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Minimizing preemption cost for path selection in Diffserv-ware MPLS networks

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Abstract

Preemption is becoming an attractive strategy for bandwidth reservation and management in DiffServ-aware Traffic Engineering. In this paper, we propose an improved heuristic algorithm for the well-known optimization formulation based on versatile preemption policy, which can minimize the preemption cost with high accuracy and less computational intractability. Simulation results show that the proposed algorithm significantly outperforms well-known algorithms recently proposed in the literature. Moreover, we present a new path selection scheme to minimize preemption. Due to preemption of those LSPs that share more links with the selected path, the proposed scheme obviously minimize rerouting in DS-TE environments.

Keywords: DiffServ-aware traffic engineering (DS-TE); Preemption; Algorithm; Path selection

1. Introduction

IP network is now evolving from a best-effort service network into an integrated network which supports multiple applications with different QoS requirements and different priorities. DiffServ-aware traffic engineering (DS-TE) proposed by IETF integrates the scalability of DiffServ architecture and the efficient routing policies of MPLS traffic engineering (MPLS-TE), and is known as a preferable solution for QoS guarantee as well as resource optimization in the multi-service network [1].

The DS-TE approach is based on the class-based bandwidth allocation in network routers and on routing an LSP through routers that have sufficient bandwidth for its QoS class. DS-TE introduces several new concepts including class types (CT), bandwidth constraints (BC), and traffic engineering classes (TE-Classes). Class types are defined as sets of traffic trunks that are governed by a specific set of bandwidth constraints. They roughly correspond to QoS classes defined in the DiffServ architecture. A DS-TE network can support up to eight CTs, where CT0 corresponds to the best effort traffic, and higher CT number correspond to traffic with more stringent QoS requirements. Bandwidth constraints are bandwidth allocations to individual CTs or groups of CTs depending on the BC model. CTs and BCs are the principal agents of transforming MPLS-TE into TS-TE. Instead of performing bandwidth accounting across the entire link bandwidth, DS-TE allows bandwidth calculations on the per-CT basis using the appropriate BC values.

TE-Classes were introduced as composite attributes that include both the traffic trunk's CT and the preemption priority of the LSP transporting it. DS-TE describes TE-Class mapping as:

$$\text{TE-Class}[i]\langle\text{--}\rangle\langle \text{CT}c, \text{preemption } p\rangle$$

Where $0 \leqslant i \leqslant 7$, $0 \leqslant c \leqslant 7$, $0 \leqslant p \leqslant 7$. Formation of TE-Classes follows several rules. The value of the preemption

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priority corresponds to the LSP's setup priority, holding priority or both. Each TE-Class represents a unique CT/P combination, but different TE-Classes may have the same CT with different values of *P* or different CTs with the same value of *P*. Once TE-Classes are formed, DS-TE compliant LSRs accept reservations only from LSPs whose attributes map into one of these TE-Classes.

TE-Classes are the primary LSP attributes in the DS-TE process. In order to support this advanced level of traffic engineering, IGP-TEs and RSVP-TE were extended beyond their MPLS-TE support, as described in [2]. Extended IGP-TEs still use the existing "Unreserved Bandwidth" sub-TLV for each of the TE-Classes instead of for each preemption priority. Extended RSVP-TE carries a new object with the LSP's CT value. Together with the existing fields for the setup and holding priorities, the RSVP-TE Path message contains complete information identifying the TE-Class.

Three BC models such as the Maximum Allocation Model (MAM) [3], the Russian Doll Model (RDM) [4] and the Maximum Allocation with Reservation (MAR) [5] have been proposed and their performance are evaluated and compared [5,6].

Preemption is an attractive strategy for bandwidth reservation and management in DS-TE. When there is a competition for available resources in a link, a new LSP with a certain priority can preempt the existing LSP with a lower priority. The preempted LSP may then be rerouted. Preemption can be used to provide available and reliable services to high priority LSPs within a DiffServ environment, especially when a network is heavily loaded and connection request arrival patterns are unknown, or when the network experiences link or node failures.

