

Label Prioritization in GMPLS-Centric All-Optical Networks

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Abstract— *When establishing lightpaths in an all-optical DWDM network, it is possible that concurrent lightpath requests will block one another if the lightpaths attempt to reserve the same wavelength on the same link. In this paper, we propose a novel signaling mechanism, referred to as label prioritization, which attempts to reduce the backward-link blocking in GMPLS-centric all-optical networks by assigning different priorities to the suggested wavelengths (labels) of each connection request. The prioritization of wavelength encourages concurrent lightpath requests to choose different wavelengths, thereby reducing the possibility that the requests will be blocked. The label prioritization mechanism consists of a signaling extension to GMPLS to support the label prioritization and a modification in the optical switch controller to support the signaling extension. Simulation results show that the label prioritization method can effectively reduce wavelength conflicts.*

Keywords—lightpath; wavelength conflict; GMPLS

I. INTRODUCTION

The Internet community is working towards extending existing IP-based Multi-Protocol Label Switching (MPLS) to support lightpath establishment. The resulting protocol of generalizing the applicability of MPLS to cover optical networks is referred to as Generalized MPLS (GMPLS)[1]. In order to establish connections, the GMPLS control plane employs the Open Shortest Path First (OSPF) protocols to maintain network state information [2] and Constraint-Based Routed Label Distribution Protocol (CR-LDP) and Resource reSerVation Protocol (RSVP) protocols to provide the basic messaging functionality for the signaling[3][4][5][6].

When provisioning an all-optical network for routing and wavelength selection in GMPLS, a connection request may fail due to one of two blocking events, namely *forward-link* and *backward-link* blocking. Forward-link blocking is primarily due to insufficient wavelength resources and non-load balancing routing algorithms. Backward-link blocking happens due to the conflict of reservations[7]. GMPLS introduces the concept of a Label Set to restrict the downstream node's choice of label for a request lightpath. However, the Label Set object is not sufficient to eliminate the backward-link blocking, which occurs when two or more egress nodes select the same label for connections that share the same links.

In this paper, we propose a label prioritization method to reduce the backward-link blocking in GMPLS-centric WDM networks with the wavelength-continuity constraint. The label prioritization scheme has two aspects: a signaling extension to GMPLS to support the label prioritization and modification in the optical switch controller to support the signaling extension. The outline of the paper is as follows: Section 2 summarizes the connection establishment procedure in GMPLS-centric all-optical networks. In Section 3, the label prioritization method is introduced. Also, GMPLS signaling extension and a new optical switch controller are described in detail. In Section 4, simulation results are given. Section 5 gives future research directions and concludes the paper.

II. GMPLS OVERVIEW

The GMPLS control plane provides network planners with the ability to design inherently more flexible networks that are capable of adapting to the hostile characteristics of Internet traffic. Moreover, the main advantage of GMPLS is that its control will reduce many of the complexities associated with defining and maintaining a separate optical layer, such as concerns over interface definitions, address assignments and resolution, internetworking with high-layer traffic policing and management, and multi-vendor interoperability.

In GMPLS, the ingress node calculates the route first using any constrained shortest path first algorithm. Then, the node sends a generalized label request to its downstream nodes by using a Path message in RSVP, or by adding generalized label request Time-Length-Value field to the Label Request message in CR-LDP. The signaling messages are carried out-of-band. From this point, we will only use RSVP terms. CR-LDP terms are straightforward. GMPLS also introduces the concept of a Label Set. An upstream node includes a Label Set in the Path message to restrict the downstream node's choice of label for the links between the upstream and the downstream node. Labels in the Label Set of a Path message are referred to as suggested labels. As the Label Set is propagated in the Path message, each downstream node may generate a new outgoing Label Set based on its own hardware capabilities and the incoming Label Set. The egress node (destination) selects any label within the incoming Label Set, and sends its selection in a Label Reservation object using a Reserve (Resv) message. Each node along the route reserves the selected label as the

Resv message travels to the ingress node. In the context of an all-optical network, a label represents a specific wavelength on each link. Note that a label may be suggested by multiple Path messages, since the label is not actually reserved until the Resv message is received. Thus, multiple Resv messages may attempt to reserve the same resource, resulting in failure for at least one connection request.

In order to support the Label Set object, optical switch controllers (OSCs) have two pools of wavelengths, namely *Used Pool (UP)* and *Available Pool (AP)*. The AP is used to suggest the wavelengths to downstream. If any wavelength within the received Label Set is in the UP, this specific wavelength is deleted from the Label Set before forwarding it to a downstream node. However, the Label Set object is not sufficient to eliminate the backward-link blocking which occurs when two or more egress nodes select the same label for connections that share the same links.

