# Multi-Service Path Switching in All-Optical GMPLS Core Network

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*Abstract*— **In this paper, we present a novel labeling scheme for Multi-service path switching in the all-optical Generalized Multi-Protocol Label Switched (GMPLS) core networks. In this scheme, we employ the Multi-Length Variable-Weight Optical Orthogonal Code (MLVW-OOC) as a multiplexing signature sequence and identifying label. In order to analyze the performance of the network, the probability of error is evaluated for arbitrary number of classes and cross-correlation values. Furthermore, the probability of performance degradation is investigated by considering the activity coefficient of connected paths. To assure the demanded performance, Label Distributed Protocol (LDP) is accommodated by a controlling mechanism which limits the number of connected paths. Finally, a four-class network is designed by the proposed labeling scheme and the probabilities of error and the performance degradation are investigated; results indicate that decreasing the upper bound of the connected paths will reduce the probability of the performance degradation.**

## I. INTRODUCTION

Optical networks exploiting the huge fiber capacity are among the best candidates to support growing data traffic. On the other hand, GMPLS has received much attention as a very promising control plane for next generation optical networks. GMPLS not only supports Packet-Switch-Capable (PSC) networks but also Time slot-Switch-Capable (TSC), Lambda-Switch-Capable (LSC), and Fiber-Switch-Capable (FSC) networks. Furthermore, GMPLS automates traffic engineering and end-to-end provisioning through a common control plane by unifying the optical and Internet Protocol (IP) layers in the network. In addition, it utilizes best feature of IP and Asynchronous Transfer Mode (ATM) in terms of Quality of Service (QoS), privacy, flexibility and scalability [1, 2].

GMPLS core network uses wavelength-routed scheme to forward data in optical domain. In this approach, the specific wavelength used is considered as the label of received data. By this consideration, data along a pre-established path, called Optical Label Switched Path (OLSP), are forwarded by wavelength changing. Although data are routed in optical domain without optical-electrical conversion, this scheme has some shortcomings. First, the smallest data granularity is a WDM window which is very coarse. Second, assigning the whole capacity of one wavelength to single OLSP squanders bandwidth and therefore degrades optical network utilization. Finally, the number of available labels which is limited to the number of wavelengths is inadequate.

To overcome the bottlenecks of the GMPLS core network, Optical Code Switched-GMPLS (OCS-GMPLS) scheme has been proposed [3-5]. OCS-GMPLS method utilizes Optical Code Division Multiplexing (OCDM) to share the bandwidth of single lambda among multiple paths. Each path uniquely is identified by lambda and code (λ, C). In other word, (λ, C) represent the label of the received data. Furthermore, label swapping is done by code switching, lambda switching, or jointly lambda and code switching. Employing OCDM in each lambda improves the optical network utilization, coarseness of data granularity, and label scarcity of GMPLS.

In all previous work on OSC-GMPLS network, it has been assumed that the established paths have the same service requirements whereas the growing multimedia applications require multi-service path switched core network [3-5]. In this paper, we propose a novel scheme to support multi-service path switching in OCS-GMPLS core network. To achieve this aim, we use Multi-Length Variable-Weight Optical Orthogonal Codes (MLVW-OOC) as the multiplexing signature sequence in each lambda. It is worth to mention that these codes are designed to provide multi-service transmission in optical access networks [6, 7]. On the other hand, in order to provide the demanded services, the length and the weight of codes are selected based on the service requirements.

The rest of this paper is organized as follows. In Section II, the architecture of proposed router is described. Section III is devoted for evaluating the probabilities of error and performance degradation. In Section IV, a typical network is designed by proposed labeling scheme. Finally, we conclude with a brief summery of results.