In this paper, we propose an improved algorithm which minimizes the preemption cost with high accuracy and less computational intractability. Furthermore, we also present a new path selection scheme for minimizing preemption in DS-TE. The rest of this paper is organized as follows. Section 2 reviews related work about preemption policy and path selection based on constrained shortest path first (CSPF) algorithm. Section 3 describes our improved preemption algorithm proposed and simulation results. In Section 4, our proposed path selection scheme for minimizing preemption cost is illustrated in detail. Finally, the paper is concluded in Section 5.

2. Related work

2.1. Preemption policy

In order to minimize wastage, the set of LSPs to be preempted can be selected by optimizing an objective function that represents three important parameters: bandwidth, preemption priority and the number of LSPs to be preempted. The objective function could also be any or a combination of the following [7,8]:

1. Preempt the connections that have the least priority (preemption priority). The QoS of high priority traffic would be better satisfied.
2. Preempt the least number of LSPs. The number of LSPs that need to be rerouted would be lower.
3. Preempt the least amount of bandwidth that still satisfies the request. Resource utilization would be improved.

After the preemption selection phase is finished, the selected LSPs must be torn down (and possibly rerouted), releasing the reserved bandwidth. The new LSP is established, using the currently available bandwidth. The unreserved bandwidth (UB) information is then updated.

Peyravian and Kshemkalyani [8] proposed two connection preemption policies that optimize the discussed criteria in a given order of importance: number of connections, bandwidth, and priority, which has polynominal complexity; and bandwidth, priority, and number of connections, which has exponential complexity. The computation complexity of the two optimal algorithms makes them non-implemental in real networks.

de Oliveira et al. [9] proposed a versatile preemption policy named as V-PREPT that can balance the objective function to be optimized in order to stress the desired criteria. Their preemption policy is complemented by an adaptive rate scheme, which can minimize service disruption and rerouting by adjusting the rate of selected low-priority LSPs. Heuristics for both simple preemption policy and adaptive preemption scheme are derived. They still proposed the similar heuristic that concerns the fourth optimization objective (i.e., the minimum of the blocking probability) in [10]. Another optimization criterion termed as "revenue index" modeled after consumer satisfaction in addition to the other three previously optimization criteria is introduced in [11] and the corresponding heuristic similar to that in [9] is also derived.

2.2. Preemption-ware path selection

There are currently two approaches used for preemption-aware path selection, i.e., the decentralized and centralized. For the decentralized approach, every node on the path would be responsible to run the preemption algorithm and determine which LSPs would be preempted in order to fit the new request. Because current IGP extensions advertise only local summarized information, which means that per-LSP information on distant links is not available, this summarized information can only tell if a link has the required resources to accommodate a new LSP on a certain priority level or TE-Class, and it is insufficient for determining which LSPs will be preempted. As a result, a decentralized approach may sometimes not lead to an optimal solution. On the contrary, the centralized approach is aware of all LSPs of the whole network (e.g., the CT, priority level, bandwidth of each LSP, and path information of each LSP), a Network Management System

(NMS) or server can run the preemption policy and determines those best LSPs to be preempted in order to free the required bandwidth in all links that compose the path. This off-line tool is usually of characteristic of computational intractability, and needs to challenge the so-called "NP-complete problem [12]".

Although detailed LSP information is not available at path calculation, it is still possible to develop heuristic algorithms for minimizing preemption cost based on today's standard IGP extensions.

Little work has been done on the relationship between routing and preemption procedures. Szviatovszki et al. [13] proposed a new CSPF algorithm for minimizing preemption of lower priority LSPs, which is based on the affected highest priority level and its amount of bandwidth preempted. These measurements are used as the second metric in CSPF algorithm. Confined by the shortest paths, the scheme can not achieve load balancing and efficient resource utilization. A preemption-aware path selection algorithm was introduced in [14], which used the amount of bandwidth to be preempted and the affected highest priority level to construct the distance function. Because this distance function is used as the first metric, the CSPF algorithm can achieve preemption minimization as well as load balancing. Both schemes use the same preemption policy, i.e., to preempt always the lowest priority LSPs first. Without consideration of the number of the preempted LSPs, the amount of bandwidth of the preempted LSPs and the paths of the preempted LSPs (e.g., one or more LSPs may share several segments of same links with the selected path), both schemes may lead to waste of resources and excessive number of rerouting decisions. Moreover, both algorithms are based the existing TE mechanisms, which only allow constraint based routing of traffic based on a single bandwidth constraint common to all "classes of service". To the best of our knowledge, there is not any investigation on minimizing preemption for path selection in DS-TE environments.

