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A Backward Recursive PCE-based Computation (BRPC) Procedure To Compute Shortest Constrained Inter-domain Traffic Engineering Label Switched Paths

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Abstract

The ability to compute shortest constrained Traffic Engineering Label Switched Paths (TE LSPs) in Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) networks across multiple domains (where a domain is a collection of network elements within a common sphere of address management or path computational responsibility such as an

IGP area or an Autonomous Systems) has been identified as a key requirement. This document specifies a procedure relying on the use of multiple Path Computation Elements (PCEs) to compute such inter-domain shortest constrained paths across a predetermined sequence of domains, using a backward recursive path computation technique. This technique preserves confidentiality across domains, which is sometimes required when domains are managed by different Service Providers.

Requirements Language

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].

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1. Introduction

The requirements for inter-area and inter-AS MPLS Traffic Engineering (TE) have been developed by the Traffic Engineering Working Group (TE WG) and have been stated in [RFC4105] and [RFC4216], respectively.

The framework for inter-domain Multiprotocol Label Switching (MPLS) Traffic Engineering (TE) has been provided in [RFC4726].

[RFC5152] defines a technique for establishing an inter-domain Generalized MPLS (GMPLS) TE Label Switched Path (LSP) whereby the path is computed during the signalling process on a per-domain basis by the entry boundary node of each domain (each node responsible for triggering the computation of a section of an inter-domain TE LSP path is always along the path of such TE LSP). This path computation technique fulfills some of the requirements stated in [RFC4105] and [RFC4216] but not all of them. In particular, it cannot guarantee to find an optimal (shortest) inter-domain constrained path. Furthermore, it cannot be efficiently used to compute a set of inter-domain diversely routed TE LSPs.

The Path Computation Element (PCE) architecture is defined in [RFC4655]. The aim of this document is to describe a PCE-based path computation procedure to compute optimal inter-domain constrained (G)MPLS TE LSPs.

Qualifying a path as optimal requires some clarification. Indeed, a globally optimal TE LSP placement usually refers to a set of TE LSPs whose placements optimize the network resources with regards to a specified objective function (e.g., a placement that reduces the maximum or average network load while satisfying the TE LSP constraints). In this document, an optimal inter-domain constrained TE LSP is defined as the shortest path satisfying the set of required constraints that would be obtained in the absence of multiple domains (in other words, in a totally flat IGP network between the source and destination of the TE LSP). Note that this requires to use consistent metric schemes in each domain (see section Section 13).

2. Terminology

ABR: Area Border Routers. Routers used to connect two IGP areas (areas in OSPF or levels in IS-IS).

ASBR: Autonomous System Border Routers. Routers used to connect together ASes of the same or different Service Providers via one or more Inter-AS links.

Boundary Node (BN): a boundary node is either an ABR in the context of inter-area Traffic Engineering or an ASBR in the context of inter-AS Traffic Engineering.

Entry BN of domain(n): a BN connecting domain(n-1) to domain(n) along a determined sequence of domains.

Exit BN of domain(n): a BN connecting domain(n) to domain(n+1) along a determined sequence of domains.

Inter-AS TE LSP: A TE LSP that crosses an AS boundary.

Inter-area TE LSP: A TE LSP that crosses an IGP area boundary.

LSR: Label Switching Router.

LSP: Label Switched Path.

PCC: Path Computation Client. Any client application requesting a path computation to be performed by the Path Computation Element.

PCE (Path Computation Element): an entity (component, application or network node) that is capable of computing a network path or route based on a network graph and applying computational constraints.

PCE(i) is a PCE with the scope of domain(i).

TED: Traffic Engineering Database.

VSPT: Virtual Shortest Path Tree.

The notion of contiguous, stitched and nested TE LSPs is defined in [RFC4726] and will not be repeated here.

