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Encoding of Objective Functions in the Path Computation Element Communication Protocol (PCEP)

Status of This Memo

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Abstract

The computation of one or a set of Traffic Engineering Label Switched Paths (TE LSPs) in MultiProtocol Label Switching (MPLS) and Generalized MPLS (GMPLS) networks is subject to a set of one or more specific optimization criteria, referred to as objective functions (e.g., minimum cost path, widest path, etc.).

In the Path Computation Element (PCE) architecture, a Path Computation Client (PCC) may want a path to be computed for one or more TE LSPs according to a specific objective function. Thus, the PCC needs to instruct the PCE to use the correct objective function. Furthermore, it is possible that not all PCEs support the same set of objective functions; therefore, it is useful for the PCC to be able to automatically discover the set of objective functions supported by each PCE.

This document defines extensions to the PCE communication Protocol (PCEP) to allow a PCE to indicate the set of objective functions it supports. Extensions are also defined so that a PCC can indicate in a path computation request the required objective function, and a PCE can report in a path computation reply the objective function that was used for path computation.

This document defines objective function code types for six objective functions previously listed in the PCE requirements work, and provides the definition of four new metric types that apply to a set of synchronized requests.

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1. Introduction

The Path Computation Element-based network architecture [RFC4655] defines a Path Computation Element (PCE) as an entity capable of computing the paths of Traffic Engineered Label Switched Paths (TE LSPs) based on a network graph and of applying computational constraints. A PCE services path computation requests that are sent by Path Computation Clients (PCC).

The PCE communication Protocol (PCEP), defined in [RFC5440], allows for communication between a PCC and a PCE or between two PCEs, in compliance with requirements and guidelines set forth in [RFC4657]. Such interactions include path computation requests and path computation replies.

The computation of one or a set of TE LSPs is subject to a set of one or more optimization criteria, called an objective function. An objective function is used by the PCE when it computes a path or a set of paths in order to select the "best" candidate paths. There is a variety of objective functions: an objective function could apply either to a set of non-synchronized path computation requests, or to a set of synchronized path computation requests. In the former case, the objective function refers to an individual path computation request (e.g., computation of the shortest constrained path where the metric is the IGP metric, computation of the least loaded constrained path, etc.). Conversely, in the latter case, the objective function refers to a set of path computation requests the computation of which is synchronized (e.g., minimize the aggregate bandwidth consumption of all LSPs, minimize the sum of the delays for two diverse paths or of the delta between those delays, etc.). Moreover, some objective functions relate to the optimization of a single metric and others to the optimization of a set of metrics (organized in a hierarchical manner, using a weighted function, etc.).

As spelled out in [RFC4674], it may be useful for a PCC to discover the set of objective functions supported by a PCE. Furthermore, [RFC4657] requires the ability for a PCC to indicate in a path computation request a required/desired objective function, as well as optional function parameters.

For these purposes, this document extends the PCE communication Protocol (PCEP). It defines PCEP extensions that allow a PCE to advertise a list of supported objective functions, as well as extensions to carry the objective function in PCEP request and reply messages. It complements the PCEP base specification [RFC5440].

Note that OSPF- and IS-IS-based PCE discovery mechanisms are defined in [RFC5088] and [RFC5089]. These mechanisms are dedicated to the discovery of a few generic parameters, while more detailed PCE parameters should be discovered using the PCE communication Protocol. Objective functions are in this second category; thus, the objective function discovery procedure is handled by PCEP.

A new PCEP TLV, named the OF-List TLV, is defined in Section 2. The OF-List TLV is carried in the PCEP OPEN object and allows a PCE to list, during PCEP session-setup phase, the objective functions that it supports.

A new PCEP object, the OF object, is defined in Section 3. The OF object is carried within a PCReq (Path Computation Request) message to indicate the required/desired objective function to be applied by a PCE, or in a PCRep (Path Computation Reply) message to indicate the objective function that was used for path computation.

