JP Vasseur (Editor)
Cisco Systems, Inc.
Arthi Ayyangar (Editor)
Juniper Networks
Raymond Zhang
Infonet Service Corporation

CCAMP Working Group
IETF Internet Draft
Expires: January, 2005

July, 2004

**draft-vasseur-ccamp-inter-domain-path-comp-00.txt**

# Inter-domain Traffic Engineering LSP path computation methods

## Status of this Memo



## Abstract

This document specifies two path computation methods for computing inter-domain Traffic Engineering (TE) Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Label Switched (LSP) paths. In this document a domain is referred to as a collection of network elements within a common sphere of address management or path computational responsibility such as IGP areas and Autonomous Systems.

The first path computation method is also called per-domain path computation whereby each entry boundary LSR is responsible for computing the path to the next exit boundary LSR (where for instance a boundary LSR is either an ARB or an ASBR) whereas in the second method a Path Computation Element (PCE)is used to compute an end to end partial or complete path across multiple domains.

Conventions used in this document

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 RFC 2119 [RFC2119].

Table of content

## 1. Terminology

LSR: Label Switch Router

LSP: MPLS Label Switched Path

PCE: Path Computation Element. An LSR in charge of computing TE LSP path for which it is not the Head-end. For instance, an ABR (inter-area) or an ASBR (Inter-AS) can play the role of PCE.

PCC: Path Computation Client (any head-end LSR) requesting a path computation from the Path Computation Element.

Local Repair: local protection techniques used to repair TE LSPs quickly when a node or link along the LSPs path fails.

Protected LSP: an LSP is said to be protected at a given hop if it has one or multiple associated backup tunnels originating at that hop.

Bypass Tunnel: an LSP that is used to protect a set of LSPs passing over a common facility.

PLR: Point of Local Repair. The head-end of a bypass tunnel.

MP: Merge Point. The LSR where bypass tunnels meet the protected LSP.

NHOP Bypass Tunnel: Next-Hop Bypass Tunnel. A backup tunnel which bypasses a single link of the protected LSP.

NNHOP Bypass Tunnel: Next-Next-Hop Bypass Tunnel. A backup tunnel which bypasses a single node of the protected LSP.

Fast Reroutable LSP: any LSP for which the "Local protection desired" bit is set in the Flag field of the SESSION_ATTRIBUTE object of its Path messages or signaled with a FAST-REROUTE object.

CSPF: Constraint-based Shortest Path First.

Inter-AS MPLS TE LSP: A TE LSP whose head-end LSR and tail-end LSR do not reside within the same Autonomous System (AS), or whose head-end LSR and tail-end LSR are both in the same AS but the TE LSPÆs path may be across different ASes. Note that this definition also applies to TE LSP whose Head-end and Tail-end LSRs reside in different sub-ASes (BGP confederations).

Inter-area MPLS TE LSP: A TE LSP where the head-end LSR and tail-end LSR do not reside in the same area or both the head-end and tail end LSR reside in the same area but the TE LSP transits one or more different areas along the path.





ABR Routers: routers used to connect two IGP areas (areas in OSPF or L1/L2 in IS-IS)

Interconnect routers or ASBR routers: routers used to connect together ASes of a different or the same Service Provider via one or more Inter-AS links.

Boundary LSR: a boundary LSR is either an ABR in the context of inter-area MPLS TE or an ASBR in the context of inter-AS MPLS TE.

TED: MPLS Traffic Engineering Database

The notion of contiguous, stitched and nested TE LSPs is defined in {INTER-DOMAIN-SIG] and will not be repeated here.

## 2. Introduction

The requirements for inter-area and inter-AS MPLS Traffic Engineering have been developed by the Traffic Engineering Working Group and have been stated in [INTER-AREA-REQS] and [INTER-AS-REQS] respectively. The framework for inter-domain MPLS Traffic Engineering has been provided in [INTER-DOMAIN-FRAMEWORK].

The set of mechanisms to establish and maintain inter-domain TE LSPs has been specified in [INTER-DOMAIN-SIG].

This document exclusively focuses on the path computation aspects and defines two methods for computing inter-domain TE LSP paths.

Note that the mechanisms proposed in this document could also be applicable to MPLS TE domains other than areas and ASes.

According to the wide set of requirements defined in [INTER-AS-TE-REQS] and [INTER-AREA-TE-REQS], coming up with a single solution covering all the requirements is certainly possible but may not be desired: indeed, as described in [INTER-AS-TE-REQS] the spectrum of deployment scenarios is quite large and designing a solution addressing the super-set of all the requirements would lead to provide a rich set of mechanisms not required in several cases. Depending on the deployment scenarios of a SP, certain requirements stated above may be strict while certain other requirements may be relaxed.

There are different ways in which inter-domain TE LSP path computation may be performed. For example, if the requirement is to get an end-to-end constraint-based shortest path across multiple domains, then a mechanism using one or more distributed PCEs could be used to compute the shortest path across different domains. Alternatively, one could also use some static or discovery mechanisms to determine the next boundary LSR per domain as the inter-domain TE LSP is being signaled. Other offline mechanisms for path computation are not precluded either.





Depending on the Service ProviderÆs requirements, one may adopt either of these techniques for inter-domain path computation.

Note that the adequate path computation method may be chosen based upon the TE LSP characteristics and requirements. Thus, the two path computation methods proposed in this document are not exclusive from each other.

## 3. General assumptions

In the rest of this document, we make the following set of assumptions:

1) Assumptions common to inter-area and inter-AS TE:

- Each area or AS in all the examples below is assumed to be capable of doing Traffic Engineering (i.e. running OSPF-TE or ISIS-TE and RSVP-TE). An AS may itself be composed of several other sub-AS(es) (BGP confederations) or areas/levels.

- The inter-area/AS LSPs are signaled using RSVP-TE ([RSVP-TE]).

- The path (ERO) for the inter-area/AS TE LSP traversing multiple areas/ASes may be signaled as a set of (loose and/or strict) hops. The hops may identify:
    - The complete strict path end to end across different areas/ASes
    - The complete strict path in the source area/AS followed by boundary LSRs (and domain identifiers, e.g. AS numbers)
    - The complete list of boundary LSRs along the path
    - The current boundary LSR and the LSP destination

In this case, the set of (loose or strict) hops can either be statically configured on the Head-end LSR or dynamically computed. In the former case, the resulting path is statically configured on the Head-end LSR. In the latter case (dynamic computation), two methods are specified in this document:
    - A distributed path computation involving some PCEs (e.g ABR/ASBR) resulting in an optimal end to end path across multiple domains consisting of a set of strict and/or loose hops,
    - Some Auto-discovery mechanism based on BGP and/or IGP information yielding the next-hop boundary LSR (ABR/ASBR) along the path as the LSP is being signaled, along with crankback mechanisms.

