the dotted line comprising nine core nodes. If the recognized margin for this route is too small, the route AC is divided into AB and BC, comprising two and three core nodes, respectively. This rule is added in routing protocols, such that when edge node A determines a route that requires too long a route, it simply defines a shorter and valid route to a node B, where B is closer to destination C than A. Then the node B finds the route to C, and the packet is labeled and forwarded to node C.

4.1 Asynchronous Correlation

The asynchronous correlation is the correlation operation by chip-by-chip shifting correlation. As shown in Table 3, the x-axis represents the lengths of routes under the prime number p, which is chosen to encode the code sequences. The lengths also represent the numbers of randomly selected code sequences which are used to encode a label and indicate the numbers of the visited core switching nodes; the y-axis represents the four coding schemes. The cross points of the x-axis and y-axis are the maximum coincidences. For example, if the core network contains 10 core switching nodes, it requires 10 code sequences. Thus we choose prime number $p = 11$, that is, there are 11 code sequences. In the PC and EQC coding schemes, we find that "coincidences= $K - 1$" and "coincidences= K" when a packet must visit 4 or 6 nodes to reach its destination. Although other coding schemes don't misjudge when a visited node recognizes the label, in the EPC coding scheme the recognized margin is quite small, 1 only. The recognized margin defines as the difference of code weight with maximum number of the coincidences in the correlation of the label. Here the coincidence is results form the correlation of the port code sequences of other node encoded in the same

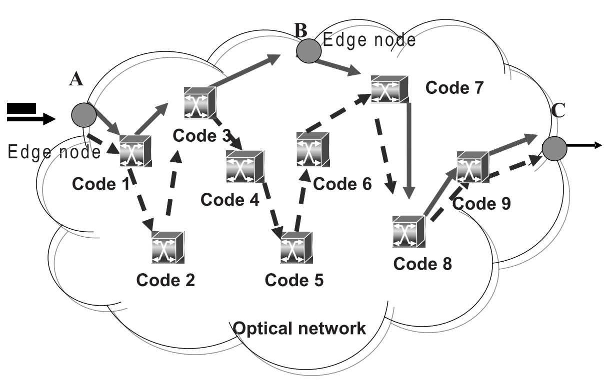

Fig. 6 Route AC is divided into two routes, AB and BC.

Table 3 The maximum number of coincidences in correlation of the label with code sequences of core switching node that visited by a path in worst cases in each case.

Code type	prime number p														
	11		13		17			19		23		29		31	
X	4	6	4	6	4	6	8	6	8	6	8	6	8	6	8
PC	11	11	13	13	17	17	17	19	19	23	23	29	29	31	31
EPC	10	10	12	12	16	16	16	18	18	22	22	28	28	30	30
QC	9	10	11	12	12	15	16	16	18	17	20	19	24	20	25
EQC	7	9	7	9	7	11	15	11	15	11	15	11	15	11	15

label within bit time duration in worst cases of each case.

Now, for example, if the core network contains 30 core switching nodes, it requires 30 code sequences for 30 nodes. Given that prime number $p = 31$, to run the program, the result is also shown in Table 3. There aren't any code schemes for PC and EPC; the result is still the same no matter how many nodes are visited; misjudgments of label recognition always happen. For QC, although this coding scheme doesn't cause misjudgment of label recognition, the recognized margin is quite small, due to too many nodes being visited. Therefore, once a packet passes through too many nodes, it causes an insufficient recognized margin and is subject to recognize interference. Hence, as mentioned above, if the length of a route is larger than 8, the system can adopt two-step routing, that is, through the third party forwarding. From the above evaluation, we can make sure that while doing correlations in asynchronous conditions, PC and EPC cannot be used for label coding. Instead, QC and EQC can.

4.2 Synchronous Correlation

While in synchronous circumstances, we try to use bit-by-bit shifting for correlation, this correlation must finish synchronization in order to align each bit. In this section, we don't consider how to synchronize, because we are presently only introducing the concept. Instead, we just analyze if the label coding is applicable in bit-by-bit shifting cases. Since one bit of a label results from the superposition sum of code sequences, i.e., one bit of label = ($code1 \cup code2 \cup code3 \cup ...$), we don't worry that, while doing correlation, the label correlator cannot judge bit = 1. On the contrary, we worry much more that the label doesn't contain code3 and misjudgment occurs at bit-by-bit shifting correlation with the bit being mistaken as 1. An example of prime code is shown in Fig. 7, assuming that a certain bit of the label bit is made up of code1, 2, 4, and 5. While correlating sums with code3, two code sequences get only one coincidence. While checking the prime code table over again, given that $p = 5$, we find that only the first chip (leftmost) overlaps when the prime code is constructed. In addition, it is the same when checking the code tables of EPC and PC; QC and EQC get two chips overlapped.

Using code1, 2, 4, and 5 to make up the label means

	bit
Code1	1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 0 0 0 0
Code2	1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1 0 0 0 0 0 1
Code4	1 0 0 0 0 0 0 0 1 0 0 1 0 0 0 0 0 0 0 1 0 0 1 0 0
Code5	1 0 0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0 1 0 0 0
SUM	1 0 0 0 0 1 1 0 1 1 1 1 1 1 0 1 0 1 1 1 1 1 1 0 1
Code3	1 0 0 0 0 0 0 1 0 0 0 0 0 0 1 0 1 0 0 0 0 0 0 1 0

Fig. 7 Example of prime code, label is made up of 1, 2, 4, 5.

Table 4 10 core switching nodes, given x to make up a label.

