Optical Coding Label Reuse Scheme to Support More Routing Paths over Multi-Protocol Label Switching Networks

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***Abstract*—In a Multi-Protocol Label Switching (MPLS) network based on Optical Code Division Multiplexing (OCDM), each core switching node is assigned one code sequence with N chips for each specific input/output pair. With optical code division multiplexing, it creates a new way to utilize optical codes as optical labels. As the users and Internet traffic continue to grow rapidly, it is expected that optical networks will support a larger number of users in the future. However, there is a scalability problem that the large the number of core nodes, the more code sequences are needed. To solve this critical problem, we consider a situation that can reuse label in order to save the number of utilized labels. Under this structure, there is a significant increase in the number of users that can be supported compared to the original ones. In this paper, we compare the relationship of the number of utilized labels and supported LSPs (label switching paths) in both situations with and without reusing labels. We also discuss the issue of cost efficiency and bandwidth efficiency. Further, the discussion of BER performance is also included.** *(Abstract*)

***Keywords- Optical code division multiplexing (OCDM); multi-protocol label switching (MPLS); label stacking; spectral amplitude coding (SAC) (key words*)**

I. INTRODUCTION

Multi-Protocol Label Switching (MPLS) is a switching protocol between data link layer (layers 2) and network layer (layer 3), which labels are added in packet headers and the labelled packets are forwarded in corresponding paths using label switching [1]. The term ‘multi-protocol’ has the meaning that it can be used in different network layer protocols. MPLS maps IP addresses into simple fixed-length protocol-specific identifiers called ‘labels’ which are distinguishing forwarding information (label) from the content of the IP headers [2], in other words, MPLS enables the forwarding of packets based on looking up the labels rather than the IP addresses [3].

Many MPLS techniques based on different multiplexing methods have been proposed in optical domain, such as Time-Division Multiplexing (TDM) [4], Wavelength-Division Multiplexing (WDM) [5], Subcarrier-Division Multiplexing (SDM) [6] and Optical Code Division Multiplexing (OCDM) [7]. With OCDM, it creates a new way to utilize optical codes as optical labels [8]. In [9], author proposes a method to check the label in the core node with the function of optical correlation, because logic operations corresponding a look-up table is the toughest challenge for optical processing.

Some researches had been proposed, focusing on increasing the user capacity in OCDMA system [10][11]. However, in the OCDM-based MPLS network, the length of a label is mainly related to the number of nodes of core network [12]. The bigger the core network is, the more core nodes are needed. When more nodes are required, the more code sequences are needed, which means the code length must be increased due to the reason that the number of code sequence is limited by the code length [13]. Therefore, we consider a scenario which can reuse labels in order to save the number of utilized labels when the number of core nodes is limited. We will compare the relationship of the number of utilized labels and supported LSPs in the situation with and without reusing labels; BER performance, cost efficiency and bandwidth efficiency in both situations are also discussed.

Spectral-Amplitude Coding (SAC) has the advantages of low-cost implementation and high switching speed. It is easy to eliminate the Multiple-Access Interference (MAI) when code sequences are with fixed in-phase cross correlation (such as M-sequence or MQC code) [14][15]. However, we use the method of label stacking based on SAC, which is compatible with label stacking, to generate labels [16]. With the label stacking method, the size of forwarding tables can be reduced, and the speed of routing process can also be increased, moreover, the repeated process of label swapping can be avoided. In our proposed system architecture, we use Arrayed Waveguide Grating (AWG) as the codec in order to generate labels and do the optical correlation.

The rest of this paper is organized as follows. Section II introduces the label stacking method base on SAC, and the system structure we used. Section III describes the concept of label reuse and we will first mention the problems from the aspect of OCDMA, then we discuss these problems when applying OCDMA to MPLS. In Section IV, we compare the relationship of the number of utilized labels and supported LSPs when labels are with or without reused, also, the cost efficiency and bandwidth efficiency are also included in the discussion. Finally, conclusions are presented in Section V.

