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QoS evaluation of diffserv-aware constraint-based routing schemes for multi-protocol label switching networks

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Abstract

Differentiated Services (DiffServ) and Multi-Protocol Label Switching (MPLS) are attracting attention as Quality of Service (QoS) technologies for the large-scale Internet. DiffServ cannot offer end-to-end QoS by itself, because it controls per-hop packet forwarding order with relative priority according to its class. Achieving end-to-end QoS requires traffic engineering support by using MPLS and Constraint-Based Routing (CBR) schemes in addition to DiffServ. CBR schemes compute explicit routes for Label-Switched Paths (LSPs), which specify packet forwarding routes in MPLS networks. In this paper, we assume two DiffServ classes: Expedited Forwarding (EF) class which corresponds to voice traffic requiring small path delay, and Best Effort (BE) class which corresponds to data traffic requiring high throughput. Four DiffServ-aware CBR schemes are constructed, based on a combination of route computation algorithms and LSP-types depending on whether or not DiffServ classes are considered. In addition to the schemes, we propose a DiffServ-aware CBR scheme that uses a different route computation algorithm for each class. By simulating path accommodations for two-class traffic between every node pair, we evaluate QoS achieved by the five DiffServ-aware CBR schemes. The results show that the proposed scheme can offer better QoS for each class.

Keywords: DiffServ; Multi-protocol label switching; Traffic engineering; Quality of service; Constraint-based routing; Simulation

1. Introduction

Voice over IP (VoIP) and video conferencing are beginning to be used on the Internet. These Internet applications communicate bi-directionally in real time. Therefore, network delay is an important performance parameter for these real-time applications, On the other hand, network throughput is an important one for the World Wide Web (WWW), which continues to be popular. Voice or video conferencing traffic requires higher Quality of Service (QoS) than other data traffic.

The Internet Engineering Task Force (IETF) has standardized Differentiated Services (DiffServ) technology as RFC2475 [1]. Packets that require higher QoS are classified as higher priority, and are forwarded in order of priority at nodes along their path. As a result, relatively better performance can be achieved for high-priority traffic. In short, voice traffic can receive higher QoS than best-effort data traffic, such as WWW by using DiffServ.

But DiffServ cannot offer end-to-end QoS by itself, because it controls the per-hop packet forwarding order with relative priority according to its class and does not consider the route. DiffServ requires other mechanisms especially for routing to achieve end-to-end QoS. One of the most popular IP routing protocols is Open Shortest Path First (OSPF), which is destination-based routing that selects the same shortest path for all traffic classes if their destinations are the same node. For a large Internet, their routes are likely to be concentrated on a few particular links. As a result, the network has hot spots, which are congested nodes.

Traffic engineering technology [2], which uses Multi-Protocol Label Switching (MPLS) [3] as a forwarding scheme and constraint-based routing (CBR) as a routing scheme including distributed route computation, is attracting attention as a technology for preventing such problems in the case of providing DiffServ in end-to-end networks. MPLS uses a 32-bit label at the head of each IP packet, and forwards packets following a Label-Switched Path (LSP), which is a route based on label information. For IP routing, the routes are independent. IP routing (e.g. OSPF) computes the shortest path using only a link metric related to link

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length or administrative cost. CBR computes an LSP route using the unreserved bandwidth of each link in addition to its metric [4]. Each link has a metric and unreserved bandwidth, which is link bandwidth minus the sum of the bandwidths of accommodated LSPs. This consideration of the unreserved bandwidth of each link enables traffic to be balanced and network congestion to be avoided. Here, note that establishing an LSP with bandwidth reservation does not mean that per-LSP scheduling is required. In short, packet scheduling is used only for DiffServ class, and MPLS decides only packet routing. An LSP for MPLS is set up between an ingress-egress node pair according to a route computed in CBR schemes. Our approach uses an LSP which aggregates flows according to DiffServ class or source-destination node pair as a routing unit, while [5] uses a per-flow routing mechanism from a circuit-switched network for VoIP traffic engineering.

