

Network Working Group  
Request for Comments: 3564  
Category: Informational

F. Le Faucheur  
Cisco Systems, Inc.  
W. Lai  
AT&T  
July 2003

Requirements for Support of Differentiated Services-aware  
MPLS Traffic Engineering

Status of this Memo

This memo provides information for the Internet community. It does not specify an Internet standard of any kind. Distribution of this memo is unlimited.

Copyright Notice

Copyright (C) The Internet Society (2003). All Rights Reserved.

Abstract

This document presents Service Provider requirements for support of Differentiated Services (Diff-Serv)-aware MPLS Traffic Engineering (DS-TE).

Its objective is to provide guidance for the definition, selection and specification of a technical solution addressing these requirements. Specification for this solution itself is outside the scope of this document.

A problem statement is first provided. Then, the document describes example applications scenarios identified by Service Providers where existing MPLS Traffic Engineering mechanisms fall short and Diff-Serv-aware Traffic Engineering can address the needs. The detailed requirements that need to be addressed by the technical solution are also reviewed. Finally, the document identifies the evaluation criteria that should be considered for selection and definition of the technical solution.

## Table of Contents

Specification Requirements .....	2
1. Introduction .....	3
1.1. Problem Statement .....	3
1.2. Definitions .....	3
1.3. Mapping of traffic to LSPs .....	5
2. Application Scenarios .....	6
2.1. Scenario 1: Limiting Proportion of Classes on a Link ...	6
2.2. Scenario 2: Maintain relative proportion of traffic ....	6
2.3. Scenario 3: Guaranteed Bandwidth Services .....	8
3. Detailed Requirements for DS-TE .....	9
3.1. DS-TE Compatibility .....	9
3.2. Class-Types .....	9
3.3. Bandwidth Constraints .....	11
3.4. Preemption and TE-Classes .....	12
3.5. Mapping of Traffic to LSPs .....	15
3.6. Dynamic Adjustment of Diff-Serv PHBs .....	15
3.7. Overbooking .....	16
3.8. Restoration .....	16
4. Solution Evaluation Criteria .....	16
4.1. Satisfying detailed requirements .....	17
4.2. Flexibility .....	17
4.3. Extendibility .....	17
4.4. Scalability .....	17
4.5. Backward compatibility/Migration .....	17
4.6. Bandwidth Constraints Model .....	18
5. Security Considerations .....	18
6. Acknowledgment .....	18
7. Normative References .....	18
8. Informative References .....	19
9. Contributing Authors .....	20
10. Editors' Addresses .....	21
11. Full Copyright Statement .....	22

## Specification Requirements

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

## 1. Introduction

### 1.1. Problem Statement

Diff-Serv is used by some Service Providers to achieve scalable network designs supporting multiple classes of services.

In some such Diff-Serv networks, where optimization of transmission resources on a network-wide basis is not sought, MPLS Traffic Engineering (TE) mechanisms may not be used.

In other networks, where optimization of transmission resources is sought, Diff-Serv mechanisms [DIFF-MPLS] may be complemented by MPLS Traffic Engineering mechanisms [TE-REQ] [ISIS-TE] [OSPF-TE] [RSVP-TE] which operate on an aggregate basis across all Diff-Serv classes of service. In this case, Diff-Serv and MPLS TE both provide their respective benefits.

To achieve fine-grained optimization of transmission resources and further enhanced network performance and efficiency, as discussed in [TEWG-FW], it may be desirable to perform traffic engineering at a per-class level instead of at an aggregate level. By mapping the traffic from a given Diff-Serv class of service on a separate LSP, it allows this traffic to utilize resources available to the given class on both shortest paths and non-shortest paths, and follow paths that meet engineering constraints which are specific to the given class. This is what we refer to as "Diff-Serv-aware Traffic Engineering (DS-TE)".

This document focuses exclusively on the specific environments which would benefit from DS-TE. Some examples include:

- networks where bandwidth is scarce (e.g., transcontinental networks)
- networks with significant amounts of delay-sensitive traffic
- networks where the relative proportion of traffic across classes of service is not uniform

This document focuses on intra-domain operation. Inter-domain operation is not considered.

### 1.2. Definitions

For the convenience of the reader, relevant Diff-Serv ([DIFF-ARCH], [DIFF-NEW] and [DIFF-PDB]) definitions are repeated herein.

Behavior Aggregate (BA): a collection of packets with the same (Diff-Serv) codepoint crossing a link in a particular direction.

Per-Hop-Behavior (PHB): the externally observable forwarding behavior applied at a DS-compliant node to a Diff-Serv behavior aggregate.

PHB Scheduling Class (PSC): A PHB group for which a common constraint is that ordering of at least those packets belonging to the same microflow must be preserved.

Ordered Aggregate (OA): a set of BAs that share an ordering constraint. The set of PHBs that are applied to this set of Behavior Aggregates constitutes a PHB scheduling class.