3. Minimizing preemption cost

3.1. Review of the V-PREPT and its heuristic

Consider a request for a new LSP setup with bandwidth b and setup preemption priority p. When preemption is needed, due to lack of available resources, the preempted LSPs will be chosen among the ones with lower holding preemption priority (higher numerical value) in order to fit $r = b - A_{\mathrm{bw}}(l)$. The constant r represents the actual bandwidth that needs to be preempted (the requested bandwidth$b$ minus the available bandwidth on link l: $A_{\mathrm{bw}}(l)$).

Define L as the set of active LSPs having a holding preemption priority lower (numerically higher) than p. $b(l)$ is the bandwidth reserved by LSP $l \in L$, expressed in bandwidth modules and $p(l)$ is the holding preemption priority of LSPl. $y(l) = 8 - p(l)$ represents a cost for each preemption priority. Define $\mathbf{y}$ as a cost vector with N components, also define $\mathbf{b}$ as a reserved bandwidth vector with dimension N, and component $b(l)$.

Mathematical formulation for V-PREPT is given as

$$F(\mathbf{z}) = \alpha(\mathbf{z} \cdot \mathbf{y}^{\mathbf{T}}) + \beta(\mathbf{z} \cdot 1^{\mathbf{T}}) + \gamma(\mathbf{z} \cdot \mathbf{b}^{\mathbf{T}}) \tag{1}$$

The vector $\mathbf{z}$ is an optimization variable and is composed of N binary variables where N is the number of on-going preemption enabled LSPs in the system.

$$Z(l) = \begin{cases} 1 & \text{if } l \text{ is preempted} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$\mathbf{z} \cdot \mathbf{y}^{\mathbf{T}}$ represents the priority of the preempted LSPs, $\mathbf{z} \cdot \mathbf{1}^{\mathbf{T}}$ represents the number of preempted LSPs ($\mathbf{1}$ is a unit vector with N dimension) and $\mathbf{z} \cdot \mathbf{b}^{\mathbf{T}}$ represents the total preempted bandwidth. Coefficients α, β, and γ are suitable weights that can be configured in order to stress the importance of each component in F. The solution of the problem is to minimize objective function $F(\mathbf{z})$ subject to the following constraint:

$$\mathbf{z} \cdot \mathbf{b}^{\mathbf{T}} \geqslant r \tag{3}$$

A heuristic rather than an optimization solution is a better choice for large networks and a large number of LSPs in consideration of time complexity. In order to simplify the online choice of LSPs to be preempted, a heuristic for V-PREPT use the following equation:

$$H(l) = \alpha y(l) + \beta\left(\frac{1}{b(l)}\right) + \gamma(b(l) - r)^2 \tag{4}$$

where $\alpha\ y(l)$ represents the priority cost of the preempted LSP l, $\beta(1/b(l))$ represents the choice of a minimum number of LSPs to be preempted in order to fit the request r, and $\gamma(b(l) - r)^2$ penalizes a choice of an LSP to be preempted that would result in high bandwidth wastage.

3.2. The preemption cost function

The novelty in V-PREPT is to propose an objective function that can be adjusted by the service providers in order to stress the desired criteria. No particular criteria order is enforced. We can observe from (1) that, due to no consideration of the adaptability of the total bandwidth for those preempted LSPs, the preemption cost is proportional to the requested b, i.e., the bigger the requested b for a new LSP, the greater the objective function $F(\mathbf{z})$ is. It does not seem to be the best optimization function for minimizing preemption cost. Furthermore, the heuristic for V-PREPT is rough and approximate for the optimal result. We make some change on optimization function V-PREPT and present an optimization function for minimizing preemption cost.

Conforming to V-PREPT's preemption policies, we only redefine the following objective function F as the preemption cost, called H-PREPT.

$$F(\mathbf{z}) = \alpha(\mathbf{z} \cdot \mathbf{y}^{\mathbf{T}}) + \beta(\mathbf{z} \cdot \mathbf{1}^{\mathbf{T}}) + \gamma(\mathbf{z} \cdot \mathbf{b}^{\mathbf{T}} - r) \tag{5}$$

where $\mathbf{z} \cdot \mathbf{b}^{\mathbf{T}} - r$ represents the total preempted bandwidth wastage. Calculated by this function, a requested LSP with bigger bandwidth has not always higher preemption cost. For example, a requested LSP with 100 Mb/s may has the same preemption cost as one with 5 Mb/s if these preempted LSPs have the same adaptability of bandwidth, which is logical. Obviously, H-PREPT does not affect the optimal result caused by V-PREPT (i.e., the **z** to be sought is the same for both optimization functions).