3. General Assumptions

In the rest of this document, we make the following set of assumptions common to inter-area and inter-AS MPLS TE:

o Each IGP area or Autonomous System (AS) is assumed to be Traffic Engineering enabled.

o No topology or resource information is distributed between domains (as mandated per [RFC4105] and [RFC4216]), which is critical to preserve IGP/BGP scalability and confidentiality.

o While certain constraints like bandwidth can be used across different domains, other TE constraints like resource affinity, color, metric, etc. as listed in [RFC2702] could be translated at domain boundaries. If required, it is assumed that, at the domain boundary nodes, there will exist some sort of local mapping based on policy agreement, in order to translate such constraints across domain boundaries during the inter-PCE communication process.

o Each AS can be made of several IGP areas. The path computation procedure described in this document applies to the case of a single AS made of multiple IGP areas, multiple ASes made of a single IGP area or any combination of the above. For the sake of simplicity, each AS will be considered to be made of a single area in this document. The case of an Inter-AS TE LSP spanning multiple ASes where some of those ASes are themselves made of multiple IGP areas can be easily derived from this case by applying the BRPC procedure described in this document, recursively.

- o The domain path (set of domains traversed to reach the destination domain) is either administratively pre-determined or discovered by some means that is outside of the scope of this document.

4. BRPC Procedure

The BRPC procedure is a Multiple-PCE path computation technique as described in [RFC4655]. A possible model consists of hosting the PCE function on boundary nodes (e.g., ABR or ASBR) but this is not mandated by the BRPC procedure.

The BRPC procedure relies on communication between cooperating PCEs. In particular, the PCC sends a PCReq to a PCE in its domain. The request is forwarded between PCEs, domain-by-domain until the PCE responsible for the domain containing the LSP destination is reached. The PCE in the destination domain creates a tree of potential paths to the destination (the Virtual Shortest Path Tree - VSPT) and passes this back to the previous PCE in a PCRep. Each PCE in turn adds to the VSPT and passes it back until the PCE in the source domain uses the VSPT to select an end-to-end path that it sends to the PCC.

The BRPC procedure does not make any assumption with regards to the nature of the inter-domain TE LSP that could be contiguous, nested or stitched.

Furthermore, no assumption is made on the actual path computation algorithm in use by a PCE (e.g., it can be any variant of CSPF or an algorithm based on linear-programming to solve multi-constraint

optimization problems).

4.1. Domain Path Selection

The PCE-based BRPC procedure applies to the computation of an optimal constrained inter-domain TE LSP. The sequence of domains to be traversed is either administratively pre-determined or discovered by some means that is outside of the scope of this document. The PCC MAY indicate the sequence of domains to be traversed using the IRO defined in [I-D.ietf-pce-pcep] so that it is available to all PCEs. Note also that a sequence of PCEs MAY be enforced by policy on the PCC and this constraint can be carried in the PCEP path computation request (as defined in [I-D.ietf-pce-monitoring]).

The BRPC procedure guarantees to compute the optimal path across a specific sequence of traversed domains (which constitutes an additional constraint). In the case of an arbitrary set of meshed domains, the BRPC procedure can be used to compute the optimal path across each domain set in order to get the optimal constrained path between the source and the destination of the TE LSP. The BRPC procedure can also be used across a subset of all domain sequences, and the best path among these sequences can then be selected.

4.2. Mode of Operation

Definition of VSPT(i)

In each domain i:

- o There is a set of X-en(i) entry BNs noted BN-en(k,i) where BN-en(k,i) is the kth entry BN of domain(i).

- o There is a set of X-ex(i) exit BNs noted BN-ex(k,i) where BN-ex(k,i) is the kth exit BN of domain(i).

VSPT(i): MP2P (MultiPoint To Point) tree returned by PCE(i) to PCE(i-1):

```
            Root (TE LSP destination)
            /         I             \
      BN-en(1,i)   BN-en(2,i) ... BN-en(j,i).
```

Where [X-en(i)] is the number of entry BNs in domain i
and j<= [X-en(i)]

Figure 1 - MP2P Tree

Each link of tree VSPT(i) represents the shortest constrained path between BN-en(j,i) and the TE LSP destination that satisfies the set of required constraints for the TE LSP (bandwidth, affinities, ...). These are path segments to reach the TE LSP destination from BN-en(j,i).

Note that PCE(i) only considers the entry BNs of domain(i). That is only the BNs that provide connectivity from domain(i-1). That is, the set BN-en(k,i) is only made of those BNs that provide connectivity from domain (i-1) to domain(i). Furthermore, some BNs may be excluded according to policy constraints (either due to local policy or policies signaled in the path computation request).