Six mandatory objective functions that must be supported by PCEP are listed in [RFC4657]. This document provides a definition of these six mandatory objective functions. Additional objective functions may be defined in other documents. Note that additional objective functions are defined for the PCE Global Concurrent Optimization (GCO) application, in [PCE-GCO].

This document also provides the definition of four new metric types that apply to a set of synchronized requests.

1.1. 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].

1.2. Terminology

LSR: Label Switching Router.

OF: Objective Function. A set of one or more optimization criteria used for the computation of a single path (e.g., path cost minimization) or for the synchronized computation of a set of paths (e.g., aggregate bandwidth consumption minimization, etc.).

PCC: Path Computation Client. Any client application requesting a path computation to be performed by a 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 of applying computational constraints.

PCEP: Path Computation Element communication Protocol.

TE LSP: Traffic Engineered Label Switched Path.

1.3. Message Formats

Message formats in this document are expressed using Reduced BNF as used in [RFC5440] and defined in [RFC5511].

2. Discovery of PCE Objective Functions

This section defines PCEP extensions (see [RFC5440]) so as to support the advertisement of the objective functions supported by a PCE.

A new PCEP OF-List (Objective Function list) TLV is defined. The PCEP OF-List TLV is carried within an OPEN object. This way, during PCEP session-setup phase, a PCE can advertise to a PCEP peer the list of objective functions it supports.

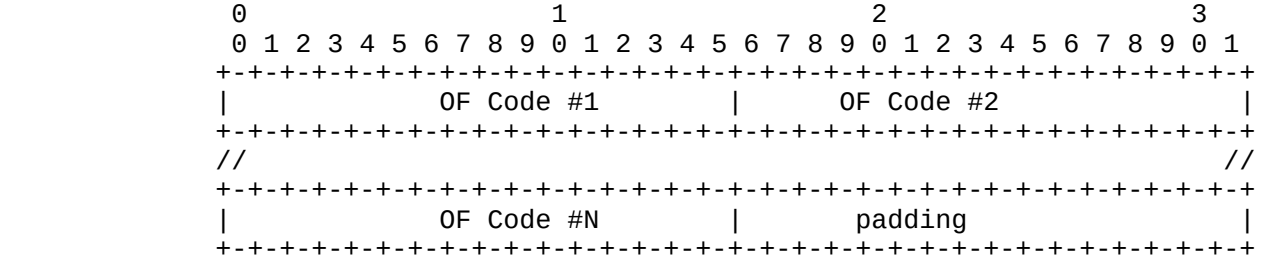
2.1. OF-List TLV

The PCEP OF-List TLV is optional. It MAY be carried within an OPEN object sent by a PCE in an Open message to a PCEP peer so as to indicate the list of supported objective functions.

The OF-List TLV format is compliant with the PCEP TLV format defined in [RFC5440]. That is, the TLV is composed of 2 octets for the type, 2 octets specifying the TLV length, and a Value field. The Length field defines the length of the value portion in octets. The TLV is padded to 4-octet alignment, and padding is not included in the Length field (e.g., a 3-octet value would have a length of three, but the total size of the TLV would be eight octets).

The PCEP OF-List TLV has the following format:

TYPE: 4
LENGTH: N * 2 (where N is the number of objective functions)
VALUE: list of 2-byte objective function code points, identifying the objective functions supported by the sender of the Open message.



OF Code (2 bytes): Objective Function code point identifier. IANA manages the "PCE Objective Function" code point registry (see Section 6).

2.2. Elements of Procedure

A PCE MAY include an OF-List TLV within an OPEN object in an Open message sent to a PCEP peer in order to advertise a set of one or more objective functions. The OF-List TLV MUST NOT appear more than once in an OPEN object. If it appears more than once, the PCEP session MUST be rejected with error type 1 and error value 1 (PCEP session establishment failure / Reception of an invalid Open message). The absence of the OF-List TLV in an OPEN object MUST be interpreted as an absence of information on the list of supported objective functions by the PCE.