- Furthermore, the boundary LSRs are assumed to be capable of performing local path computation for expansion of a loose next-hop in the signaled ERO if the path is not signaled by the head-end LSR as a set of strict hops or if the strict hop is an abstract node (e.g. an AS). This can be done by performing a CSPF computation up to that next loose hop as opposed to the TE LSP destination or by making use of some





PCEs. In any case, no topology or resource information needs to be distributed between areas/ASes (as mandated per [INTER-AREA-REQS] and [INTER-AS-REQS]), which is critical to preserve IGP/BGP scalability and confidentiality in the case of TE LSPs spanning multiple routing domains.

- The paths for the intra-area/AS FA-LSPs or LSP segments or for a contiguous TE LSP within the area/AS, may be pre-configured or computed dynamically based on the arriving inter-area/AS LSP setup request; depending on the requirements of the transit area/AS. Note that this capability is explicitly specified as a requirement in [INTER-AS-TE-REQS]. When the paths for the FA-LSPs/LSP segments are pre-configured, the constraints as well as other parameters like local protection scheme for the intra-area/AS FA-LSP/LSP segment are also pre-configured.

- While certain constraints like bandwidth can be used across different areas/ASes, certain other TE constraints like resource affinity, color, metric, etc. as listed in [RFC2702] could be translated at areas/ASes boundaries. If required, it is assumed that, at the area/AS boundary LSRs, there will exist some sort of local mapping based on offline policy agreement, in order to translate such constraints across area/AS boundaries. It is expected that such an assumption particularly applies to inter-AS TE: for example, the local mapping would be similar to the Inter-AS TE Agreement Enforcement Polices stated in [INTER-AS-TE-REQS].

2) Example of topology for the inter-area TE case

The following example will be used for the inter-area TE case in this document.

```
<--area1--><---area0---><----area2----->
 ------ABR1------------ABRÆ1-------
 |    /   |              |  \     |
R0--X1    |              |   X2---X3--R1
 |        |              |  /     |
 -------ABR2-----------ABRÆ2------
<=========== Inter-area TE LSP =======>
```

Assumptions

- ABR1, ABR2, ABRÆ1 and ABRÆ2 are ABRs,
- X1: an LSR in area 1,
- X2, X3: LSRs in area 2,
- An inter-area TE LSP T0 originated at R0 in area1 and terminating at R1 in area2,

Notes:
- The terminology used in the example above corresponds to OSPF but the path computation methods proposed in this document equally applies to the case of an IS-IS multi-levels network.





- Just a few routers in each area are depicted in the diagram above for the sake of simplicity.

3) Example of topology for the inter-AS TE case:

We will consider the following general case, built on a superset of the various scenarios defined in [INTER-AS-TE-REQS]:

```
     <-- AS 1 ---> <------- AS 2 ----->< --- AS 3 ---->

               <---BGP--->            <---BGP-->
CE1---R0---X1-ASBR1-----ASBR4ù-R3---ASBR7-ù--ASBR9----R6
      |\     \ |       / |   / |   / |          |      |
      | \     ASBR2---/ ASBR5  | --  |          |      |
      |  \     |         |     |/    |          |      |
      R1-R2ù--ASBR3ù----ASBR6ù-R4---ASBR8ù---ASBR10ù--R7---CE2

      <======= Inter-AS TE LSP(LSR to LSR)===========>
or

<========= Inter-AS TE LSP (CE to ASBR =>

or

<================== Inter-AS TE LSP (CE to CE)===============>
```

The diagram above covers all the inter-AS TE deployment cases described in [INTER-AS-TE-REQS].

Assumptions:

- Three interconnected ASes, respectively AS1, AS2, and AS3. Note that AS3 might be AS1 in some scenarios described in [INTER-AS-TE-REQS],

- The various ASBRs are BGP peers, without any IGP running on the single hop links interconnecting the ASBRs and also referred to as inter-ASBR links,

- Each AS runs an IGP (IS-IS or OSPF) with the required IGP TE extensions (see [OSPF-TE] and [IS-IS-TE]). In other words, the ASes are TE enabled,

- Each AS can be made of several IGP areas. The path computation techniques described in this document applies to the case of a single AS made of multiple IGP areas, multiples ASes made of a single IGP areas or any combination of the above. For the sake of simplicity, each routing domain will be considered as single area in this document.

- An inter-AS TE LSP T1 originated at R0 in AS1 and terminating at R6 in AS3,

- In the example above, ASBR1, ASBR8 and ASBR9 could have the function of PCE for the AS 1, 2 and 3 respectively (the notion of PCE applies to the scenario 2 of this document).

## 4. Scenario 1: Next-hop resolution during inter-domain TE LSP set up (per-domain path computation)

### 4.1. Path computation algorithm

Regardless of the nature of the inter-domain TE LSP (contiguous, stitched or nested), a similar set of mechanisms for local TE LSP path computation (next hop resolution) can be used.

When an ABR/ASBR receives a Path message with a loose next-hop or an abstract node in the ERO, then it carries out the following actions:

1) It checks if the loose next-hop is accessible via the TED. If the loose next-hop is not present in the TED, then it checks if the next-hop at least has IP reachability (via IGP or BGP). If the next-hop is not reachable, then the path computation stops and the LSR sends back a PathErr upstream. If the next-hop is reachable, then it finds an ABR/ASBR to get to the next-hop. In the absence of an auto-discovery mechanism, the ABR in the case of inter-area TE or the ASBR in the next-hop AS in the case of inter-AS TE should be the loose next-hop in the ERO and hence should be accessible via the TED, otherwise the path computation for the inter-area/AS TE LSP will fail.

