          Path Computation Element Communication Protocol (PCECP) Specific
          Requirements for Inter-Area MPLS and GMPLS Traffic Engineering

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Abstract

   For scalability purposes, a network may comprise multiple Interior
   Gateway Protocol (IGP) areas. An inter-area Traffic Engineered Label
   Switched Path (TE-LSP) is an LSP that transits through at least two
   IGP areas. In a multi-area network, topology visibility remains
   local to a given area, and a head-end Label Switching Router (LSR)
   cannot compute an inter-area shortest constrained path. One key
   application of the Path Computation Element (PCE)-based architecture
   is the computation of inter-area TE-LSP paths. The PCE Communication
   Protocol (PCECP) is used to communicate computation requests from
   Path Computation Clients (PCCs) to PCEs, and to return computed paths
   in responses. This document lists a detailed set of PCECP-specific
   requirements for support of inter-area TE-LSP path computation. It
   complements the generic requirements for a PCE Communication
   Protocol.

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1. **Introduction**

   [RFC4105] lists a set of motivations and requirements for setting up
   TE-LSPs across IGP area boundaries. These LSPs are called inter-area
   TE-LSPs. These requirements include the computation of inter-area
   shortest constrained paths with a key guideline being to respect the
   IGP hierarchy concept, and particularly the containment of topology
   information. The main challenge with inter-area MPLS-TE lies in path
   computation. Indeed, the head-end LSR cannot compute an explicit
   path across areas, as its topology visibility is limited to its own
   area.

   Inter-area path computation is one of the key applications of the
   PCE-based architecture [RFC4655]. The computation of optimal inter-
   area paths may be achieved using the services of one or more PCEs.

   Such PCE-based inter-area path computation could rely for instance on
   a single multi-area PCE that has the TE database of all the areas in
   the IGP domain and can directly compute an end-to-end constrained
   shortest path. Alternatively, this could rely on the cooperation
   between PCEs whereby each PCE covers one or more IGP areas and the
   full set of PCEs covers all areas.

The generic requirements for a PCE Communication Protocol (PCECP),
which allows a PCC to send path computation requests to a PCE and the
PCE to send path computation responses to a PCC, are set forth in
[RFC4657]. The use of a PCE-based approach for inter-area path
computation implies specific requirements on a PCE Communication
Protocol, in addition to the generic requirements already listed in
[RFC4657]. This document complements these generic requirements by
listing a detailed set of PCECP requirements specific to inter-area
path computation.

It is expected that PCECP procedures be defined to satisfy these
requirements.

Note that PCE-based inter-area path computation may require a
mechanism for automatic PCE discovery across areas, which is out of
the scope of this document. Detailed requirements for such a
mechanism are discussed in [RFC4674].

2. Terminology

LSR: Label Switching Router.

LSP: MPLS Label Switched Path.

TE-LSP: Traffic Engineered Label Switched Path.

IGP area: OSPF area or IS-IS level.

ABR: IGP Area Border Router, a router that is attached to more than
one IGP area (ABR in OSPF or L1/L2 router in IS-IS).

Inter-Area TE-LSP: TE-LSP that traverses more than one IGP area.

CSPF: Constrained Shortest Path First.

SRLG: Shared Risk Link Group.

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.

PCC: Path Computation Client, any application that request path
computation to be performed by a PCE.

PCECP: PCE Communication Protocol, a protocol for communication
between PCCs and PCEs, and between PCEs.

   ERO: Resource Reservation Protocol (RSVP)-TE Explicit Route Object.
   It encodes the explicit path followed by a TE-LSP.

2.1. 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 [RFC2119].

3. Motivations for PCE-Based Inter-Area Path Computation

   IGP hierarchy enables improved IGP scalability by dividing the IGP
   domain into areas and limiting the flooding scope of topology
   information to within area boundaries. A router in an area has full
   topology information for its own area, but only information about
   reachability to destinations in other areas. Thus, a head-end LSR
   cannot compute an end-to-end path that crosses the boundary of its
   IGP area(s).

   A current solution for computing inter-area TE-LSP path relies on a
   per-domain path computation [PD-COMP]. It is based on loose hop
   routing with an ERO expansion on each ABR. This allows an LSP to be
   set up following a constrained path, but faces two major limitations:

   - This does guarantee the use of an optimal constrained path.