We have studied [6] operation methods involving a combination of DiffServ and MPLS traffic engineering to provide predictive end-to-end QoS for one management domain. The previous approaches assumed the use of one route computation algorithm. In our approach, CBR schemes may select an appropriate route computation algorithm considering the QoS required for each DiffServ class. But it is unknown whether more than one algorithm will work well in the same network from the viewpoint of QoS.

In this paper, we assume two DiffServ classes: Expedited Forwarding (EF) class, which corresponds to voice traffic requiring small path delay, and BE class which corresponds to data traffic requiring high throughput. Four DiffServ-aware CBR schemes are constructed, based on a combination of route computation algorithms and LSP-types depending on whether or not DiffServ classes are considered. In addition to the schemes, we propose a DiffServ-aware CBR scheme that uses a different route computation algorithm for each class. By simulating path accommodations for two-class traffic between every node pair, we evaluate QoS achieved by the five DiffServ-aware CBR schemes.

This paper is organized as follows: Section 2 shows DiffServ classes and their QoS requirements assumed in this paper. DiffServ-aware CBR schemes including a proposed one are described in Section 3. And their effect on end-to-end QoS for each DiffServ class are evaluated by routing simulation. The results are shown in Section 5 and are discussed in Section 6. Finally, conclusions are presented in Section 7.

2. DiffServ classes and their QoS requirements

We assume two DiffServ classes: EF class [7], and Best Effort (BE) class. EF packets are transferred with higher priority than BE packets by using a priority queue in every node in a DiffServ domain.

EF traffic is required to minimize end-to-end delay in the DiffServ domain, because it is assumed to correspond to voice traffic. Delay induced by path length cannot be controlled and reduced, but queueing delay in each node along the path can be reduced by good accommodation of EF traffic, because EF traffic is not affected by BE traffic when we use priority queues on the nodes. Route computation algorithms for the EF path are required to reduce path length.

BE traffic is required to maximize path throughput, because it is assumed to correspond to data traffic. Throughput of BE traffic is affected by the total traffic volume (which is the sum of EF and BE traffic), because BE traffic is treated as a lower priority class in each node than EF traffic. A bottleneck in path throughput is a link whose available bandwidth, which is defined by the link bandwidth minus the traffic volume of the link, is the minimum along the path, and its throughput is related to the minimum available bandwidth. We choose available bandwidth in links instead of path throughput as an evaluation measure in the following sections. Route computation algorithms for the BE path are required to maximize the minimum available bandwidth of each link.

The route computation algorithms are required to minimize delay induced by path length for EF traffic and to maximize available bandwidth of each link for BE traffic. Though packet loss is an important QoS parameter for both classes, it is excluded in this paper for simplicity.

3. DiffServ-aware constraint-based routing schemes

For DiffServ-aware MPLS, two class-to-label mappings are being discussed at IETF [8]. One is EXP-Inferred-PSC LSP (E-LSP), which identifies the class in the EXP field in an MPLS label [9]. The other is Label-Only-Inferred-PSC LSP (L-LSP), which identifies the class in the label field in an MPLS label (Fig. 1).

Here, for E-LSP, multiple classes will be accommodated in one LSP. And packets in the LSP that share the same link are treated only according to their classes by the DiffServ control in each node. For L-LSP, even if the source-destination pair is the same, LSPs may have different routes for different classes. And packets in the LSP that share the same link are treated only according to their class by the DiffServ control in each node, like E-LSP. In short, if it is the same source-destination pair, all classes can be treated as one LSP for E-LSP, while different routes can be used for the EF-class LSP and the BE-class LSP for L-LSP.

Here, as routing algorithms for dynamically computing LSP routes on the nodes such as OSPF, the one based on Dijkstra's algorithm, which computes the shortest path using a small amount of computation time, is chosen as a route computation algorithm for LSP routes.