3.3. The proposed heuristic for H-PREPT

The choice of LSPs to be preempted is known to be an NP-complete problem [12]. For N LSPs to be preempted, the computational complexity is 2^N, expressed as the sum of the binomial coefficients

$$2^N = C_N^0 + C_N^1 + \cdots + C_N^N \tag{6}$$

In order to simplify the online or off-line choice of LSPs to be preempted, we propose a heuristic used for H-PREPT. Our algorithm can be illustrated as follows:

STEP1: Arrange N LSPs in increasing order according to their bandwidth size. The bandwidth for the ith LSP is $B[i]$, and the maximum bandwidth $(MAX_B) = B[N]$.

STEP2: If the bandwidth r to be preempted $\leqslant MAX_B$, find all LSPs from N LSPs that satisfy r. The preemption cost of each LSP is calculated as

$$C = \alpha y(l) + \beta + \gamma(B[i] - r) \tag{7}$$

from (7) the minimum preemption cost (MIN_C) can be found. Pick 2 different LSPs from the remainder which are assumed to be $N1$ LSPs and the number of the combinations is C_{N1}^2. Find that combination where their total bandwidth satisfies r and $F(\mathbf{z})$ is minimized together. If all combinations satisfy r, or this minimum $F(\mathbf{z})$ is greater than the MIN_C, computation is over and the **z** to be sought is derived from the combination that has minimum MIN_C. Otherwise, if this minimum $F(\mathbf{z})$ is less than MIN_C, the previous MIN_C is replaced by $F(\mathbf{z})$. Iterate the previous procedure and search for the **z** that minimizes the value MIN_C from $C_{N1}^3, C_{N1}^4, \ldots$, etc., till the number of the selected LSPs reaches a given upper limit value M.

STEP3: If the bandwidth r to be preempted $> MAX_B$, calculate the total bandwidth (SUM_B) of the m LSPs which begin from the maximum $B[N]$ in decreasing order until $SUM_B \geqslant r$. Based on this number m found, we can find the combination from C_N^m that satisfies r and minimizes $F(\mathbf{z})$ together, and let the variable $MIN_C = F(\mathbf{z})$, which is the minimum of the combinations from C_N^m. If all combinations from C_N^m satisfy r, end the computation. Otherwise, similar to STEP2, search for the **z** that minimizes the value MIN_C from $C_N^{m+1}, C_N^{m+2}, \ldots$, etc., till the number of the selected LSPs reaches a given upper limit value M.

When the number N of LSPs to be taken into account for preemption is enough great (which is less likely scenario for over 5000 LSPs on a link), more time is needed to seek the MIN_C in order to get the accurate result. We can adjust the upper limit value M according to the number of LSPs that are considered to be preempted. The choice of low upper limit value M can reduce computational complexity, but may bring a result of lower accuracy. On the other hand, high limit value M implies more number of LSPs to be preempted when the minimum MIN_C is obtained from C_N^M, which results in more LSPs to be rerouted. A fast and accurate way is used to complement the above algorithm as follows:

In STEP 3 above, when the number m found $>M$(e.g., for a big bandwidth r), we slide m LSPs forward in decreasing order till their total bandwidth still satisfies r. Begin from this lowest sequence number into which the m LSPs are slid to the last sequence number N in the queue, we can count the number of LSPs that are taken into account for preemption as $N2$. Choose the combination from C_{N2}^m that has minimal $F(\mathbf{z})$.

3.4. Simulation results

Consider a link composed of 100 LSPs with reserved bandwidth b, preemption holding priority p, and priority cost y equal to 8-p. A request for an LSP establishment arrives with r, which is a variable, and $p = 0$ (highest priority, which implies that all LSPs with $p > 0$ will be considered). Assume the link has no available bandwidth. In order to prove the validity and accuracy of the proposed algorithm, we make 100 LSPs whose bandwidth varies from 1 to 100 Mb/s in integer with random distribution, uniform distribution and Gaussian distribution, respectively, and each LSP has a holding priority p distributed randomly from 1 to 7.