II. LABEL STACKING BASED ON SPECTRAL-AMPLITUDE CODING

A label stacking method based on SAC is first proposed in [16]. With this approach, each label is assigned to each intermediate node rather than link. Here, one label means a specific bond, in other words, the forwarding information of two links adjacent to an intermediate node. At the ingress node, it chooses the path and sends all the labels corresponding to the intermediate node attached to the payload, and the intermediate node only needs to check a short label that is assigned to it. This approach reduces the size of forwarding tables and increases the speed of routing processing; moreover, the repeated process of label swapping can be avoided.

Here, we take an example of simple MPLS network in order to introduce the concept of label stacking based on SAC with the proposed scheme that AWG is used as the codec. The example is shown in Figure 1, which we assume that the ingress node has chosen two Label Switching Paths (LSPs) and each of them contains three core nodes. In one LSP, each core node is assigned with a specific code sequence (label), in this example, labels $\boldsymbol{C}_1$ to $\boldsymbol{C}_3$ belong to LSP1 and $\boldsymbol{C}_4$ to $\boldsymbol{C}_6$ belong to LSP2.

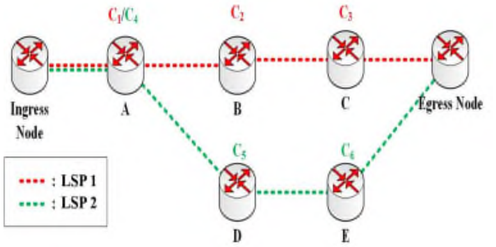


Figure 1. Example of a simple MPLS network topology.

Figure 2 illustrates the system structure of the ingress node. The broadband light source will be sent to the splitter, then, the light source will be encoded on the spectrum in order to generate the corresponding code sequences. Here, we utilize AWG as the codec to encode and decode code sequences, and the M-sequence with code length 7, code weight 4 and correlation value 2 is also used as the label. On the other hand, the electrical header has the information of the desired LSP for the user and it determines the corresponding code sequences to be encoded into a label stack.

After the label stack has been chosen, the label stack will modulate the payload bit with intensity modulation in order to generate the labelled packet. Therefore, each bit in the labelled packet includes the information of label stack, in other words, the payload and the label stack occupy the same bandwidth in the labelled packet, which also increases the bandwidth efficiency. Figure 3 shows the spectrums of the labelled packet bit of LSP1 and LSP2.

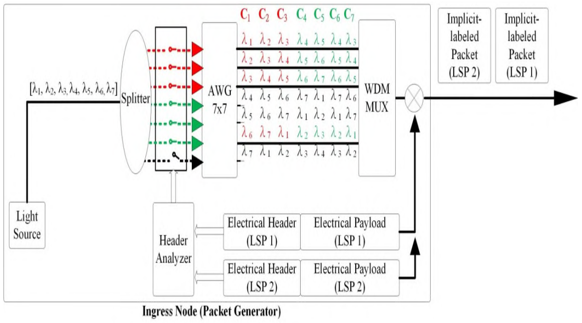
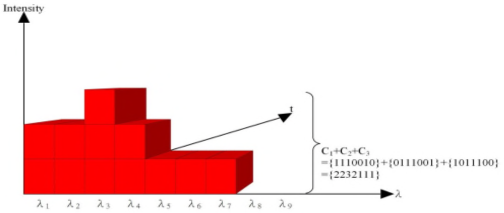
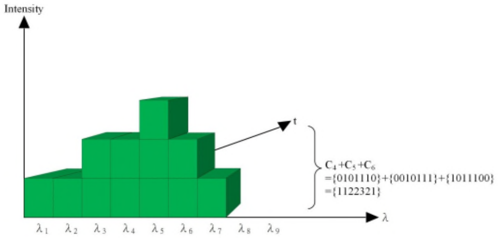


Figure 2. System structure of ingress node.



(a) Implicit Packet (LSP 1) Bit 1



(b) Implicit Packet (LSP 2) Bit 1

Figure 3. Spectrum of the labelled packet bit of (a). user of LSP1; and (b). user of LSP2.