As route computation algorithms for CBR [10], which consider metric delay and available bandwidth in LSP route

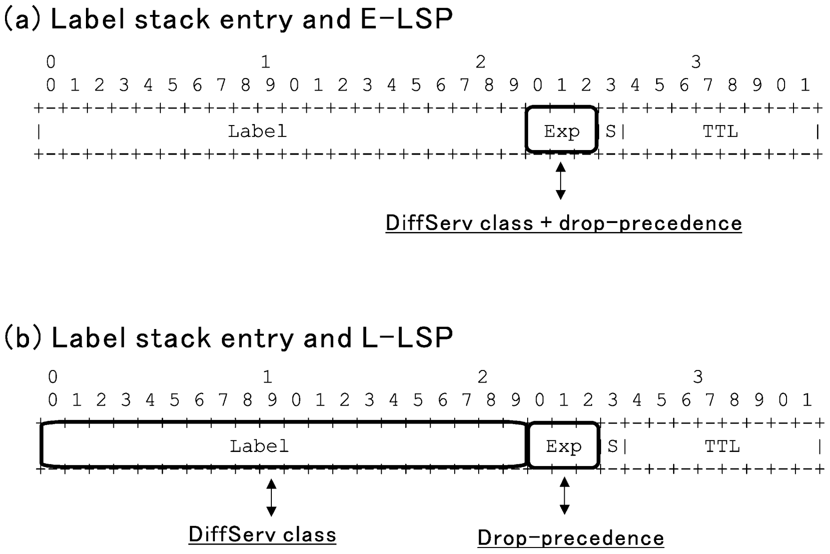

Fig. 1. Label format for E-LSP and L-LSP.

computation, we choose: the *widest–shortest* (W–S) path algorithm, which chooses the maximum available bandwidth one among the shortest paths, and the *shortest–widest* (S–W) path algorithm, which chooses the shortest one among the maximum available bandwidth paths.

Five DiffServ-aware CBR schemes are constructed, based on different route computation algorithms for CBR and different LSP-types depending on whether or not DiffServ classes are considered. As DiffServ-aware CBR schemes, we selected: (1) E-LSP and W–S path algorithm, (2) L-LSP and W–S path algorithm, (3) E-LSP and S–W path algorithm, and (4) L-LSP and S–W path algorithm. Moreover, schemes for L-LSP can also select different route computation algorithms for different classes. Our proposed scheme is (5) W–S path algorithm for EF class requiring small delay and S–W path algorithm for BE class requiring low link usage.

It is not known how effective the schemes with L-LSP are, though L-LSP has an advantage that its path unit is smaller than E-LSP's. Because the proposed scheme can set different routes for different classes, it has a possibility of offering appropriate QoS corresponding to the class. But it is also not known how effective the proposed scheme is and what influence two route computation algorithms in the scheme have on each other. It is necessary to clarify differences among the E-LSP-type schemes, the L-LSP-type ones, and the proposed one from the viewpoint of QoS.

4. Evaluation

We evaluate QoS provided by the CBR schemes by simulation. For EF class, the maximum delay of LSPs is evaluated, because the class is assumed to require small delay. For simplicity, queueing delay in transit routers is assumed to be much lower than propagation delay of transit links, so path delay is considered to be the same as propagation delay. For BE class, we select the minimum available bandwidth in links through the path as a metric for simplicity, though path throughput is an important performance parameter for the class. Here, the available bandwidth is defined as being equal to the link bandwidth minus the total traffic volume in the link.

The CBR schemes are evaluated on a 3×5 lattice topology network (Fig. 2), where every link has the same bandwidth of 100. And link metrics for CBR are selected to be integer values 1–10 with the same probability. The metrics are related to link delay. EF and BE traffic are carried between every node pair. E-LSP has one LSP for every node pair, while L-LSP has two LSPs, which are related to EF and BE, for every node pair. Here, the orders in which routes are computed are different between trials, because the node pairs are selected randomly without duplication in each trial. The CBR schemes are evaluated for different traffic volumes (pattern 1) or different ratios of EF to BE (pattern 2).

For pattern 1, LSP's traffic volumes are selected to be integer values 1 to N with the same probability, where the mean traffic volume between every node pair is $(N+1)/2$.