2) If the next-hop boundary LSR is present in the TED.

a) Case of a contiguous TE LSP. The ABR/ASBR just performs an ERO expansion (unless not allowed by policy) after having computed the path to the next loose hop (ABR/ASBR) that obeys the set of required constraints. If no path satisfying the set of constraints can be found, the path computation stops and a Path Error MUST be sent for the inter-area/AS TE LSP.

b) Case of stitched or nested LSP

i) if the ABR/ASBR (receiving the LSP setup request) is a candidate LSR for intra-area FA-LSP/LSP segment setup, and if there is no FA-LSP/LSP segment from this LSR to the next-hop boundary LSR (satisfying the constraints) it SHOULD signal a FA-LSP/LSP segment to the next-hop boundary LSR. If pre-configured FA-LSP(s) or LSP segment(s) already exist, then it SHOULD try to select from among those intra-area/AS LSPs. Depending on local policy, it MAY signal a new FA-LSP/LSP segment if this selection fails. If the FA-LSP/LSP segment is successfully signaled or selected, it propagates the inter-area/AS Path message to the next-hop following





the procedures described in [LSP-HIER]. If, for some reason the dynamic FA-LSP/LSP segment setup to the next-hop boundary LSR fails, the path computation stops and a PathErr is sent upstream for the inter-area/AS LSP. Similarly, if selection of a preconfigured FA-LSP/LSP segment fails and local policy prevents dynamic FA-LSP/LSP segment setup, then the path computation stops and a PathErr is sent upstream for the inter-area/AS TE LSP.

ii) If, however, the boundary LSR is not a FA-LSP/LSP segment candidate, then it SHOULD simply compute a CSPF path up to the next-hop boundary LSR carry out an ERO expansion to the next-hop boundary LSR) and propagate the Path message downstream. The outgoing ERO is modified after the ERO expansion to the loose next-hop.

Note that in both cases, path computation may be stopped due to some local policy.

### 4.2. Example with an inter-area TE LSP

#### 4.2.1. Case 1: T1 is a contiguous TE LSP

When the path message reaches ABR1, it first determines the egress LSR from its area 0 along the LSP path (say ABRÆ1), either directly from the ERO (if for example the next hop ABR is specified as a loose hop in the ERO) or by using some constraint-aware auto-discovery mechanism. In the former case, every inter-AS TE LSP path is defined as a set of loose and strict hops but at least the ABRs traversed by the inter-area TE LSP MUST be specified as loose hops on the head-End LSR.

- Example 1 (set of strict hops end to end): R0-X1-ABR1-ABRÆ1-X2-X3-R1
- Example 2 (set of loose hops): R0-ABR1(loose)-ABRÆ1(loose)-R1(loose)
- Example 3 (mix of strict and loose hops): R0-X1-ASBR1-ABRÆ1(loose)-X2-X3-R1

At least, the set of ABRs from the TE LSP head-end to the tail-End MUST be present in the ERO as a set of loose hops. Optionally, a set of paths can be configured on the head-end LSR, ordered by priority. Each priority path can be associated with a different set of constraints. Typically, it might be desirable to systematically have a last resort option with no constraint to ensure that the inter-area TE LSP could always be set up if at least a path exists between the inter-area TE LSP source and destination. Note that in case of set up failure or when an RSVP Path Error is received indicating the TE LSP has suffered a failure, an implementation might support the possibility to retry a particular path option a specific amount of time (optionally with dynamic intervals between each trial) before trying a lower priority path option. Any path can be defined as a set of loose and strict hops.





In other words, in some cases, it might be desirable to rely on the dynamic path computation in some area, and exert a strict control on the path in other areas (defining strict hops).

Once it has computed the path up to the next ABR, ABR1 sends the Path message for the inter-area TE LSP to ABRÆ1. ABRÆ1 then repeats the a similar procedure and the Path message for the inter-area TE LSP will reach the destination R1. If ABRÆ1 cannot find a path obeying the set of constraints for the inter-area TE LSP, the path computation stops and ABRÆ1 MUST send a PathErr message to ABR1. Then ABR1 can in turn triggers a new computation by selecting another egress boundary LSR (ABRÆ2 in the example above) if crankback is allowed for this inter-area TE LSP (see [CRANBACK]). If crankback is not allowed for that inter-area TE LSP or if ABR1 has been configured not to perform crankback, then ABR1 MUST stop any path computation for the TE LSP and MUST forward a PathErr up to the head-end LSR (R0) without trying to select another egress LSR.

#### 4.2.2. Case 2: T2 is a stitched or nested TE LSP

When the path message reaches ABR1, ABR1 first determines the egress LSR from its area 0 along the LSP path (say ABRÆ1), either directly from the ERO or by using some constraint-aware auto-discovery mechanism.

ABR1 will check if it has a FA-LSP or LSP segment to ABRÆ1 matching the constraints carried in the inter-area TE LSP Path message. If not, ABR1 will compute the path for a FA-LSP or LSP segment from ABR1 to ABRÆ1 satisfying the constraint and will set it up accordingly. Note that the FA-LSP or LSP segment could have also been pre-configured.

Once the ABR has selected the FA-LSP/LSP segment for the inter-area

LSP, using the signaling procedures described in [LSP-HIER], ABR1 sends the Path message for inter-area TE LSP to ABRÆ1. Note that irrespective of whether ABR1 does nesting or stitching, the Path message for the inter-area TE LSP is always forwarded to ABRÆ1. ABRÆ1 then repeats the exact same procedures and the Path message for the inter-area TE LSP will reach the destination R1. If ABRÆ1 cannot find a path obeying the set of constraints for the inter-area TE LSP, then ABRÆ1 MUST send a PathErr message to ABR1. Then ABR1 can in turn either select another FA-LSP/LSP segment to ABRÆ1 if such an LSP exists or select another egress boundary LSR (ABRÆ2 in the example above) if crankback is allowed for this inter-area TE LSP (see [CRANBACK]). If crankback is not allowed for that inter-area TE LSP or if ABR1 has been configured not to perform crankback, then ABR1 MUST forward a PathErr up to the inter-area head-end LSR (R0) without trying to select another egress LSR.

### 4.3. Example with an inter-AS TE LSP





The procedures for establishing an inter-AS TE LSP are very similar to those of an inter-area TE LSP described above. The main difference is related to the presence of inter-ASBRs link(s).

The links interconnecting ASBRs are usually not TE enabled and no IGP is running at the AS boundaries. An implementation supporting inter-AS MPLS TE MUST obviously allow the set up of inter-AS TE LSP over the region interconnecting multiple ASBRs. In other words, an ASBR compliant with this document MUST support the set up of TE LSP over ASBR to ASBR links, performing all the usual operations related to MPLS Traffic Engineering (call admission control, à) as defined in [RSVP-TE].

