PAPER

Bidirectional Path Setup Scheme Using on Upstream Label Set in Optical GMPLS Networks

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SUMMARY Generalized Multi-Protocol Label Switching (GMPLS) is being developed in the Internet Engineering Task Force (IETF). In GMPLS-based wavelength-division-multiplexing (WDM) optical networks, a wavelength in a fiber is used as a label. In the existing GMPLS signaling protocol for bidirectional paths in WDM networks with the wavelength continuity constraint, bidirectional path setup fails with high probability because the upstream label allocated by the previous hop node may not be accepted at the transit node. To solve this problem, this paper proposes an efficient bidirectional label switched path (LSP) setup scheme based on an upstream label set. Called the Upstream Label Set (ULS) scheme, it is an extension of the existing GMPLS signaling protocol. The ULS scheme is consistent with the existing GMPLS signaling procedure and so offers backward compatibility. The numerical results suggest that when the number of the LSP setup retries is limited, the ULS scheme offers lower blocking probability than the existing GMPLS signaling scheme which uses only with the upstream label (UL). In addition, under the condition that the constraint of the number of LSP setup retries is relaxed, the LSP setup time of the ULS scheme is faster than that of the existing scheme. Furthermore, by using our developed prototype of the GMPLS control system, in which the ULS scheme was installed, we demonstrated that the ULS scheme successfully setup bidirectional LSPs.

key words: *optical network, GMPLS, bidirectional path, WDM, RSVP signaling, label set*

1. Introduction

Generalized Multi-Protocol Label Switching (GMPLS) is being developed in the Internet Engineering Task Force (IETF) [1], [2]. It is an extended version of Multi-Protocol Label Switching (MPLS). While MPLS was originally developed to control packet-based networks, GMPLS controls several layers, such as IP-packet, Time-Division-Multiplexing (TDM), wavelength, and optical-fiber layers, in a distributed manner [3].

In GMPLS-based wavelength-division-multiplexing (WDM) optical networks, a wavelength in a fiber is used as a label. This enables us to setup lightpaths in WDM networks in a distributed manner in the same way as label switched paths (LSPs) in IP/MPLS networks. We simply refer to a lightpath in a WDM network as an LSP in this paper.

Distributed-controlled traffic engineering (TE) is considered to be a promising way of realizing cost-effective and flexible optical WDM networks [4], [5]. In GMPLS-based WDM networks, an ingress node uses the routing protocol of Open Shortest Path First (OSPF) to find an appropriate LSP route based on link-state information. Each node in the network advertises and collects link resource utilization over the entire network. In other words, each node knows only how many wavelengths are available in each fiber link over the entire network. However, contrary to well-known routing and wavelength assignment (RWA) problems in a centralized manner [8], it does not know the availability of each wavelength over the entire network, so advertised link-state information is reduced and routing stability can be maintained [6], [7]. Therefore, after the route of an LSP is chosen, a wavelength for each fiber link is adaptively set by using the signaling protocol of Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) and taking account of the wavelength continuity constraint [2]. When a node does not have any or full wavelength conversion capability, the wavelength continuity constraint must be considered for label allocation [9].

The signaling protocol of GMPLS RSVP-TE setups an unidirectional/bidirectional LSP in WDM networks while satisfying the wavelength continuity constraint by using a Label Set object as follows [10], [11]. We start by describing unidirectional LSP setup (downstream) to make the bidirectional LSP setup procedure easier to understand. An ingress node sends a Path message in a hop-by-hop basis along the LSP route to the egress node. The Path message includes a group of labels, called an Label Set object, to indicate available labels, or wavelengths, between two neighbor nodes. There are four ways to indicate available labels by using an Label Set object, which are an inclusive list, an exclusive list, an inclusive range, and an exclusive range [10]. Inclusive and exclusive lists explicitly indicate available and exclusive labels in the Label Set object, respectively. Inclusive and exclusive ranges indicate the range of inclusive and exclusive labels, respectively. In this paper, we assume that an inclusive list is used to simply our explanation without losing generality.

The labels in the set must satisfy the wavelength continuity constraint. Let us assume that transit nodes on the LSP route do not have any wavelength conversion capability. A transit node that receives a Path message including a Label Set object from the previous hop node (the upstream node), must create a new label set for the next hop node. It does this by deleting from the Label Set object those labels that cannot be used on the link to the next hop node. If all labels are deleted from the received Label Set object, the LSP setup request is rejected. The Label Set object in the Path

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message is intended to be transmitted along the LSP route from the ingress node to the egress node.

