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Path Computation Element Communication Protocol (PCEP) Extensions to  
Enable IFIT  
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## Abstract

In-situ Flow Information Telemetry (IFIT) refers to network OAM data plane on-path telemetry techniques, in particular In-situ OAM (IOAM) and Alternate Marking. This document defines PCEP extensions to allow a Path Computation Client (PCC) to indicate which IFIT features it supports, and a Path Computation Element (PCE) to configure IFIT behavior at a PCC for a specific path in the stateful PCE model. The application to Segment Routing (SR) is reported. However, the PCEP extensions described in this document can be generalized for all path types, but that is out of scope of this document.

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## 1. Introduction

In-situ Flow Information Telemetry (IFIT) refers to network OAM (Operations, Administration, and Maintenance) data plane on-path telemetry techniques, including In-situ OAM (IOAM) [RFC9197] and Alternate Marking [RFC9341]. It can provide flow information on the entire forwarding path on a per- packet basis in real time.

RFC 5440 [RFC5440] describes the Path Computation Element Protocol (PCEP) as a communication mechanism between a Path Computation Client (PCC) and a Path Computation Element (PCE), or between a PCE and a PCE.

RFC 8231 [RFC8231] specifies extensions to PCEP to enable stateful control and it describes two modes of operation: passive stateful PCE and active stateful PCE. Further, RFC 8281 [RFC8281] describes the setup, maintenance, and teardown of PCE-initiated LSPs for the stateful PCE model.

This document defines PCEP extensions to allow a Path Computation Client (PCC) to indicate which IFIT features it supports, and a Path Computation Element (PCE) to configure IFIT behavior at a PCC for a specific path in the stateful PCE model. The PCEP extensions defined in this document allow to distribute paths carrying IFIT information, so that IFIT methods can be enabled automatically when the path is instantiated.

When a PCE is used to initiate paths using PCEP, the head end of the path should also support the IFIT method that is intended for the path. When PCEP is used for path initiation it makes sense that PCEP is also used to carry the IFIT attributes that describe the IOAM or Alternate Marking procedures that needs to be applied.

The PCEP extension defined in this document is generalized and allows to signal the IFIT capabilities for all path types as long as they support the IFIT methods. The flexibility and dynamicity of the IFIT applications are given by the use of additional functions on the controller and on the network nodes, but this is out of scope here.

IFIT is a solution focusing on network domains according to [RFC8799] that introduces the concept of specific domain solutions. A network domain consists of a set of network devices or entities within a single administration. As mentioned in [RFC8799], for a number of reasons, such as policies, options supported, style of network management and security requirements, it is suggested to limit applications including the emerging IFIT techniques to a controlled domain. Hence, the IFIT methods MUST be typically deployed in such controlled domains.

The Use Case of Segment Routing (SR) is discussed considering that IFIT methods are becoming mature for Segment Routing over the MPLS data plane (SR-MPLS) and Segment Routing over IPv6 data plane (SRv6). SR policy [RFC9256] is a set of candidate SR paths consisting of one or more segment lists and necessary path attributes. It enables instantiation of an ordered list of segments with a specific intent for traffic steering. The PCEP extension defined in this document

also enables SR policy with native IFIT, that can facilitate the closed loop control and enable the automation of SR service. An additional example that can be done is for IP network by leveraging [RFC9757].

It is to be noted the companion document [I-D.ietf-idr-sr-policy-ifit] that proposes the BGP extension to enable IFIT methods for SR policy. Both documents complement the deployment scenario described in [I-D.song-opsawg-ifit-framework] and [I-D.ietf-ippm-alt-mark-deployment].

### 1.1. 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 in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

## 2. PCEP Extensions for IFIT Attributes

This document is to add IFIT attribute TLVs as PCEP Extensions. The following sections will describe the requirement and usage of different IFIT modes, and define the corresponding TLV encoding in PCEP.

The IFIT attributes here described can be generalized and included as TLVs carried inside the LSPA (LSP Attributes) object in order to be applied for all path types, as long as they support the relevant data plane telemetry method. IFIT Attributes TLVs are optional and can be taken into account by the PCE during path computation and by the PCC during path setup. In general, the LSPA object can be carried within a PCInitiate message, a PCUpd message, or a PCRpt message in the stateful PCE model.