Traffic Aggregate (TA): a collection of packets with a codepoint that maps to the same PHB, usually in a DS domain or some subset of a DS domain. A traffic aggregate marked for the foo PHB is referred to as the "foo traffic aggregate" or "foo aggregate" interchangeably. This generalizes the concept of Behavior Aggregate from a link to a network.

Per-Domain Behavior (PDB): the expected treatment that an identifiable or target group of packets will receive from "edge-to-edge" of a DS domain. A particular PHB (or, if applicable, list of PHBs) and traffic conditioning requirements are associated with each PDB.

We also repeat the following definition from [TE-REQ]:

Traffic Trunk: an aggregation of traffic flows of the same class which are placed inside a Label Switched Path.

In the context of the present document, "flows of the same class" is to be interpreted as "flows from the same Forwarding Equivalence Class which are to be treated equivalently from the DS-TE perspective".

We refer to the set of TAs corresponding to the set of PHBs of a given PSC, as a {TA}PSC. A given {TA}PSC will receive the treatment of the PDB associated with the corresponding PSC. In this document, we also loosely refer to a {TA}PSC as a "Diff-Serv class of service", or a "class of service". As an example, the set of packets within a DS domain with a codepoint that maps to the EF PHB may form one {TA}PSC in that domain. As another example, the set of packets within a DS domain with a codepoint that maps to the AF11 or AF12 or AF13 PHB may form another {TA}PSC in that domain.

We refer to the collection of packets which belong to a given Traffic Aggregate and are associated with a given MPLS Forwarding Equivalence Class (FEC) ([MPLS-ARCH]) as a <FEC/TA>.

We refer to the set of <FEC/TA> whose TAs belong to a given {TA}PSC as a <FEC/{TA}PSC>.

### 1.3. Mapping of traffic to LSPs

A network may have multiple Traffic Aggregates (TAs) it wishes to service. Recalling from [DIFF-MPLS], there are several options on how the set of <FEC/{TA}PSC> of a given FEC can be split into Traffic Trunks for mapping onto LSPs when running MPLS Traffic Engineering.

One option is to not split this set of <FEC/{TA}PSC> so that each Traffic Trunk comprises traffic from all the {TA}/PSC. This option is typically used when aggregate traffic engineering is deployed using current MPLS TE mechanisms. In that case, all the <FEC/{TA}PSC> of a given FEC are routed collectively according to a single shared set of constraints and will follow the same path. Note that the LSP transporting such a Traffic Trunk is, by definition, an E-LSP as defined in [DIFF-MPLS].

Another option is to split the different <FEC/{TA}PSC> of a given FEC into multiple Traffic Trunks on the basis of the {TA}PSC. In other words, traffic, from one given node to another, is split, based on the "classes of service", into multiple Traffic Trunks which are transported over separate LSP and can potentially follow different paths through the network. DS-TE takes advantage of this and computes a separate path for each LSP. In so doing, DS-TE can take into account the specific requirements of the Traffic Trunk transported on each LSP (e.g., bandwidth requirement, preemption priority). Moreover DS-TE can take into account the specific engineering constraints to be enforced for these sets of Traffic Trunks (e.g., limit all Traffic Trunks transporting a particular {TA}PSC to x% of link capacity). DS-TE achieves per LSP constraint based routing with paths that match specific objectives of the traffic while forming the corresponding Traffic Trunk.

For simplicity, and because this is the specific topic of this document, the above paragraphs in this section only considered splitting traffic of a given FEC into multiple Traffic Aggregates on the basis of {TA}PSC. However, it should be noted that, in addition to this, traffic from every {TA}PSC may also be split into multiple Traffic Trunks for load balancing purposes.

## 2. Application Scenarios

### 2.1. Scenario 1: Limiting Proportion of Classes on a Link

An IP/MPLS network may need to carry a significant amount of VoIP traffic compared to its link capacity. For example, 10,000 uncompressed calls at 20ms packetization result in about 1Gbps of IP traffic, which is significant on an OC-48c based network. In case of topology changes such as link/node failure, VoIP traffic levels can even approach the full bandwidth on certain links.

For delay/jitter reasons, some network administrators see it as undesirable to carry more than a certain percentage of VoIP traffic on any link. The rest of the available link bandwidth can be used to route other "classes of service" corresponding to delay/jitter insensitive traffic (e.g., Best Effort Internet traffic). The exact determination of this "certain" percentage is outside the scope of this requirements document.

During normal operations, the VoIP traffic should be able to preempt other "classes of service" (if these other classes are designated as preemptable and they have lower preemption priority), so that it will be able to use the shortest available path, only constrained by the maximum defined link utilization ratio/percentage of the VoIP class.

Existing TE mechanisms only allow constraint based routing of traffic based on a single bandwidth constraint common to all "classes of service", which does not satisfy the needs described here. This leads to the requirement for DS-TE to be able to enforce a different bandwidth constraint for different "classes of service". In the above example, the bandwidth constraint to be enforced for VoIP traffic may be the "certain" percentage of each link capacity, while the bandwidth constraint to be enforced for the rest of the "classes of service" might have their own constraints or have access to the rest of the link capacity.