As shown in Figure 4, at the core node, the bit of the labelled packet is first sent to the splitter, and the label processor will do the optical correlation by the optical decoder, also, the optical switch will forward the packet to the correct output. The structure of the decoder ($\boldsymbol{C}_1$) is illustrated in Figure 5, it will remove the power of undesired code sequences by the balanced detector, and the output of the decoder is used as the control signal to order the corresponding optical switch to forward the packet to the correct output port.

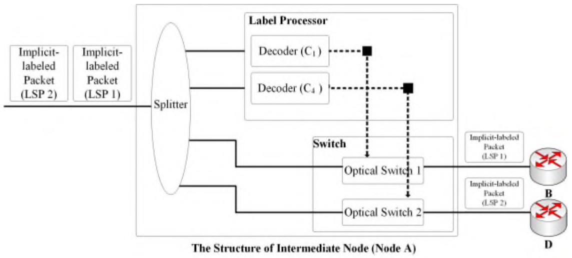


Figure 4. The structure of core node (node A).

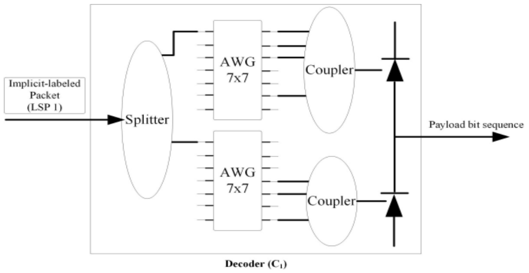


Figure 5. The structure of decoder (C1).

III. CONCEPT OF LABEL REUSE

From the aspect of OCDM, the most direct method to support more users is increasing the code length. Most Optical Orthogonal Codes (OOCs) have limited number of users for a reasonable code-length and code-weight, for example, the M-sequence codes with code length 3 and code weight 2 can only support 3 users, as shown in Figure 6. If we want to support more users, then the code length must be increased for the reason that the code length increases with the increase in the number of users.

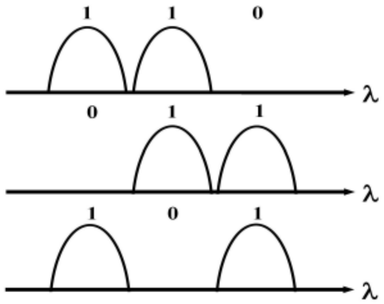


Figure 6. M-sequence code (length 3, weight 2).

When the bandwidth of the broadband light source is fixed and we increase the code length, as shown in Figure 7, the port numbers of AWG codec will also increase, resulting in a higher cost. In second case, the bandwidth of the wavelength channels is fixed and two times the bandwidth of broadband light source is used than before increasing the code length, as shown in Figure 8. This situation causes a lower bandwidth efficiency.

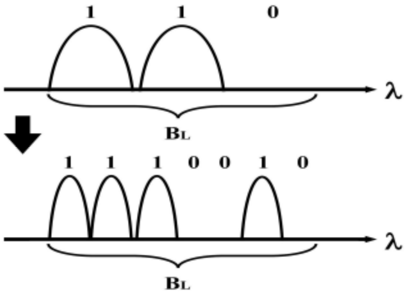


Figure 7. Increasing code length when the bandwidth of the broadband light source is fixed.

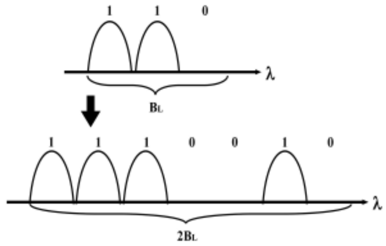


Figure 8. Increasing code length when the bandwidth of the wavelength channels is fixed.

As mentioned above, from the aspect of OCDM, the discussions are focused on how to increase the number of supported users. However, when applying OCDM to MPLS, the point will be how to save the number of utilized labels and support more LSPs when the number of available labels is limited. The following will describe the concept of label reuse with a simple example. The concept of label reuse is quite intuitive. When one intermediate node is not intersected with other LSP, a specific label which has been assigned to other node can be reused by this intermediate node. An example is shown in Figures 9 and 10.

