

Internet Engineering Task Force (IETF)
Request for Comments: 8780
Category: Standards Track
ISSN: 2070-1721

Y. Lee, Ed.
Samsung Electronics
R. Casellas, Ed.
CTTC
July 2020

The Path Computation Element Communication Protocol (PCEP) Extension for
Wavelength Switched Optical Network (WSO) Routing and Wavelength
Assignment (RWA)

Abstract

This document provides Path Computation Element Communication Protocol (PCEP) extensions for the support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSOs). Path provisioning in WSOs requires an RWA process. From a path computation perspective, wavelength assignment is the process of determining which wavelength can be used on each hop of a path and forms an additional routing constraint to optical path computation.

Status of This Memo

This is an Internet Standards Track document.

This document is a product of the Internet Engineering Task Force (IETF). It represents the consensus of the IETF community. It has received public review and has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on Internet Standards is available in Section 2 of RFC 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <https://www.rfc-editor.org/info/rfc8780>.

Copyright Notice

Copyright (c) 2020 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<https://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

Table of Contents

1. Introduction
2. Terminology
3. Requirements Language
4. Encoding of an RWA Path Request
 - 4.1. Wavelength Assignment (WA) Object
 - 4.2. Wavelength Selection TLV
 - 4.3. Wavelength Restriction TLV
 - 4.3.1. Link Identifier Field
 - 4.3.2. Wavelength Constraint Field
 - 4.4. Signal Processing Capability Restrictions

4.4.1.	Signal Processing Exclusion
4.4.2.	Signal Processing Inclusion
5.	Encoding of an RWA Path Reply
5.1.	Wavelength Allocation TLV
5.2.	Error Indicator
5.3.	NO-PATH Indicator
6.	Manageability Considerations
6.1.	Control of Function and Policy
6.2.	Liveness Detection and Monitoring
6.3.	Verifying Correct Operation
6.4.	Requirements on Other Protocols and Functional Components
6.5.	Impact on Network Operation
7.	Security Considerations
8.	IANA Considerations
8.1.	New PCEP Object: Wavelength Assignment Object
8.2.	WA Object Flag Field
8.3.	New PCEP TLV: Wavelength Selection TLV
8.4.	New PCEP TLV: Wavelength Restriction TLV
8.5.	Wavelength Restriction TLV Action Values
8.6.	New PCEP TLV: Wavelength Allocation TLV
8.7.	Wavelength Allocation TLV Flag Field
8.8.	New PCEP TLV: Optical Interface Class List TLV
8.9.	New PCEP TLV: Client Signal Information TLV
8.10.	New Bit Flag for NO-PATH-VECTOR TLV
8.11.	New Error-Types and Error-Values
8.12.	New Subobjects for the Exclude Route Object
8.13.	New Subobjects for the Include Route Object
8.14.	Request for Updated Note for LMP TE Link Object Class Type
9.	References
9.1.	Normative References
9.2.	Informative References
	Acknowledgments
	Contributors
	Authors' Addresses

1. Introduction

[RFC5440] specifies the Path Computation Element Communication Protocol (PCEP) for communications between a Path Computation Client (PCC) and a PCE, or between two PCEs. Such interactions include Path Computation Requests (PCReqs) and Path Computation Replies (PCReps) as well as notifications of specific states related to the use of a PCE in the context of Multiprotocol Label Switching (MPLS) and Generalized MPLS (GMPLS) Traffic Engineering (TE).

A PCC is said to be any network component that makes such a request and may be, for instance, an optical switching element within a Wavelength Division Multiplexing (WDM) network. The PCE, itself, can be located anywhere within the network and may be within an optical switching element, a Network Management System (NMS), or an Operational Support System (OSS), or it may be an independent network server.

This document provides the PCEP extensions for the support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSONs) based on the requirements specified in [RFC6163] and [RFC7449].

WSON refers to WDM-based optical networks in which switching is performed selectively based on the wavelength of an optical signal. The devices used in WSONs that are able to switch signals based on signal wavelength are known as Lambda Switch Capable (LSC). WSONs can be transparent or translucent. A transparent optical network is made up of optical devices that can switch but not convert from one wavelength to another, all within the optical domain. On the other hand, translucent networks include 3R regenerators (reamplification,

reshaping, and retiming) that are sparsely placed. The main function of the 3R regenerators is to convert one optical wavelength to another.

An LSC Label Switched Path (LSP) may span one or several transparent segments, which are delimited by 3R regenerators typically with electronic regenerator and optional wavelength conversion. Each transparent segment or path in WSON is referred to as an optical path. An optical path may span multiple fiber links, and the path should be assigned the same wavelength for each link. In a case, the optical path is said to satisfy the wavelength-continuity constraint. Figure 1 illustrates the relationship between an LSC LSP and transparent segments (optical paths).

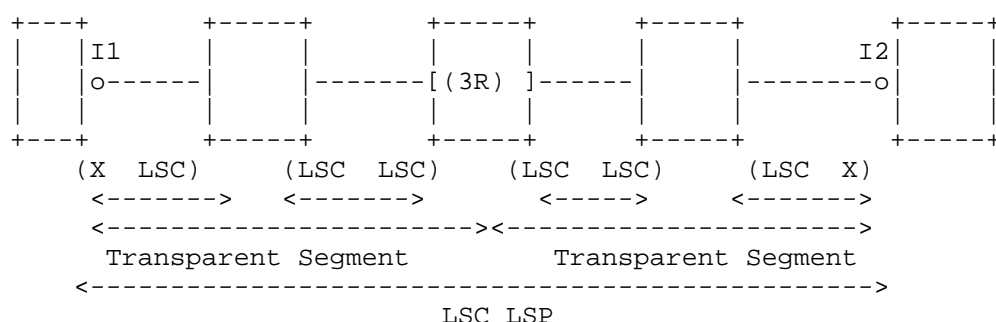


Figure 1: Illustration of an LSC LSP and Transparent Segments

Note that two transparent segments within a WSON LSP do not need to operate on the same wavelength (due to wavelength conversion capabilities). Two optical channels that share a common fiber link cannot be assigned the same wavelength; otherwise, the two signals would interfere with each other. Note that advanced additional multiplexing techniques such as polarization-based multiplexing are not addressed in this document since the physical-layer aspects are not currently standardized. Therefore, assigning the proper wavelength on a path is an essential requirement in the optical path computation process.