## II. ARCHITECTURE OF THE PROPOSED SCHEME

In order to support multi-rate, multi-QoS, and jointly multi-rate and multi-QoS transmission on incoherent OCDMA networks, Multi-Length Optical Orthogonal Code (OOC), Multi-Weight OOC, and Multi-Length-Variable-Weight OOC (MLVW-OCC) have been designed, respectively [6-11]. We denote these variants of OOC as Generalized OOC (GOOC). In GOOC families, codeword can have dissimilar weight, length, or jointly weight and length. The short length and the high weight codewords are assigned to high rate and high quality subscribers, respectively. Let $(\{L_1, L_2, ..., L_Q\}, \{w_1, w_2, ..., w_Q\}, \{NC_1, NC_2, ..., NC_Q\}, Q, I)$ denotes the GOOC parameters where

$L_i$ : length of codeword;
$w_i$ : weight of codeword;
$NC_i$ : the number of available codeword;
$Q$ : the number of defined classes;
$I$ : cross correlation matrix;

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Subscript $i$ determines that the parameters belong to class $i$. $I$ is defined as

$$I = \begin{bmatrix} I_{(1,1)} & \ldots\ldots & I_{(1,Q)} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ I_{(Q,1)} & \ldots\ldots & I_{(Q,Q)} \end{bmatrix} \tag{1}$$

Let $C_k^n$ denotes $k$th codeword of class $n$. Then $I_{(n,m)}$ is defined as

$$\sum_{t=0}^{L_n-1} C_k^n(t) C_f^m(t+\tau) \le I_{(n,m)} \tag{2}$$

where $C_f^m(t+\tau)$ denotes the shift of $C_f^m$ by an integer τ and $0 < \tau < L_m$.

We apply MLVW-OOC as a signature sequence of incoherent OCDM in each lambda to provide multi-service path switching in OCS-GMPLS core network. As can be seen in Fig. 1, in each lambda, Q code sets are considered for Q classes. Code set of each class is designed based on the requirements of the demanded services.

In the MLVW-OOC labeled network, the Number of available Label of class i ($NL_i$) in each link is equal to $NW \times NC_i$ where $NW$ is the Number of Wavelength in single link (fiber). Figure 2 illustrates the architecture of multi-service OCS-GMPLS router.

In order to identify the label of the received data, wavelengths of each input fiber are separated by wavelength de-multiplexer and in each wavelength, Optical Decoder Bank (ODB) is used to recognize the code of the received data. After recognizing input optical code, the output label ($\lambda_{out}$, $C_{out}$) is determined according to the forwarding table and the input label ($\lambda_{in}$, $C_{in}$). Optical switch forwards decoded signal to relevant optical encoder of $C_{out}$. If $\lambda_{out}$ and $\lambda_{in}$ are not equal, optical switch changes $\lambda_{in}$ into $\lambda_{out}$ and then forwards decoded signal to its encoder.

In ODB and OEB, AND Logic Gate (ALG) and Tapped Delay Line (TDL) structures are used as decoder and encoder, respectively. As shown in Fig.3, the number of delay lines in these structures is equal to the weight of code (w). In addition, the delay of each line represents nonzero position of codeword [12].

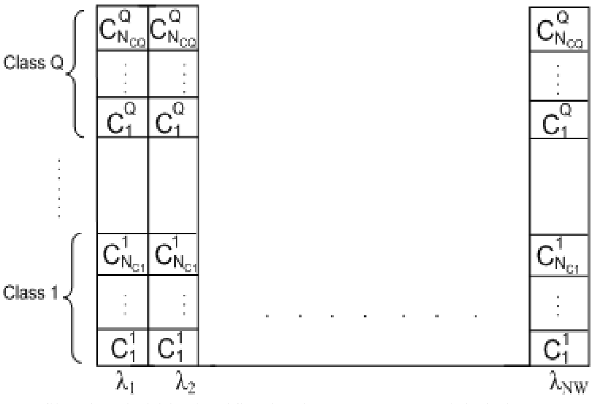


Fig. 1: fiber-bandwidth classification in MLVW-OOC labeled OCS-GMPLS network.