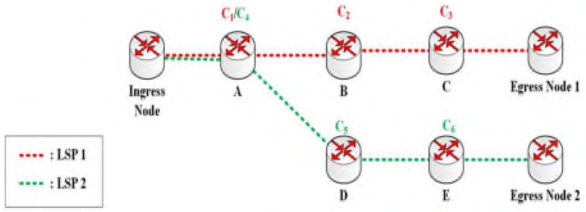


Figure 9. Example of MPLS network (without label reuse).

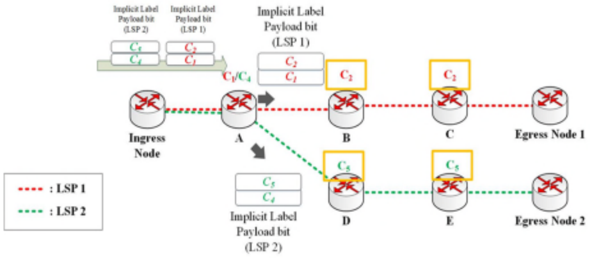


Figure 10. Example of MPLS network (with label reuse).

Two LSPs are assumed. Two payload bits, each with different label stack. Except intermediate node A, the nodes in LSP1 and those in LSP2 are independent. Therefore, as illustrated in Figure 10, it is intuitive that $\boldsymbol{C}_2$ and $\boldsymbol{C}_5$ can be reused in LSP1 and LSP2, separately.

IV. COMPARISON AND DISCUSSION

We want to know the difference between the label-reused scenario and the situation without reusing the labels. In the following examples of grid topology, we assume that every LSP has only three intermediate nodes, and only one of them intersects by other LSPs, in other words, the rest two nodes are not related to other LSPs. Here, we discuss the relationship between the number of utilized labels and supported LSPs when labels are with or without reused. We first fix the number of supported LSP to compare the number of utilized labels between the label-reused scenario and the situation without reusing labels. It is assumed that the number of supported LSPs is 2, and we take examples of the grid topology to illustrate this case in Figures 11 and 12. As illustrated in Table I, according to Figures 11 and 12, we can save two labels from being utilized when reusing labels (case 1 in Table I).

In order to see a more obvious change, we consider two more cases that the fixed number of supported LSPs is set as 6 and 10. As shown in Table I, in case 2, the number of utilized labels is 18 without label reused, however, we can save four labels when reusing labels. On the other hand, in case 3, the number of utilized labels will be decreased down to 20 when reusing labels, in the contrast, it is 30 when labels without reused.

Here, we fix the number of utilized labels to compare the number of supported LSP between the label-reused scenario and the situation without reusing labels. We assume that the number of utilized labels is 2, and we take examples of the grid topology to illustrate this case in Figures 11 and 13 (case 1 in Table II). Table II shows that, in case 1, only two LSP can be supported when labels are not reused, however, in the label-reused scenario, the number of supported LSP reaches to 4.

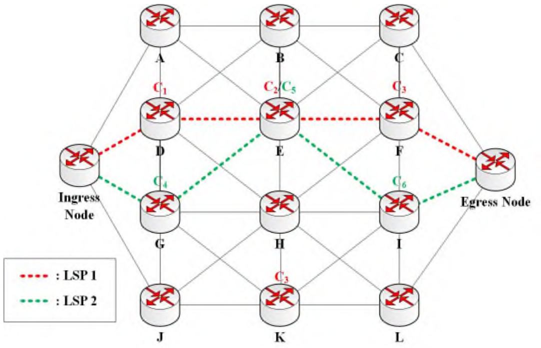


Figure 11. Grid topology (without label reuse).

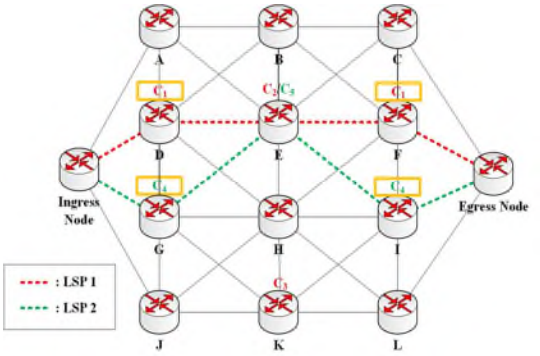


Figure 12. Grid topology (with label reuse / fixed number of supported LSPs).