### 2.2. Scenario 2: Maintain relative proportion of traffic

Suppose an IP/MPLS network supports 3 "classes of service". The network administrator wants to perform Traffic Engineering to distribute the traffic load. Also assume that proportion across "classes of service" varies significantly depending on the source/destination POPs.

With existing TE mechanisms, the proportion of traffic from each "class of service" on a given link will vary depending on multiple factors including:

- in which order the different TE-LSPs are established
- the preemption priority associated with the different TE-LSPs
- link/node failure situations

This may make it difficult or impossible for the network administrator to configure the Diff-Serv PHBs (e.g., queue bandwidth) to ensure that each "class of service" gets the appropriate treatment. This leads again to the requirement for DS-TE to be able to enforce a different bandwidth constraint for different "classes of service". This could be used to ensure that, regardless of the order in which tunnels are routed, regardless of their preemption priority and regardless of the failure situation, the amount of traffic of each "class of service" routed over a link matches the Diff-Serv scheduler configuration on that link to the corresponding class (e.g., queue bandwidth).

As an illustration of how DS-TE would address this scenario, the network administrator may configure the service rate of Diff-Serv queues to (45%,35%,20%) for "classes of service" (1,2,3) respectively. The administrator would then split the traffic into separate Traffic Trunks for each "class of service" and associate a bandwidth to each LSP transporting those Traffic Trunks. The network administrator may also want to configure preemption priorities of each LSP in order to give highest restoration priority to the highest priority "class of service" and medium priority to the medium "class of service". Then DS-TE could ensure that after a failure, "class of service" 1 traffic would be rerouted with first access at link capacity without exceeding its service rate of 45% of the link bandwidth. "Class of service" 2 traffic would be rerouted with second access at the link capacity without exceeding its allotment. Note that where "class of service" 3 is the Best-Effort service, the requirement on DS-TE may be to ensure that the total amount of traffic routed across all "classes of service" does not exceed the total link capacity of 100% (as opposed to separately limiting the amount of Best Effort traffic to 20 even if there was little "class of service" 1 and "class of service" 2 traffic).

In this scenario, DS-TE would allow for the maintenance of a more steady distribution of "classes of service", even during rerouting. This would rely on the required capability of DS-TE to adjust the amount of traffic of each "class of service" routed on a link based on the configuration of the scheduler and the amount of bandwidth available for each "class of service".

Alternatively, some network administrators may want to solve the problem by having the scheduler dynamically adjusted based on the amount of bandwidth of the LSPs admitted for each "class of service". This is an optional additional requirement on the DS-TE solution.

### 2.3. Scenario 3: Guaranteed Bandwidth Services

In addition to the Best effort service, an IP/MPLS network operator may desire to offer a point-to-point "guaranteed bandwidth" service whereby the provider pledges to provide a given level of performance (bandwidth/delay/loss...) end-to-end through its network from an ingress port to an egress port. The goal is to ensure that all the "guaranteed" traffic under the scope of a subscribed service level specification, will be delivered within the tolerances of this service level specification.

One approach for deploying such "guaranteed" service involves:

- dedicating a Diff-Serv PHB (or a Diff-Serv PSC as defined in [DIFF-NEW]) to the "guaranteed" traffic
- policing guaranteed traffic on ingress against the traffic contract and marking the "guaranteed" packets with the corresponding DSCP/EXP value

Where a very high level of performance is targeted for the "guaranteed" service, it may be necessary to ensure that the amount of "guaranteed" traffic remains below a given percentage of link capacity on every link. Where the proportion of "guaranteed" traffic is high, constraint based routing can be used to enforce such a constraint.

However, the network operator may also want to simultaneously perform Traffic Engineering for the rest of the traffic (i.e., non-guaranteed traffic) which would require that constraint based routing is also capable of enforcing a different bandwidth constraint, which would be less stringent than the one for guaranteed traffic.

Again, this combination of requirements can not be addressed with existing TE mechanisms. DS-TE mechanisms allowing enforcement of a different bandwidth constraint for guaranteed traffic and for non-guaranteed traffic are required.

### 3. Detailed Requirements for DS-TE

This section specifies the functionality that the above scenarios require out of the DS-TE solution. Actual technical protocol mechanisms and procedures to achieve such functionality are outside the scope of this document.

#### 3.1. DS-TE Compatibility

Since DS-TE may impact scalability (as discussed later in this document) and operational practices, DS-TE is expected to be used when existing TE mechanisms combined with Diff-Serv cannot address the network design requirements (i.e., where constraint based routing is required and where it needs to enforce different bandwidth constraints for different "classes of service", such as in the scenarios described above in section 2). Where the benefits of DSTE are only required in a topological subset of their network, some network operators may wish to only deploy DS-TE in this topological subset.