When a switching node has the ability to perform wavelength conversion, the wavelength-continuity constraint can be relaxed, and an LSP may use different wavelengths on different links along its route from origin to destination. It is, however, to be noted that wavelength converters may be limited due to their relatively high cost, while the number of WDM channels that can be supported in a fiber is also limited. As a WSON can be composed of network nodes that cannot perform wavelength conversion, nodes with limited wavelength conversion, and nodes with full wavelength conversion abilities, wavelength assignment is an additional routing constraint to be considered in all optical path computation.

For example (see Figure 1), within a translucent WSON, an LSC LSP may be established between interfaces I1 and I2, spanning two transparent segments (optical paths) where the wavelength continuity constraint applies (i.e., the same unique wavelength must be assigned to the LSP at each TE link of the segment). If the LSC LSP induced a Forwarding Adjacency / TE link, the switching capabilities of the TE link would be (X X), where X refers to the switching capability of I1 and I2. For example, X can be Packet Switch Capable (PSC), Time-Division Multiplexing (TDM), etc.

This document aligns with [RFC8779] for generic properties such as label, label set, and label assignment, noting that a wavelength is a type of label. Wavelength restrictions and constraints are also formulated in terms of labels per [RFC7579].

The optical modulation properties, which are also referred to as signal compatibility, are already considered in the signaling in [RFC7581] and [RFC7688]. In order to improve the signal quality and limit some optical effects, several advanced modulation processing capabilities are used by the mechanisms specified in this document. These modulation capabilities not only contribute to optical signal quality checks but also constrain the selection of sender and receiver, as they should have matching signal processing capabilities. This document includes signal compatibility constraints as part of RWA path computation. That is, the signal processing capabilities (e.g., modulation and Forward Error Correction (FEC)) indicated by means of the Optical Interface Class (OIC) must be compatible between the sender and the receiver of the optical path across all optical elements.

This document, however, does not address optical impairments as part of RWA path computation. See [RFC6566] for the framework for optical impairments.

2. Terminology

This document uses the terminology defined in [RFC4655] and [RFC5440].

3. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

4. Encoding of an RWA Path Request

Figure 2 shows one typical PCE-based implementation, which is referred to as the Combined Process (R&WA). With this architecture, the two processes of routing and wavelength assignment are accessed via a single PCE. This architecture is the base architecture specified in [RFC6163], and the PCEP extensions that are specified in this document are based on this architecture.

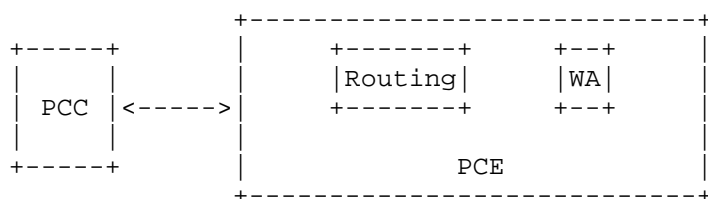


Figure 2: Combined Process (R&WA) Architecture

4.1. Wavelength Assignment (WA) Object

Wavelength allocation can be performed by the PCE by means of:

- (a) Explicit Label Control [RFC3471] where the PCE allocates which label to use for each interface/node along the path. The allocated labels MAY appear after an interface route subobject.
- (b) A Label Set where the PCE provides a range of potential labels to be allocated by each node along the path.

Option (b) allows distributed label allocation (performed during signaling) to complete wavelength assignment.

Additionally, given a range of potential labels to allocate, a PCReq

SHOULD convey the heuristic or mechanism used for the allocation.

Per [RFC5440], the format of a PCReq message after incorporating the Wavelength Assignment (WA) object is as follows:

```
<PCReq Message> ::= <Common Header>

                        [<svec-list>]

                        <request-list>
```

Where:

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

<request> ::= <RP>
              <END-POINTS>

              <WA>

              [other optional objects...]
```

If the WA object is present in the request, it MUST be encoded after the END-POINTS object as defined in [RFC8779]. The WA object is mandatory in this document. Orderings for the other optional objects are irrelevant.

For the WA object, the Object-Class is 42, and the Object-Type is 1.

The format of the WA object body is as follows:

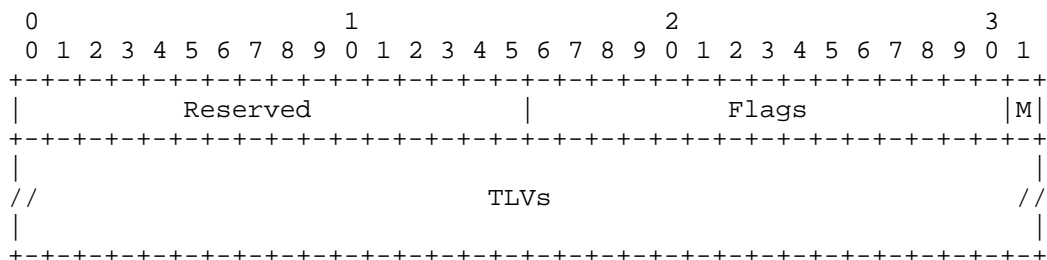


Figure 3: WA Object

Reserved (16 bits): Reserved for future use and SHOULD be zeroed and ignored on receipt.

Flags field (16 bits): One flag bit is allocated as follows:

M (1 bit): Wavelength Allocation Mode. The M bit is used to indicate the mode of wavelength assignment. When the M bit is set to 1, this indicates that the label assigned by the PCE must be explicit. That is, the selected way to convey the allocated wavelength is by means of Explicit Label Control for each hop of a computed LSP. Otherwise (M bit is set to 0), the label assigned by the PCE need not be explicit (i.e., it can be suggested in the form of Label Set objects in the corresponding response, to allow distributed WA. If M is 0, the PCE MUST return a Label Set Field as described in Section 2.6 of [RFC7579] in the response. See Section 5 of this document for the encoding discussion of a Label Set Field in a PCRep message.

All unused flags SHOULD be zeroed. IANA has created a new registry to manage the Flags field of the WA object.

TLVs (variable): In the TLVs field, the following two TLVs are

Wavelength Selection TLV: The type of this TLV is 8, and it has a fixed length of 32 bits. This TLV indicates the wavelength selection. See Section 4.2 for details.

Wavelength Restriction TLV: The type of this TLV is 9, and it has a variable length. This TLV indicates wavelength restrictions. See Section 4.3 for details.

The Wavelength Selection TLV is used to indicate the wavelength selection constraint in regard to the order of wavelength assignment to be returned by the PCE. This TLV is only applied when the M bit is set in the WA object specified in Section 4.1. This TLV MUST NOT be used when the M bit is cleared.

The encoding of this TLV is specified as the WavelengthSelection sub-TLV in Section 4.2.2 of [RFC7689]. IANA has allocated a new TLV type for the Wavelength Selection TLV (Type 8).

For any request that contains a wavelength assignment, the requester (PCC) MUST specify a restriction on the wavelengths to be used. This restriction is to be interpreted by the PCE as a constraint on the tuning ability of the origination laser transmitter or on any other maintenance-related constraints. Note that if the LSC LSP spans different segments, the PCE must have mechanisms to know the tunability restrictions of the involved wavelength converters/regenerators, e.g., by means of the Traffic Engineering Database (TED) via either IGP or NMS. Even if the PCE knows the tunability of the transmitter, the PCC must be able to apply additional constraints to the request.