Code type	Take X for label							
(No. of sequences)	10	9	8	7	6	5	4	3
PC (11)	1	1	1	1	1	1	1	1
EPC (11)	1	1	1	1	1	1	1	1
QC (10)	2	2	2	2	2	2	2	2
EQC (10)	2	2	2	2	2	2	2	2

that the label doesn't pass through node3 and it doesn't correlate with code3. We come out with a result that is shown in Table 4, with 10 core switching nodes, coincidences are all small. PC and EPC get only one chip overlapped. Both QC and EQC get two chips overlapped. Even when adding more core switching nodes, the result is the same. Hence, if correlation is done via bit-by-bit shifting in synchronous condition, four coding rules can be used for making up the label. Moreover, the recognized margins of both PC and EPC are larger than QC and EQC by 1. Furthermore, the code length of PC is shorter that EPC. Therefore, to adopt PC will shorten the label much more.

Although using code1, 2, 4, 5 to make up the label means that the label doesn't pass through node3 and it doesn't correlate with code3. We come out with a little conclusion. As shown in Table 4, with 10 core switching nodes, coincidences are all small. PC and EPC get only one chip overlapped. Both QC and EQC get two chips overlapped. Even when adding more core switching nodes, the result is the same.

Hence, if correlation is done via bit-by-bit shifting, four coding rules can be used for making up the label. Moreover, the noise margins of both PC and EPC are larger than QC and EQC by 1. Furthermore, the code length of PC is shorter that EPC. Therefore, to adopt PC will shorten the label much more.

4.3 Scalability

The length of a label is mainly related to the number of nodes of the core network. The bigger the core network is, the more nodes there are. The more code sequence the core network requires, the larger p it must choose. Thus, the code sequence becomes longer, too. However, as indicated by [22], a core network with 10–30 core switching nodes is quite enough. Hence, if the core network has 30 nodes, it requires 30 code sequences. Given that $p = 31$, N_{QC} is 961 chips and N_{EQC} is 1,891 chips. Assuming that the optical pulse generator is 10 GHz, then a chip time $\tau = 1/10\,\mathrm{G}$, and it takes 3 k/10 G= 0.3 μs and 3×2 k/10 G= 0.6 μs to complete a 3-bit correlation. In addition, from Table 3, we discovered that when the number of core-switching nodes becomes larger, under the condition that QC and EQC pick up 3 7groups (i.e., passing through 3 7 nodes), the recognized margin becomes wider. This means that if the core network gets bigger with more nodes, the recognized margin will get wider.

On the other hand, in Fig. 7 of [13], with 50 core switching nodes, the frequency of the used route length of 8 (i.e., visited 8 nodes) is about 2%. The higher usage-rate route lengths are 3, 4, 5, and 6. Based on this fact, plus the result of Table 3, we come out with a conclusion: within 50 core-switching nodes, the route lengths of the highest average usage rate take place at 3, 4, 5, and 6 nodes. If a core network is within 30 core-switching nodes, then the curve shifts leftward and the route lengths of the highest average usage rate take place between 2 5. Under such circumstances, when encoding our desired label in the worst case, then the recognized margin of QC and EQC is fair (within 30 nodes, in Table 3, the recognized margin gets wider).

5. Conclusion

A photonic packet routing method by using optical correlator in IP over optical packet-switched network has been proposed basing on source routing. We take advantage of existing OCDM coding schemes to encapsulate the labels, which are called OCDM-labels. The label was prefixed to a packet for transmission, which can achieve optical packet switching without header modification/label swapping techniques, with ideal switching avoid the O/E/O conversion procedure at each switching device. That is, the forwarding optical packets without converting them to electronics in order to process and update their labels at each core node in optical network.

In this paper, we consider the feasibility of the four kinds of coding technique under synchronous or asynchronous circumstances. Through the computer emulation, we found that all the four codes are feasible under synchronous circumstances but only QC and EQC codes are feasible under asynchronous circumstances. However, for the synchronous implementation, additional cost for hardware and circuits is needed to synchronous the bit clock. In addition, with considering the length of label, we use PC coding technique for synchronous circumstances and we use QC coding technique for asynchronous circumstances in order to shorten the label length. This method simplifies the design of switch devices in the optical domain to simplify the packet forwarding process, speeds up packet forwarding and increases throughput significantly.

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Wang-Hsai Yang was born in Tainan, Taiwan, in 1972. He received his M.S. degree in Department of Mathematics from Tunghai University in 1996. Currently, he is a doctoral student of Department of Electrical Engineering at National Chung Cheng University. His research interests cover routing in wavelength assignment in WDM, high survivable WDM network and Optical label switching, and so on.

Cheng-Shong Wu was born in Taoyuan, Taiwan, in 1961. He received the B.S. and M.S. degrees in electrical engineering in 1983 and 1985 from National Taiwan University, Taiwan, and Ph.D. degree in electrical engineering from University of Southern California, USA, in 1990. During 1991, he was a Visiting Assistant Professor in the Center for Advanced Computer Studies in the University of Southwestern Louisiana. He joined the Department of Electrical Engineering at National Chung-Cheng University, Taiwan, in fall of 1991. Currently he is a Professor in the department. His researching interests include broadband networks, wireless networks, queuing theory, and mathematical programming.

Hui-Kai Su received the B.S. (Electronic Engineering) degree from I-Shou University, Taiwan, in 1999. He earned his M.S. and Ph.D. (Electrical Engineering) degrees from National Chung-Cheng University, Taiwan, in 2001 and 2006, respectively. He is an Assistant Professor of Department of Computer Science and Information Engineering at Nanhua University, Taiwan. His research interests include QoS control, resource management and survivability for multimedia applications in QoS-Enabled IP/MPLS networks.