Upon receiving the Path message, the egress node allocates a label† for the link between the egress node and its upstream node. The allocated label is chosen from those listed in the Label Set object. If the egress node receives the Label Set object that includes at least one label in the Path message, it means that the wavelength continuity condition is satisfied on the LSP route from the ingress node to the egress node. The egress node sends the Resv message, which carries the allocated label as a Label object, to the previous hop node. A transit node that receives the Resv message allocates the same label to the link between the node and the next upstream hop node. In this way, label allocation proceeds back up the path until the Resv message reaches the ingress node, which completes LSP setup. Thus, the Label Set object in the Path message, which is defined in [10], [11], enables us to efficiently setup unidirectional LSPs in WDM networks while meeting, if possible, the wavelength continuity constraint.

Bidirectional LSP setup uses an Upstream Label object. If the Path message includes an Upstream Label object, it indicates bidirectional LSP setup [10], [11]. An Upstream Label object includes a permissible upstream label. A bidirectional LSP, which consists of the downstream data path and the upstream data path, is setup by using the Path and Resv messages in the same way as unidirectional LSP setup. This paper uses the terms "ingress" and "egress" from the signaling viewpoint. The downstream data path of the bidirectional LSP transmits data from the ingress node to the egress node, while the upstream data path does so from the egress node to the ingress node.

For the downstream data path of the bidirectional LSP, a Label Set object is used and label†† allocation is performed during Resv message processing. On the other hand, upstream label allocation is performed during Path message processing. This is because a node is supposed to allocate each label/upstream label for its incoming link from the data transmission point of view. When an upstream label is allocated at a node, the node does not know if the allocated upstream label satisfies the wavelength continuity condition for the downstream nodes.

Although this process is straightforward, bidirectional LSP setup will fail with high probability. This is because it is highly possibility that an upstream label created at the previous hop node can not be accepted at the transit node due to the wavelength constraint. On the other hand, it is more probable that at least one entry in the downstream label set can be accepted. When the bidirectional LSP setup request fails, it can be repeated by the ingress node by trying to use another upstream label for each setup request. However, this would greatly increases the LSP setup time. For bidirectional LSP setup, the advantage of the label set is not fully utilized in WDM networks. This problem was pointed out in IETF [12] and it needs to be solved so that a bidirectional LSPs can be setup effectively.

This paper proposes an efficient bidirectional path setup scheme based on an upstream label set for WDM networks with the wavelength continuity constraint. We call it the Upstream Label Set (ULS) scheme†††. The upstream label set is implemented by extending the existing RSVP-TE signaling protocol. The ULS scheme is consistent with the existing GMPLS RSVP-TE procedure and so offers backward compatibility. Performance of the ULS scheme was evaluated by simulations. The results suggest that the ULS scheme provides lower blocking probability, when the number of LSP setup retries is limited, than the existing GMPLS RSVP-TE signaling scheme, which uses only upstream labels (UL). We call the existing scheme the UL scheme. If the constraint of the number of LSP setup retries is relaxed, the ULS scheme yields faster LSP setup than the UL scheme. Furthermore, we describe our GMPLS controller prototype, which includes the ULS scheme. Experiments confirm that the ULS scheme can successfully setups bidirectional LSPs.

This paper is organized as follows. Section 2 clarifies the problem of the UL scheme, which is the existing GMPLS RSVP-TE scheme. Section 3 presents the proposed ULS scheme. Section 4 describes its performance. Section 5 introduces an experiment on the ULS scheme. Finally, we make some closing remarks in Sect. 6.