```
<Wavelength Restriction> ::=
    (<Action> <Count> <Reserved>
     <Link Identifiers> <Wavelength Constraint>)...

```

$$\langle \text{Link Identifiers} \rangle ::= \langle \text{Link Identifier} \rangle [\langle \text{Link Identifiers} \rangle]$$

These fields (i.e., <Action>, <Link Identifiers>, and <Wavelength Constraint>, etc.) MAY appear together more than once to be able to specify multiple actions and their restrictions.

The TLV data is defined as follows:

0										1										2										3									
0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1	2	3	4	5	6	7	8	9	0	1								
Action										Count										Reserved																			
Link Identifiers										Link Identifiers										Link Identifiers																			
//										//										//																			

```

+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Wavelength Constraint                                     |
//                                                                                       //
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
~                                                                                       ~
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
| Action          | Count          | Reserved          |
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Link Identifiers                                     |
//                                                                                       //
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+
|                                     Wavelength Constraint                                     |
//                                                                                       //
+-----+-----+-----+-----+-----+-----+-----+-----+-----+-----+

```

Figure 4: Wavelength Restriction TLV Encoding

Action (8 bits):

- 0: Inclusive List. Indicates that one or more link identifiers are included in the Link Set. Each identifies a separate link that is part of the set.
- 1: Inclusive Range. Indicates that the Link Set defines a range of links. It contains two link identifiers. The first identifier indicates the start of the range (inclusive). The second identifier indicates the end of the range (inclusive). All links with numeric values between the bounds are considered to be part of the set. A value of zero in either position indicates that there is no bound on the corresponding portion of the range.
- 2-255: Unassigned.

IANA has created a new registry to manage the Action values of the Wavelength Restriction TLV.

If a PCE receives an unrecognized Action value, the PCE MUST send a PCEP Error (PCErr) message with a PCEP-ERROR object with Error-Type=27 and an Error-value=3. See Section 5.2 for details.

Note that "links" are assumed to be bidirectional.

Count (8 bits):

The number of the link identifiers.

Note that a PCC MAY add a Wavelength restriction that applies to all links by setting the Count field to zero and specifying just a set of wavelengths.

Note that all link identifiers in the same list MUST be of the same type.

Reserved (16 bits):

Reserved for future use and SHOULD be zeroed and ignored on receipt.

Link Identifiers:

Identifies each link ID for which restriction is applied. The length is dependent on the link format and the Count field. See Section 4.3.1 for encoding of the Link Identifier field.

Wavelength Constraint:

See Section 4.3.2 for the encoding of the Wavelength Constraint field.

Various encoding errors are possible with this TLV (e.g., not exactly

two link identifiers with the range case, unknown identifier types, no matching link for a given identifier, etc.). To indicate errors associated with this encoding, a PCEP speaker MUST send a PCErr message with Error-Type=27 and Error-value=3. See Section 5.2 for details.

4.3.1. Link Identifier Field

The Link Identifier field can be an IPv4 [RFC3630], IPv6 [RFC5329], or unnumbered interface ID [RFC4203].

<Link Identifier> ::=

<IPv4 Address> | <IPv6 Address> | <Unnumbered IF ID>

The encoding of each case is as follows.

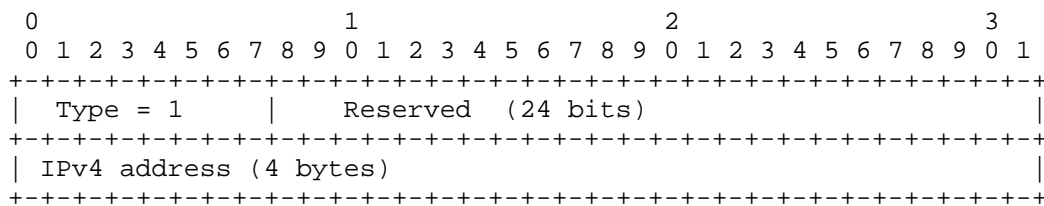


Figure 5: IPv4 Address Field

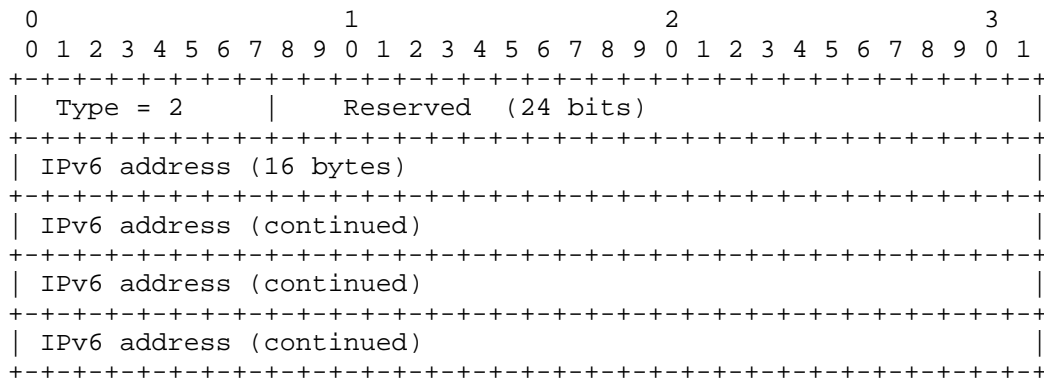


Figure 6: IPv6 Address Field