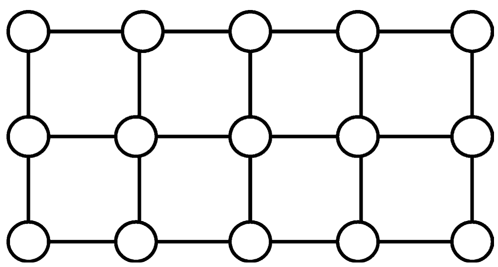

Fig. 2. Network topology for simulation evaluation.

And the ratio of the traffic volume of EF class to that of BE class is 1:4 for the same node pair, and the traffic between a node pair is divided by EF and BE class LSPs with ratio 1:4 for L-LSP. If $N > 7$, some LSPs are not accommodated by the model network. N is set to 2, 5 or 7 for one simulation, because we assume LSPs should be set up for every node pair in real operation. Here, every mean traffic volume is less than 4.

For pattern 2, we assume the ratio of EF to BE class traffic volume to be 1:M, and M is set to 1, 4 or 9 for one simulation, EF traffic is 50, 20 or 10% for each M value. The traffic volume for every node pair is selected to be an integer value from 1 to 5 with the same probability. Here, the mean traffic volume is 3.

5. Results

5.1. Maximum path delay for EF-class traffic

Fig. 3 shows simulation results for the maximum path delay for EF-class traffic under various mean traffic volumes between a node pair and under a fixed ratio of EF to BE. Fig. 4 shows simulation results for the maximum path delay for EF-class traffic under various ratios of EF to the sum of EF and BE traffic and under a fixed mean traffic volume between a node pair. For both figures, each plot is the mean value of 100 trials. Because the 95% confidence intervals of these plots are small enough and less than ±0.90, the confidence intervals are not shown in the figures.

Schemes (1) and (2) with the W–S path algorithm and our proposed one (5) gave about 40% smaller delay than schemes (3) and (4) with the S–W path algorithm. Maximum path delay for EF-class traffic was almost the same value, even though the ratio of EF or mean traffic volumes varied. And when the route computation algorithms were the same, the results showed no difference between E-LSP and L-LSP: i.e. no difference between (1) and (2) or between (3) and (4).

Here, to analyze the results in detail, we compare delay of every path in addition to the maximum path delay. Fig. 5 shows delay of every path for EF class in order of numerical value for one trial by using the proposed scheme with the W–S path algorithm for EF class and by using the L-LSP scheme with the S–W path algorithm. Mean traffic volume is 3, and the ratio of the traffic volume of EF class to that of BE class is 1:4 for the same node pair. The results for the schemes with the W–S path algorithm are not shown in the figure because the values were almost the same as those obtained using the proposed scheme. The proposed scheme decreased delay of every path, especially for maximum one. For other trials, the results showed same trends.

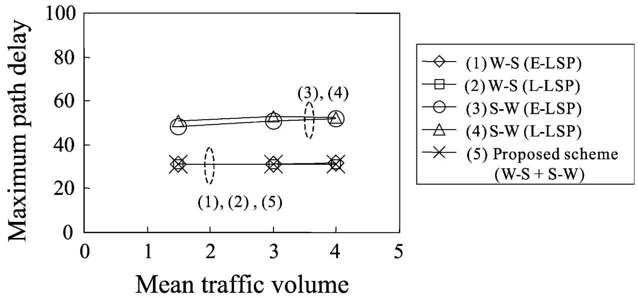

Fig. 3. Maximum path delay for EF-class traffic versus mean traffic volume.

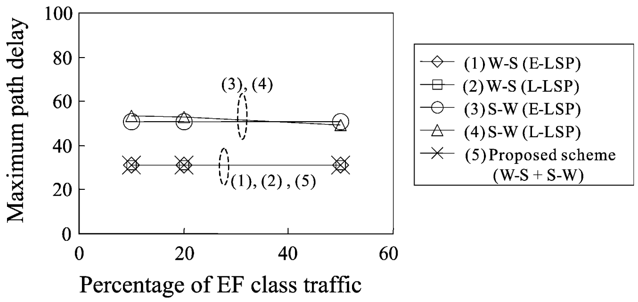

Fig. 4. Maximum path delay for EF-class versus percentage of EF-class traffic.