In term of computation of an inter-AS TE LSP path, an interesting optimization consists of allowing the ASBRs to flood the TE information related to the inter-ASBR link(s) although no IGP TE is enabled over those links (and so there is no IGP adjacency over the inter-ASBR links). This of course implies for the inter-ASBR links to be TE-enabled although no IGP is running on those links. This allows a head-end LSR to make a more appropriate route selection up to the first ASBR in the next hop AS in the case of scenario 1 and will significantly reduce the number of signaling steps in route computation. This also allows the entry ASBR in an AS to make a more appropriate route selection up to the entry ASBR in the next hop AS taking into account constraints associated with the ASBR-ASBR links. Moreover, this reduces the risk of call set up failure due to inter-ASBR links not satisfying the inter-AS TE LSP set of constraints. Note that the TE information is only related to the inter-ASBR links: the TE LSA/LSP flooded by the ASBR includes not only the TE-enabled links contained in the AS but also the inter-ASBR links.

Note that no summarized TE information is leaked between ASes in any of the proposed scenarios in this document which is compliant with the requirements listed in [INTER-AREA-TE-REQS] and [INTER-AS-TE-REQS].

Example:

```
               <---BGP--->           <---BGP-->
CE1---R0---X1-ASBR1-----ASBR4ù-R3---ASBR7-ù--ASBR9---R6
      |\     \ |       / |   / |   / |          |     |
      | \     ASBR2---/ ASBR5  | --  |          |     |
      |  \     |         |     |/    |          |     |
      R1-R2ù--ASBR3ù----ASBR6ù-R4---ASBR8ù---ASBR10---R7---CE2
```

For instance, in the diagram depicted above, when ASBR1 floods its IGP TE LSA (opaque LSA for OSPF)/LSP (TLV 22 for IS-IS) in its routing domain, it reflects the reservation states and TE properties of the following links: X1-ASBR1, ASBR1-ASBR2 and ASBR1-ASBR4.

Thanks to such an optimization, the inter-ASBRs TE link information corresponding to the links originated by the ASBR is made available in





the TED of other LSRs in the same area/AS that the ASBR belongs to. Consequently, the CSPF computation for an inter-AS TE LSP path can also take into account the inter-ASBR link(s). This will improve the chance of successful path computation up to the next AS in case of a bottleneck on some inter-ASBR links and it potentially reduces one level of crankback. Note that no topology information is flooded and these links are not used in IGP SPF computations. Only the TE information for the links originated by the ASBR is advertised.

#### 4.3.1. Case 1: T1 is a contiguous TE LSP

The inter-AS TE path may be configured on the head-end LSR as a set of strict hops, loose hops or a combination of both.

- Example 1 (set of strict hops end to end): R0-X1-ASBR1-ASBR4-ASBR5-

R3-ASBR7-ASBR9-R6
- Example 2 (set of loose hops): R0-ASBR4(loose)-ASBR9(loose)-R6(loose)
- Example 3 (mix of strict and loose hops): R0-R2-ASBR3-ASBR2-ASBR1-ASBR4(loose)-ASBR10(loose)-ASBR9-R6

When a next hop is a loose hop, a dynamic path calculation (also called ERO expansion) is required taking into account the topology and TE information of its own AS and the set of TE LSP constraints. In the example 1 above, the inter-AS TE LSP path is statically configured as a set of strict hops; thus, in this case, no dynamic computation is required. Conversely, in the example 2, a per-AS path computation is performed, respectively on R0 for AS1, ASBR4 for AS2 and ASBR9 for AS3. Note that when an LSR has to perform an ERO expansion, the next hop must either belong to the same AS, or must be the ASBR directly connected to the next hops AS. In this later case, the ASBR reachability MUST be announced in the IGP TE LSA/LSP originated by its neighboring ASBR. Indeed, in the example 2 above, the TE LSP path is defined as: R0-ASBR4(loose)-ASBR9(loose)-R6(loose). This implies that R0 must compute the path from R0 to ASBR4, hence the need for R0 to get the TE reservation state related to the ASBR1-ASBR4 link (flooded in AS1 by ASBR1). In addition, ASBR1 MUST also announce the IP address of ASBR4 specified in the T1 path configuration.

If an auto-discovery mechanism is available, every LSR receiving an RSVP Path message, will have to determine automatically the next hop ASBR, based on the IGP/BGP reachability of the TE LSP destination. With such a scheme, the head-end LSR and every downstream ASBR loose hop (except the last loose hop that computes the path to the final destination) automatically computes the path up to the next ASBR, the next loose hop based on the IGP/BGP reachability of the TE LSP destination. If a particular destination is reachable via multiple loose hops (ASBRs), local heuristics may be implemented by the head-end LSR/ASBRs to select the next hop an ASBR among a list of possible choices (closest exit point, metric advertised for the IP destination (ex: OSPF LSA External - Type 2), local policy,...). Once the next ASBR has been determined, an ERO expansion is performed as in the previous





case.

Once it has computed the path up to the next ASBR, ASBR1 sends the Path message for the inter-area TE LSP to ASBR4 (supposing that ASBR4 is the selected next hop ASBR). ASBR4 then repeats the exact same procedures and the Path message for the inter-AS TE LSP will reach the destination R1. If ASBR4 cannot find a path obeying the set of constraints for the inter-AS TE LSP, then ASBR4 MUST send a PathErr message to ASBR1. Then ASBR1 can in turn either select another ASBR (ASBR5 in the example above) if crankback is allowed for this inter-AS TE LSP (see [CRANBACK]). If crankback is not allowed for that inter-AS TE LSP or if ASBR1 has been configured not to perform crankback, then ABR1 MUST stop the path computation and MUST forward a PathErr up to the head-end LSR (R0) without trying to select another egress LSR. In this case, the head-end LSR can in turn select another sequence of loose hops, if configured. Alternatively, the head-end LSR may decide to retry the same path; this can be useful in case of set up failure due an outdated IGP TE database in some downstream AS. An alternative could also be for the head-end LSR to retry to same sequence of loose hops after having relaxed some constraint(s).

### 4.3.2. Case 2: T1 is a stitched or nested TE LSP

The signaling procedures are very similar to the inter-area LSP setup case described earlier. In this case, the FA-LSPs or LSP segments will only be originated by the ASBRs at the entry to the AS.

## 5. Scenario 2: end to end shortest path computation

### 5.1. Introduction and definition of an optimal path

Qualifying a path as optimal requires some clarification. Indeed, a globally optimal TE LSP placement usually refers to a set of TE LSP whose placements optimize the network resources (i.e a placement that reduces the maximum or average network load for instance). In this document, an optimal inter-domain TE LSP path is defined as the shortest path satisfying the set of required constraints path that would be obtained in the absence of AS/Areas, in a totally flat network between the source and destination of the TE LSP.