Thus, the DS-TE solution MUST be developed in such a way that:

- (i) it raises no interoperability issues with existing deployed TE mechanisms.
- (ii) it allows DS-TE deployment to the required level of granularity and scope (e.g., only in a subset of the topology, or only for the number of classes required in the considered network)

#### 3.2. Class-Types

The fundamental requirement for DS-TE is to be able to enforce different bandwidth constraints for different sets of Traffic Trunks.

[TEWG-FW] introduces the concept of Class-Types when discussing operations of MPLS Traffic Engineering in a Diff-Serv environment.

We refine this definition into the following:

Class-Type (CT): the set of Traffic Trunks crossing a link, that is governed by a specific set of Bandwidth constraints. CT is used for the purposes of link bandwidth allocation, constraint based routing and admission control. A given Traffic Trunk belongs to the same CT on all links.

Note that different LSPs transporting Traffic Trunks from the same CT may be using the same or different preemption priorities as explained in more details in section 3.4 below.

Mapping of {TA}PSC to Class-Types is flexible. Different {TA}PSC can be mapped to different CTs, multiple {TA}PSC can be mapped to the same CT and one {TA}PSC can be mapped to multiple CTs.

For illustration purposes, let's consider the case of a network running 4 Diff-Serv PDBs which are respectively based on the EF PHB [EF], the AF1x PSC [AF], the AF2x PSC and the Default (i.e., Best-Effort) PHB [DIFF-FIELD]. The network administrator may decide to deploy DS-TE in the following way:

- o from every DS-TE Head-end to every DS-TE Tail-end, split the traffic into 4 Traffic Trunks: one for traffic of each {TA}PSC
- o because the QoS objectives for the AF1x PDB and for the AF2x PDB may be of similar nature (e.g., both targeting low loss albeit at different levels perhaps), the same (set of) Bandwidth Constraint(s) may be applied collectively over the AF1x Traffic Trunks and the AF2x Traffic Trunks. Thus, the network administrator may only define three CTs: one for the EF Traffic Trunks, one for the AF1x and AF2x Traffic Trunks and one for the Best Effort Traffic Trunks.

As another example of mapping of {TA}PSC to CTs, a network operator may split the traffic from the {TA}PSC associated with EF into two different sets of traffic trunks, so that each set of traffic trunks is subject to different constraints on the bandwidth it can access. In this case, two distinct CTs are defined for the EF {TA}PSC traffic: one for the traffic subset subject to the first (set of) bandwidth constraint(s), the other for the traffic subset subject to the second (set of) bandwidth constraint(s).

The DS-TE solution MUST support up to 8 CTs. Those are referred to as CT<sub>c</sub>,  $0 \leq c \leq \text{MaxCT}-1 = 7$ .

The DS-TE solution MUST be able to enforce a different set of Bandwidth Constraints for each CT.

A DS-TE implementation MUST support at least 2 CTs, and MAY support up to 8 CTs.

In a given network, the DS-TE solution MUST NOT require the network administrator to always deploy the maximum number of CTs. The DS-TE solution MUST allow the network administrator to deploy only the number of CTs actually utilized.

### 3.3. Bandwidth Constraints

We refer to a Bandwidth Constraint Model as the set of rules defining:

- the maximum number of Bandwidth Constraints; and
- which CTs each Bandwidth Constraint applies to and how.

By definition of CT, each CT is assigned either a Bandwidth Constraint, or a set of Bandwidth Constraints.

We refer to the Bandwidth Constraints as  $BC_b$ ,  $0 \leq b \leq \text{MaxBC}-1$

For a given Class-Type  $CT_c$ ,  $0 \leq c \leq \text{MaxCT}-1$ , let us define "Reserved( $CT_c$ )" as the sum of the bandwidth reserved by all established LSPs which belong to  $CT_c$ .

Different models of Bandwidth Constraints are conceivable for control of the CTs.

For example, a model with one separate Bandwidth Constraint per CT could be defined. This model is referred to as the "Maximum Allocation Model" and is defined by:

- $\text{MaxBC} = \text{MaxCT}$
- for each value of  $b$  in the range  $0 \leq b \leq (\text{MaxCT} - 1)$ :  
 $\text{Reserved}(CT_b) \leq BC_b$

For illustration purposes, on a link of 100 unit of bandwidth where three CTs are used, the network administrator might then configure  $BC_0=20$ ,  $BC_1= 50$ ,  $BC_2=30$  such that:

- All LSPs supporting Traffic Trunks from  $CT_2$  use no more than 30 (e.g., Voice  $\leq 30$ )
- All LSPs supporting Traffic Trunks from  $CT_1$  use no more than 50 (e.g., Premium Data  $\leq 50$ )
- All LSPs supporting Traffic Trunks from  $CT_0$  use no more than 20 (e.g., Best Effort  $\leq 20$ )

As another example, a "Russian Doll" model of Bandwidth Constraints may be defined whereby:

- $\text{MaxBC} = \text{MaxCT}$
- for each value of  $b$  in the range  $0 \leq b \leq (\text{MaxCT} - 1)$ :  
 $\text{SUM}(\text{Reserved}(CT_c)) \leq BC_b$ ,  
 for all " $c$ " in the range  $b \leq c \leq (\text{MaxCT} - 1)$

For illustration purposes, on a link of 100 units of bandwidth where three CTs are used, the network administrator might then configure BC0=100, BC1= 80, BC2=60 such that:

- All LSPs supporting Traffic Trunks from CT2 use no more than 60 (e.g., Voice <= 60)
- All LSPs supporting Traffic Trunks from CT1 or CT2 use no more than 80 (e.g., Voice + Premium Data <= 80)
- All LSPs supporting Traffic Trunks from CT0 or CT1 or CT2 use no more than 100 (e.g., Voice + Premium Data + Best Effort <= 100).