Step 1: the PCC needs to first determine the PCE capable of serving its path computation request (this can be done thanks to local configuration or via IGP discovery (see [RFC5088] and [RFC5089])). The path computation request is then relayed until reaching a PCE(n) such that the TE LSP destination resides in the domain(n). At each step of the process, the next PCE can either be statically configured or dynamically discovered via IGP/BGP extensions. If no next PCE can be found or the next hop PCE of choice is unavailable, the procedure stops and a path computation error is returned (see Section 9). If PCE(i-1) discovers multiple PCEs for the adjacent domain(i), PCE(i) may select a subset of these PCEs based on some local policies or heuristics. The PCE selection process is outside of the scope of this document.

Step 2: PCE(n) computes VSPT(n) made of the list of shortest constrained paths between every BN-en(j,n) and the TE LSP destination using a suitable path computation algorithm (e.g. CSPF) and returns the computed VSPT(n) to PCE(n-1).

Step i:

- For i=n-1 to 2: PCE(i) computes VSPT(i), the tree made of the shortest constrained paths between each BN-en(j,i) and the TE LSP destination. It does this by considering its own TED and the information in VSPT(i+1).

In the case of Inter-AS TE LSP computation, this requires to also add the inter-AS TE links connecting the domain(i) to the domain(i+1).

Step n

Finally PCE(1) computes the end-to-end shortest constrained path from the source to the destination and returns the corresponding path to the requesting PCC in the form of a PCRep message as defined in [I-D.ietf-pce-pcep].

Each branch of the VSPT tree (path) may be returned in the form of an explicit path (in which case all the hops along the path segment are listed) or a loose path (in which case only the BN is specified) so as to preserve confidentiality along with the respective cost. In the later case, various techniques can be used in order to retrieve the computed explicit paths on a per domain basis during the signaling process thanks to the use of path keys as described in [I-D.ietf-pce-path-key].

A PCE that can compute the requested path for more than one consecutive domain on the path SHOULD perform this computation for all such domains before passing the PCRep to the previous PCE in the sequence.

BRPC guarantees to find the optimal (shortest) constrained inter-domain TE LSP according to a set of defined domains to be traversed. Note that other variants of the BRPC procedure 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. PCEP Protocol Extensions

The BRPC procedure requires the specification of a new flag of the RP object carried within the PCReq message (defined in [I-D.ietf-pce-pcep]) to specify that the shortest paths satisfying the constraints from the destination to the set of entry boundary nodes are requested (such set of paths forms the downstream VSPT as specified in Section 4.2).

The following new flag of the RP object is defined:

VSPT Flag

Bit Number	Name Flag
7	VSPT

When set, the VSPT Flag indicates that the PCC requests the computation of an inter-domain TE LSP using the BRPC procedure defined in this document.

Because path segments computed by a downstream PCE in the context of the BRPC procedure MUST be provided along with their respective path costs, the C flag of the METRIC object carried within the PCReq message MUST be set. It is the choice of the requester to appropriately set the O bit of the RP object.

6. VSPT Encoding

The VSPT is returned within a PCRep message. The encoding consists of a non-ordered lists of EROs where each ERO represents a path segment from a BN to the destination specified in the END-POINT object of the corresponding PCReq message.

Example:

```
<---- area 1 ----><---- area 0 -----><------ area 2 ------>
                                    ABR1-A-B-+
                                     |       |
                                    ABR2-----D
                                     |       |
                                    ABR3--C--+
```

Figure 2 - An Example of VPST Encoding Using a Set of EROs

In the simple example shown in figure 2, if we make the assumption that a constrained path exists between each ABR and the destination D, the VSPT computed by a PCE serving area 2 consists of the following non-ordered set of EROs:

- o ERO1: ABR1(TE Router ID)-A(Interface IP address)-B(Interface IP address)-D(TE Router ID)
- o ERO2: ABR2(TE Router ID)-D(TE Router ID)
- o ERO3: ABR3(TE Router ID)-C(interface IP adress)-D(TE Router ID)

The PCReq message, PCRep message, PCEP END-POINT and ERO objects are defined in [I-D.ietf-pce-pcep]

7. Inter-AS TE Links

In the case of Inter-AS TE LSP path computation, the BRPC procedure requires the knowledge of the traffic engineering attributes of the Inter-AS TE links: the process by which the PCE acquires this information is out of the scope of the BRPC procedure, which is compliant with the PCE architecture defined in [RFC4655].