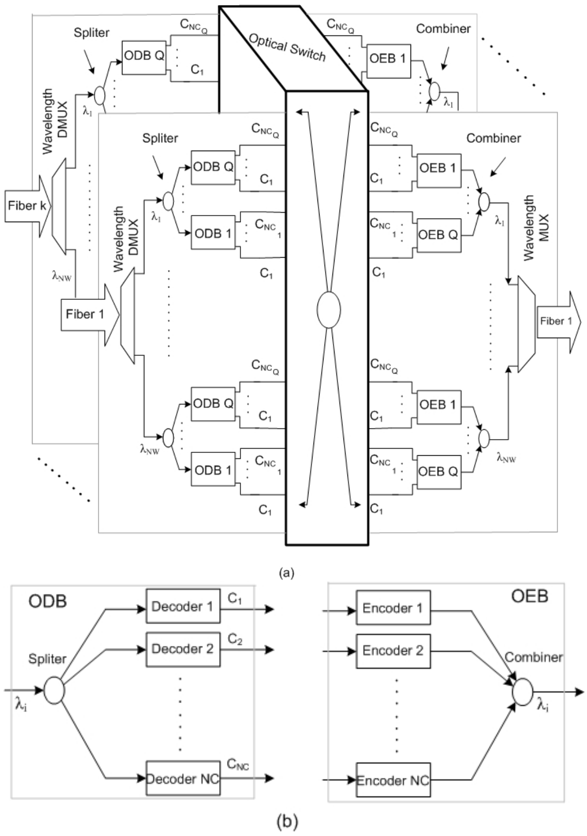
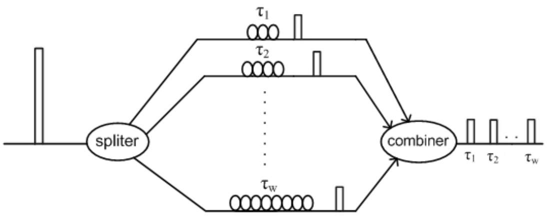
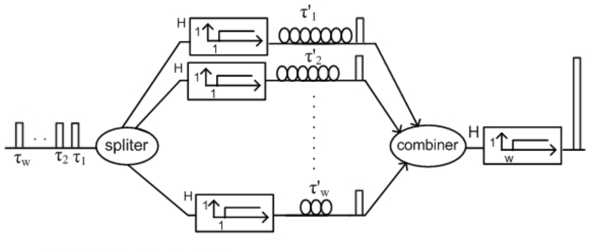


Fig. 2: Multi-Service OCS-GMPLS router, ODB (Optical Decoder Bank) and OEB (Optical Encoder Bank) structures.



TDL : Tapped Delay Line



ALG : AND Logic Gate

H : Hard limiter

Fig. 3:TDL and ALG structures.

## III. Performance Analysis

We consider the probability of error of the optical decoder as the benchmark of the performance analysis. Therefore, we obtain the probability of error of the MLVW-OOC-based OCDM system. To the best of our knowledge, the probability of error for this scheme has been evaluated previously for two special cases: in [7], authors assumed that interference has the Poisson distribution and in [6], authors solved this problem for

*Q=2* and *I=1*. Here, we evaluate precisely the probability of error for arbitrary *Q* and *I*. In our evaluation, it is assumed that the desired user has the first codeword of class 1 ($C_1^1$ is the codeword of the desired user) and the channel is ideal. $P_e^{(1)}$ is evaluated as follow

$$P_e^{(1)} = \frac{1}{2}P(error|1) + \frac{1}{2}P(error|0) \tag{3}$$

However, since the system is positive and additive, and in addition the channel is considered ideal, $P(error|1) = 0$ . Therefore,

$$P_e^{(1)} = \frac{1}{2}P(error|0) \tag{4}$$

In the ALG decoder, error is occurred when the interfering users fill the nonzero positions of the desired code. Hence, $P_e^{(1)}$ can be expressed as

$$P_e^{(1)} = \frac{1}{2}P(\alpha_1 \geq 1, \alpha_2 \geq 1, ..., \alpha_{w_1} \geq 1) \tag{5}$$

where $\alpha_i$ denotes the number of interference on the *i*th nonzero position of the desired code (see Fig. 4).