III. LABEL PRIORITIZATION

In order to reduce backward-link blocking effectively, we propose a third pool, namely *Flagged Pool (FP)*, maintained at the OSC. The FP points to the wavelengths that have been suggested by a lightpath request node but that have not yet been selected by a Resv message. Thus the FP provides a gray area of the wavelengths that is subject to collision. We call wavelengths in the FP *flagged wavelengths*. We also propose a signaling extension to RSVP in order to suggest wavelengths from the FP.

A. Flagged Pool at Optical Switch Controllers

The FP at an OSC is defined by a flagging operation. We propose three modes of flagging operation with variables as shown in Table 1:

- Aggressive Flagging (AF) : $\{\lambda_i \mid T_s < T_i < T_e\}$
- Full Flagging (FF) : $\{\lambda_i \mid T_i < T_e\}$, where $T_i = S_e - S_p$
- Reservation time-based Flagging (RF) : $\{\lambda_i \mid D_i < T_e\}$, where $D_i = R_e - R_p$

TABLE I. VARIABLES FOR FLAGGED POOL

Variables	Descriptions
T_s	A short-time duration for which a wavelength is reserved in forward direction
$T_e, T_{e'}$	An expiration threshold required for a wavelength to transit from the FP to the AP
S_e	The local time when a wavelength has just been suggested by current Path message
S_p	The local time when a wavelength was suggested by previous Path message
R_p	The estimate of the latest reservation time for a wavelength, which is derived from the arrival times of previous Path messages and their propagation delays.
R_e	The estimate of the reservation time for a wavelength, which is derived from current Path message and its propagation delay

The term T_i is defined as the amount of time that has passed since wavelength λ_i was last suggested by a Path message, while the term D_i is defined as the amount of time difference

between the latest among estimated reservation times by previous Path messages and the estimated reservation time by current Path message. The RF scheme considers the residual propagation delay of a Path message to estimate the expected reservation time of wavelengths. Thus the expiration threshold is fixed in AF and FF schemes, while varying in RF scheme, which are represented by T_e and $T_{e'}$, respectively in Table 1.

The idea behind the AF and FF schemes is that if a wavelength has been suggested by two lightpath requests at times close enough to differ by less than a given threshold, the wavelength is considered to be subject to collision, and will be placed in the FP. More specifically, in the AF scheme, a wavelength which has just been suggested by a current Path message will be reserved for a short-time duration, T_s , and placed in the FP after the time of T_s . During this short-time duration, the wavelength cannot be suggested in other Path messages. During the time from T_s to T_e , when the wavelength is in the FP, the wavelength may be suggested in other Path messages, but will be marked as being flagged. When these Path messages reach the egress node, the egress node will select the flagged wavelengths with lower probability than available wavelengths, thereby reducing the probability of a wavelength conflict with another Path message. If the time threshold of T_e is reached without any other suggestion, the wavelength will be returned to the AP. Otherwise, if the wavelength is suggested by another lightpath request, the wavelength will remain in the FP. The FF scheme operates similarly to the AF scheme except that the wavelength is not exclusively reserved for the short time reservation, T_s .

The RF scheme keeps a wavelength in the FP for a variable amount of time which is proportional to the propagation delay from the local node to the destination of the Path message. The motivation behind RF scheme is that Path messages which are further from the egress node will require more time for the corresponding Resv message to return and reserve resources at the node. In terms of implementation, all flagging operations require OSCs to maintain a timestamp associated with a wavelength in the FP. For the AF and FF schemes, the timestamp indicates the time when a wavelength was last suggested in a Path message, while, for the RF scheme, representing the estimate of the latest reservation time at which a wavelength was expected to be reserved by a Resv message.

B. New RSVP Extension

In order to suggest wavelengths from the FP, we propose a new object called *Flagged Set* object. A Flagged Set object contains wavelengths that are in the FP of at least one node on a path traversed by its Path message, and excludes wavelengths that are in the UP of any nodes. For example, if a wavelength is in the Label Set of a Path message, and the wavelength is also in the AP of a node, then the wavelength will remain in the Label Set of the Path message. If a wavelength is either in the Label Set or Flagged set of a Path message, and the wavelength is in the UP of a node, then the wavelength will be removed from the Label Set or Flagged Set of the Path message. If a wavelength is either in the Label Set or Flagged Set of a Path message, and the wavelength is in the FP of a node, then the wavelength will be placed in the Flagged Set of the Path

message. At the egress node, wavelengths in the Label Set will be preferentially selected over wavelengths in the Flagged Set.