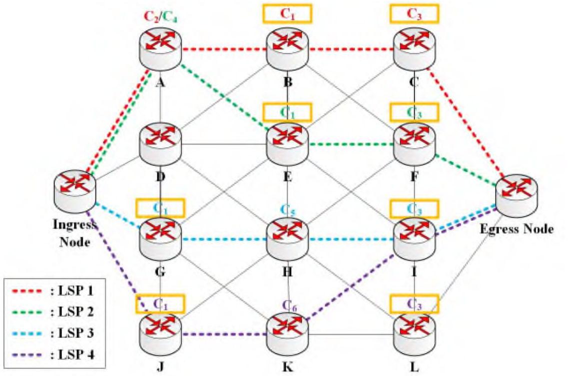


Figure 13. Grid topology (with label-reuse / fixed number of utilized labels).

TABLE I. NUMBER OF UTILIZED LABELS AND SUPPORTED LSP WITH AND WITHOUT LABELS REUSING WHEN THE FIXED NUMBER OF SUPPORTED LSP IS 2/6/10.

Case		**The number of utilized labels**	**The number of supported LSPs**
Case1	***Lwor***	6	2
	Lwr	4	2
Case2	***Lwor***	18	6
	Lwr	12	6
Case3	***Lwor***	30	10
	Lwr	20	10
Lwor: Labels without reuse / *Lwr*: Labels with reuse.			

TABLE II. NUMBER OF UTILIZED LABELS AND SUPPORTED LSP WITH AND WITHOUT LABELS REUSING WHEN THE FIXED NUMBER OF SUPPORTED LSP IS 6/15/30

Case		**The number of utilized labels**	**The number of supported LSPs**
Case1	***Lwor***	6	2
	Lwr	6	3
Case2	***Lwor***	15	5
	Lwr	15	8
Case3	***Lwor***	30	10
	Lwr	30	15
Lwor: Labels without reuse / *Lwr*: Labels with reuse.			

In addition for viewing a more explicit change, we also consider other two cases that the fixed number of utilized labels is set to be 15 and 30. In case 2, we let the number of utilized labels be 15. If labels are not reused, the number of supported can only be 5, however, it can be up to 8 when reusing labels. On the other side, in case 3, the number of supported LSPs increases from 10 to 15.

From the cases of comparison above, we can derive the mathematical relationship between the number of utilized labels and supported LSPs in a intuitive way. First, we assume the following parameters:

n: The number of core nodes in every LSP.

α: The number of core nodes which intersect with other LSPs in each LSP.

K: The number of utilized labels.

L: The number of supported labels.

As mentioned, from the cases of comparison above, we can derive the mathematical relationship intuitively. The mathematical relationship between the number of utilized labels and supported LSPs is as follows:

$$K = n \cdot L. \tag{1}$$

$$K = \text{ceiling}\ (\alpha \cdot L + L) = \text{ceiling}\ (L \cdot (\alpha + 1)). \tag{2}$$

where ceiling(x) is the ceiling function which gives the smallest integer greater than or equal to x.

Equation (1) denotes the relationship between the numbers of utilized labels and supported LSPs when labels are without reused. On the other hand, (2) is for the case that labels are reused. For example, if labels are without reused and there are two LSPs (L=2), every of them has five core nodes (n=5), one of these nodes are intersected with other LSPs (α = 1), then from (1), we can obtain the number of utilized labels K is 10 ($K = n \cdot L = 5 \cdot 2 = 10$). On the other hand, if in the label-reused scenario, we can obtain from (2) that the number of utilized labels K is 4 ($K = L \cdot (\alpha+1) = 2 \cdot (1+1) = 4$).