Equation (5) can be rewritten as

$$\begin{aligned} &P(\alpha_1 \geq 1, \alpha_2 \geq 1, ..., \alpha_{w_1} \geq 1) \\ &= 1 - P(\alpha_1 = 0 \ or \ \alpha_2 = 0 \ or ... \ \alpha_{w_1} = 0) \\ &= \sum_{k=0}^{w_1} (-1)^k \binom{w_1}{k} P(\alpha_1 = \alpha_2 = .... \alpha_k = 0) \end{aligned} \tag{6}$$

Since users of various classes are independent, we have

$$\begin{aligned} &P(\alpha_1 = \alpha_2 = ...\alpha_k = 0) \\ &= \prod_{f=1}^{Q} \left( PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_k = 0) \right) \end{aligned} \tag{7}$$

where $PI^{(f)}(.)$ is the probability of interference of users in class *f*. Furthermore, since the users of each class are independent, $PI^{(f)}(.)$ is evaluated as

$$\begin{aligned} &PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_k = 0) \\ &= \left[ PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_k = 0 \mid one\ user) \right]^{NI_f} \end{aligned} \tag{8}$$

where $NI_f$ indicates the number of interfering users of class *f*. $PI^{(f)}(.)$ for a user of class *f* is

$$\begin{aligned} &PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_k = 0 \mid one\ \ user) = \\ &1 - PI^{(f)}(\alpha_1 = 1 \ or \ \alpha_2 = 1 ... \ or \ \alpha_k = 1 \mid one\ \ user) \end{aligned} \tag{9}$$

By extending $PI^{(f)}(\alpha_1 = 1 \, or .. \, or \ \alpha_k = 1 \mid one\ user)$, we get

$$\begin{aligned} &PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_k = 0 \mid one\ user) = \\ &1 + \sum_{j=1}^{I_{(1,f)}} \left( (-1)^j \binom{k}{j} PI^{(f)}(\alpha_1 = ...\alpha_j = 1 \mid one\ user) \right) \end{aligned} \tag{10}$$

We define $P_m^{(k,f)}$ as the probability that the codeword of class *f* produces *m* interferences in the codeword of class *k*. Obviously the total probability of interference which is produced by one interfering user of class *f* in a user of class *k* is equal to $(w_f w_k / 2L_f)$, and we have

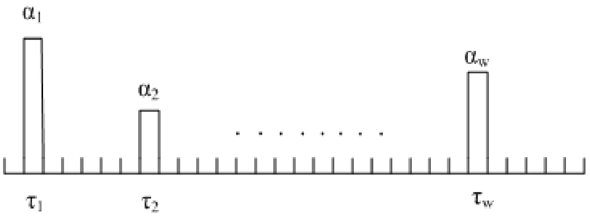


Fig. 4: the interference on the nonzero position of desired.

$$\sum_{m=0}^{I_{(k,f)}} m \binom{w_k}{m} P_m^{(k,f)} = \frac{w_k w_f}{2L_f} \tag{11}$$

Using the above definition, we have

$$\begin{aligned} &PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_j = 1 \mid one\ user) = P_j^{(1,f)} + \\ &\binom{w_1 - j}{1} P_{j+1}^{(1,f)} + ... + \binom{w_1 - I_{(1,f)}}{I_{(1,f)} - j} P_{I_{(1,f)}}^{(1,f)} \\ &= \sum_{m=j}^{I_{(1,f)}} \left( \binom{w_1 - m}{m - j} P_m^{(1,f)} \right) \end{aligned} \tag{12}$$