That said, a straightforward solution consists of allowing the ASBRs to flood the TE information related to the inter-ASBR links although no IGP TE is enabled over those links (there is no IGP adjacency over the inter-ASBR links). This allows the PCE of a domain to get entire TE visibility up to the set of entry ASBRs in the downstream domain

(see the IGP extensions defined in [I-D.ietf-ccamp-isis-interas-te-extension] and [I-D.ietf-ccamp-ospf-interas-te-extension]).

8. Usage In Conjunction With Per-domain Path Computation

The BRPC procedure may be used to compute path segments in conjunction with other path computation techniques (such as the per-domain path computation technique defined in [RFC5152]) to compute the end-to-end path. In this case end-to-end path optimality can no longer be guaranteed.

9. BRPC Procedure Completion Failure

If the BRPC procedure cannot be completed because a PCE along the domain does not recognize the procedure (VSPT flag of the RP object), as stated in [I-D.ietf-pce-pcep], the PCE sends a PCErr message to the upstream PCE with an Error-Type=4 (not supported object), Error-value-4 (Unsupported paramater). The PCE may include the parent object (RP object) up to and including (but no further than) the unknown or unsupported parameter. In this case where the unknown or unsupported parameter is a bit flag (VSPT flag), the included RP object should contain the whole bit flag field with all bits after the parameter at issue set to zero. The corresponding path computation request is then cancelled by the PCE without further notification.

If the BRPC procedure cannot be completed because a PCE along the domain path recognises but does not support the procedure, it MUST return a PCErr message to the upstream PCE with an Error-Type "BRPC procedure completion failure".

The PCErr message MUST be relayed to the requesting PCC.

PCEP-ERROR objects are used to report a PCEP protocol error and are characterized by an Error-Type which specifies the type of error and an Error-value that provides additional information about the error type. Both the Error-Type and the Error-Value are managed by IANA. A new Error-Type is defined that relates to the BRPC procedure.


```
  Error-type        Meaning
      13            BRPC procedure completion failure
                    Error-value
                      1: BRPC procedure not supported by one or more PCEs
                         along the domain path
```

10. Applicability

As discussed in Section 3, the requirements for inter-area and inter-AS MPLS Traffic Engineering have been developed by the Traffic Engineering Working Group (TE WG) and have been stated in [RFC4105] and [RFC4216], respectively. Among the set of requirements, both documents indicate the need for some solution providing the ability to compute an optimal (shortest) constrained inter-domain TE LSP and to compute a set of diverse inter-domain TE LSPs.

10.1. Diverse end-to-end path computation

PCEP (see [I-D.ietf-pce-pcep]) allows a PCC to request the computation of a set of diverse TE LSPs thanks to the SVEC object by setting the flags L, N or S to request link, node or SRLG diversity respectively. Such requests MUST be taken into account by each PCE along the path computation chain during the VSPT computation. In the context of the BRPC procedure, a set of diversely routed TE LSPs between two LSRs can be computed since the paths segments of the VSPT are simultaneously computed by a given PCE. The BRPC procedure 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).

By constrast, with a 2-step approach consisting of computing the first path followed by the computation of the second path after having removed the set of network elements traversed by the first path (if that does not violate confidentiality preservation), one cannot guarantee that a solution will be found even if such solution exists. Furthermore, even if a solution is found, it may not be the most optimal one with respect to an objective function such as minimizing the sum of the paths costs, bounding the path delays of both paths and so on. Finally, it must be noted that such a 2-step path computation approach is usually less efficient in term of signalling delays since it requires two serialized TE LSP set up.

10.2. Path Optimality

BRPC guarantees that the optimal (shortest) constrained inter-domain path will always be found subject to policy constraints. When combined with other local path computation techniques (e.g. in the

case of stitched/nested TE LSP) and in the case where a domain has more than one BN-en or more than one BN-ex, optimality after some network change within the domain can only be guaranteed by re-executing the BRPC procedure.

11. Reoptimization Of An Inter-domain TE LSP

The ability to reoptimize an existing inter-domain TE LSP path has been explicitly listed as a requirement in [RFC4105] and [RFC4216]. In the case of a TE LSP reoptimization request, the reoptimization procedure defined in [I-D.ietf-pce-pcep] applies where the path in use (if available on the head-end) is provided as part of the path computation request in order for the PCEs involved in the reoptimization request to avoid double bandwidth accounting.