5.2. Minimum available bandwidth of network links

Fig. 6 shows simulation results for minimum available bandwidth of links under various mean traffic volumes between a node pair and under a fixed ratio of EF to BE. Fig. 7 shows simulation results for minimum available bandwidth of links under various ratios of EF to the sum of EF and BE traffic and under a fixed mean traffic volume between a node pair. For both figures, each plot is the mean value of 100 trials. Because 95% confidence intervals of these plots are small enough and less than ±0.82, the confidence intervals are not shown in the figures.

Schemes (3) and (4) with the S–W path algorithm and proposed one (5) gave available bandwidth of about 10–20 more than W–S path algorithms (1) and (2). The minimum available bandwidths were almost same values, even though

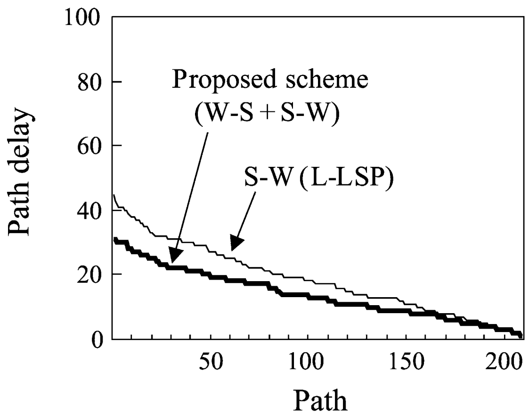

Fig. 5. Delay of each path for EF class.

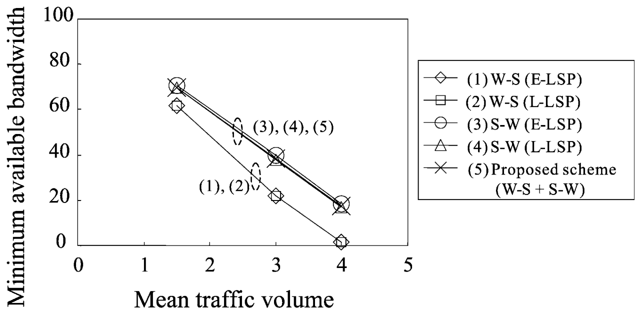

Fig. 6. Minimum available bandwidth of network links versus mean traffic volume.

the ratio of EF to BE varied. And when the route computation algorithms were the same, the results showed no difference between E-LSP and L-LSP: i.e. no difference between (1) and (2) or between (3) and (4).

Here, to analyze the results in detail, we compare available bandwidth of every link in addition to the minimum link available bandwidth. Fig. 8 shows available bandwidth of every link in order of numerical value for one trial by using the proposed scheme and the L-LSP scheme with the W–S path algorithm. Mean traffic volume is 3, and the ratio of the traffic volume of EF class to that of BE class is 1:4 for the same node pair. The results for the schemes with the S–W path algorithm are not shown in the figure because the values were almost the same as those obtained using the proposed scheme. For the proposed scheme, available bandwidth of every link got closer to the same value, because each link was used uniformly. The proposed scheme decreased links with low available bandwidth, while links with high available bandwidth were used more. For other trials, the results showed same trends.

6. Discussion

The evaluation results in the previous section are summarized below.

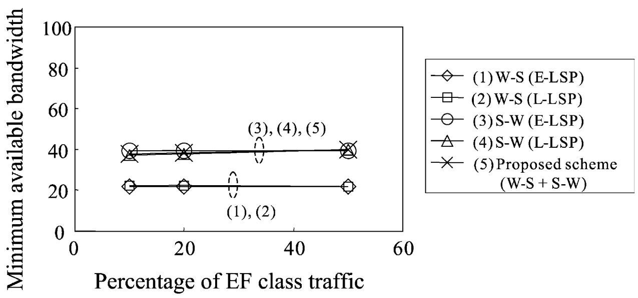

Fig. 7. Minimum available bandwidth of network links versus percentage of EF-class traffic.