1) Flagged Set Object

The structure of a Flagged Set object is the same as that of the Label Set object, which only carries the wavelength information. The format of a Flagged Set object consists of three fields: Action, Type and Wavelengths. The operation of the object is as follows:

- A Specific wavelength can be added to the Flagged Set via Action zero (0).
- A range of wavelengths can be added to the Flagged Set via Action one (1).
- Type Field represents the priority of the Flagged Set object which will be discussed in the next.

2) Label Prioritization

We will describe the behavior of the FF scheme since the AF and RF schemes operate similarly to the FF scheme. A Path message may maintain multiple Flagged Set objects, and priorities may be assigned to these Flagged Set objects in order to provide further differentiation when choosing a wavelength at the egress node. When a Path message arrives at an OSC, the OSC examines the Label Set object and the Flagged Set objects of the Path message, and locally updates the local timestamp for the wavelengths which are not in the UP of the local node, i.e., those wavelengths which are still *eligible* to be suggested. If an eligible wavelength is a flagged wavelength (in the FP of the OSC), then the OSC calculates the value of the variable T_i defined in Table 1.

Based on the value of T_i , OSCs can assign a priority to an eligible flagged wavelength and place the wavelength into the appropriate Flagged Set object of the Path message. For example, a higher priority can be given to an eligible flagged wavelength with greater value of T_i since collision possibility decreases as the value of T_i increases. If an eligible flagged wavelength in the FP of the OSC has lower priority compared to the corresponding priority of the same wavelength in the incoming Path message, then the OSC may assign the wavelength into the lower priority Flagged Set object of the Path message. If the corresponding Flagged Set object doesn't exist, the OSC inserts a new Flagged Set object with the lower priority into the Path message before forwarding the Path message to its downstream node. Each downstream OSC updates Flagged Set objects in a Path message unidirectionally such that a wavelength can be moved only from a high-priority object to a lower-priority object as follows: *Label Set* \rightarrow *Flagged Set (0)* \rightarrow *Flagged Set (1)* \rightarrow ... \rightarrow *Flagged Set (N-1)*. In this way, wavelengths can be prioritized in a global manner without synchronization.

3) Label Selection of Egress Node

When an egress node receives a Path message, it randomly selects a wavelength from the Label Set. If there are no wavelengths in the Label Set, then the egress node randomly selects a wavelength from the Flagged Set with next highest

priority, and so on. When egress node selects the label, it encapsulates the label into Resv message, and forwards the Resv message to its upstream node.

4) Label Prioritization Example

Fig. 1 shows a label prioritization example for the FF scheme, in which the followings are assumed:

- A lightpath request arrives to the node 1 at time t_3 , with a destination of the node 3
- The request arrives to node 2 at time t_4 .
- The number of priority levels is 2.
- The value of T_e is 2 sec.
- If the value of T_i is between 0 and 1 sec, a priority of 1 is assigned to corresponding wavelength. Otherwise, a priority of 0 is given.