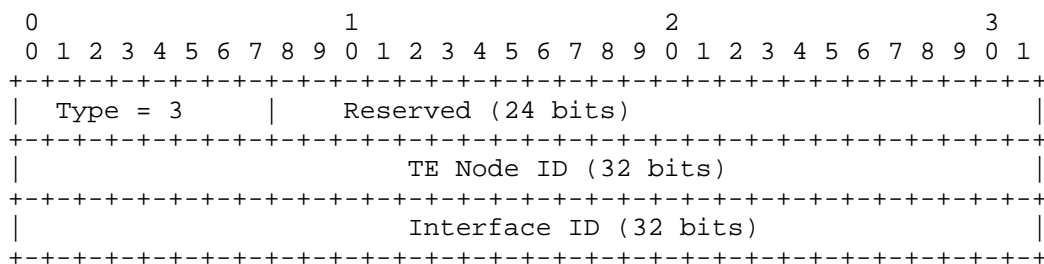


Figure 7: Unnumbered Interface ID Address Field

Type (8 bits): Indicates the type of the link identifier.

Reserved (24 bits): Reserved for future use and SHOULD be zeroed and ignored on receipt.

Link Identifier: When the Type field is 1, a 4-byte IPv4 address is encoded; when the Type field is 2, a 16-byte IPv6 address is encoded; and when the Type field is 3, a tuple of a 4-byte TE node ID and a 4-byte interface ID is encoded.

The Type field is extensible and matches the "TE_LINK Object Class

type name space (Value 11)" registry created for the Link Management Protocol (LMP) [RFC4204] (see [LMP-PARAM]). IANA has added an introductory note before the aforementioned registry stating that the values have additional usage for the Link Identifier Type field. See Section 8.14.

4.3.2. Wavelength Constraint Field

The Wavelength Constraint field of the Wavelength Restriction TLV is encoded as a Label Set Field as specified in Section 2.6 of [RFC7579] with the base label encoded as a 32-bit LSC label, as defined in [RFC6205]. The Label Set format is repeated here for convenience, with the base label internal structure included. See [RFC6205] for a description of Grid, Channel Spacing (C.S.), Identifier, and n, and see [RFC7579] for the details of each action.

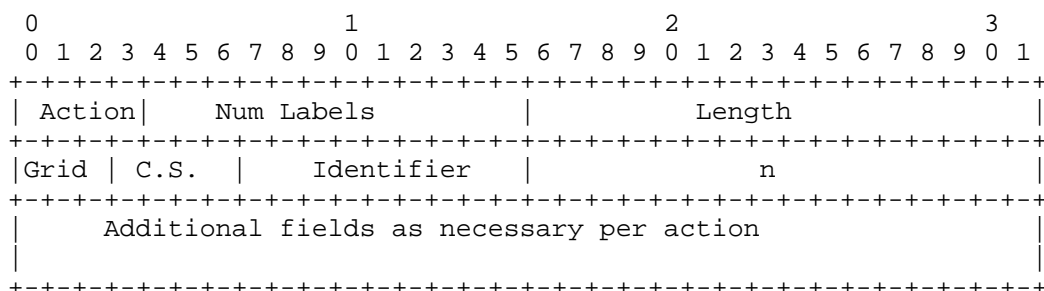


Figure 8: Wavelength Constraint Field

Action (4 bits):

- 0: Inclusive List
- 1: Exclusive List
- 2: Inclusive Range
- 3: Exclusive Range
- 4: Bitmap Set

Num Labels (12 bits):

It is generally the number of labels. It has a specific meaning depending on the action value.

Length (16 bits):

It is the length in bytes of the entire Wavelength Constraint field.

Identifier (9 bits):

The Identifier is always set to 0. If PCC receives the value of the identifier other than 0, it will ignore.

See Sections 2.6.1-2.6.3 of [RFC7579] for details on additional field discussion for each action.

4.4. Signal Processing Capability Restrictions

Path computation for WSON includes the checking of signal processing capabilities at each interface against requested capability; the PCE MUST have mechanisms to know the signal processing capabilities at each interface, e.g., by means of (TED) via either IGP or NMS. Moreover, a PCC should be able to indicate additional restrictions to signal processing compatibility, on either the endpoint or any given link.

The supported signal processing capabilities considered in the RWA

Information Model [RFC7446] are:

- * Optical Interface Class List
- * Bit Rate
- * Client Signal

The bit rate restriction is already expressed in the BANDWIDTH object in [RFC8779].

In order to support the optical interface class information and the client signal information, new TLVs are introduced as endpoint restrictions in the END-POINTS type Generalized Endpoint:

- * Client Signal Information TLV
- * Optical Interface Class List TLV

The END-POINTS type Generalized Endpoint is extended as follows:

```
<endpoint-restriction> ::=
    <LABEL-REQUEST> <label-restriction-list>

<label-restriction-list> ::= <label-restriction>
    [<label-restriction-list>]

<label-restriction> ::= (<LABEL-SET>|
    [<Wavelength Restriction>]
    [<signal-compatibility-restriction>])
```

Where:

```
<signal-compatibility-restriction> ::=
    [<Optical Interface Class List>] [<Client Signal Information>]
```

The Wavelength Restriction TLV is defined in Section 4.3.

A new Optical Interface Class List TLV (Type 11) is defined; the encoding of the value part of this TLV is described in Section 4.1 of [RFC7581].

A new Client Signal Information TLV (Type 12) is defined; the encoding of the value part of this TLV is described in Section 4.2 of [RFC7581].

4.4.1. Signal Processing Exclusion

The PCC/PCE should be able to exclude particular types of signal processing along the path in order to handle client restriction or multi-domain path computation. [RFC5521] defines how the Exclude Route Object (XRO) subobject is used. In this document, we add two new XRO Signal Processing Exclusion subobjects.

The first XRO subobject type (8) is the Optical Interface Class List, which is defined as follows:

```

0          1          2          3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-----+-----+-----+-----+-----+-----+-----+-----+
|X|  Type=8   |      Length      |   Reserved   | Attribute   |
+-----+-----+-----+-----+-----+-----+-----+-----+
//                Optical Interface Class List                //
```

Figure 9: Optical Interface Class List XRO Subobject

Refer to [RFC5521] for the definitions of X, Length, and Attribute.

Type (7 bits): The type of the Signaling Processing Exclusion field.
IANA has assigned value 8 for the Optical Interface Class List XRO subobject type.

Reserved bits (8 bits): These are for future use and SHOULD be zeroed and ignored on receipt.

Attribute (8 bits): [RFC5521] defines several Attribute values; the only permitted Attribute values for this field are 0 (Interface) or 1 (Node).

Optical Interface Class List: This field is encoded as described in Section 4.1 of [RFC7581].

The second XRO subobject type (9) is the Client Signal Information, which is defined as follows:

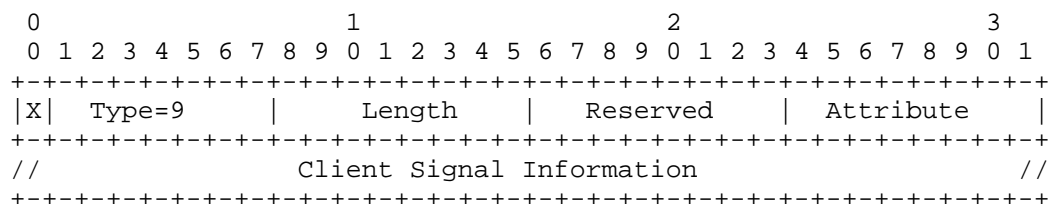


Figure 10: Client Signal Information XRO Subobject

Refer to [RFC5521] for the definitions of X, Length, and Attribute.

Type (7 bits): The type of the Signaling Processing Exclusion field.
IANA has assigned value 9 for the Client Signal Information XRO subobject type.

Reserved bits (8 bits): These are for future use and SHOULD be zeroed and ignored on receipt.

Attribute (8 bits): [RFC5521] defines several Attribute values; the only permitted Attribute values for this field are 0 (Interface) or 1 (Node).

Client Signal Information: This field is encoded as described in Section 4.2 of [RFC7581].

The XRO needs to support the new Signaling Processing Exclusion XRO subobject types:

8: Optical Interface Class List

9: Client Signal Information

4.4.2. Signal Processing Inclusion

Similar to the XRO subobject, the PCC/PCE should be able to include particular types of signal processing along the path in order to handle client restriction or multi-domain path computation. [RFC5440] defines how the Include Route Object (IRO) subobject is used. In this document, we add two new Signal Processing Inclusion subobjects.

The IRO needs to support the new IRO subobject types (8 and 9) for the PCEP IRO object [RFC5440]:

8: Optical Interface Class List

9: Client Signal Information

The encoding of the Signal Processing Inclusion subobjects is similar to the process in Section 4.4.1 where the 'X' field is replaced with the 'L' field; all the other fields remain the same. The 'L' field is described in [RFC3209].

5. Encoding of an RWA Path Reply

This section provides the encoding of an RWA Path Reply for a wavelength allocation request as discussed in Section 4.

5.1. Wavelength Allocation TLV

Recall that wavelength allocation can be performed by the PCE by means of:

- (a) Explicit Label Control (ELC) where the PCE allocates which label to use for each interface/node along the path.
- (b) A Label Set where the PCE provides a range of potential labels to be allocated by each node along the path.

Option (b) allows distributed label allocation (performed during signaling) to complete wavelength allocation.

The type for the Wavelength Allocation TLV is 10 (see Section 8.4). Note that this TLV is used for both (a) and (b) above. The TLV data is defined as follows:

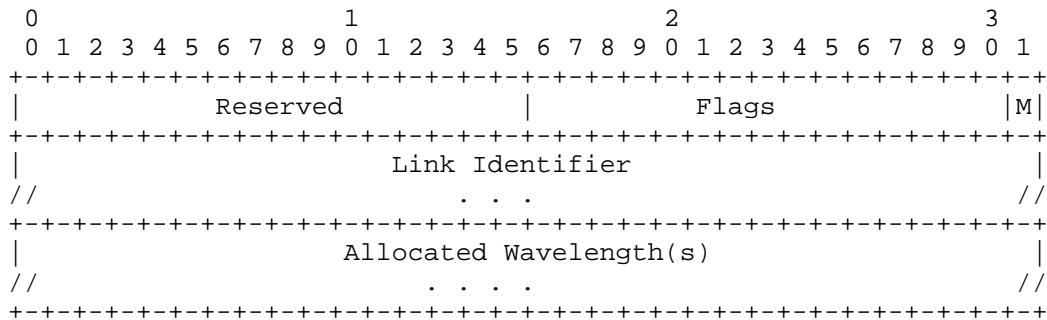


Figure 11: Wavelength Allocation TLV Encoding

Reserved (16 bits): Reserved for future use.

Flags field (16 bits): One flag bit is allocated as follows:

M (1 bit): Wavelength Allocation Mode.

0: Indicates the allocation relies on the use of Label Sets.

1: Indicates the allocation is done using Explicit Label Control.

IANA has created a new registry to manage the Flags field of the Wavelength Allocation TLV.

Link Identifier: Identifies the interface to which the assignment wavelength(s) is applied. See Section 4.3.1 for encoding of the Link Identifier field.

Allocated Wavelength(s): Indicates the allocated wavelength(s) to be associated with the link identifier. See Section 4.3.2 for encoding details.

This TLV is carried in a PCRep message as an Attribute TLV [RFC5420] in the Hop Attribute subobjects [RFC7570] in the Explicit Route Object (ERO) [RFC5440].

5.2. Error Indicator

To indicate errors associated with the RWA request, a new Error-Type 27 (WSON RWA Error) and subsequent Error-values are defined as follows for inclusion in the PCEP-ERROR object:

- * Error-Type=27; Error-value=1: If a PCE receives an RWA request and the PCE is not capable of processing the request due to insufficient memory, the PCE MUST send a PCErr message with a PCEP-ERROR object with Error-Type=27 and Error-value=1. The PCE stops processing the request. The corresponding RWA request MUST be canceled at the PCC.
- * Error-Type=27; Error-value=2: If a PCE receives an RWA request and the PCE is not capable of RWA computation, the PCE MUST send a PCErr message with a PCEP-ERROR object with Error-Type=27 and Error-value=2. The PCE stops processing the request. The corresponding RWA computation MUST be canceled at the PCC.
- * Error-Type=27; Error-value=3: If a PCE receives an RWA request and there are syntactical encoding errors (e.g., not exactly two link identifiers with the range case, unknown identifier types, no matching link for a given identifier, unknown Action value, etc.), the PCE MUST send a PCErr message with a PCEP-ERROR object with Error-Type=27 and Error-value=3.