As specified in [RFC5440], a PCEP peer that does not recognize the OF-List TLV will silently ignore it.

3. Objective Function in PCEP Path Computation Request and Reply Messages

This section defines PCEP extensions [RFC5440] so as to support the communication of objective functions in PCEP path computation request and reply messages. A new PCEP OF (Objective Function) object is defined, to be carried within a PCReq message in order for the PCC to indicate the required/desired objective function.

The PCEP OF object may also be carried within a PCRep message in order for the PCE to indicate the objective function that was used by the PCE.

A new flag is defined in the RP (Request Parameters) object. The flag is used in a PCReq message to indicate that the PCE MUST include an OF object in the PCRep message to indicate the objective function that was used during path computation.

Also, new PCEP error types and values are defined.

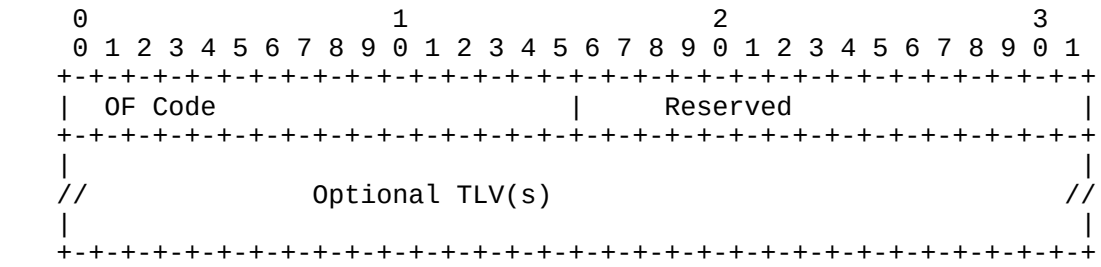
3.1. OF Object

The PCEP OF (Objective Function) object is optional. It MAY be carried within a PCReq message so as to indicate the desired/required objective function to be applied by the PCE during path computation or within a PCRep message so as to indicate the objective function that was used by the PCE during path computation.

The OF object format is compliant with the PCEP object format defined in [RFC5440].

The OF Object-Class is 21.
The OF Object-Type is 1.

The format of the OF object body is:



OF Code (2 bytes): The identifier of the objective function. IANA manages the "PCE Objective Function" code point registry (see Section 6).

Reserved (2 bytes): This field MUST be set to zero on transmission and MUST be ignored on receipt.

Optional TLVs may be defined in the future so as to encode objective function parameters.

3.1.1. Elements of Procedure

To request the use of a specific objective function by the PCE, a PCC includes an OF object in the PCReq message.

[RFC5440] specifies a bit flag, referred to as the P bit, carried in the common PCEP object header. The P bit is set by a PCC to mandate that a PCE must take the information carried in the object into account during the path computation.

If the P bit is set in the OF object, the objective function is mandatory (required objective function) and the PCE MUST use the objective function during path computation. If the P bit is clear in the OF object, the objective function is optional (desired objective function) and the PCE SHOULD apply the function if it is supported but MAY choose to apply a different objective function, according to local capabilities and policies.

On receipt of a PCReq message with an OF object, a PCE MUST proceed as follows:

- If the OF object is unknown/unsupported, the PCE MUST follow procedures defined in [RFC5440]. That is, if the P bit is set, the PCE sends a PCErr message with error type 3 or 4 (Unknown / Not supported object) and error value 1 or 2 (unknown / unsupported object class / object type), and the related path computation request MUST be discarded. If the P bit is cleared, the PCE is free to ignore the object.

- If the objective function is unknown/unsupported and the P bit is set, the PCE MUST send a PCErr message with error type 3 or 4 (Unknown / Not supported object) and error value 4 (Unrecognized/Unsupported parameter), and the related path computation request MUST be discarded.

- If the objective function is unknown/unsupported and the P bit is cleared, the PCE SHOULD apply another (default) objective function.