2. UL Scheme

Successful and unsuccessful examples of bidirectional LSP setup by the UL scheme are shown in Figs. 1 and 2, respectively. The signaling procedure consists of three steps. Step

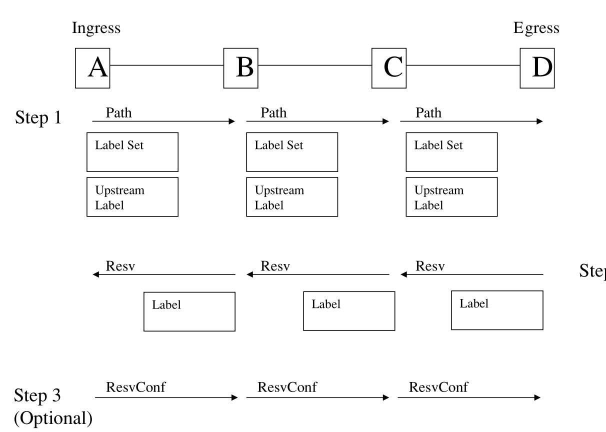

Fig. 1 Successful example of upstream label (UL) scheme.

†Allocating a label means establishing the data path and allocating a label.

††We refer to downstream labels as just labels, while upstream labels keep their full name.

†††The draft [12] describes the ULS scheme. While it includes some mistakes, the problem statements are correct. This paper provides a corrected version of the ULS scheme. For example, while an acceptable upstream label set was used in [12], this paper does not use it.

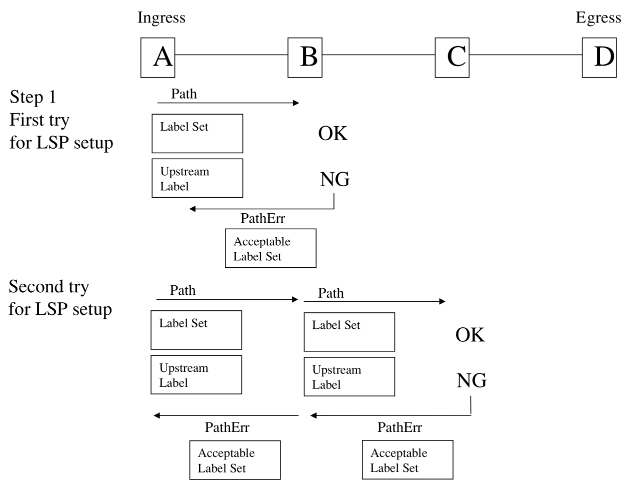

Fig. 2 Retry example of upstream label (UL) scheme.

1 is processing of Path messages. Step 2 is processing of Resv messages. Step 3 is processing of ResvConf (Resv Confirm) messages; note that step 3 is optional.

2.1 Successful LSP Setup

In Fig. 1, the ingress node (node A) transmits a Path message that includes a Label Set object and an Upstream Label object in step 1. Node A has already allocated the upstream label before transmitting the Path message. Bidirectional LSP setup is indicated by the presence of the Upstream Label object in the Path message. Node B receives the Path message from A. Node B creates a new label set for link BC by taking account of the wavelength continuity constraint between link AB and BC. If the wavelength continuity condition exists, permissible labels that can be included in the Label Set object are limited. For an LSP in the upstream direction, node B checks if the upstream label from A can satisfy the wavelength continuity constraint on link BC. If this is true, node B allocates the upstream label, which is carried on the Path message from node B to node C. In this example, the egress node (node D) successfully receives a Label Set object and an Upstream Label object. This means that the downstream and upstream paths can be set; that is, all the labels in the Label Set object and the upstream label in the Upstream Label object satisfy the wavelength continuity constraint.

In step 2, node D picks up a label from the Label Set object and places it in the Resv message which is then passed along the LSP route to node A. In step 3, if the egress node requests a ResvConf message from the ingress node, the ingress node transmits ResvConf message to the egress node through the LSP route to let the egress node know of LSP setup completion. This option is indicated by a Confirm object in the Resv message.

Note that [10], [11] allows the egress node to start transmitting the upstream data when the Path message is received and the receiving upstream label is set, in other words, when step 1 is completed. However, from the network operators' point of view, they often want to start upstream and downstream data transmission only after they confirm LSP setup completion in both directions. In this case, the egress node starts to transmit the upstream data, when the ResvConf message is received, in other words, when step 3 is completed.

2.2 Unsuccessful LSP Setup and Retry

Figure 2 shows that, at the first LSP setup attempt, node B is not able to find an upstream label due to wavelength continuity violation on link BC, while some labels in the downstream label set remain. Node B issues a PathErr (Path Error) message with an Acceptable Label Set object in the backward direction to indicate that the LSP setup failed. The Acceptable Label Set object includes the upstream labels available on link BC. The Acceptable Label Set object is transmitted in a hop-by-hop basis and the wavelength continuity constraint is checked at each node in the same way as the Label Set object, although the forwarding direction is opposite. The ingress node can choose one upstream label from the Acceptable Label Set object to be used in the next LSP setup attempt.