### 5.2. Notion of PCE (Path Computation Element)

An LSR is said to be a PCE (Path Computation Element) when it has the ability to compute an inter-domain TE LSP path for a TE LSP it is not the head-end of. Ideal candidates to support a PCE function are ABRs in the context of inter-area TE (since each ABR has the view of two of more areas in its TED) and ASBR in the context of inter-AS TE. Note that in this document an LSR supporting the function of PCE is simply referred to as a PCE. As in the case of intra-area TE, no assumption is made on the actual path computation algorithm in use by the PCE (it can be any variant of CSPF, algorithm based on linear-programming to solve multi-constraints optimization problems and so on).

### 5.3. Dynamic PCE discovery

PCE(s) can either be statically configured on each LSR requesting an inter-domain TE LSP path computation or dynamically discovered by means of IGP extensions defined in [OSPF-CAP], [OSPF-TE-CAP], [ISIS-CAP] and [ISIS-TE-CAP]. This allows an Operator to elect a subset of ABRs/ASBRs to act as PCEs.

Note that if the domain is made of multiple areas/levels, [OSPF-CAP] and [ISIS-CAP] support the capabilities announcements across the entire routing domain (making use of TLV leaking procedure for IS-IS and OSPF opaque LSA type 11 for OSPF).

### 5.4. PCE selection

It belongs to an LSR informed of the existence of multiple PCEs having the capability to serve an inter-domain TE LSP path computation request to select the preferred PCE. For instance, an LSR may select the closest PCE based on the IGP metric or may just randomly select one of the PCE. In case of multiple PCEs, the PCE selection process SHOULD be such that the requests are balanced across multiple PCEs. In addition, an LSR MUST be able to select another PCE if its preferred PCE does not respond to its request after some configurable and potentially dynamically computed amount of time (e.g. using some back-off algorithm). Note that the PCE may or may not be along the TE LSP Path. This implies that the PCE is just responsible for the TE LSP path computation, not for its maintenance. Moreover, the PCE may compute just a path segment, not the whole path end to end; in this case, the returned computed path will contain loose hops so as to preserve confidentiality across domain for instance.

### 5.5. LSR-PCE signaling protocol

The use of a PCE-based path computation method requires some signaling protocol between the requesting LSR and the PCE so as:

- For the requesting LSR (also referred to as PCC) to send a path computation request
- For the PCE to return the computed path by means of a path computation reply

Such a signaling protocol has been defined in [PATH-COMP] as well as a set of optional objects characterizing the constraints.

The protocol state machine is also defined in [PATH-COMP].

### 5.6. Dynamic computation of an optimal end to end TE LSP path

This section specifies a PCE-based mechanism allowing for the computation of an optimal (shortest) inter-domain TE LSP path obeying a set of specified constraints.

Each step of the mechanism is illustrated by means of an inter-AS TE LSP path computation example: the shortest path of an inter-AS TE LSP T1 from R0 in AS1 to R6 in AS3. The case of inter-area TE LSP optimal path computation is very similar.

Elements of procedure

1) Step 1: discovery by the head-end LSR of a PCE capable of serving its path computation request. The PCE will either be an ABR (inter-area TE) or an ASBR (Inter-AS TE). In the case of inter-AS TE, the PCE must be able to serve the source AS and can compute inter-AS TE LSP path terminating in the destination ASn. As mentioned above, the PCE can either be statically configured or dynamically discovered via IGP extensions. If multiple PCEs are discovered, the head-end LSR selects one PCE based on some local policies/heuristics.

Ex: R1 selects ASBR1 as the PCE serving its request for the T1 path computation.

2) Step 2: a Path computation request is sent to the selected PCE.

Case of inter-area MPLS TE: the head-end LSR sends its path computation requests to the selected PCE (ABR).

Case of inter-AS MPLS TE: the path computation request can be sent either (1) to a PCE in the same AS which will in turn relay the request to a PCE of the next hop AS (Ex: R0 sends an RSVP path computation request to ASBR1 which relays the request to say ASBR4) or (2) to the PCE in the next hop AS if the head-end LSR has a complete topology and TE view up to the next hop PCE (Ex: R0 sends an RSVP path computation request to ASBR4). It is expected that (1) will be the most common inter-AS TE deployment scenario for security issues.

Note that it may be desirable to set up some policies on the PCE to limit the access to specific LSRs. Moreover, authentication process may be required when sending a path computation request to a PCE (usual RSVP authentication can be used in the case of [PATH-COMP]).

Step i: the PCE of ASi relays the path computation request to the selected PCE peer in AS(i+1) located in the next hop AS. Note that the address of the list of PCE(es) in the next hop AS must be statically configured on the PCE. This only implies some static configuration on the PCE.

Ex: ASBR1 relays the path computation request to ASBR4 in AS2.





If the TE LSP destination is in AS(i+1), then the PCE provides the list of shortest paths (with their corresponding ERO (potentially partial ERO) + Path-cost) from every ASBR to the TE LSP destination. A detailed example is provided below.

If the TE LSP destination is not in AS(i+1), the PCE relays the path computation request to the targeted PCE peer in AS(i+2) in the next hop AS.

The process is iterated until the destination AS is reached.

Ex: ASBR4 relays the path computation request to ASBR9 which determines that T1Æs destination address belongs to its locally attached AS (AS3). ASBR9 then returns a path computation reply to the requesting PCE (ASBR4). The path computation reply contains two paths (provided that two paths obeying the set of constraints exist):

- ERO 1: ASBR9-R6, Cost=c1,
- ERO 2: ASBR10-R7-R6, Cost=c2

Note that the ERO object might be made of loose hop to preserve confidentiality.