- If the objective function is supported but policy does not permit applying it and if the P bit is set, the PCE MUST send a PCErr message with the PCEP error type "policy-violation" (type 5) and a new error value, "objective function not allowed", which is defined in this document.

- If the objective function is supported but policy does not allow applying it and if the P bit is cleared, the PCE SHOULD apply another (default) objective function.

- If the objective function is supported and policy allows applying it and if the P bit is set, the PCE MUST apply the requested objective function. Otherwise, if the P bit is cleared, the PCE is free to apply any other objective function.

The default objective function may be locally configured.

3.2. Carrying The OF Object In a PCEP Message

The OF object MAY be carried within a PCReq message. If an objective function is to be applied to a set of synchronized path computation requests, the OF object MUST be carried just after the corresponding SVEC (Synchronization VECtor) object and MUST NOT be repeated for each elementary request.

Similarly, if a metric is to be applied to a set of synchronized requests, the METRIC object MUST follow the SVEC object and MUST NOT be repeated for each elementary request. Note that metrics applied to a set of synchronized requests are defined in Section 5.

An OF object specifying an objective function that applies to an individual path computation request (non-synchronized case) MUST follow the RP object for which it applies.

The format of the PCReq message is updated as follows. Please see Appendix A for a full set of RBNF fragments defined in this document and the necessary code license.

```
 <PCReq Message> ::= <Common Header>
                     [<svec-list>]
                     <request-list>
where:
     <svec-list> ::= <SVEC>
                     [<OF>]
                     [<metric-list>]
                     [<svec-list>]

     <request-list> ::= <request> [<request-list>]

     <request> ::= <RP>
                   <END-POINTS>
                   [<LSPA>]
                   [<BANDWIDTH>]
                   [<metric-list>]
                   [<OF>]
                   [<RRO>[<BANDWIDTH>]]
                   [<IRO>]
                   [<LOAD-BALANCING>]
```

and where:

```
     <metric-list> ::= <METRIC>[<metric-list>]
```

The OF object MAY be carried within a PCRep message to indicate the objective function used by the PCE during path computation.

When the PCE wants to indicate to the PCC the objective function that was used for the synchronized computation of a set of paths, the PCRep message MUST include the corresponding SVEC object directly followed by the OF object, which MUST NOT be repeated for each elementary request. If a metric is applicable to the set of paths, the METRIC object MUST directly follow the SVEC object and MUST NOT be repeated for each elementary request.

An OF object specifying an objective function used for an individual path computation (non-synchronized case) MUST follow the RP object for which it applies.

The format of the PCRep message is updated as follows. Please see Appendix A for a full set of RBNF fragments defined in this document and the necessary code license.

```
<PCRep Message> ::= <Common Header>
                    [<svec-list>]
                    <response-list>
```

where:

```
      <svec-list> ::= <SVEC>
                      [<OF>]
                      [<metric-list>]
                      [<svec-list>]

     <response-list> ::= <response> [<response-list>]

     <response> ::= <RP>
                    [<NO-PATH>]
                    [<attribute-list>]
                    [<path-list>]

     <path-list> ::= <path> [<path-list>]

     <path> ::= <ERO>
                <attribute-list>
```

and where:

```
     <attribute-list> ::= [<OF>]
                          [<LSPA>]
                          [<BANDWIDTH>]
                          [<metric-list>]
                          [<IRO>]

     <metric-list> ::= <METRIC> [<metric-list>]
```

Note: The OF object MAY be associated to a negative reply, i.e., a reply with a NO-PATH object.

3.3. New RP Object Flag

In some cases, where no objective function is specified in the request or an optional objective function is desired (P flag cleared in the OF object common header) but the PCE does not follow the request, the PCC may desire to know the objective function that was used by the PCE during path computation. To that end, a new flag is defined in the RP object, named the OF flag, allowing a PCC to request for the inclusion in the path computation reply of the objective function that was used by the PCE during path computation.