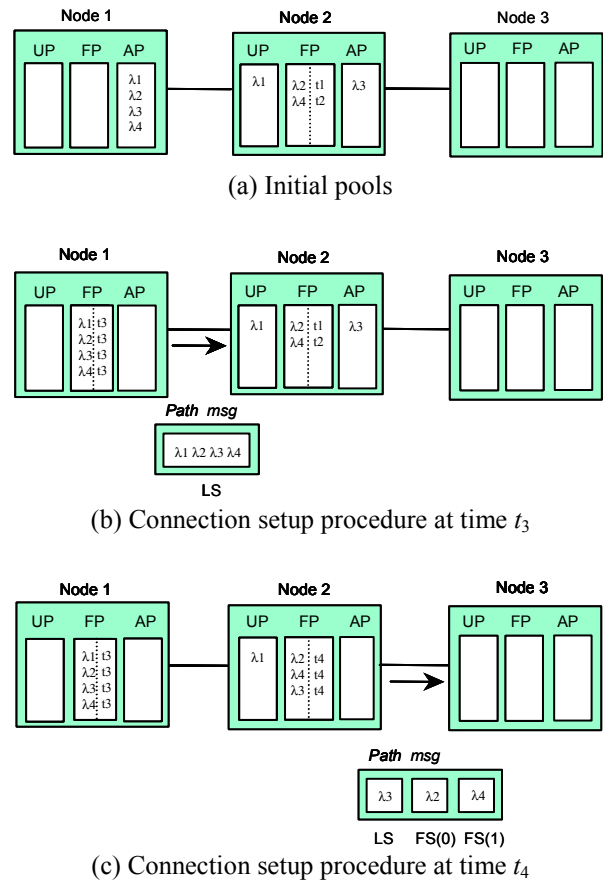


Figure 1. Label Prioritization Example – FF operation

Step 0 : Initially, all wavelengths at node 1 are in the AP. In node 2, λ_1 is already in-use (in UP), λ_2 and λ_4 have been suggested to different LSPs at local timestamps, t_1 and t_2 , respectively where $t_1 < t_2$ and wavelength λ_3 is available. The initial configuration is illustrated in Fig. 1(a).

Step 1 : Node 1 places all four wavelengths into the Label Set of a Path message in order to set up the path, and node 1 also places all of these wavelengths into the FP with timestamp t_3 . The Path message is then forwarded to node 2. This step is illustrated in Fig. 1(b).

Step 2 : When the Path message arrives at t_4 , Node 2 takes the following actions:

- Since λ_1 is in the UP, it is extracted from the Label Set.
- For λ_2 , if $1.0 < (t_4 - t_1) < 2.0$, then move λ_2 from Label Set to Flagged Set with priority 0 in the Path message. If $0 < (t_4 - t_1) \leq 1.0$, then move λ_2 from Label Set to Flagged Set with priority 1 in the Path message. Let us assume that $1.0 < (t_4 - t_1) < 2.0$; thus λ_2 is inserted into Flagged Set with a priority of 0 in the Path message.
- Since λ_3 is in the AP, keep λ_3 in the Label Set.
- For λ_4 , λ_4 is inserted into Flagged Set with priority 1, assuming that $0 < (t_4 - t_2) \leq 1.0$.
- Update the timestamps for λ_2 , λ_3 and λ_4 .

Node 2 then inserts the Flagged Set objects, and forwards the Path message to node 3. This step is illustrated in Fig. 1(c). Node 3 would then select and attempt to reserve wavelength λ_3 . Had wavelength λ_3 not been in the Label Set, node 3 would have attempted to reserve wavelength λ_2 .

IV. SIMULATION

We evaluate the performance of the proposed label prioritization scheme on the 16-node NSFNET network shown in Fig. 2. The numbers on the links represent link distances in units of 10 km. We assume the following conditions:

- There are 40 wavelengths per link.
- There is no wavelength conversion.
- Traffic is uniform over each source-destination pair.
- Connection requests arrive to each node according to a Poisson process with rate λ requests per second.
- Connection holding time is exponentially distributed with mean $1/\mu = 100\text{ms}$.
- The load at each node, measured in Erlangs, is λ/μ .
- Message processing time at each node is $10\ \mu\text{s}$.
- Fixed shortest path routing is assumed.
- An offered load of 0.2 is assumed for all simulations.

The number of Flagged Set objects per Path message is varied from 1 to 4. For a given number N of priority levels, a priority level of $(N-n-1)$ is assigned to a wavelength if the corresponding T_i variable is in the range the range of $(T_{\min} + n*(T_e - T_{\min})/N, T_{\min} + (n+1)*(T_e - T_{\min})/N]$, where T_{\min} is the minimum value of the variable T_i . For the RF scheme, the highest priority is assigned when D_i is negative. Otherwise, the label prioritization method similar to the FF scheme is used.

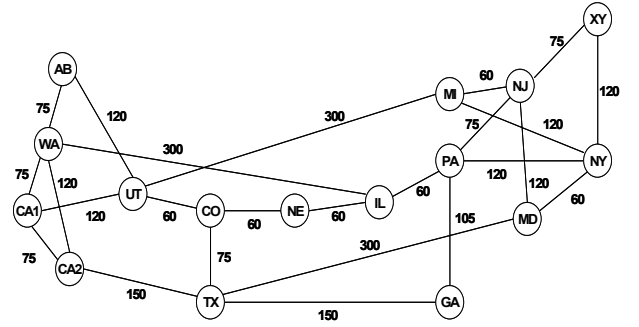


Figure 2. NSFNET network topology

First, we examine the performance of the AF scheme. Fig. 3 shows the call blocking probability as a function of T_s . The value of T_e is assume to be 10 ms, which was found through simulation to provide the lowest blocking probability for the case in which only one Flagged Set was defined.