Other Bandwidth Constraints model can also be conceived. Those could involve arbitrary relationships between BCb and CTc. Those could also involve additional concepts such as associating minimum reservable bandwidth to a CT.

The DS-TE technical solution MUST have the capability to support multiple Bandwidth Constraints models. The DS-TE technical solution MUST specify at least one bandwidth constraint model and MAY specify multiple Bandwidth Constraints models. Additional Bandwidth Constraints models MAY also be specified at a later stage if deemed useful based on operational experience from DS-TE deployments. The choice of which (or which set of) Bandwidth Constraints model(s) is to be supported by a given DS-TE implementation, is an implementation choice. For simplicity, a network operator may elect to use the same Bandwidth Constraints Model on all the links of his/her network. However, if he/she wishes/needs to do so, the network operator may elect to use different Bandwidth Constraints models on different links in a given network.

Regardless of the Bandwidth Constraint Model, the DS-TE solution MUST allow support for up to 8 BCs.

#### 3.4. Preemption and TE-Classes

[TEWG-FW] defines the notion of preemption and preemption priority. The DS-TE solution MUST retain full support of such preemption. However, a network administrator preferring not to use preemption for user traffic MUST be able to disable the preemption mechanisms described below.

The preemption attributes defined in [TE-REQ] MUST be retained and applicable across all Class Types. The preemption attributes of setup priority and holding priority MUST retain existing semantics, and in particular these semantics MUST not be affected by the Ordered Aggregate transported by the LSP or by the LSP's Class Type. This means that if LSP1 contends with LSP2 for resources, LSP1 may preempt LSP2 if LSP1 has a higher set-up preemption priority (i.e., lower

numerical priority value) than LSP2's holding preemption priority regardless of LSP1's OA/CT and LSP2's OA/CT.

We introduce the following definition:

TE-Class: A pair of:

- (i) a Class-Type
- (ii) a preemption priority allowed for that Class-Type. This means that an LSP transporting a Traffic Trunk from that Class-Type can use that preemption priority as the set-up priority, as the holding priority or both.

Note that by definition:

- for a given Class-Type, there may be one or multiple TE-classes using that Class-Type, each using a different preemption priority
- for a given preemption priority, there may be one or multiple TE-Class(es) using that preemption priority, each using a different Class-Type.

The DS-TE solution MUST allow all LSPs transporting Traffic Trunks of a given Class-Type to use the same preemption priority. In other words, the DS-TE solution MUST allow a Class-Type to be used by single TE-Class. This effectively allows the network administrator to ensure that no preemption happens within that Class-Type, when so desired.

As an example, the DS-TE solution MUST allow the network administrator to define a Class-Type comprising a single TE-class using preemption 0.

The DS-TE solution MUST allow two LSPs transporting Traffic Trunks of the same Class-Type to use different preemption priorities, and allow the LSP with higher (numerically lower) set-up priority to preempt the LSP with lower (numerically higher) holding priority when they contend for resources. In other words, the DS-TE solution MUST allow multiple TE-Classes to be defined for a given Class-Type. This effectively allows the network administrator to enable preemption within a Class-Type, when so desired.

As an example, the DS-TE solution MUST allow the network administrator to define a Class-Type comprising three TE-Classes; one using preemption 0, one using preemption 1 and one using preemption 4.

The DS-TE solution MUST allow two LSPs transporting Traffic Trunks from different Class-Types to use different preemption priorities, and allow the LSP with higher setup priority to preempt the one with lower holding priority when they contend for resources.

As an example, the DS-TE solution MUST allow the network administrator to define two Class-Types (CT0 and CT1) each comprising two TE-Classes where say:

- one TE-Class groups CT0 and preemption 0
- one TE-Class groups CT0 and preemption 2
- one TE-Class groups CT1 and preemption 1
- one TE-Class groups CT1 and preemption 3

The network administrator would then, in particular, be able to:

- transport a CT0 Traffic Trunk over an LSP with setup priority=0 and holding priority=0
- transport a CT0 Traffic Trunk over an LSP with setup priority=2 and holding priority=0
- transport a CT1 Traffic Trunk over an LSP with setup priority=1 and holding priority=1
- transport a CT1 Traffic Trunk over an LSP with setup priority=3 and holding priority=1.