Step 3: once a requesting PCEi receives a Path computation reply, the shortest path is computed from ASi to ASi+1 by route concatenation. This is done by computing a virtual SPT (Shortest Path Tree) rooted at the TE LSP destination (using for instance a CSPF-based algorithm) where the nodes are the ABSRs connected by virtual links whose costs are equal to the shortest path connecting the ASBRs.

```
               <---BGP--->            <---BGP-->
CE1---R0---X1-ASBR1-----ASBR4ù-R3---ASBR7-ù--ASBR9---R6
      |\     \ |       / |   / |   / |          |     |
      | \     ASBR2---/ ASBR5  | --  |          |     |
```

```
      |  \     |         |     |/    |          |     |
      R1-R2ù--ASBR3ù----ASBR6ù-R4---ASBR8ù---ASBR10---R7---CE2
```

Resulting Virtual SPT computed by ASBR 4

```
ASBR4---ASBR7---ASBR9---R6
| |  \ /  /| \  / |    /
| |   \  / |  \/  |   /
| |  / \/  |  /\  |  /
| | /  /\  | /  \ | /
|ASBR5--ASBR8---ASBR10
| |   / /
| |  / /
| | / /
| |/ /
ASBR6
```

First, we define a ASBR-ASBR virtual link as the shortest path within a particular AS satisfying the TE LSP constraints.





Within ASi, the cost of each ASBR-ASBR virtual link is equal to the shortest path cost satisfying the TE LSP constraints. This information is computed by PCEi.

As described earlier, the cost of the inter-ASBR links between ASi and AS(i+1) is also known by the PCEi by means of the IGP-extensions.

Within ASi+1, the cost of the ASBR-ASBR virtual link(s) is provided in the path computation reply from the PCEi+1.

Ex: ASBR4 computes the shortest path for the TE LSP traversing AS2 and AS3 and returns the following virtual SPT (along with the path costs) to ASBR1:

```
ASBR4---R6
       /
      /
ASBR6
```

Then the process is reiterated recursively until the optimal (shortest) end-to-end Path computation is computed. The whole path may not be seen by each PCE for confidentiality reason. This process guarantees that the shortest path is computed.

Example: the resulting virtual SPT computed by ASBR1 will finally be:

```
R0-----ASBR1-----ASBR4----R6
| \     |  |\ \ /  /||   / |
|  \    |  | \ \  / ||  /  |
|   \   |  |  / \/  || /   |
|    \  |  | / \/\  ||/    |
|     \-|-ASBR2ùASBR5      |
|       |  |\  /\/  ||     |
|       |  | \/ /\  ||     |
|       |  | /\/  \ ||     |
|       |  |/ /\   \||     |
--------|-ASBR3-ùASBR6-----|
```

Then once the optimal end to end path is computed and returned to the Head-end, it signals the inter-domain TE LSP using a complete list of ERO if the various PCEs have provided the list of ERO or some loose hops otherwise.

An implementation MAY decide to support local caching of path computation in order to optimize the path computation process. The downside of path caching is the potential increase of call set up failure. When caching is in use, it must be flushed upon TE LSP set up failure provided that the PCE is along the inter-area/AS TE LSP path.





By contrast with scenario 1, an end-to-end shortest path obeying the set of required constraint is computed. In that sense, the path is optimal.

Some other variants of such an algorithm relying on the same principles are also possible.

Note also that in case of ECMP paths, more than one path could be returned to the requesting LSR.

### 5.7. Metric normalization

In the case of inter-area TE, the same IGP/TE metric scheme is usually adopted for all the areas (e.g. based on the link-speed, propagation delay or some other combination of constraints). Hence, the proposed set of mechanism always computes the shortest path across multiple areas obeying the required set of constraints. In the case of Inter-AS TE, in order for this path computation to be meaningful, a metric normalization between ASes is required. One solution to avoid IGP metric modification would be for the SPs to agree on a TE metric normalization and use the TE metric for TE LSP path computation (in that case, this must be requested in the Path computation request via the METRIC-COST object in the case of [PATH-COMP]).

## 5.8. Diverse end to end path computation

The RSVP signaling protocol defined in [PATH-COMP] allows an LSR to request the computation of a set of N diversely routed TE LSPs. Then in this scenario, a set of diversely routed TE LSP between two LSRs can be computed since both paths are simultaneously computed. Such a PCE-based path computation method allows for the computation of diverse paths under various objective functions (such as minimizing the sum of the costs of the N diverse paths, etc) in a very efficient manner (avoiding the well-known ôtrappingö problem whereby a sequential placement of the two TE LSPs may lead to the inability to find a path for the second TE LSP due to the placement of the first TE LSP) both in terms of objective function and number of passes required to compute those paths.

## 6. Path optimality/diversity

In the case of scenario, since the inter-domain path is computed on a per domain (area, AS) basis, one cannot guarantee that the shortest inter-domain path can be found. Conversely, scenario 2 guarantees that the shortest inter-domain path will always be computed.
Moreover, computing two diverse paths might not be possible with scenario 1 in some topologies (due to the well-known ôtrappingö problem) whereas such a limitation does not exist with scenario 2 since both paths are dynamically and simultaneously computed.





As already pointed out, the required path computation method can be selected by the Operator on a per LSP basis.

## 7. MPLS Traffic Engineering Fast Reroute for inter-domain TE LSPs

The signaling aspects of Fast Reroute and related constraints for each

TE LSP types in the case of inter-domain TE LSP has been covered in [INTER-DOMAIN-SIG] and will not be repeated in this document.

There are multiple failure scenarios to consider in the case of Fast Reroute for inter-domain TE LSPs.

### 7.1. Failure of an internal network element

The case of a failure of a network element within an area/AS such as a link, SRLG or a node does not differ from Fast Reroute for intra-domain TE LSP.

### 7.2. Failure of an inter-ASBR links (inter-AS TE)

In order to protect inter-domain TE LSPs from the failure of an inter-ASBR link, this requires the computation of a backup tunnel path that crosses an non IGP TE-enabled region (between two ASes). In both scenario 1 and 2, if the inter-ASBR TE related information is flooded in the IGPs, each ASBR is capable of computing the path according to the backup tunnel constraints. Otherwise, the backup tunnel path MUST be statically configured.

### 7.3. Failure of an ABR or an ASBR node

The constraints to be taken into account during the backup tunnel path computation significantly differs upon the TE LSP type, network element to protect (entry/exit boundary node) and the Fast Reroute method in use (facility backup versus one-to-one). Those constraints have been explored in detail in [INTER-DOMAIN-SIG] but since the backup tunnel is itself an inter-domain TE LSP, its path computation can be performed according to the two path computation methods described in this document.

## 8. Reoptimization of an inter-area/AS TE LSP

The ability to reoptimize an existing inter-area/AS TE LSP path is of course a requirement. The reoptimization process significantly differs based upon the nature of the TE LSP and the mechanism in use for the TE LSP path computation.