Next, node A tries again to setup the bidirectional LSP by using the upstream label selected from the acceptable label set, as shown in Fig. 2. We note that this acceptable label set assures upstream label availability in links AB and BC, but not in link CD. In this example, node C fails to find an acceptable upstream label for link CD and issues a PathErr message with an Acceptable Label Set object.

Thus, although the UL scheme uses acceptable label sets, there is no assurance of path setup for the next request. This is because the information is effective to extend only one hop from the node issuing the acceptable label set. The maximum number of LSP setup attempts is h, where h is the number of LSP hops. This makes the time for bidirectional LSP setup long when the number of hops is large.

3. ULS Scheme

This section describes in detail the procedures of the ULS scheme, which offers backward compatibility.

The key point to the ULS scheme is its use of the Upstream Label Set object, in addition to the Upstream Label object. Bidirectional LSP setup is indicated by the presence of either an Upstream Label object or an Upstream Label Set object in the Path message. For a bidirectional LSP setup, the Upstream Label Set object is optional. An Upstream Label object and an Upstream Label Set object can co-exist in a Path message.

When a Path message contains an Upstream Label object without an an Upstream Label Set object, the procedure follows the UL scheme. This meets the requirement of backward compatibility.

Next, let us consider two cases in which the Path message contains an Upstream Label Set object. Two examples are shown in Figs. 3 and 4. The ULS scheme also consists

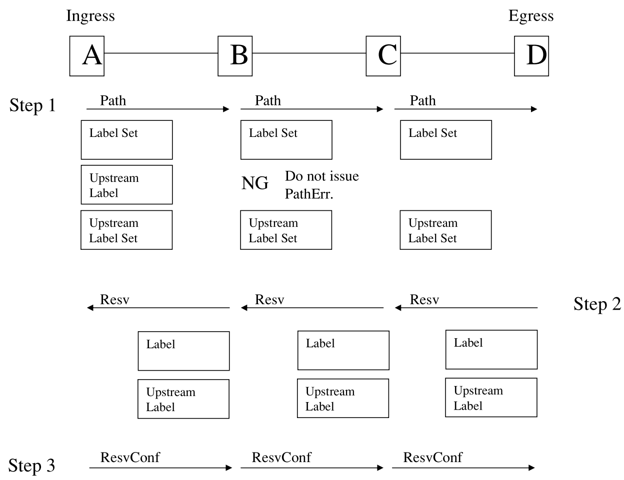

Fig. 3 Upstream label set (ULS) scheme (case 1).

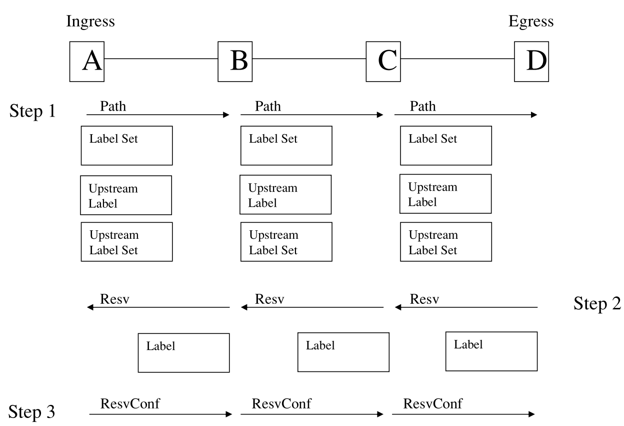

Fig. 4 Upstream label set (ULS) scheme (case 2).

of three steps.

3.1 Step 1

When a Path message containing both an Upstream Label object and an Upstream Label Set object is received, the receiver node first verifies if the upstream label in the Upstream Label object is acceptable. Even if the upstream label is not acceptable, the receiver does not issue a PathErr message, as shown in Fig. 3. This is because the Path message includes an Upstream Label Set object. The receiver node second verifies the Upstream Label Set object. If the node is unable to pick an upstream label out of the Upstream Label Set object, then the request is terminated and a PathErr message is generated. Whether the upstream label is acceptable or not, the Upstream Label Set object is propagated via the Path message in the same way as a downstream label set, as long as the upstream label set is acceptable at each transit node.