5.3. NO-PATH Indicator

To communicate the reason(s) for not being able to find RWA for the path request, the NO-PATH object can be used in the corresponding response. The format of the NO-PATH object body is defined in [RFC5440]. The object may contain a NO-PATH-VECTOR TLV to provide additional information about why a path computation has failed.

This document defines a new bit flag to be carried in the Flags field in the NO-PATH-VECTOR TLV, which is carried in the NO-PATH object:

Bit 23: When set, the PCE indicates no feasible route was found that meets all the constraints (e.g., wavelength restriction, signal compatibility, etc.) associated with RWA.

6. Manageability Considerations

Manageability of WSON RWA with PCE must address the considerations in the following subsections.

6.1. Control of Function and Policy

In addition to the parameters already listed in Section 8.1 of [RFC5440], a PCEP implementation SHOULD allow configuration of the following PCEP session parameters on a PCC:

- * The ability to send a WSON RWA request.

In addition to the parameters already listed in Section 8.1 of [RFC5440], a PCEP implementation SHOULD allow configuration of the following PCEP session parameters on a PCE:

- * The support for WSON RWA.
- * A set of WSON-RWA-specific policies (authorized sender, request

rate limiter, etc).

These parameters may be configured as default parameters for any PCEP session the PCEP speaker participates in, or they may apply to a specific session with a given PCEP peer or a specific group of sessions with a specific group of PCEP peers.

6.2. Liveness Detection and Monitoring

Mechanisms defined in this document do not imply any new liveness detection and monitoring requirements, aside from those already listed in Section 8.3 of [RFC5440].

6.3. Verifying Correct Operation

Mechanisms defined in this document do not imply any new verification requirements, aside from those already listed in Section 8.4 of [RFC5440].

6.4. Requirements on Other Protocols and Functional Components

The PCEP Link-State mechanism [PCEP-LS] may be used to advertise WSON RWA path computation capabilities to PCCs.

6.5. Impact on Network Operation

Mechanisms defined in this document do not imply any new network operation requirements, aside from those already listed in Section 8.6 of [RFC5440].

7. Security Considerations

The security considerations discussed in [RFC5440] are relevant for this document; this document does not introduce any new security issues. If an operator wishes to keep the information distributed by WSON private, PCEPS (Usage of TLS to Provide a Secure Transport for PCEP) [RFC8253] SHOULD be used.

8. IANA Considerations

IANA maintains a registry of PCEP parameters. IANA has made allocations from the subregistries as described in the following sections.

8.1. New PCEP Object: Wavelength Assignment Object

As described in Section 4.1, a new PCEP object is defined to carry wavelength-assignment-related constraints. IANA has allocated the following in the "PCEP Objects" subregistry [PCEP-NUMBERS]:

Object-Class Value	Name	Object-Type	Reference
42	WA	0: Reserved	RFC 8780
		1: Wavelength Assignment	RFC 8780

Table 1

8.2. WA Object Flag Field

As described in Section 4.1, IANA has created the "WA Object Flag Field" subregistry under the "Path Computation Element Protocol (PCEP) Numbers" registry [PCEP-NUMBERS] to manage the Flags field of the WA object. New values are to be assigned by Standards Action

[RFC8126]. Each bit should be tracked with the following qualities:

- * Bit number (counting from bit 0 as the most significant bit)
- * Capability description
- * Defining RFC

The initial contents of this registry are shown below. One bit has been allocated for the flag defined in this document:

Bit	Description	Reference
0-14	Unassigned	
15	Wavelength Allocation Mode	RFC 8780

Table 2

8.3. New PCEP TLV: Wavelength Selection TLV

In Section 4.2, a new PCEP TLV is defined to indicate wavelength selection constraints. IANA has made the following allocation in the "PCEP TLV Type Indicators" subregistry [PCEP-NUMBERS]:

Value	Description	Reference
8	Wavelength Selection	RFC 8780

Table 3

8.4. New PCEP TLV: Wavelength Restriction TLV

In Section 4.3, a new PCEP TLV is defined to indicate wavelength restrictions. IANA has made the following allocation in the "PCEP TLV Type Indicators" subregistry [PCEP-NUMBERS]:

Value	Description	Reference
9	Wavelength Restriction	RFC 8780

Table 4

8.5. Wavelength Restriction TLV Action Values

As described in Section 4.3, IANA has created the new "Wavelength Restriction TLV Action Values" subregistry under the "Path Computation Element Protocol (PCEP) Numbers" registry [PCEP-NUMBERS] to manage the Action values of the Action field of the Wavelength Restriction TLV. New values are assigned by Standards Action [RFC8126]. Each value should be tracked with the following qualities:

- * Value
- * Meaning
- * Defining RFC

The initial contents of this registry are shown below:

Value	Meaning	Reference
0	Inclusive List	RFC 8780
1	Inclusive Range	RFC 8780
2-255	Unassigned	

Table 5

8.6. New PCEP TLV: Wavelength Allocation TLV

In Section 5.1, a new PCEP TLV is defined to indicate the allocation of the wavelength(s) by the PCE in response to a request by the PCC. IANA has made the following allocation in "PCEP TLV Type Indicators" subregistry [PCEP-NUMBERS]:

Value	Description	Reference
10	Wavelength Allocation	RFC 8780

Table 6

8.7. Wavelength Allocation TLV Flag Field

As described in Section 5.1, IANA has created a new "Wavelength Allocation TLV Flag Field" subregistry under the "Path Computation Element Protocol (PCEP) Numbers" registry [PCEP-NUMBERS] to manage the Flags field of the Wavelength Allocation TLV. New values are to be assigned by Standards Action [RFC8126]. Each bit should be tracked with the following qualities:

- * Bit number (counting from bit 0 as the most significant bit)
- * Capability description
- * Defining RFC

One bit is defined for the flag defined in this document. The initial contents of this registry are shown below:

Bit	Description	Reference
0-14	Unassigned	
15	Wavelength Allocation Mode	RFC 8780

Table 7

8.8. New PCEP TLV: Optical Interface Class List TLV

In Section 4.4, a new PCEP TLV is defined to indicate the Optical Interface Class List. IANA has made the following allocation in the "PCEP TLV Type Indicators" subregistry [PCEP-NUMBERS]:

Value	Description	Reference
11	Optical Interface Class List	RFC 8780

+-----+-----+-----+-----+-----+-----+

Table 8

8.9. New PCEP TLV: Client Signal Information TLV

In Section 4.4, a new PCEP TLV is defined to indicate the Client Signal Information. IANA has made the following allocation in the "PCEP TLV Type Indicators" subregistry [PCEP-NUMBERS]:

Value	Description	Reference
12	Client Signal Information	RFC 8780

Table 9

8.10. New Bit Flag for NO-PATH-VECTOR TLV

In Section 5.3, a new bit flag is defined to be carried in the Flags field in the NO-PATH-VECTOR TLV, which is carried in the NO-PATH object. This flag, when set, indicates that no feasible route was found that meets all the RWA constraints (e.g., wavelength restriction, signal compatibility, etc.) associated with an RWA path computation request.

IANA has made the following allocation for this new bit flag in the "NO-PATH-VECTOR TLV Flag Field" subregistry [PCEP-NUMBERS]:

Bit	Description	Reference
23	No RWA constraints met	RFC 8780

Table 10

8.11. New Error-Types and Error-Values

In Section 5.2, new PCEP error codes are defined for WSON RWA errors. IANA has made the following allocations in the "PCEP-ERROR Object Error Types and Values" subregistry [PCEP-NUMBERS]:

Error-Type	Meaning	Error-value	Reference
27	WSON RWA error	0: Unassigned	RFC 8780
		1: Insufficient memory	RFC 8780
		2: RWA computation not supported	RFC 8780
		3: Syntactical encoding error	RFC 8780
		4-255: Unassigned	RFC 8780

Table 11

8.12. New Subobjects for the Exclude Route Object

The "Path Computation Element Protocol (PCEP) Numbers" registry contains a subregistry titled "XRO Subobjects" [PCEP-NUMBERS]. Per

Section 4.4.1, IANA has added the following subobjects that can be carried in the XRO:

Value	Description	Reference
8	Optical Interface Class List	RFC 8780
9	Client Signal Information	RFC 8780

Table 12

8.13. New Subobjects for the Include Route Object

The "Path Computation Element Protocol (PCEP) Numbers" registry contains a subregistry titled "IRO Subobjects" [PCEP-NUMBERS]. Per Section 4.4.2, IANA has added the following subobjects that can be carried in the IRO:

Value	Description	Reference
8	Optical Interface Class List	RFC 8780
9	Client Signal Information	RFC 8780

Table 13

8.14. Request for Updated Note for LMP TE Link Object Class Type

The "TE_LINK Object Class type name space (Value 11)" registry was created for the Link Management Protocol (LMP) [RFC4204]. As discussed in Section 4.3.1, IANA has added the following note at the top of the "TE_LINK Object Class type name space (Value 11)" registry [LMP-PARAM]:

These values have additional usage for the Link Identifier Type field.

9. References

9.1. Normative References

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://www.rfc-editor.org/info/rfc2119>>.
- [RFC3209] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V., and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP Tunnels", RFC 3209, DOI 10.17487/RFC3209, December 2001, <<https://www.rfc-editor.org/info/rfc3209>>.
- [RFC3630] Katz, D., Kompella, K., and D. Yeung, "Traffic Engineering (TE) Extensions to OSPF Version 2", RFC 3630, DOI 10.17487/RFC3630, September 2003, <<https://www.rfc-editor.org/info/rfc3630>>.
- [RFC5329] Ishiguro, K., Manral, V., Davey, A., and A. Lindem, Ed., "Traffic Engineering Extensions to OSPF Version 3", RFC 5329, DOI 10.17487/RFC5329, September 2008, <<https://www.rfc-editor.org/info/rfc5329>>.
- [RFC5440] Vasseur, JP., Ed. and JL. Le Roux, Ed., "Path Computation

- Element (PCE) Communication Protocol (PCEP)", RFC 5440, DOI 10.17487/RFC5440, March 2009, <<https://www.rfc-editor.org/info/rfc5440>>.
- [RFC6205] Otani, T., Ed. and D. Li, Ed., "Generalized Labels for Lambda-Switch-Capable (LSC) Label Switching Routers", RFC 6205, DOI 10.17487/RFC6205, March 2011, <<https://www.rfc-editor.org/info/rfc6205>>.
- [RFC7570] Margaria, C., Ed., Martinelli, G., Balls, S., and B. Wright, "Label Switched Path (LSP) Attribute in the Explicit Route Object (ERO)", RFC 7570, DOI 10.17487/RFC7570, July 2015, <<https://www.rfc-editor.org/info/rfc7570>>.
- [RFC7579] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "General Network Element Constraint Encoding for GMPLS-Controlled Networks", RFC 7579, DOI 10.17487/RFC7579, June 2015, <<https://www.rfc-editor.org/info/rfc7579>>.