Substituting (12) into (10), we obtain

$$\begin{aligned} &PI^{(f)}(\alpha_1 = \alpha_2 = ...\alpha_k = 0 \mid one\ user) = \\ &1 + \sum_{j=1}^{I_{(1,f)}} \sum_{m=j}^{I_{(1,f)}} \left( (-1)^j \binom{k}{j} \binom{w_1 - m}{m - j} P_m^{(1,f)} \right) \end{aligned} \tag{13}$$

According to (13) and (8), (7) can be rewritten as

$$\begin{aligned} &P(\alpha_1 = \alpha_2 = ...\alpha_k = 0) = \\ &\prod_{f=1}^{Q} \left[ 1 + \sum_{j=1}^{I_{(1,f)}} \sum_{m=j}^{I_{(1,f)}} ((-1)^j \binom{k}{j} \binom{w_1 - m}{m - j} P_m^{(1,f)}) \right]^{NI_f} \end{aligned} \tag{14}$$

Substituting (14) in (6), $P_e$ can be given as

$$\begin{aligned} &P_e^{(1)} = 0.5 \times \sum_{k=0}^{w_1} \left[ (-1)^k \binom{w_1}{k} \right. \\ &\left. \prod_{f=1}^{Q} \left( 1 + \sum_{j=1}^{I_{(1,f)}} \sum_{m=j}^{I_{(1,f)}} ((-1)^j \binom{k}{j} \binom{w_1 - m}{m - j} P_m^{(1,f)}) \right)^{NI_f} \right] \end{aligned} \tag{15}$$

If $P_m^{(1,f)} = 0$ for $m = 1,..,(I_{(1,f)} - 1)$ then according to (11) we have

$$P_{I_{(1,f)}}^{(1,f)} = \frac{w_1 w_f}{2L_f I_{(1,f)} \binom{w_1}{I_{(1,f)}}} = \frac{w_f (I_{(1,f)} - 1)! (w_1 - I_{(1,f)})!}{2L_f (w_1 - 1)!} \tag{16}$$

and by employing this assumption, an upper bound on $P_e^{(1)}$ can be evaluated by inserting (16) into (15). Hence an upper bound on $P_e^{(1)}$ is

$$P_e^{(1)} \le 0.5 \times \sum_{k=1}^{w_1} \left[ (-1)^k \binom{w_1}{k} \right.$$
$$\left. \prod_{f=1}^{Q} \left( 1 + \sum_{j=1}^{I_{(1,f)}} ((-1)^j \binom{k}{j} \binom{w_1 - I_{(1,f)}}{I_{(1,f)} - j} \frac{w_f (I_{(1,f)} - 1)!(w_1 - I_{(1,f)})!}{2 L_f (w_1 - 1)!}) \right)^{NI_f} \right] \tag{17}$$

Equation (16) shows that the probability of error is a function of $NI_i$ (the number of interfering users) and each class has a specific maximum allowable$NI_i$ (we name this value of $NI_i$ "Degradation Threshold"). If the number of active OLSPs exceeds the Degradation Threshold (DT), the requested QoS degrades. Therefore, in order to assure the desired QoS, a controlling mechanism is needed to limit the number of connected OLSPs. One proposal is that $DT_i$ is assumed as the upper bound of connected OLSPs and when the Number of Connected OLSPs (NCO) reaches to $DT_i$ then the new request for OLSP establishment is refused. Although this proposal assures the requested QoS, but considering $DT_i$ as the upper bound of NCO decreases available *NL*. Furthermore, the connected OLSPs are not active simultaneously and their activity coefficient (ρ) should be considered. By considering activity coefficient of connected OLSPs, upper bound of NCO can be chosen greater than DT.