When an Upstream Label object is to be included in an outgoing Path message, whether or not an Upstream Label Set object is also included, an upstream label is allocated before sending the Path message to keep the backward compatibility. This is consistent with the UL scheme. Note that, when the allocated upstream label indicated by the Path message becomes unavailable on the LSP route, the Resv message re-allocates the upstream label.

When an upstream label in the Upstream Label object is not available and the option that uses an upstream label set is adopted, a Path message includes only an upstream label set, as shown in Fig. 3. In this case, a transit node should not allocate an upstream label on the outgoing interface. When a Resv message is received at a transit node, the node allocates an upstream label on the outgoing interface, as will be described in Sect. 3.2.

If a Path message contains both an Upstream Label object and an Upstream Label Set object, the egress node processes the Path message in the same way as the UL scheme. In this case, the Upstream Label Set object is ignored, as shown in Fig. 4. The upstream label can immediately be used to transport data traffic associated with the LSP in the upstream direction.

When a path message contains an Upstream Label Set object without an Upstream Label object, the egress node selects one upstream label from the Upstream Label Set object and sends the selected upstream label in the Resv message in the upstream direction. Contrary to the case that a Path message contains an Upstream Label object to the egress node, the selected upstream label cannot be used to transport data traffic associated with the LSP upstream towards the ingress node before the egress node receives a ResvConf message.

3.2 Steps 2 and 3

An Upstream Label object can optionally appear in a Resv message. When a transit node processes a Resv message, the upstream label propagated on the LSP route towards the ingress must fall within the upstream label set that was received in the Path message from the upstream node.

When a Resv message is received at a transit node and the Path message transmitted to the next hop node did not include an Upstream Label object, or the Resv message includes an Upstream Label Object that does not match the upstream label transmitted in the Path message, the upstream label is allocated before sending a Resv message. However, the upstream label is not guaranteed to be successfully allocated, because other LSP setup requests may allocate the upstream label before it is allocated for LSP setup. To avoid this conflict, when the upstream label set is transferred in the Path message process, all the upstream labels in the upstream label set are reserved in advance. Then, when one upstream label is chosen in the Resv message process, the other upstream labels are released. Although advanced reservation may lower the utilization of upstream labels, its impact on utilization is very small when the average interval time of the LSP setup requests is much larger than the average LSP setup time.

In the ULS scheme, when upstream label allocation is performed by Resv messages, the ResvConf message is mandatory. This is because the egress node needs to confirm that the upstream LSP is setup before transmitting upstream data.

4. Performance of ULS Scheme

The performance of the ULS scheme was evaluated by simulation. The network model in our evaluation is shown in Fig. 5. We assume that each node does not have wavelength conversion capability to simplify the discussion. Each fiber link has w wavelengths. An ingress node sets up a bidirectional LSP to an egress node with h hops. Each wavelength is used with load probability of ρ. In other words, the probability of a wavelength being vacant is 1-ρ. We randomly generated 10^8 requests to setup bidirectional LSPs to collect statistical performance data. We compared the blocking probability and LSP setup time of the ULS scheme with those of the UL scheme. We consider the advanced reservation of upstream labels in the Path message process, as described in Sect. 3.2. Since we assume that the average interval time of the LSP setup requests is much larger than the average LSP setup time, the impact of the utilization of upstream labels is ignored.

Figure 6 shows that the ULS scheme offers lower blocking probability for bidirectional LSP setup than the UL scheme; the values of h=6 and w = 32 were set. In the ULS scheme, LSP setup is attempted only once, because the upstream label set by propagated by a Path message collects information of available wavelengths on the LSP route considering the wavelength continuity constraint. On the other hand, in the UL scheme, setup blocking occurs because the upstream label generated by the previous hop node may not meet the wavelength continuity constraint. Therefore, the UL scheme needs to send the setup request again based on information of the acceptable label set, as described in Sect. 2. T is denoted as the number of allowable number of LSP setup attempts in the UL scheme. Network operators can set T after taking account of the maximum admissible LSP setup time. When T is small, the blocking probability of the UL scheme is high. As T increases, the blocking probability of the UL scheme approaches that of the ULS scheme at the cost of long setup times. As h is set to 6, the blocking probability of the UL scheme with T = 6 equals that of the ULS scheme.