The following new bit flag of the RP object is defined:

The Supply OF on response flag (bit number 24). When set in a PCReq message, this indicates that the PCE MUST provide the applied objective function (should a path satisfying the constraints be found) in the PCRep message. When set in a PCRep message, this indicates that the objective function that was used during path computation is included.

3.3.1. Elements Of Procedure

If the PCC wants to know the objective function used by the PCE during path computation for a given request, it sets the OF flag in the RP object.

On receipt of a PCReq message with the OF flag in the RP object set, the PCE proceeds as follows:

- If policy permits, it MUST include in the PCRep message an OF object indicating the objective function it used during path computation.

- If policy does not permit, it MUST send a PCErr message with the PCEP error code "policy-violation" (type 5) and a new error value, "objective function indication not allowed", which is defined in this document.

Note that a legacy PCE might not recognize the OF flag in the RP object. According to the definition of the Flags field for the RP object (Section 7.4.1 of [RFC5440]), the legacy PCE will ignore the unknown flag, resulting in it sending a PCRep that does not contain an OF object. In this case, the PCC's behavior is an implementation choice. The PCC might:

- Discard the PCRep because it really wanted the OF object returned.

- Accept the PCRep without the knowledge of the OF that was applied.

Note also that these procedures can give rise to the situation where a PCC receives a PCRep that contains an OF object with an objective function identifier that the PCC does not recognize. In this situation, the PCC behavior is dependent on implementation and configuration. The PCC could choose any of the following (or some other action):

- Ignore the OF object and use the computed path.

- Add the objective function to its view of the PCE's repertoire for inclusion in future computation requests.

- Discard the PCRep (i.e., the computed path) and send a PCReq to another PCE.

- Discard the PCRep (i.e., the computed path) and send another PCReq to the same PCE explicitly requiring the use of some other objective function (i.e., by setting the P bit in the OF object).

4. Objective Functions Definition

Six objective functions that must be supported by PCEP are listed in [RFC4657]. Objective function codes have been assigned by IANA and are described below.

Objective functions are formulated using the following terminology:

- A network comprises a set of N links {Li, (i=1...N)}.

- A path P is a list of K links {Lpi,(i=1...K)}.

- Metric of link L is denoted M(L). This can be the IGP metric, the TE metric, or any other metric.

- The cost of a path P is denoted C(P), where C(P) = sum {M(Lpi), (i=1...K)}.

- Residual bandwidth on link L is denoted r(L).

- Maximum reservable bandwidth on link L is denoted R(L).

There are three objective functions that apply to the computation of a single path:

Objective Function Code: 1
Name: Minimum Cost Path (MCP)
Description: Find a path P such that C(P) is minimized.

Objective Function Code: 2
Name: Minimum Load Path (MLP)
Description: Find a path P such that
(Max {(R(Lpi) - r(Lpi)) / R(Lpi), i=1...K }) is minimized.

Objective Function Code: 3
Name: Maximum residual Bandwidth Path (MBP)
Description: Find a path P such that
(Min { r(Lpi), i=1...K }) is maximized.

There are three objective functions that apply to a set of path computation requests the computation of which is synchronized:

Objective Function Code: 4
Name: Minimize aggregate Bandwidth Consumption (MBC)
Description: Find a set of paths such that
(Sum {R(Li) - r(Li), i=1...N}) is minimized.

Objective Function Code: 5
Name: Minimize the Load of the most loaded Link (MLL)
Description: Find a set of paths such that
(Max { (R(Li) - r(Li)) / R(Li), i=1...N}) is minimized.

Objective Function Code: 6
Name: Minimize the Cumulative Cost of a set of paths (MCC)
Description: Find a set of paths {P1...Pm} such that
(Sum { C(Pi), i=1...m}) is minimized.

Other objective functions may be defined in separate documents.