Here we use the concept of continuous random variable to define the distribution of discrete bandwidth. In uniform distribution, the bandwidth of each LSP is distributed with equal probability between 1 and 100 Mb/s. Gaussian distribution is subject to

$$\xi \sim N(\mu, \sigma^2) \tag{8}$$

where we let $\mu = 50$, $\sigma = 17$, so, bandwidth size of all LSPs lie in $[\mu - 3\sigma, \mu + 3\sigma]$ with probability equal to 0.9974, i.e., all bandwidth of 100 LSPs fall between 1 and 100 Mb/s with probability 1. Table 1 gives bandwidth distribution of 100 LSPs with Gaussian distribution, and bandwidth size of each LSP in each bandwidth zone is derived randomly.

Table 1
Bandwidth distribution of 100 LSPs with Gaussian distribution

Number of LSPs	1∗2	2∗2	5∗2	8∗2
Bandwidth zone	[1,10] [91,100]	[11,20] [81,90]	[21,27] [74,80]	[28,34] [67,73]
Number of LSPs	8∗2	11∗2	30	
Bandwidth zone	[35,39] [62,66]	[40,44] [57,61]	[45,56]	

To take into account the number of LSPs preempted, the preemption priority, and the amount of bandwidth preempted together, we may set $\alpha = \beta = \gamma = 1$, and $\alpha = 1$, $\beta = 10$, $\gamma = 0.1$, respectively. In both cases, we will verify the validity of the proposed algorithm.

We set the limit M of be preempted LSPs to 5, which is suitable for both the requested r and accuracy (the number of preempted LSPs is less than 5 in this case). Vary the value of the request r and compare the simulation results calculated by the optimization formulation H-PREPT, the