The network administrator would then, in particular, NOT be able to:

- transport a CT0 Traffic Trunk over an LSP with setup priority=1 and holding priority=1
- transport a CT1 Traffic Trunk over an LSP with setup priority=0 and holding priority=0

The DS-TE solution MUST allow two LSPs transporting Traffic Trunks from different Class-Types to use the same preemption priority. In other words, the DS-TE solution MUST allow TE-classes using different CTs to use the same preemption priority. This effectively allows the network administrator to ensure that no preemption happens across Class-Types, if so desired.

As an example, the DS-TE solution MUST allow the network administrator to define three Class-Types (CT0, CT1 and CT2) each comprising one TE-Class which uses preemption 0. In that case, no preemption will ever occur.

Since there are 8 preemption priorities and up to 8 Class-Types, there could theoretically be up to 64 TE-Classes in a network. This is felt to be beyond current practical requirements. The current practical requirement is that the DS-TE solution MUST allow support

for up to 8 TE-classes. The DS-TE solution MUST allow these TE-classes to comprise any arbitrary subset of 8 (or less) from the (64) possible combinations of (8) Class-Types and (8) preemption priorities.

As with existing TE, an LSP which gets preempted is torn down at preemption time. The Head-end of the preempted LSP may then attempt to reestablish that LSP, which involves re-computing a path by Constraint Based Routing based on updated available bandwidth information and then signaling for LSP establishment along the new path. It is to be noted that there may be cases where the preempted LSP cannot be reestablished (e.g., no possible path satisfying LSP bandwidth constraints as well as other constraints). In such cases, the Head-end behavior is left to implementation. It may involve periodic attempts at reestablishing the LSP, relaxing of the LSP constraints, or other behaviors.

### 3.5. Mapping of Traffic to LSPs

The DS-TE solution MUST allow operation over E-LSPs onto which a single <FEC/{TA}PSC> is transported.

The DS-TE solution MUST allow operation over L-LSPs.

The DS-TE solution MAY allow operation over E-LSPs onto which multiple <FEC/{TA}PSC> of a given FEC are transported, under the condition that those multiple <FEC/{TA}PSC> can effectively be treated by DS-TE as a single atomic traffic trunk (in particular this means that those multiple <FEC/{TA}PSC> are routed as a whole based on a single collective bandwidth requirement, a single affinity attribute, a single preemption level, a single Class-Type, etc.). In that case, it is also assumed that the multiple {TA}PSCs are grouped together in a consistent manner throughout the DS-TE domain (e.g., if <FECx/{TA}PSC1> and <FECx/{TA}PSC2> are transported together on an E-LSP, then there will not be any L-LSP transporting <FECy/{TA}PSC1> or <FECy/{TA}PSC2> on its own, and there will not be any E-LSP transporting <FECz/{TA}PSC1> and/or <FECz/{TA}PSC2> with <FECz/{TA}PSC3>).

### 3.6. Dynamic Adjustment of Diff-Serv PHBs

As discussed in section 2.2, the DS-TE solution MAY support adjustment of Diff-Serv PHBs parameters (e.g., queue bandwidth) based on the amount of TE-LSPs established for each OA/Class-Type. Such dynamic adjustment is optional for DS-TE implementations.

Where this dynamic adjustment is supported, it MUST allow for disabling via configuration (thus reverting to PHB treatment with static scheduler configuration independent of DS-TE operations). It MAY involve a number of configurable parameters which are outside the scope of this specification. Those MAY include configurable parameters controlling how scheduling resources (e.g., service rates) need to be apportioned across multiple OAs when those belong to the same Class-Type and are transported together on the same E-LSP.

Where supported, the dynamic adjustment MUST take account of the performance requirements of each PDB when computing required adjustments.

### 3.7. Overbooking

Existing TE mechanisms allow overbooking to be applied on LSPs for Constraint Based Routing and admission control. Historically, this has been achieved in TE deployment through factoring overbooking ratios at the time of sizing the LSP bandwidth and/or at the time of configuring the Maximum Reservable Bandwidth on links.

The DS-TE solution MUST also allow overbooking and MUST effectively allow different overbooking ratios to be enforced for different CTs.

The DS-TE solution SHOULD optionally allow the effective overbooking ratio of a given CT to be tweaked differently in different parts of the network.

### 3.8. Restoration

With existing TE, restoration policies use standard priority mechanisms such as, for example, the preemption priority to effectively control the order/importance of LSPs for restoration purposes.

The DS-TE solution MUST ensure that similar application of the use of standard priority mechanisms for implementation of restoration policy are not prevented since those are expected to be required for achieving the survivability requirements of DS-TE networks.

Further discussion of restoration requirements are presented in the output document of the TEWG Requirements Design Team [SURVIV-REQ].

## 4. Solution Evaluation Criteria

A range of solutions is possible for the support of the DS-TE requirements discussed above. For example, some solutions may require that all current TE protocols syntax (IGP, RSVP-TE,) be

extended in various ways. For instance, current TE protocols could be modified to support multiple bandwidth constraints rather than the existing single aggregate bandwidth constraint. Alternatively, other solutions may keep the existing TE protocols syntax unchanged but modify their semantics to allow for the multiple bandwidth constraints.