The ULS scheme has shorter LSP setup time than the UL scheme, as shown in Fig. 7. It is assumed that the LSP setup times are proportional to the number of hops and that the Path, Resv, and ResvConf messages must pass through to complete the requested LSP setup. The time for each message to propagate one hop was assumed to be 100 [msec], which includes the message transmission delay on a fiber link and the processing delay at a node. LSP setup time was considered only when the LSP setup request succeeded. As the ULS scheme can always determine with only one try whether a request is accepted, the LSP setup time of the ULS scheme is constant. On the other hand, the number of LSP setup attempts varies in the UL scheme, the LSP setup times are distributed. Therefore, average value and 99% value are depicted in Fig. 7. Note that T is set to h(= 6) in the UL scheme, where the worst case in the UL scheme is considered to focus on the comparison of LSP setup times. This means that the blocking probabilities of both schemes are the same. Since the UL scheme has to send requests for LSP setup many times, the LSP setup time becomes large. Although the constant value of the ULS scheme is equal to 1800 [msec] (=100 [mesec] × (6 × 3 hops)), the UL scheme has longer LSP setup time than the ULS scheme. This is because iterated LSP setup requests are needed to achieve LSP setup completion. The number of total message transmission hops to complete LSP setup in the UL scheme becomes larger than 6 × 3 hops in the ULS scheme. A message processing time in each node is ignored to evaluate the LSP setup time. The LSP setup time depends on the number of total message transmission hops to complete LSP setup. We observe that the ULS scheme shortens the LSP setup time by more than 60% compared to the 99% value of the UL scheme.

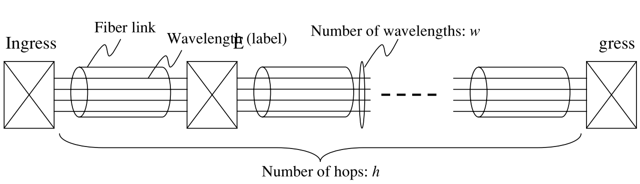

Fig. 5 Network model.

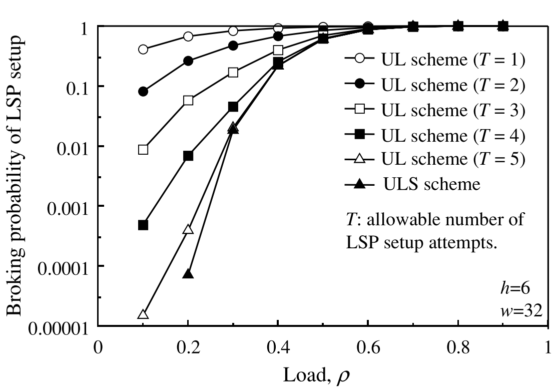

Fig. 6 Blocking probability of LSP setup.

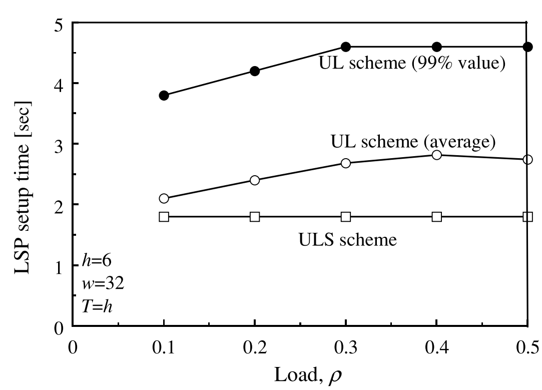

Fig. 7 Comparison of LSP setup time.

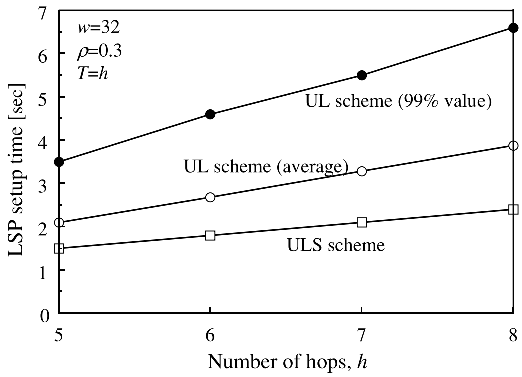

Fig. 8 Impact of number of hops on LSP setup time.