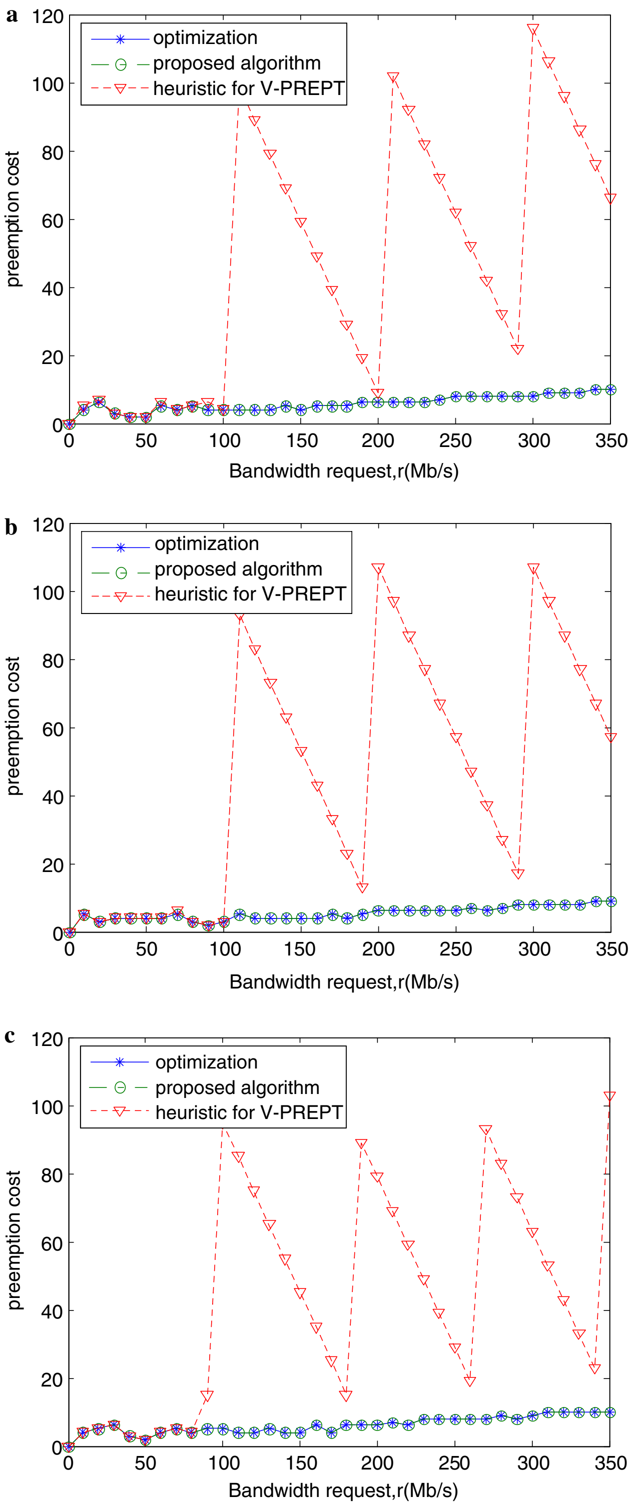

Fig. 1. Preemption cost at different algorithms ($\alpha = \beta = \gamma = 1$). (a) Random distribution, (b) uniform distribution, (c) Gaussian distribution.

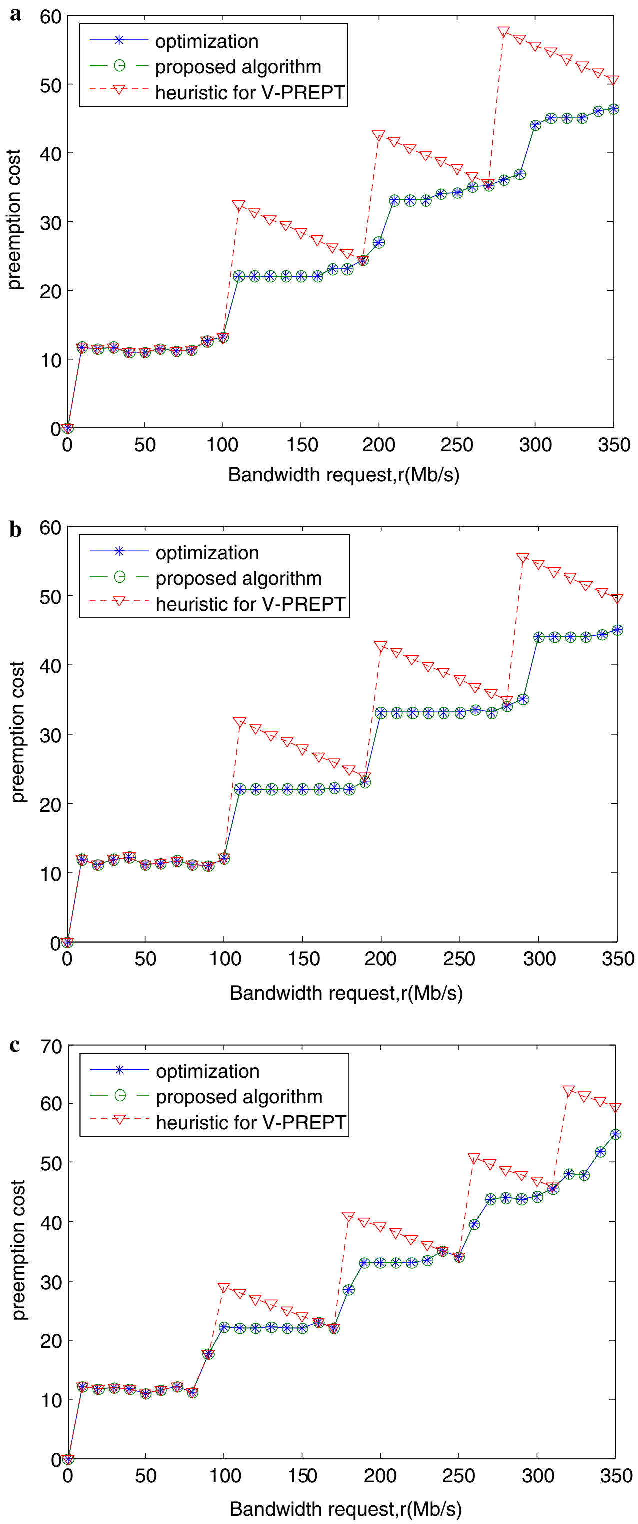

Fig. 2. Preemption cost at different algorithms ($\alpha = 1$, $\beta = 10$, $\gamma = 0.1$). (a) Random distribution, (b) uniform distribution, (c) Gaussian distribution.

proposed heuristic for H-PREPT and the heuristic for V-PREPT.