   - This may lead to several crankback signaling messages and hence
     delay the LSP setup, and may also invoke possible alternate routing
     activities.

   Note that, here, by optimal constrained path we mean the shortest
   constrained path across multiple areas, taking into account either
   the IGP or TE metric [RFC3785]. In other words, such a path is the
   path that would have been computed by making use of some CSPF
   algorithm in the absence of multiple IGP areas.

   The PCE-based architecture [RFC4655] is well suited to inter-area
   path computation. It allows the path computation limitations
   resulting from the limited topology visibility to be overcome by
   introducing path computation entities with more topology visibility,
   or by allowing cooperation between path computation entities in each
   area.

There are two main approaches for the computation of an inter-area
optimal path:

- Single-PCE computation: The path is computed by a single PCE that
  has topology visibility in all areas and can compute an end-to-end
  optimal constrained path on its own.

- Multiple-PCE computation with inter-PCE communication: The path
  computation is distributed on multiple PCEs, which have partial
  topology visibility. They compute path segments in their domains
  of visibility and collaborate with each other so as to arrive at an
  end-to-end optimal constrained path. Such collaboration is ensured
  thanks to inter-PCE communication.

Note that the use of a PCE-based approach to perform inter-area path
computation implies specific functional requirements in a PCECP, in
addition to the generic requirements listed in [RFC4657]. These
specific requirements are discussed in the next section.

4. Detailed Inter-Area Specific Requirements on PCECP

This section lists a set of additional requirements for the PCECP
that complement requirements listed in [RFC4657] and are specific to
inter-area (G)MPLS-TE path computation.

4.1. Control and Recording of Area Crossing

In addition to the path constraints specified in [RFC4657], the
request message MUST allow indicating whether or not area crossing is
permitted. Indeed, when the source and destination reside in the
same IGP area, there may be intra-area and inter-area feasible paths.
As set forth in [RFC4105], if the shortest path is an inter-area
path, an operator either may want to avoid, as far as possible,
crossing areas and thus may prefer selecting a sub-optimal intra-area
path or, conversely, may prefer to use a shortest path, even if it
crosses areas.

Also, when the source and destination reside in the same area it may
be useful to know whether the returned path is an inter-area path.
Hence, the response message MUST allow indicating whether the
computed path is crossing areas.

4.2. Area Recording

It may be useful for the PCC to know the set of areas crossed by an
inter-area path and the corresponding path segments. Hence, the
response message MUST allow identifying the crossed areas. Also, the
response message MUST allow segmenting the returned path and marking
each segment so that it is possible to tell which piece of the path
lies within which area.

4.3. Strict Explicit Path and Loose Path

A Strict Explicit Path is defined as a set of strict hops, while a
Loose Path is defined as a set of at least one loose hop and zero,
one or more strict hops. An inter-area path may be strictly explicit
or loose (e.g., a list of ABRs as loose hops). It may be useful to
indicate to the PCE if a Strict Explicit path is required or not.
Hence, the PCECP request message MUST allow indicating whether a
Strict Explicit Path is required/desired.

4.4. PCE List Enforcement and Recording in Multiple-PCE Computation

In case of multiple-PCE inter-area path computation, a PCC may want
to indicate a preferred list of PCEs to be used, one per area. In
each area, the preferred PCE should be tried before another PCE is
selected. Note that if there is no preferred PCE indicated for an
area, any PCE in that area may be used.

Hence, the PCECP request message MUST support the inclusion of a list
of preferred PCEs per area. Note that this requires that a PCC in
one area has knowledge of PCEs in other areas. This could rely on
configuration or on a PCE discovery mechanism, allowing discovery
across area boundaries (see [RFC4674]).

Also, it would be useful to know the list of PCEs that effectively
participated in the computation. Hence, the request message MUST
support a request for PCE recording, and the response message MUST
support the recording of the set of one or more PCEs that took part
in the computation.

It may also be useful to know the path segments computed by each PCE.
Hence, the request message SHOULD allow a request for the
identification of path segments computed by a PCE, and the response
message SHOULD allow identifying the path segments computed by each
PCE.