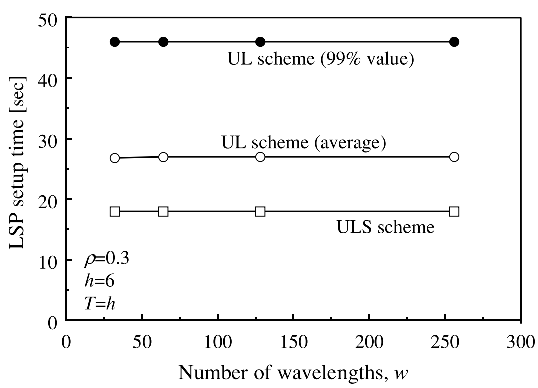

Fig. 9 Impact of number of wavelengths.

The above evaluation assumes that in the UL scheme a ResvConf message is used to complete a requested LSP setup, although using a ResvConf message is not mandatory according to [10], [11]. This is because network operators want to start upstream and downstream data transmission only after they confirm LSP setup completion in both directions, as described in Sect. 2.1. Consider that a ResvConf message is not used in the UL scheme although it is not desired from the network operators' point of view. In this case, both average value and 99.9% value for the LSP setup time of the UL scheme are decreased by 600 [msec] (=100 [msec] × 6 hops). Therefore, the average value of the UL scheme becomes shorter than the LSP setup time of the ULS scheme, while the 99.9% value of the UL scheme is still longer than the LSP setup time of the ULS scheme. In the following evaluations, we also assume that a ResvConf message is used to complete a requested LSP setup as is the case in Fig. 7, because it is desired by network operators.

As h increases, the differences in LSP setup time between the ULS scheme and the UL scheme become large, as shown in Fig. 8. A large value of h makes the advantage of the ULS scheme stand out. The ULS scheme is not affected by h very much, unlike the UL scheme. This is because requests fail more often in the UL scheme as h increases. This makes the LSP setup time large in the UL scheme. As a result, for a large-sized network, the ULS scheme is much more efficient than the UL scheme.

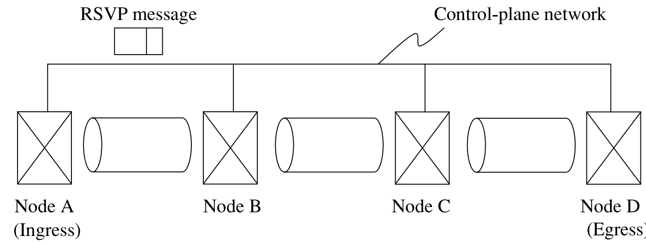

Fig. 10 Demonstration of ULS scheme.

Figure 9 shows the impact of the number of wavelengths on the LSP setup times. The differences in setup time between the ULS scheme and the UL scheme are almost the same. w does not impact the effectiveness of the ULS scheme.

5. Demonstration of ULS Scheme

We developed a prototype of GMPLS control system [4], in which the ULS scheme was installed. Unlike MPLS networks, the control plane is separated from the data plane in GMPLS networks. The prototype demonstrated GMPLS RSVP-TE signaling with the ULS scheme to focus on the control plane. The network used in the ULS demonstration is shown in Fig. 10. The control-plane network was structured on 10/100 Ethernet. RSVP messages propagated through the control-plane network. We confirmed that the procedure of the ULS scheme was performed successfully. A captured Path message transmitted from node A (ingress node) to node B (transit node) is presented in Fig. 11, where the Label Set object held four labels, the Upstream Label object had an upstream label, and the Upstream Label Set object have four upstream labels.

6. Conclusions

This paper proposed the ULS scheme for GMPLS-based optical WDM networks. It replaces the inefficient GMPLS existing signaling protocol, the UL scheme, and solves the problem of wavelength continuity. An upstream label set was introduced by extending the UL scheme. The ULS scheme is consistent with the existing GMPLS signaling procedure of the UL scheme and so offers backward compatibility.