If the head-end LSR uses a dynamic and distributed path computation technique such as the PCE-based path computation (described in section 6), then the head-end LSR can leverage this to send re-optimization requests to the PCE to obtain an optimal end-to-end path. On the other hand, in the absence of such a mechanism, the following mechanisms can be used for re-optimization, which are dependent on the nature of the inter-area/AS TE LSP.

## 8.1. Contiguous TE LSPs

### 8.1.1. Per-area/AS path computation (scenario 1)

After an inter-AS TE LSP has been set up, a more optimal route might appear in the various traversed ASes. Then in this case, it is desirable to get the ability to reroute an inter-AS TE LSP in a non-disruptive fashion (making use of the so called Make Before Break procedure) to follow this more optimal path. This is a known as a TE LSP reoptimization procedure.

[LOOSE-REOPT] proposes a mechanisms allowing:

- The head-end LSR to trigger on every LSR whose next hop is a loose hop the re evaluation of the current path in order to detect a potentially more optimal path. This is done via explicit signaling request: the head-end LSR sets the ôERO Expansion requestö bit of the SESSION-ATTRIBUTE object carried in the RSVP Path message.

- An LSR whose next hop is a loose-hop to signal to the head-end LSR that a better path exists. This is performed by sending an RSVP Path Error Notify message (ERROR-CODE = 25), sub-code 6 (Better path exists).

  This indication may be sent either:

  - In response to a query sent by the head-end LSR,
  - Spontaneously by any LSR having detected a more optimal path

Such a mechanism allows for the reoptimization of a TE LSP if and only if a better path is some downstream area/AS is detected.

The reoptimization event can either be timer or event-driven based (a link UP event for instance).

Note that the reoptimization MUST always be performed in a non-disruptive fashion.

Once the head-end LSR is informed of the existence of a more optimal path either in its head-end area/AS or in another AS, the inter-AS TE Path computation is triggered using the same set of mechanisms as when the TE LSP is first set up (per-AS path computation as in scenario 1 or involving some PCE(s) in scenario 2). Then the inter-AS TE LSP is set up following the more optimal path, making use of the make before break procedure. In case of a contiguous LSP, the reoptimization process is strictly controlled by the head-end LSR which triggers the make-before-





break procedure, regardless of the location where the more optimal path is.

### 8.1.2. End to end shortest path computation (scenario 2)

[PATH-COMP] provides the ability to request a path reoptimization. In order to avoid double bandwidth accounting which could result in falsely triggered call set up failure the requesting LSR just provides the current path of the inter-area/AS TE LSP path to be reoptimized.

Note that in the case of loose hop reoptimization, the TE LSP may follow a preferable path within one or more domain(s) whereas in the PCE-based reoptimization process, since a shortest end to end path is computed this may lead to following a completely different inter-domain path (including a different set of ABRs/ASBRs).

## 8.2. Stitched or nested (non-contiguous) TE LSPs

In the case of a stitched or nested inter-domain TE LSP, the re-optimization process is treated as a local matter to any Area/AS. The main reason is that the inter-domain TE LSP is a different LSP (and therefore different RSVP session) from the intra-domain LSP segment or FA-LSP in an area or an AS. Therefore, reoptimization in an area/AS is done by locally reoptimizing the intra-domain LSP segment. Since the inter-domain TE LSPs are transported using LSP segments or FA-LSP across each domain, optimality of the inter-domain TE LSP in an area/AS is dependent on the optimality of the corresponding LSP segments or FA-LSPs. If, after an inter-domain LSP is setup, a more optimal path is available within an area/AS, the corresponding LSP segment(s) or FA-LSP will be re-optimized using "make-before-break" techniques discussed in [RSVP-TE]. Reoptimization of the LSP segment automatically reoptimizes the inter-domain TE LSPs that the LSP segment transports. Reoptimization parameters like frequency of reoptimization, criteria for reoptimization like metric or bandwidth availability; etc can vary from one area/AS to another and can be configured as required, per intra-area/AS TE LSP segment or FA-LSP if it is preconfigured or based on some global policy within the area/AS.

Hence, in this scheme, since each area/AS takes care of reoptimizing its own LSP segments or FA-LSPs, and therefore the corresponding inter-domain TE LSPs, the make-before-break can happen locally and is not triggered by the head-end LSR for the inter-area/AS LSP. So, no additional RSVP signaling is required for LSP re-optimization and reoptimization is transparent to the HE LSR of the inter-area/AS TE LSP.

If, however, an operator desires to manually trigger reoptimization at the head-end LSR for the inter-domain TE LSP, then this solution does not prevent that. A manual trigger for reoptimization at the head-end LSR SHOULD force a reoptimization thereby signaling a "new" path for the same LSP (along the optimal path) making use of the make-before-





break procedure. In response to this new setup request, the boundary LSR may either initiate new LSP segment setup, in case the inter-area/AS TE LSP is being stitched to the intra-area/AS LSP segment or it may select an existing FA-LSP in case of nesting. When the LSP setup along the current optimal path is complete, the head end should switchover the traffic onto that path and the old path is eventually torn down. Note that the head-end LSR does not know a priori whether a more optimal path exists. Such a manual trigger from the head-end LSR of the inter-area/AS TE LSP is, however, not considered to be a frequent occurrence.

Note that because stitching or nesting rely on local optimization, the reoptimization process allows to locally reoptimize each TE LSP segment or FA-LSP: hence, the reoptimization is not global and cannot guarantee that the optimal path end to end is found.

## 9. Routing traffic onto inter-domain TE LSPs

Once an inter-domain TE LSP has been set up, the head-end LSR has to determine the set of traffic to be routed onto the TE LSP.

In the case of an intra-domain TE LSP, various options are available:

(1) Modify the IGP SPF such that shortest path calculation can be performed taking into account existing TE LSP, with some path preference,

(2) Make use of static routing. Note that the recursive route resolution of BGP allows routing any traffic to a particular (MP)BGP peer making use of a unique static route pointing the BGP peer address to the TE LSP. So any routes advertised by the BGP peer (IPv4/VPNv4 routes) will be reached using the TE LSP.

With an inter-domain TE LSP, just the mode (2) is available, as the TE

LSP head-end does not have any topology information related to the destination area/AS.

## 10. Security Considerations

When signaling an inter-AS TE, an Operator may make use of the already defined security features related to RSVP (authentication). This may require some coordination between SPs to share the keys (see RFC 2747 and RFC 3097).

## 11. Intellectual Property Considerations









## 12. Acknowledgments

We would like to acknowledge input and helpful comments from Adrian Farrel.