- [RFC7581] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", RFC 7581, DOI 10.17487/RFC7581, June 2015, <<https://www.rfc-editor.org/info/rfc7581>>.
- [RFC7688] Lee, Y., Ed. and G. Bernstein, Ed., "GMPLS OSPF Enhancement for Signal and Network Element Compatibility for Wavelength Switched Optical Networks", RFC 7688, DOI 10.17487/RFC7688, November 2015, <<https://www.rfc-editor.org/info/rfc7688>>.
- [RFC7689] Bernstein, G., Ed., Xu, S., Lee, Y., Ed., Martinelli, G., and H. Harai, "Signaling Extensions for Wavelength Switched Optical Networks", RFC 7689, DOI 10.17487/RFC7689, November 2015, <<https://www.rfc-editor.org/info/rfc7689>>.
- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.
- [RFC8253] Lopez, D., Gonzalez de Dios, O., Wu, Q., and D. Dhody, "PCEPS: Usage of TLS to Provide a Secure Transport for the Path Computation Element Communication Protocol (PCEP)", RFC 8253, DOI 10.17487/RFC8253, October 2017, <<https://www.rfc-editor.org/info/rfc8253>>.
- [RFC8779] Margaria, C., Ed., Gonzalez de Dios, O., Ed., and F. Zhang, Ed., "Path Computation Element Communication Protocol (PCEP) Extensions for GMPLS", RFC 8779, DOI 10.17487/RFC8779, July 2020, <<https://www.rfc-editor.org/info/rfc8779>>.

9.2. Informative References

- [LMP-PARAM] IANA, "Link Management Protocol (LMP) Parameters", <<https://www.iana.org/assignments/lmp-parameters/>>.
- [PCEP-LS] Lee, Y., Zheng, H., Ceccarelli, D., Wang, W., Park, P., and B. Yoon, "PCEP Extension for Distribution of Link-State and TE information for Optical Networks", Work in Progress, Internet-Draft, draft-lee-pce-pcep-ls-optical-09, 9 March 2020, <<https://tools.ietf.org/html/draft-lee->

pce-pcep-ls-optical-09>.

[PCEP-NUMBERS]

IANA, "Path Computation Element Protocol (PCEP) Numbers",
<<https://www.iana.org/assignments/pcep/>>.

- [RFC3471] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description", RFC 3471, DOI 10.17487/RFC3471, January 2003, <<https://www.rfc-editor.org/info/rfc3471>>.
- [RFC4203] Kompella, K., Ed. and Y. Rekhter, Ed., "OSPF Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)", RFC 4203, DOI 10.17487/RFC4203, October 2005, <<https://www.rfc-editor.org/info/rfc4203>>.
- [RFC4204] Lang, J., Ed., "Link Management Protocol (LMP)", RFC 4204, DOI 10.17487/RFC4204, October 2005, <<https://www.rfc-editor.org/info/rfc4204>>.
- [RFC4655] Farrel, A., Vasseur, J.-P., and J. Ash, "A Path Computation Element (PCE)-Based Architecture", RFC 4655, DOI 10.17487/RFC4655, August 2006, <<https://www.rfc-editor.org/info/rfc4655>>.
- [RFC5420] Farrel, A., Ed., Papadimitriou, D., Vasseur, JP., and A. Ayyangar, "Encoding of Attributes for MPLS LSP Establishment Using Resource Reservation Protocol Traffic Engineering (RSVP-TE)", RFC 5420, DOI 10.17487/RFC5420, February 2009, <<https://www.rfc-editor.org/info/rfc5420>>.
- [RFC5521] Oki, E., Takeda, T., and A. Farrel, "Extensions to the Path Computation Element Communication Protocol (PCEP) for Route Exclusions", RFC 5521, DOI 10.17487/RFC5521, April 2009, <<https://www.rfc-editor.org/info/rfc5521>>.
- [RFC6163] Lee, Y., Ed., Bernstein, G., Ed., and W. Imajuku, "Framework for GMPLS and Path Computation Element (PCE) Control of Wavelength Switched Optical Networks (WSONs)", RFC 6163, DOI 10.17487/RFC6163, April 2011, <<https://www.rfc-editor.org/info/rfc6163>>.
- [RFC6566] Lee, Y., Ed., Bernstein, G., Ed., Li, D., and G. Martinelli, "A Framework for the Control of Wavelength Switched Optical Networks (WSONs) with Impairments", RFC 6566, DOI 10.17487/RFC6566, March 2012, <<https://www.rfc-editor.org/info/rfc6566>>.
- [RFC7446] Lee, Y., Ed., Bernstein, G., Ed., Li, D., and W. Imajuku, "Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks", RFC 7446, DOI 10.17487/RFC7446, February 2015, <<https://www.rfc-editor.org/info/rfc7446>>.
- [RFC7449] Lee, Y., Ed., Bernstein, G., Ed., Martensson, J., Takeda, T., Tsuritani, T., and O. Gonzalez de Dios, "Path Computation Element Communication Protocol (PCEP) Requirements for Wavelength Switched Optical Network (WSON) Routing and Wavelength Assignment", RFC 7449, DOI 10.17487/RFC7449, February 2015, <<https://www.rfc-editor.org/info/rfc7449>>.
- [RFC8126] Cotton, M., Leiba, B., and T. Narten, "Guidelines for Writing an IANA Considerations Section in RFCs", BCP 26, RFC 8126, DOI 10.17487/RFC8126, June 2017, <<https://www.rfc-editor.org/info/rfc8126>>.

Acknowledgments

The authors would like to thank Adrian Farrel, Julien Meuric, Dhruv Dhody, and Benjamin Kaduk for many helpful comments that greatly improved the contents of this document.

Contributors

Fatai Zhang
Huawei Technologies

Email: zhangfatai@huawei.com

Cyril Margaria
Nokia Siemens Networks
St. Martin Strasse 76
81541 Munich
Germany

Phone: +49 89 5159 16934
Email: cyril.margaria@nsn.com

Oscar Gonzalez de Dios
Telefonica Investigacion y Desarrollo
C/ Emilio Vargas 6
28043 Madrid
Spain

Phone: +34 91 3374013
Email: ogondio@tid.es

Greg Bernstein
Grotto Networking
Fremont, CA
United States of America

Phone: +1 510 573 2237
Email: gregb@grotto-networking.com

Authors' Addresses

Young Lee (editor)
Samsung Electronics

Email: younglee.tx@gmail.com

Ramon Casellas, Editor (editor)
CTTC
Carl Friedrich Gauss 7
PMT Ed B4 Av.
08860 Castelldefels Barcelona
Spain

Phone: +34 936452916
Email: ramon.casellas@cttc.es