The result shows that, for very small values of T_s , the AF scheme performs better than the reservation scheme without Flagged Set object (GMPLS). However, for large values of T_s greater than 0.2, we confirmed through simulations that the AF scheme is worse than the GMPLS signaling scheme. The reason for this behavior is that, for very small values of the time threshold, even though a very short time reservation in forward direction leads to slightly higher blocking in the forward direction, the Flagged Set object results in much less blocking due to wavelength conflicts. For large values of T_s , the increase in blocking in the forward direction is greater than the reduced blocking due to fewer wavelength conflicts. Note that the AF scheme with a short time threshold value of 0 is the same as the FF scheme. We also observe that, for a given value of T_s , the performance increases as the number of Flagged Set objects increases. The reason for this improvement is that, for calls arriving within a given value of T_s , a suggested wavelength will be distributed to different Flagged Sets for different calls.

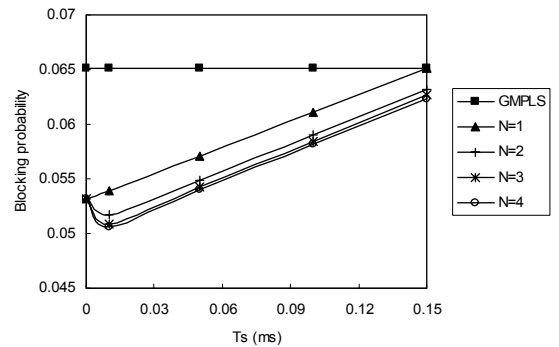


Figure 3. Blocking probabilities of AF Scheme

Fig. 4 shows the relationship between T_e and the number of Flagged Sets for the FF scheme. Note that the FF scheme with

T_e of value 0 is the same as the GMPLS signaling scheme.

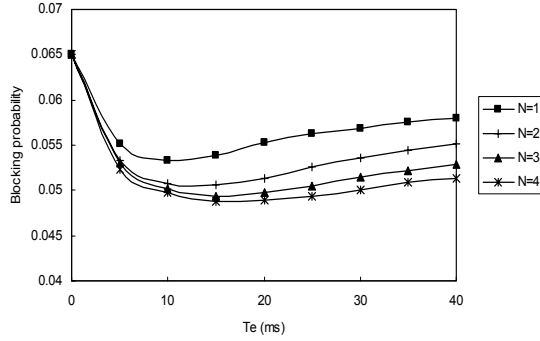


Figure 4. Blocking Probability of FF Scheme

The FF scheme performs better than the GMPLS signaling scheme. As mentioned above, at a given value of T_e , performance increases as the number of Flagged Set objects increases; however, there exists an optimal value for the number of Flagged Set objects, above which there is no significant gain in blocking probability. We also observe that, for a given number of Flagged Sets, blocking probability increases as the value of T_e (larger than the optimal threshold) increases. The reason is that the large value of T_e leads a suggested wavelength into the same Flagged Set as for competitive calls, increasing the possibility of wavelength collisions. It is also observed that blocking probability decreases as T_e and N increase simultaneously.

Fig. 5 shows the performances of all three flagging operations when offered load is low and 2-level prioritization is used. The value of T_s and T_e (or $T_{e'}$) are assumed to be 0.01 ms and 10 ms, respectively. With low traffic, flagging operations perform better than GMPLS. All flagging operations have similar performance, but the RF scheme is slightly better.

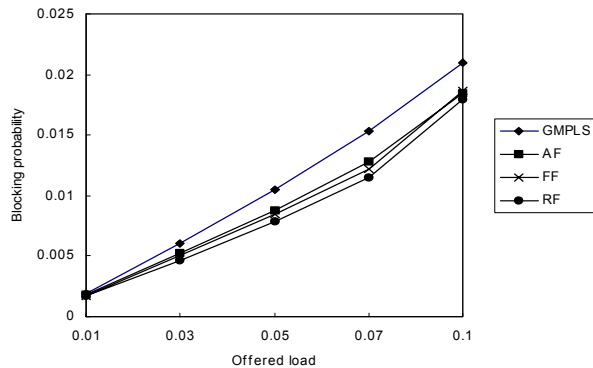


Figure 5. Blocking probabilities vs offered load

V. CONCLUSION

In this paper, we introduced a label prioritization scheme to reduce wavelength conflicts. The label prioritization method has two aspects: a signaling extension to GMPLS and label prioritization based on timestamps and thresholds in optical switch controllers. The concepts of Flagged Set object and

Flagged Pool were introduced in order to prioritize wavelengths.

Further investigation is required in order to determine the optimal number of Flagged Set objects, and to determine the optimal threshold values which minimize the blocking probability for a given network topology and a given offered load.

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