Normative References

[RFC] Bradner, S., "Key words for use in RFCs to indicate requirements levels", RFC 2119, March 1997.

[RFC3667] Bradner, S., "IETF Rights in Contributions", BCP 78, RFC 3667, February 2004.

[RFC3668] Bradner, S., Ed., "Intellectual Property Rights in IETF Technology", BCP 79, RFC 3668, February 2004.

[RSVP] Braden, et al, " Resource ReSerVation Protocol (RSVP) ¡ Version 1, Functional Specificationö, RFC 2205, September 1997.

[RSVP-TE] Awduche, et al, "Extensions to RSVP for LSP Tunnels", RFC 3209, December 2001.

[REFRESH-REDUCTION] Berger et al, ôRSVP Refresh Overhead Reduction Extensionsö, RFC2961, April 2001.





[FAST-REROUTE] Ping Pan, et al, "Fast Reroute Extensions to RSVP-TE for LSP Tunnels", draft-ietf-mpls-rsvp-lsp-fastreroute-03.txt, December 2003.

[OSPF-TE] Katz, D., Yeung, D., Kompella, K., "Traffic Engineering Extensions to OSPF Version 2", RFC 3630, September 2003.

[ISIS-TE] Li, T., Smit, H., "IS-IS extensions for Traffic Engineering", RFC 3784, June 2004.

Informative references

[OSPF-CAP] Lindem, A., Shen, N., Aggarwal, R., Shaffer, S., Vasseur, J.P., "Extensions to OSPF for advertising Optional Router Capabilities", draft-ietf-ospf-cap-03.txt, work in progress.

[OSPF-TE-CAP] Vasseur, J.P., Psenak, P., Yasukawa, S., "OSPF MPLS Traffic Engineering Capabilities", draft-vasseur-ospf-te-caps-00.txt, work in progress.

[ISIS-CAP] Vasseur, J.P., Aggarwal, R., Shen, N., "IS-IS extensions for advertising router information", draft-vasseur-isis-caps-02.txt, work in progress.

[ISIS-TE-CAP] Vasseur, J.P, Previdi, S., Mabey, P., Le Roux, J.L., "IS-IS MPLS Traffic Engineering Capabilities", draft-vasseur-isis-te-caps-00.txt, work in progress.

[IGP-TE-CAP] Vasseur JP, Le Roux et al. ôRouting extensions for discovery of TE router informationö, draft-vasseur-ccamp-te-router-info-00.txt, work in progress.

[INT-AREA-REQ] Le Roux, J.L., Vasseur, J.P., Boyle, J., "Requirements for inter-area MPLS Traffic Engineering", draft-ietf-tewg-interarea-mpls-te-req-02.txt, work in progress.

[INT-AS-REQ] Zhang, R., Vasseur, J.P., "MPLS Inter-AS Traffic Engineering Requirements", draft-ietf-tewg-interas-mpls-te-req-07.txt, work in progress.

[INT-DOMAIN-FRWK] Farrel, A., Vasseur, J.P., Ayyangar, A., "A Framework for Inter-Domain MPLS Traffic Engineering", draft-farrel-ccamp-inter-domain-framework-01.txt, work in progress.

[FACILITY-BACKUP] Le Roux, J.L., Vasseur, J.P. et al. "Framework for PCE based MPLS Facility Backup Path Computation", draft-leroux-pce-backup-comp-frwk-00.txt, work in progress

[INTER-DOMAIN-SIG] Ayyangar, A., Vasseur, JP. ôInter-domain MPLS Traffic Engineering ¡ RSVP extensionsö, draft-ayyangar-ccamp-inter-domain-rsvp-te, work in progress.





[PATH-COMP] Vasseur et al, ôRSVP Path computation request and reply messagesö, draft-vasseur-mpls-computation-rsvp-05.txt, work in progress.

[RSVP-CONSTRAINTS] Kompella, K., "Carrying Constraints in RSVP", work in progress.

[LSP-ATTRIBUTE] Farrel A. et al, "Encoding of Attributes for Multiprotocol Label Switching (MPLS) Label Switched Path (LSP)

Establishment Using RSVP-TE", (work in progress).

[GMPLS-OVERLAY] G. Swallow et al, "GMPLS RSVP Support for the Overlay Model", (work in progress).

[EXCLUDE-ROUTE] Lee et all, Exclude Routes - Extension to RSVP-TE, draft-ietf-ccamp-rsvp-te-exclude-route-00.txt, work in progress.

[INTER-AREA-TE] Kompella et all,öMulti-area MPLS Traffic Engineeringö, draft-kompella-mpls-multiarea-te-04.txt, work in progress.

[LSPPING] Kompella, K., Pan, P., Sheth, N., Cooper, D.,Swallow, G., Wadhwa, S., Bonica, R., " Detecting Data Plane Liveliness in MPLS", Internet Draft <draft-ietf-mpls-lsp-ping-02.txt>, October 2002. (Work in Progress)

[MPLS-TTL], Agarwal, et al, "Time to Live (TTL) Processing in MPLS Networks", RFC 3443 Updates RFC 3032) ", January 2003

[LOOSE-PATH-REOPT] Vasseur, Ikejiri and Zhang ôReoptimization of an explicit loosely routed MPLS TE pathsö, draft-vasseur-ccamp-loose-path-reopt-02.txt, July 2004, Work in Progress.

[NODE-ID] Vasseur, Ali and Sivabalan, ôDefinition of an RRO node-id subobjectö, draft-ietf-mpls-nodeid-subobject-02.txt, work in progress.

[LSP-HIER] Kompella K., Rekhter Y., "LSP Hierarchy with Generalized MPLS TE", draft-ietf-mpls-lsp-hierarchy-08.txt, March 2002.

[MPLS-TTL], Agarwal, et al, "Time to Live (TTL) Processing in MPLS Networks", RFC 3443 (Updates RFC 3032) ", January 2003.

Authors' Address:

Jean-Philippe Vasseur (Editor)
Cisco Systems, Inc.
**300 Beaver Brook Road**
Boxborough , MA - 01719
USA
Email: jpv@cisco.com





Arthi Ayyangar (Editor)

Juniper Networks, Inc
1194 **N.Mathilda Ave**
Sunnyvale, CA 94089
USA
e-mail: arthi@juniper.net

Raymond Zhang
Infonet Services Corporation
2160 **E. Grand Ave.**
El Segundo, CA 90025
USA
Email: raymond_zhang@infonet.com