The performance of the ULS scheme was evaluated by simulation. The numerical results suggest that the ULS scheme lowers the blocking probability compared to the UL scheme when the number of the LSP setup retries is limited. In addition, when the constraint of the number of LSP setup retries is relaxed, the ULS scheme offers faster LSP setup than is possible with the UL scheme. The ULS scheme reduces the LSP setup time by more than 60% compared to the UL scheme. We also observed that the ULS scheme becomes much more effective than the UL scheme as network size increases. By using our developed GMPLS control system, in which the ULS scheme was installed, we confirmed

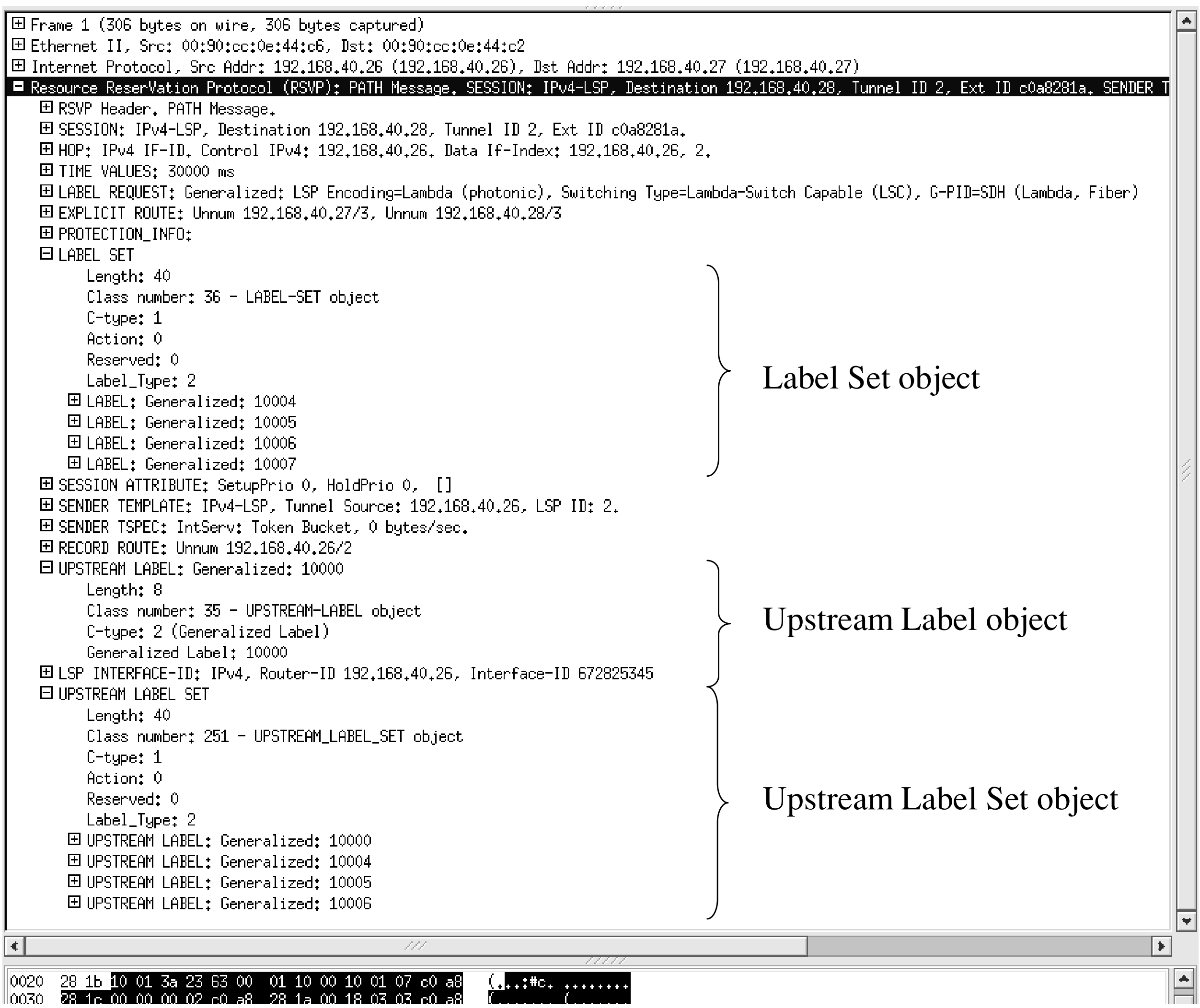

Fig. 11 Example of captured Path message.

that the procedure of the ULS scheme was successfully performed.

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