12. Path Computation Failure

If a PCE requires to relay a path computation request according to the BRPC procedure defined in this document to a downstream PCE and no such PCE is available, the PCE MUST send a negative path computation reply to the requester using a PCReq message as specified in [I-D.ietf-pce-pcep] that contains a NO-PATH object. In such case, the NO-PATH object MUST carry a NO-PATH-VECTOR TLV (defined in [I-D.ietf-pce-pcep]) with the newly defined bit named "BRPC Path Computation chain unavailable" set.

Bit number	Name Flag
4	BRPC Path computation chain unavailable

13. Metric Normalization

In the case of inter-area TE, the same IGP/TE metric scheme is usually adopted for all the IGP areas (e.g., based on the link-speed, propagation delay or some other combination of link attributes). Hence, the proposed set of mechanisms always computes the shortest path across multiple areas obeying the required set of constraints with respect to a specified objective function. Conversely, in the case of Inter-AS TE, in order for this path computation to be meaningful, metric normalization between ASes may be required. One solution to avoid IGP metric modification would be for the Service Providers to agree on a TE metric normalization scheme and use the TE metric for TE LSP path computation (in that case, this must be requested in the PCEP Path computation request) using the METRIC object (defined in [I-D.ietf-pce-pcep]).

14. Manageability Considerations

This section follows the guidance of [I-D.ietf-pce-manageability-requirements].

14.1. Control of Function And Policy

The only configurable item is the support of the BRPC procedure on a

PCE. The support of the BRPC procedure by the PCE MAY be controlled by a policy module governing the conditions under which a PCE should participate to the BRPC procedure (origin of the requests, number of requests per second, ...). If the BRPC is not supported/allowed on a PCE, it MUST send a PCErr message as specified in Section 9.

14.2. Information And Data Models

A BRPC MIB module will be specified in a separate document.

14.3. Liveness Detection and Monitoring

The BRPC procedure is a Multiple-PCE path computation technique and as such a set of PCEs are involved in the path computation chain. If the path computation chain is not operational either because at least one PCE does not support the BRPC procedure or because one of the PCEs that must be involved in the path computation chain is not available, procedures are defined to report such failures in Section 9 and Section 12 respectively. Furthermore, a built-in diagnostic tool to check the availability and performances of a PCE chain is defined in [I-D.ietf-pce-monitoring].

14.4. Verifying Correct Operation

Verifying the correct operation of BRPC can be performed by monitoring a set of parameters. A BRPC implementation SHOULD provide the following parameters:

o Number of successful BRPC Procedure completions on a per PCE peer basis,

o Number of BRPC procedure completion failures because the VSPT flag was not recognized (on a per PCE peer basis),

o Number of BRPC procedure completetion failures because the BRPC procedure was not supported (on a per PCE peer basis),

14.5. Requirements on Other Protocols and Functional Components

The BRPC procedure does not put any new requirements on other protocol. That said, since the BRPC procedure relies on the PCEP protocol, there is a dependency between BRPC and PCEP; consequently the BRPC procedure inherently makes use of the management functions developed for PCEP.

14.6. Impact on Network Operation

The BRPC procedure does not have any significant impact on network operation: indeed, BRPC is a Multiple-PCE path computation scheme as defined in [RFC4655] and does not differ from any other path computation request.

14.7. Path Computation Chain Monitoring

[I-D.ietf-pce-monitoring] specifies a set of mechanisms that can be used to gather PCE state metrics. Because BRPC is a Multiple-PCE path computation techniques, such mechanism could be advantageously used in the context of the BRPC procedure to check the liveness of the path computation chain, locate a faulty component, monitor the overall performance and so on.

15. IANA Considerations

15.1. New Flag Of The RP Object

A new flag of the RP object (specified in [I-D.ietf-pce-pcep]) is defined in this document.

```
VSPT Flag
Bit Number       Name Flag    Reference
  7                VSPT       This document
```

15.2. New Error-Type And Error-Value

A new Error-Type is defined in this document (Error-Type and Error-value to be assigned by IANA).