5. New Metric Types

Three metric types are defined in PCEP for the METRIC object: TE metric, IGP metric, and hop count. These metric types apply to an individual request. Here, we define four new metric types that apply to a set of synchronized requests:

Type 4: Aggregate bandwidth consumption.

Type 5: Load of the most loaded link.

Type 6: Cumulative IGP cost.

Type 7: Cumulative TE cost.

These metrics may be used in a PCReq to indicate a bound (B bit set in the METRIC object) or to request the computation of a metric (C bit set in the METRIC object), or in a PCRep to indicate a computed metric.

A METRIC object with one of these four types follows the SVEC object for which it applies.

6. IANA Considerations

6.1. PCE Objective Function Sub-Registry

This document defines a 16-bit PCE objective function identifier to be carried within the PCEP OF object, and also defines the PCEP OF-List TLV.

IANA created and now manages the 16-bit "PCE Objective Function" code point registry, starting from 1 and continuing through 32767, as follows:

- Objective Function code point value
- Objective Function name
- Defining RFC

The same registry is applicable to the OF object and the OF-List TLV that are defined in this document.

The guidelines (using terms defined in [RFC5226]) for the assignment of objective function code point values are as follows:

- Function code value 0 is reserved.

- Function code values in the range 1-32767 are assigned as follows:

  o Function code values 1 through 1023 are assigned by IANA using the "IETF Review" policy.

  o Function code values 1024 through 32767 are assigned by IANA, using the "First Come First Served" policy.

  o Function code values in the range 32768-65535 are for "Private Use".

Six objective functions are defined in Section 4 of this document and have been assigned by IANA:

Code Point	Name	Reference
1	MCP	RFC 5541
2	MLP	RFC 5541
3	MBP	RFC 5541
4	MBC	RFC 5541
5	MLL	RFC 5541
6	MCC	RFC 5541

6.2. PCEP Code Points

6.2.1. OF Object

IANA manages the PCEP Objects code point registry (see [RFC5440]). This is maintained as the "PCEP Objects" sub-registry of the "Path Computation Element Protocol (PCEP) Numbers" registry.

This document defines a new PCEP object, the OF object, to be carried in PCReq and PCRep messages. IANA has made the following allocation:

Object Class	Name	Object Type	Name	Reference
21	OF	1	Objective Function	RFC 5541

6.2.2. OF-List TLV

IANA manages the PCEP TLV code point registry (see [RFC5440]). This is maintained as the "PCEP TLV Type Indicators" sub-registry of the "Path Computation Element Protocol (PCEP) Numbers" registry.

This document defines a new PCEP TLV, the OF-List TLV, to be carried in the OPEN object. IANA has made the following allocation:

Type	TLV name	References
4	OF-List	RFC 5541

6.2.3. PCEP Error Values

IANA maintains a registry of Error-types and Error-values for use in PCEP messages. This is maintained as the "PCEP-ERROR Object Error Types and Values" sub-registry of the "Path Computation Element Protocol (PCEP) Numbers" registry.

Two new Error-values are defined for the Error-type "policy violation" (type 5):

Error-type	Meaning and error values	Reference
5	Policy violation	
	Error-value=3: objective function not allowed (request rejected)	RFC 5541
	Error-value=4: OF bit of the RP object set (request rejected)	RFC 5541

6.2.4. RP Object Flag

A new flag of the RP object (specified in [RFC5440]) is defined in this document. IANA maintains a registry of RP object flags in the "RP Object Flag Field" sub-registry of the "Path Computation Element Protocol (PCEP) Numbers" registry.

IANA has made the following allocation:

Bit	Description	Reference
24	Supply OF on response	RFC 5541

6.2.5. Metric Types

Four new metric types are defined in this document for the METRIC object (specified in [RFC5440]). IANA maintains a registry of metric types in the "METRIC Object T Field" sub-registry of the "Path Computation Element Protocol (PCEP) Numbers" registry.