Based on the assumption that every LSP has only three intermediate nodes and only one of them intersects by other LSPs, under the situation that the bandwidth of the broadband light source is fixed, if we let the number of supported LSPs is 10, then the number of utilized labels will be 30, which means we need the codes with code length at least 30. However, in the label-reused scenario, we only need code with code length with at least 20. This situation is related to the cost of AWG codecs. In other words, if we use codes with longer code length as the labels, then we need AWG codecs with more ports which increases the cost. Therefore, the situation with label-reused is more cost efficient.

Based on the same assumption that every LSP has only three intermediate nodes and only one of them intersects by other LSPs, if we let the number of supported LSPs is 10 and the bandwidth of wavelength channel of AWG is fixed, then we need the codes with code length at least 30, therefore, the bandwidth of broadband light source will be 30 times the one of wavelength channel. However, in the label-reused scenario, we only need code with code length with at least 20, in other words, the bandwidth of broadband light source will only need to be 20 times the one of wavelength channel. So, the bandwidth of the broadband light source will not be wasted too much when labels are reused, therefore, the bandwidth efficiency is better.

We analyze the BER performance in both situations that with and without label reuse. It is assumed that the number of core nodes in every LSP is 6 (n=6), the number of core nodes which intersect with other LSPs in each LSP is 1 (α=1) and the number of supported labels is 4 (L=4). Besides, we use M-sequence code with code length 15, code weight 8 and correlation value 4 as the label sequence. As illustrated in Figure 14, when labels are without reuse, the BER is higher for the reason that the label stack contains six code sequences. However, if labels are reused, the BER performance becomes better, because when reusing labels, the number of code sequences in the label stack will decrease. For example, in this case, the number of code sequences in the label stack is two when reusing labels. In the previous research [17], the BER performance between labels coded with stuffed quadratic congruence (SQC) codes and conventional M-sequence codes had been discussed. The BER of M-sequence label in [17] at the power level of -16 dBm is about 10^{-11}, however, as seen in Figure 14, at the same power level, the BER of M-sequence labels with label reuse is about 10^{-67} theoretically, which is much better than the result derived in [17].

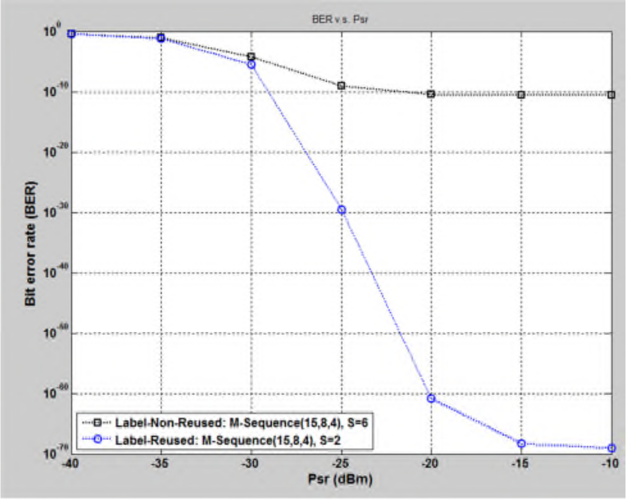


Figure 14. BER vs. effective received power when labels are with and without reuse.

V. CONCLUSION

Mathematical relationship of the number of utilized labels and supported LSPs when labels are reused or not reused were well derived. Some advantages with label reuse were found out as following: (1). If the number of utilized labels was limited, then the number of supported LSPs increased when labels were reused; (2). If the number of supported LSPs was limited, then we can save more labels being utilized when reusing labels; (3). When labels were reused and the bandwidth of broadband light source was fixed, the cost of AWG codecs will be decreased due to the smaller code length of the utilized code which was because the number of utilized labels was smaller; and (4). When the labels are reused and the bandwidth of wavelength channels of AWG codecs was fixed, more bandwidth can be saves due to due to the smaller code length of the utilized code. It was concluded that the number of code sequences in one label stack can be reduced when labels were reused. Therefore, the BER performance in the label-reused scenario will be better than the situation without reusing labels.

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