This section identifies the evaluation criteria that **MUST** be used to assess potential DS-TE solutions for selection.

#### 4.1. Satisfying detailed requirements

The solution **MUST** address all the scenarios described in section 2 and satisfy all the requirements listed in section 3.

#### 4.2. Flexibility

- number of Class-Types that can be supported, compared to number identified in Requirements section
- number of PDBs within a Class-Type

#### 4.3. Extendibility

- how far can the solution be extended in the future if requirements for more Class-Types are identified in the future.

#### 4.4. Scalability

- impact on network scalability in what is propagated, processed, stored and computed (IGP signaling, IGP processing, IGP database, TE-Tunnel signaling ,...).
- how does scalability impact evolve with number of Class-Types/PDBs actually deployed in a network. In particular, is it possible to keep overhead small for a large networks which only use a small number of Class-Types/PDBs, while allowing higher number of Class-Types/PDBs in smaller networks which can bear higher overhead)

#### 4.5. Backward compatibility/Migration

- backward compatibility/migration with/from existing TE mechanisms
- backward compatibility/migration when increasing/decreasing the number of Class-Types actually deployed in a given network.

#### 4.6. Bandwidth Constraints Model

Work is currently in progress to investigate the performance and trade-offs of different operational aspects of Bandwidth Constraints models (for example see [BC-MODEL], [BC-CONS] and [MAR]). In this investigation, at least the following criteria are expected to be considered:

- (1) addresses the scenarios in Section 2
- (2) works well under both normal and overload conditions
- (3) applies equally when preemption is either enabled or disabled
- (4) minimizes signaling load processing requirements
- (5) maximizes efficient use of the network
- (6) Minimizes implementation and deployment complexity.

In selection criteria (2), "normal condition" means that the network is attempting to establish a volume of DS-TE LSPs for which it is designed; "overload condition" means that the network is attempting to establish a volume of DS-TE LSPs beyond the one it is designed for; "works well" means that under these conditions, the network should be able to sustain the expected performance, e.g., under overload it is x times worse than its normal performance.

#### 5. Security Considerations

The solution developed to address the DS-TE requirements defined in this document MUST address security aspects. DS-TE does not raise any specific additional security requirements beyond the existing security requirements of MPLS TE and Diff-Serv. The solution MUST ensure that the existing security mechanisms (including those protecting against DOS attacks) of MPLS TE and Diff-Serv are not compromised by the protocol/procedure extensions of the DS-TE solution or otherwise MUST provide security mechanisms to address this.

#### 6. Acknowledgment

We thank David Allen for his help in aligning with up-to-date Diff-Serv terminology.

#### 7. Normative References

- [AF] Heinanen, J., Baker, F., Weiss, W. and J. Wroclawski, "Assured Forwarding PHB Group", RFC 2597, June 1999.
- [DIFF-ARCH] Blake, S., Black, D., Carlson, M., Davies, E., Wang, Z. and W. Weiss, "An Architecture for Differentiated Services", RFC 2475, December 1998.

- [DIFF-FIELD] Nichols, K., Blake, S., Baker, F. and D. Black, "Definition of the Differentiated Services Field (DS Field) in the IPv4 and IPv6 Headers", RFC 2474, December 1998.
- [MPLS-ARCH] Rosen, E., Viswanathan, A. and R. Callon, "Multiprotocol Label Switching Architecture", RFC 3031, January 2001.
- [DIFF-MPLS] Le Faucheur, F., Wu, L., Davie, B., Davari, S., Vaananen, P., Krishnan, R., Cheval, P. and J. Heinanen, "Multi-Protocol Label Switching (MPLS) Support of Differentiated Services", RFC 3270, May 2002.
- [DIFF-NEW] Grossman, D., "New Terminology and Clarifications for Diffserv", RFC 3260, April 2002.
- [EF] Davie, B., Charny, A., Bennet, J.C.R., Benson, K., Le Boudec, J.Y., Davari, S., Courtney, W., Firioiu, V. and D. Stiliadis, "An Expedited Forwarding PHB (Per-Hop Behavior)", RFC 3246, March 2002.
- [TEWG-FW] Awduche, D., Chiu, A., Elwalid, A., Widjaja, I. and X. Xiao, "Overview and Principles of Internet Traffic Engineering", RFC 3272, May 2002.
- [TE-REQ] Awduche, D., Malcolm, J., Agogbua, J., O'Dell, M. and J. McManus, "Requirements for Traffic Engineering over MPLS", RFC 2702, September 1999.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

## 8. Informative References

- [DIFF-PDB] Nichols, K. and B. Carpenter, "Definition of Differentiated Services Per Domain Behaviors and Rules for their Specification", RFC 3086, April 2001.
- [ISIS-TE] Smit, Li, "IS-IS extensions for Traffic Engineering", Work in Progress, December 2002.
- [OSPF-TE] Katz, et al., "Traffic Engineering Extensions to OSPF", Work in Progress, October 2002.
- [RSVP-TE] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V. and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP Tunnels", RFC 3209, December 2001.