The results in Figs. 1 and 2 show that, in different bandwidth distribution and different weights for three factors, the proposed heuristic always wins the same accuracy as optimization formulation, and significantly outperforms the heuristic for V-PREPT. We also observe that when a LSP is preempted, three algorithms always find almost same cost solution. However, more than one LSP are preempted, the heuristic for V-PREPT causes more preemption cost, because it can not find the right preempted LSPs. Furthermore, the proposed heuristic can be unchanged for extension to support more criteria to be taken into account without increasing computational complexity.

We ran the heuristic on a link with 1000 LSPs and the decision on which LSPs to preempt in that link was taken in less than 40 ms (using a Pentium III PC, 1 GHz, 256 MB), which can meet the real-time need of the router's online computation.

4. Proposed path selection scheme

4.1. CSPF algorithm-based path selection

As is mentioned in Section 1, in order to support DS-TE, IGP-TEs and RSVP-TE were extended beyond the existing MPLS-TE support. Extended IGP-TEs still use the existing "Unreserved Bandwidth" sub-TLV for each of the TE-Classes instead of for each preemption priority. It should be noted that each LSR in MPLS networks computes "Unreserved TE-Class[i]" and implement admission control rules independently. To ensure coherent operation, the same TE-Classes must be configured in every LSR in the DS-TE domain, and all LSRs must conform to the same Bandwidth Constraints Model in computing "Unreserved TE-Class[i]". Formulas for computing "Unreserved TE-Class [i]" depend on the Bandwidth Constraints Model in use and must reflect how BCs apply to CTs. For MAM model [3], the "Unreserved TE-Class[i]" ($\mathrm{UB_i}$) can be calculated using the following formula:

$$\begin{aligned}\mathrm{UB}_i = \mathrm{MIN}[&[\mathrm{BCc} - \mathrm{SUM}(\mathrm{Reserved}\ (\mathrm{CTc},q))]\ \text{for}\\ &q \leqslant p, [\text{Maximum Reservable Bandwidth}\\ &\quad - \mathrm{SUM}\ (\mathrm{Reserved}(\mathrm{CTb},q))]\ \text{for}\\ &q \leqslant p\ \text{and}\ 0 \leqslant b \leqslant 7,]\end{aligned} \tag{9}$$

For RDM model [4], UB_i can be calculated as:

$$\begin{aligned}\mathrm{UB}_i = \mathrm{MIN}[&[\mathrm{BCc} - \mathrm{SUM}\ (\mathrm{Reserved}(\mathrm{CT_b},q))]\ \text{for}\\ &q \leqslant p\ \text{and}\ c \leqslant b \leqslant 7, [\mathrm{BC}(c-1)\\ &\quad - \mathrm{SUM}\ (\mathrm{Reserved}(\mathrm{CT_b}, q))]\ \text{for}\\ &q \leqslant p\ \text{and}\ (c-1) \leqslant b \leqslant 7, \ldots, [\mathrm{BC0}\\ &\quad - \mathrm{SUM}(\mathrm{Reserved}(\mathrm{CT_b}, q))]\ \text{for}\\ &q \leqslant p\ \text{and}\ 0 \leqslant b \leqslant 7,]\end{aligned} \tag{10}$$

We have also noted that, after computing the special CSPF algorithm for the given LSP, the head-end Label Edge Router (LER) is aware of the selected path composed of particular LSRs. All path information of LSPs originated from this head-end LER are saved in its TE link manager, including the Class-Type, priority level, bandwidth of each LSP on each link. When the head-end LER uses RSVP-TE to set up a label switched path for a new LSP, it sends PATH message through the explicit path downstream, and the EXPICIT_ROUTE object defines the nodes the tunnel must traverse. Every next hop receives the PATH message and deletes itself from the EXPICIT_ROUTE object [15]. During establishment of a LSP corresponding to each TE-Class, the LSR must perform admission control over the bandwidth available for that particular TE-Class.