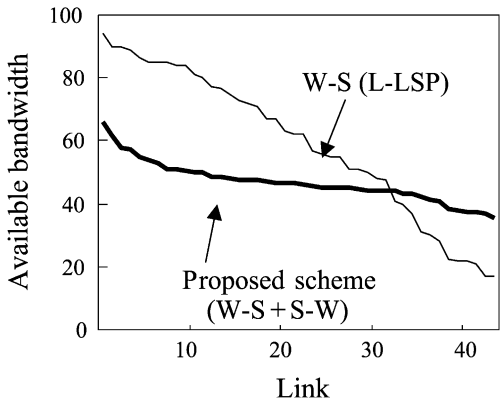

Fig. 8. Available bandwidth of each network link.

- While L-LSP has an advantage that its path unit is smaller than E-LSP's, the results show no difference between E-LSP and L-LSP if the same route computation algorithm is used.
- The proposed scheme can achieve as small path delay for EF-class traffic as L-LSP and E-LSP with W–S path algorithms.
- The proposed scheme can achieve as large an available bandwidth as L-LSP and E-LSP with S–W path algorithms.
- Though the proposed scheme has different route computation algorithms for each traffic class, these route computation algorithms do not have a bad influence on each other.

Thus, the proposed scheme can achieve the appropriate quality required for each traffic class: small delay for EF-class traffic and high throughput for BE class traffic, which is equivalent to large link available bandwidth.

Each scheme was evaluated only for a 3×5 lattice topology network (Fig. 2). Reference [11] shows that the relationships among their relative qualities were conserved, though the qualities achieved by their route computation algorithms were different for different network topologies for non-DiffServ MPLS networks using only one route computation algorithm. Therefore, except for the proposed scheme, the above results are expected to be acceptable for other network topologies because those four schemes use only one route computation algorithm for all paths. The proposed scheme requires alternative routes because different QoS-type traffic is accommodated in different routes computed by different algorithms. Therefore the proposed scheme will be less effective in sparse network topologies with few alternative routes.

We assumed that network traffic was classified into only two classes, and EF- and BE-class traffic required small delay and high throughput respectively. The applicability of these results for three or more traffic class needs to be studied in terms of the quality required for the third class, a route computation algorithm to be selected, etc.

We did not evaluate the complexity of implementing the schemes. The schemes with L-LSP increase the number of LSPs according to the number of classes. They have the advantage that the path unit to set up can be smaller than those with E-LSP, but there was no difference between the schemes with E-LSP and L-LSP from a viewpoint of QoS if a route computation algorithm was the same. The proposed scheme needs to implement two different route computation algorithms at the same time. Quality and implementation simplicity have a tradeoff relationship. To avoid a complex implementation, E-LSP-type schemes may be selected rather than L-LSP-type schemes, because they use only one route computation algorithm and can decrease the number of LSPs.

From the viewpoint of the resultant QoS for each class, the proposed CBR scheme achieved the expected QoS for EF and BE classes in network topologies with alternative routes. E-LSP, which uses an appropriate route computation algorithm, is better than L-LSP or the proposed one, if simplicity is required.

7. Conclusions

We categorized DiffServ-aware CBR schemes for MPLS, based on route computation algorithms for each LSP (W–S path algorithm or S–W path algorithm), and LSP-type (E-LSP or L-LSP). For E-LSP, traffic of all classes between the same source-destination node pair is accommodated in one LSP, and in short all traffic is on the same route. For L-LSP, each traffic class between the same source-destination node pair is accommodated in a different LSP, and each traffic class may take a different route.

In this paper, we considered two traffic classes: EF-class traffic, which requires small delay, such as voice traffic, and BE-class traffic, which requires high throughput, such as data traffic. We proposed the DiffServ-aware CBR scheme which use the W–S path algorithm for EF class and the S–W path algorithm for BE class.

From the viewpoint of the QoS for each class, we evaluated the five DiffServ-aware CBR schemes mentioned above by simulating path accommodations. Our proposed CBR scheme, which uses a different route computation algorithm for each class, could achieve the expected QoS for both classes in network topologies with alternative routes.

If we accommodate video traffic in addition to voice and data traffic in the same network, then the three-class case should be evaluated. The applicability of the results for three or more classes is for further study.

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