- [SURVIV-REQ] Lai, W. and D. McDysan, "Network Hierarchy and Multilayer Survivability", RFC 3386, November 2002.
- [BC-MODEL] Lai, W., "Bandwidth Constraints Models for Diffserv-aware MPLS Traffic Engineering: Performance Evaluation", Work in Progress, June 2002.
- [BC-CONS] F. Le Faucheur, "Considerations on Bandwidth Constraints Models for DS-TE", Work in Progress, June 2002.
- [MAR] Ash, J., "Max Allocation with Reservation Bandwidth Constraint Model for MPLS/DiffServ TE & Performance Comparisons", Work in Progress, May 2003.

## 9. Contributing Authors

This document was the collective work of several people. The text and content of this document was contributed by the editors and the co-authors listed below. (The contact information for the editors appears below.)

Martin Tatham  
BT  
Aastral Park, Martlesham Heath,  
Ipswich IP5 3RE, UK  
Phone: +44-1473-606349  
EMail: martin.tatham@bt.com

Thomas Telkamp  
Global Crossing  
Oudkerkhof 51, 3512 GJ Utrecht  
The Netherlands  
Phone: +31 30 238 1250  
EMail: telkamp@gblix.net

David Cooper  
Global Crossing  
960 Hamlin Court  
Sunnyvale, CA 94089, USA  
Phone: (916) 415-0437  
EMail: dcooper@gblix.net

Jim Boyle  
Protocol Driven Networks, Inc.  
1381 Kildaire Farm Road #288  
Cary, NC 27511, USA  
Phone: (919) 852-5160  
EMail: jboyle@pdnets.com

Luyuan Fang  
AT&T Labs  
200 Laurel Avenue  
Middletown, New Jersey 07748, USA  
Phone: (732) 420-1921  
EMail: luyuanfang@att.com

Gerald R. Ash  
AT&T Labs  
200 Laurel Avenue  
Middletown, New Jersey 07748, USA  
Phone: (732) 420-4578  
EMail: gash@att.com

Pete Hicks  
CoreExpress, Inc  
12655 Olive Blvd, Suite 500  
St. Louis, MO 63141, USA  
Phone: (314) 317-7504  
EMail: pete.hicks@coreexpress.net

Angela Chiu  
AT&T Labs-Research  
200 Laurel Ave. Rm A5-1F13  
Middletown, NJ 07748, USA  
Phone: (732) 420-9061  
EMail: chiu@research.att.com

William Townsend  
Tenor Networks  
100 Nagog Park  
Acton, MA 01720, USA  
Phone: +1 978-264-4900  
EMail: btownsend@tenornetworks.com

Thomas D. Nadeau  
Cisco Systems, Inc.  
300 Beaver Brook Road  
Boxborough, MA 01719  
Phone: +1-978-936-1470  
EMail: tnadeau@cisco.com

Darek Skalecki  
Nortel Networks  
3500 Carling Ave,  
Nepean K2H 8E9,  
Phone: (613) 765-2252  
EMail: dareks@nortelnetworks.com

#### 10. Editors' Addresses

Francois Le Faucheur  
Cisco Systems, Inc.  
Village d'Entreprise Green Side - Batiment T3  
400, Avenue de Roumanille  
06410 Biot-Sophia Antipolis, France  
  
Phone: +33 4 97 23 26 19  
EMail: flefauch@cisco.com

Wai Sum Lai  
AT&T Labs  
200 Laurel Avenue  
Middletown, New Jersey 07748, USA  
  
Phone: (732) 420-3712  
EMail: wlai@att.com

## 11. Full Copyright Statement

Copyright (C) The Internet Society (2003). All Rights Reserved.

This document and translations of it may be copied and furnished to others, and derivative works that comment on or otherwise explain it or assist in its implementation may be prepared, copied, published and distributed, in whole or in part, without restriction of any kind, provided that the above copyright notice and this paragraph are included on all such copies and derivative works. However, this document itself may not be modified in any way, such as by removing the copyright notice or references to the Internet Society or other Internet organizations, except as needed for the purpose of developing Internet standards in which case the procedures for copyrights defined in the Internet Standards process must be followed, or as required to translate it into languages other than English.

The limited permissions granted above are perpetual and will not be revoked by the Internet Society or its successors or assigns.

This document and the information contained herein is provided on an "AS IS" basis and THE INTERNET SOCIETY AND THE INTERNET ENGINEERING TASK FORCE DISCLAIMS ALL WARRANTIES, EXPRESS OR IMPLIED, INCLUDING BUT NOT LIMITED TO ANY WARRANTY THAT THE USE OF THE INFORMATION HEREIN WILL NOT INFRINGE ANY RIGHTS OR ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

## Acknowledgement

Funding for the RFC Editor function is currently provided by the Internet Society.