4.5. Inclusion of Area IDs in Request

Knowledge of the areas in which the source and destination lie would
allow a PCE to select an appropriate downstream PCE. This would be
useful when the area ID(s) of a PCE (i.e., the area(s) where it has
visibility) is/are known, which can be achieved by the PCE Discovery
Protocol (see [RFC4674]) or by any other means.

A PCE may not have any visibility of the source/destination area and
hence may not be able to determine the area of the
source/destination. In such a situation, it would be useful for a
PCC to indicate the source and destination area IDs in its request
message.

For that purpose, the request message MUST support the inclusion of
the source and destination area IDs. Note that this information
could be learned by the PCC through configuration.

4.6. Area Inclusion/Exclusion

In some situations, it may be useful for the request message to
indicate one or more area(s) that must be followed by the path to be
computed. It may also be useful for the request message to indicate
one or more area(s) that must be avoided by the path to be computed
(e.g., request for a path between LSRs in two stub areas connected to
the same ABR(s), which must not cross the backbone area). Hence, the
request message MUST allow indicating a set of one or more area(s)
that must be explicitly included in the path, and a set of one or
more area(s) that must be explicitly excluded from the path.

4.7. Inter-Area Diverse Path Computation

For various reasons, including protection and load balancing, the
computation of diverse inter-area paths may be required. There are
various levels of diversity in an inter-area context:

   - Per-area diversity (intra-area path segments are link, node, or
     SRLG disjoint)

   - Inter-area diversity (end-to-end inter-area paths are link,
     node, or SRLG disjoint)

Note that two paths may be disjoint in the backbone area but non-
disjoint in peripheral areas. Also two paths may be node-disjoint
within areas but may share ABRs, in which case path segments within
an area are node-disjoint, but end-to-end paths are not node
disjoint.

The request message MUST allow requesting the computation of a set of
inter-area diverse paths between the same node pair or between
distinct node pairs. It MUST allow indicating the required level of
diversity of a set of inter-area paths (link, node, and SRLG
diversity), as well as the required level of diversity of a set of
intra-area segments of inter-area paths (link, node, and SRLG
diversity) on a per-area basis.

The response message MUST allow indicating the level of diversity of
a set of computed inter-area loose paths (link, node, and SRLG
diversity), globally, and on a per-area basis (link, node, and SRLG
diversity of intra-area path segments).

Note that, in order to ensure SRLG consistency, SRLG identifiers
within the IGP domain should be assigned and allocated by the same
entity.

Note that specific objective functions may be requested for diverse
path computation, such as minimizing the cumulated cost of a set of
diverse paths as set forth in [RFC4657].

4.8. Inter-Area Policies

In addition to the policy requirements discussed in [RFC4657], the
application of inter-area path computation policies requires some
additional information to be carried in the PCECP request messages.
The request message MUST allow for the inclusion of the address of
the originating PCC. This may be useful in a multiple-PCE
computation, so as to apply policies not only based on the PCECP peer
but also based on the originating PCC.

Note that work on supported policy models and the corresponding
requirements/implications is being undertaken as a separate work item
in the PCE working group [PCE-POL-FMWK].

4.9. Loop Avoidance

In case of multiple-PCE inter-area path computation, there may be
risks of PCECP request loops. A mechanism MUST be defined to detect
and correct PCECP request message loops. This may rely, for
instance, on the recording, in the request message, of the set of
traversed PCEs.

Also, the returned path in a response message MUST be loop free.

5. Manageability Considerations

The inter-area application implies some new manageability requirements in addition to those already listed in [RFC4657]. The PCECP PCC and PCE MIB modules MUST allow recording the proportion of inter-area requests and the success rate of inter-area requests. The PCECP PCC MIB module MUST also allow recording the performances of a PCE chain (minimum, maximum, and average response times), in case of multiple-PCE inter-area path computation.

It is really important, for diagnostic and troubleshooting reasons, to monitor the availability and performances of each PCE of a PCE chain used for inter-area path computation. Particularly, it is really important to identify the PCE(s) responsible for a delayed reply.

Hence, a mechanism MUST be defined to monitor the performances of a PCE chain. It MUST allow determining the availability of each PCE of the chain as well as its minimum, maximum, and average response times.

6. Security Considerations

IGP areas are administrated by the same entity. Hence, the inter-area application does not imply a new trust model or new security issues beyond those already defined in [RFC4657].

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