IANA has made the following allocations:

- Type 4: Aggregate bandwidth consumption
- Type 5: Load of the most loaded link
- Type 6: Cumulative IGP cost
- Type 7: Cumulative TE cost

7. Security Considerations

PCEP security mechanisms are described in [RFC5440] and are used to secure entire PCEP messages. Nothing in this document changes the message flows or introduces any new messages, so the security mechanisms set out in [RFC5440] continue to be applicable.

This document introduces a single new object that may optionally be carried on PCEP messages and will be automatically secured using the mechanisms described in [RFC5440].

If a PCEP message is vulnerable to attack (for example, because the security mechanisms are not used), then the OF object could be used as part of an attack; however, it is likely that other objects will provide far more significant ways of attacking a PCE or PCC in this case.

8. Manageability Considerations

8.1. Control of Function and Policy

It MUST be possible to configure the activation/deactivation of objective function discovery in PCEP.

In addition to the parameters already listed in Section 8.1 of [RFC5440], a PCEP implementation SHOULD allow configuring a list of authorized objective functions on a PCE. This may apply to any session the PCEP speaker participates in, to a specific session with a given PCEP peer, or to a specific group of sessions with a specific group of PCEP peers.

Note that it is not mandatory for an implementation to support all objective functions defined in Section 4.

It MUST be possible to configure a default objective function used for path computation when a path request is received that requests to use an optional objective function.

8.2. Information and Data Models

The PCEP MIB Module defined in [PCEP-MIB] could be extended to include objective functions.

8.3. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements in addition to those already listed in [RFC5440].

8.4. Verify Correct Operations

Mechanisms defined in this document do not imply any new operation verification requirements in addition to those already listed in [RFC5440].

8.5. Requirements On Other Protocols

Mechanisms defined in this document do not imply any requirements on other protocols in addition to those already listed in [RFC5440].

8.6. Impact On Network Operations

Mechanisms defined in this document do not have any impact on network operations in addition to those already listed in [RFC5440].

9. Acknowledgments

The authors would like to thank Jerry Ash, Fabien Verhaeghe, Robert Sparks, and Adrian Farrel for their useful comments.

10. References

10.1. Normative References

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10.2. Informative References

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[PCE-GCO] Lee, Y., Le Roux, JL., King, D., and E. Oki, "Path Computation Element Communication Protocol (PCEP) Requirements and Protocol Extensions in Support of Global Concurrent Optimization", Work in Progress, March 2009.

[PCEP-MIB] Koushik, K., and E. Stephan, "PCE Communication Protocol (PCEP) Management Information Base", Work in Progress, January 2009.

[RFC5511] Farrel, A., "Routing Backus-Naur Form (RBNF) - A Syntax Used to Form Encoding Rules in Various Routing Protocol Specifications", RFC 5511, April 2009.

Appendix A. RBNF Code Fragments

This appendix contains the full set of code fragments defined in this document.


```
<PCReq Message> ::= <Common Header>
                    [<svec-list>]
                    <request-list>

<PCRep Message> ::= <Common Header>
                    [<svec-list>]
                    <response-list>
```

```
<svec-list> ::= <SVEC>
                [<OF>]
                [<metric-list>]
                [<svec-list>]

<request-list> ::= <request> [<request-list>]

<request> ::= <RP>
              <END-POINTS>
              [<LSPA>]
              [<BANDWIDTH>]
              [<metric-list>]
              [<OF>]
              [<RRO>[<BANDWIDTH>]]
              [<IRO>]
              [<LOAD-BALANCING>]

<metric-list> ::= <METRIC>[<metric-list>]

<response-list> ::= <response> [<response-list>]

<response> ::= <RP>
               [<NO-PATH>]
               [<attribute-list>]
               [<path-list>]

<path-list> ::= <path> [<path-list>]

<path> ::= <ERO>
           <attribute-list>

<attribute-list> ::= [<OF>]
                     [<LSPA>]
                     [<BANDWIDTH>]
                     [<metric-list>]
                     [<IRO>]
```

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