Error-type	Meaning	Reference
13	BRPC procedure completion failure Error-value 1: BRPC procedure not supported by one a PCE along the domain path	This document

15.3. New Flag Of The NO-PATH-VECTOR TLV

A new flag of the NO-PATH-VECTOR TLV defined in [I-D.ietf-pce-pcep]) is specified in this document.

Bit number	Meaning	Reference
4	BRPC Path computation chain unavailable	This document

16. Security Considerations

The BRPC procedure relies on the use of the PCEP protocol and as such is subjected to the potential attacks listed in section 11 of [I-D.ietf-pce-pcep]. In addition to the security mechanisms described in [I-D.ietf-pce-pcep] with regards to spoofing, snooping, falsification and Denial of Service, an implementation MAY support a policy module governing the conditions under which a PCE should participate to the BRPC procedure.

The BRPC procedure does not increase the information exchanged between ASes and preserves topology confidentiality, in compliance with [RFC4105] and [RFC4216].

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18. References

18.1. Normative References

[I-D.ietf-pce-pcep]
Ayyangar, A., Oki, E., Atlas, A., Dolganow, A., Ikejiri,

Y., Kumaki, K., Vasseur, J., and J. Roux, "Path Computation Element (PCE) Communication Protocol (PCEP)",

draft-ietf-pce-pcep-12 (work in progress), March 2008.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

18.2. Informative References

[I-D.ietf-ccamp-isis-interas-te-extension]
Chen, M., Zhang, R., and X. Duan, "ISIS Extensions in Support of Inter-AS Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Traffic Engineering", draft-ietf-ccamp-isis-interas-te-extension-02 (work in progress), April 2008.

[I-D.ietf-ccamp-ospf-interas-te-extension]
Chen, M., Zhang, R., and X. Duan, "OSPF Extensions in Support of Inter-AS Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Traffic Engineering", draft-ietf-ccamp-ospf-interas-te-extension-05 (work in progress), April 2008.

[I-D.ietf-pce-manageability-requirements]
Farrel, A., "Inclusion of Manageability Sections in PCE Working Group Drafts", draft-ietf-pce-manageability-requirements-03 (work in progress), February 2008.

[I-D.ietf-pce-monitoring]
Vasseur, J., Roux, J., and Y. Ikejiri, "A set of monitoring tools for Path Computation Element based Architecture", draft-ietf-pce-monitoring-01 (work in progress), February 2008.

[I-D.ietf-pce-path-key]
Bradford, R. and J. Vasseur, "Preserving Topology Confidentiality in Inter-Domain Path Computation Using a Key-Based Mechanism", draft-ietf-pce-path-key-02 (work in progress), February 2008.

[RFC2702] Awduche, D., Malcolm, J., Agogbua, J., O'Dell, M., and J. McManus, "Requirements for Traffic Engineering Over MPLS", RFC 2702, September 1999.

[RFC4105] Le Roux, J., Vasseur, J., and J. Boyle, "Requirements for Inter-Area MPLS Traffic Engineering", RFC 4105, June 2005.

[RFC4216] Zhang, R. and J. Vasseur, "MPLS Inter-Autonomous System (AS) Traffic Engineering (TE) Requirements", RFC 4216,

November 2005.

[RFC4655] Farrel, A., Vasseur, J., and J. Ash, "A Path Computation Element (PCE)-Based Architecture", RFC 4655, August 2006.

[RFC4726] Farrel, A., Vasseur, J., and A. Ayyangar, "A Framework for Inter-Domain Multiprotocol Label Switching Traffic Engineering", RFC 4726, November 2006.

[RFC5088] Le Roux, JL., Vasseur, JP., Ikejiri, Y., and R. Zhang, "OSPF Protocol Extensions for Path Computation Element (PCE) Discovery", RFC 5088, January 2008.

[RFC5089] Le Roux, JL., Vasseur, JP., Ikejiri, Y., and R. Zhang, "IS-IS Protocol Extensions for Path Computation Element (PCE) Discovery", RFC 5089, January 2008.

[RFC5152] Vasseur, JP., Ayyangar, A., and R. Zhang, "A Per-Domain Path Computation Method for Establishing Inter-Domain Traffic Engineering (TE) Label Switched Paths (LSPs)", RFC 5152, February 2008.

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