It is noteworthy that, the probability density function of the number of simultaneously active OLSPs , $P_A(a)$, is evaluated as

$$P_{Ai}(a_i) = \binom{NCO_i}{a_i} (\rho_i)^{a_i} (1 - \rho_i)^{(NCO_i - a_i)} \tag{18}$$

where subscript i denotes the class of OLSP. Using the $P_{Ai}(.)$ of the classes, the probability of the performance degradation ($P_{deg}$) can be given as

$$P_{\deg} = P(a_1 > DT_1 \; or \; a_1 > DT_2 ... or \;\; a_Q > DT_Q) \tag{19}$$

$P_{deg}$ can be rewritten as

$$P_{\deg} = 1 - P(a_1 < DT_1 , a_1 < DT_2 ..., \; a_Q < DT_Q) \tag{20}$$

Employing the independency of the active users in various classes, (20) is simplified as

$$P_{\deg} = 1 - \prod_{i=1}^{Q} P_{Ai}(a_i \le DT_i) \tag{21}$$

Substituting (18) into (21), we get

$$P_{\deg} = 1 - \prod_{i=1}^{Q} \left[ \sum_{a_i=0}^{DT_i} \left( \binom{NCO_i}{a_i} (\rho_i)^{a_i} (1 - \rho_i)^{(NCO_i - a_i)} \right) \right] \tag{22}$$

If $NCO_i$ is chosen equal to $DT_i$ then $P_{deg}$=0. As mentioned, this approach decreases available NL and therefore, $NCO_i$ should be chosen based on $\rho_i$ so that the acceptable $P_{deg}$ ( $P_{\deg}^{\max}$ ) is achieved.

## IV. NUMERICAL RESULTS

In our numerical results, we consider a four-class OCS-GMPLS network which its classes are specified by $P_e$= {$10^{-12}$, $10^{-6}$} and L= {500, 1500}. These four classes are defined as follows

**Class1**: high rate and high QoS, ($L_1$=*500*, $P_e \le 10^{12}$).

**Class2**: high rate and low QoS, ($L_2$=*500*, $P_e \le 10^{6}$).

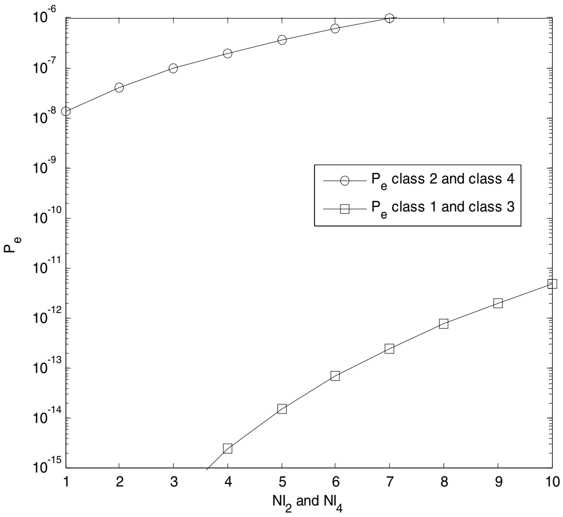


Fig. 5: the probability of error of the defined classes versus $NI_2$ and $NI_4$, ($NI_1$ and $NI_2$= 3).

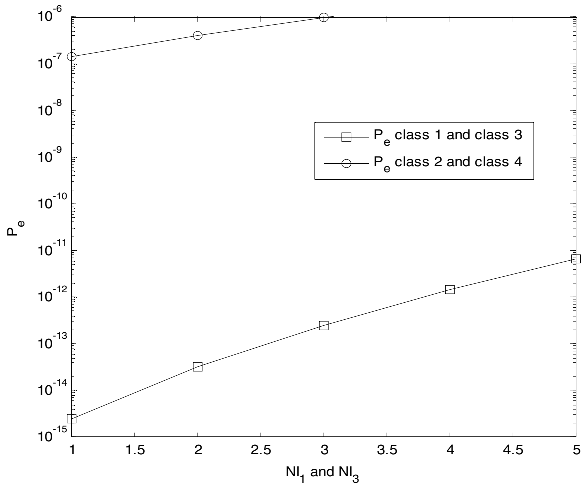


Fig. 6: the probability of error of the defined classes versus $NI_1$ and $NI_3$, ($NI_2$ and $NI_4$= 7).