4.2. Proposed path selection scheme

Our path selection scheme is based on the above preemption policy, i.e., to take into account the number of LSPs preempted, the preemption priority, and the amount of bandwidth preempted together. We first consider an especial case, in which the path for a new requested LSP is a single segment of link, or is composed of several segments of links, each link running the same LSPs. We implement the heuristic for H-PREPT to decide on which LSPs to be preempted. But in real networks, where the requested LSP setup usually consists of several segments of links, and every link runs different LSPs, the H-PREPT that can minimize preemption in a single link not always lead to minimum preemption cost for the selected path. We propose a new path selection algorithm, described as follows.

Step 1: Prune the links with the Unreserved TE-Class [i] < the requested bandwidth r in the topology. By using the available bandwidth (i.e., residual bandwidth) of each link on the resulting topology as route metric, we run CSPF algorithm to find the suitable path. If there exist more than one path, the path that traverses the least hops is selected.

Step 2: If all links along the selected path have the available bandwidth that satisfies the requested bandwidth r, the head-end LER uses RSVP-TE to set up a label switched path for the requested LSP, and all affected LSRs update Unreserved TE-Class [i]. The only change is that every node along the selected path is required to record the path information from the EXPICIT_ROUTE object for the requested LSP. The downstream path information of each LSP saved in LSR is used to compare with the new selected path to decide to what extent each LSP shares the same links with the selected path when next new requested LSP has not sufficient bandwidth available and need to preempt resources.

Step 3: If there exist one or more links that can not satisfy the requested bandwidth r, those nodes whose attached links have not enough residual bandwidth to accommodate

r will perform the preemption. Preemption equation is given as

$$Y = \alpha p + \varepsilon 1/|(b - r)| + \delta n \tag{11}$$

where p is the priority level of the LSP to be preempted, $1/|(b - r)|$ represents the choice of the LSP of the best bandwidth adaptability and n is the number of links which the LSP to be preempted shares with the selected path, these links having not enough residual bandwidth to accommodate r, in order to minimize the number of LSPs preempted. Coefficients α, ε and δ are suitable weights that can be configured in order to stress the importance of each component in Y. Y is calculated for each LSP on the link that has not enough residual bandwidth. The LSPs to be preempted are chosen in decreasing order of Y until the amount of bandwidth released can accommodate r. The upstream node starts with preemption until all nodes along the path finish the preemption. When the upstream node withdraws the preempted LSPs, all affected nodes update Unreserved TE-Class [i], including the bandwidth available on the every link. Based on the previous preemption, the downstream nodes choose to remove those LSPs according to preemption equation Y. When all nodes along the path finish the preemption and the requested bandwidth r is satisfied, repeat Step 2. The requested LSP will be established finally.

In contrast with the existing preemption-enable path selection scheme, our proposed path selection scheme has some distinct characteristic:

Firstly, by using the available bandwidth of each link as route metric, we run CSPF algorithm to find the selected path for the requested LSP, therefore, it makes it possible to minimize preemption for path selection on the whole.

Secondly, based on the existing MPLS-TE or currently proposed DS-TE, every intermediate node has no knowledge of path information of all established LSPs. We only let every node along the selected path to record the path information from the EXPICIT_ROUTE object for the requested LSP. When preemption is required, those LSPs that share more links with the selected path for a new requested LSP are preempted, minimizing the number of the rerouted LSPs. No other change is needed.

At last, we present a flexible preemption equation. The network operator can configure the weight of each coefficient in order to stress the importance of the number of LSPs preempted, the preemption priority, and the amount of bandwidth preempted together.

Our proposed path selection scheme is versatile and simple, and can accomplish minimizing preemption cost for a requested LSP, which is suitable for both the existing MPLS-TE and DS-TE environments.

5. Conclusion

In this paper, we present an optimization formulation H-PREPT for minimizing preemption cost, and we propose an improved heuristic algorithm for the well-known optimization formulation based on versatile preemption policy. Simulation results show that the proposed algorithm significantly outperforms the heuristic for V-PREPT. Moreover, we also propose a new path selection scheme to minimize preemption. This scheme is flexible and efficient, combining the three main preemption optimization criteria: number of LSPs to be preempted, priority of LSPs to be preempted, and amount of bandwidth to be preempted. Due to preemption of those LSPs that share more links that can not satisfy the requested bandwidth with the selected path, the proposed path selection scheme obviously minimize rerouting in DS-TE environments. Further studies regarding the accuracy of the proposed path selection scheme for minimizing preemption is in progress.

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