**Class3**: low rate and high QoS, ($L_3$=*1500*, $P_e \le 10^{12}$).

**Class4**: low rate and low QoS, ($L_4$=*1500*, $P_e \le 10^{6}$).

To design this network, we choose the MLVW-OOC set according to the code construction algorithm introduced in [7]. In this algorithm, $NC_i$ must obey the following inequality

$$\frac{\sum_{i=1}^{Q} NC_i \times w_i \times (w_i - 1)}{L_Q - 1} \le 1 \tag{23}$$

Our proposed code set is characterized by (*L*= {500, 500, 1500, 1500}, *W*= {10, 5, 10, 5}, *NC*= {5, 10, 5, 10}, *Q*=4, *I*) which *I* is given as

$$I = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 \end{bmatrix} \tag{24}$$

Proposed code set is chosen according to the characteristics of the service and the constraint (23). Figure 5 and 6 show $P_e$ of the classes in this network.

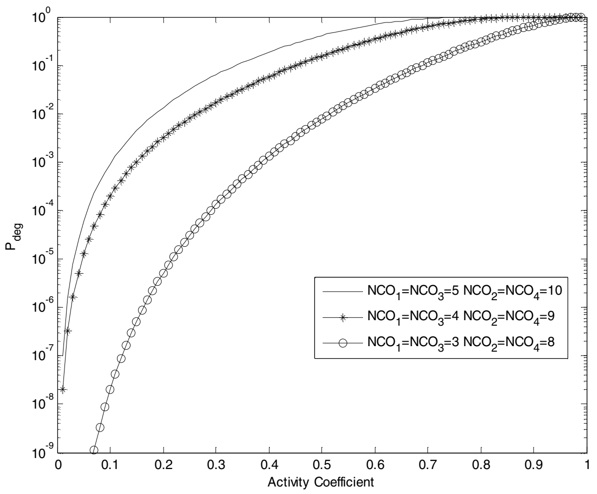


Fig. 7: the probability of the performance degradation versus activity coefficient for various NCO.

As shown in Fig. 4 and Fig. 5, DTs of the defined classes are obtained as follow

$$DT_1=3,\ DT_2=7,\ DT_3=3 \text{ and } DT_4=7.$$

In order to assure demanded performance, the discussed controlling mechanism in Section 3 is applied. As shown in Fig. 7, variation of *NCO* affects $P_{deg}$; decreasing of NCO results to the performance improvement so that if $NCO=DT$ then $P_{deg}$=0.

Note that as the difference between $NC_i$ (Number of Code) and $DT_i$ is increased, $NCO_i$ has greater variation between $NC_i$ and $DT_i$.

## V. CONCLUSION

In this paper, a novel scheme for multi-service path switching in the all-optical GMPLS core network has been presented. Network behavior and router architecture was described. Furthermore, the probability of error for the arbitrary number of classes ($Q$) and cross-correlation values ($I$) was evaluated. Considering activity coefficient of connected OLSP, we derived the probability of the performance degradation. In order to assure the desired QoS, a controlling mechanism was proposed. In each class, the controlling mechanism considers an upper bound for the connected OLSP and when the number of connected OLSP reaches to this bound, a new request for Path establishment is refused. In addition, Label Distribution Protocol (LDP) should be accommodated to support this controlling mechanism. As an example, four-class network was designed by proposed labeling scheme. The probabilities of error and the performance degradation of the designed network were plotted. Considering the desired QoS, degradation thresholds of the classes were determined. By plotting the $P_{deg}$ for various upper bounds of connected OLSP we conclude that decreasing of upper bound improves $P_{deg}$ such that if $NCO_i=DT_i$ then $P_{deg}$=0.

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