If a PCE instantiates a path on the PCC with an IFIT capability enabled, it is supposed that there are at least two nodes (e.g. starting and ending node) which support it. If nodes on the path do not support some capabilities, they should simply forward the packet without any changes to the data fields according to RFC 9197 [RFC9197] and Alternate Marking [RFC9341].

In this document it is considered the case of SR Policy since IOAM and Alternate Marking are more mature especially for Segment Routing (SR) and for IPv6.

It is to be noted that, if it is needed to apply different IFIT methods for each Segment List, the IFIT attributes can be added into the PATH-ATTRIB object, instead of the LSPA object, according to [I-D.ietf-pce-multipath] that defines PCEP Extensions for Signaling Multipath Information.

3. IFIT capability advertisement TLV

During the PCEP initialization phase, PCEP speakers (PCE or PCC) SHOULD advertise their support of IFIT methods (e.g. IOAM and Alternate Marking).

A PCEP speaker includes the IFIT-CAPABILITY TLVs in the OPEN object to advertise its support for PCEP IFIT extensions. The presence of the IFIT-CAPABILITY TLV in the OPEN object indicates that the IFIT methods are supported.

RFC 8664 [RFC8664] and RFC 9603 [RFC9603] define a new Path Setup Type (PST) for SR and also define the SR-PCE-CAPABILITY sub-TLV. This document defined a new IFIT-CAPABILITY TLV, that is an optional TLV for use in the OPEN Object for IFIT attributes via PCEP capability advertisement.

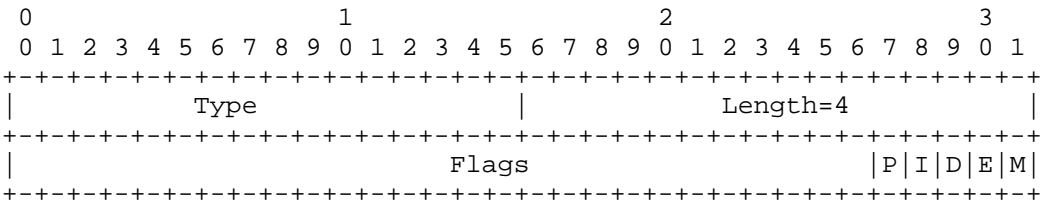


Figure 1: Fig. 1 IFIT-CAPABILITY TLV Format

Where:

Type: to be assigned by IANA.

Length: 4.

Flags: The following flags are defined in this document:

P: IOAM Pre-allocated Trace Option Type-enabled flag RFC 9197 [RFC9197]. If set to 1 by a PCC, the P flag indicates that the PCC allows instantiation of the IOAM Pre-allocated Trace feature by a PCE. If set to 1 by a PCE, the P flag indicates that the PCE supports the IOAM Pre-allocated Trace feature instantiation. The P flag MUST be set by both PCC and PCE in order to support the IOAM Pre-allocated Trace instantiation

I: IOAM Incremental Trace Option Type-enabled flag RFC 9197 [RFC9197]. If set to 1 by a PCC, the I flag indicates that the PCC allows instantiation of the IOAM Incremental Trace feature by a PCE. If set to 1 by a PCE, the I flag indicates that the PCE supports the relative IOAM Incremental Trace feature instantiation. The I flag MUST be set by both PCC and PCE in order to support the IOAM Incremental Trace feature instantiation

D: IOAM DEX Option Type-enabled flag RFC 9326 [RFC9326]. If set to 1 by a PCC, the D flag indicates that the PCC allows instantiation of the relative IOAM DEX feature by a PCE. If set to 1 by a PCE, the D flag indicates that the PCE supports the relative IOAM DEX feature instantiation. The D flag MUST be set by both PCC and PCE in order to support the IOAM DEX feature instantiation

E: IOAM E2E Option Type-enabled flag RFC 9197 [RFC9197] . If set to 1 by a PCC, the E flag indicates that the PCC allows instantiation of the relative IOAM E2E feature by a PCE. If set to 1 by a PCE, the E flag indicates that the PCE supports the relative IOAM E2E feature instantiation. The E flag MUST be set by both PCC and PCE in order to support the IOAM E2E feature instantiation

M: Alternate Marking enabled flag Alternate Marking [RFC9341]. If set to 1 by a PCC, the M flag indicates that the PCC allows instantiation of the relative Alternate Marking feature by a PCE. If set to 1 by a PCE, the M flag indicates that the PCE supports the relative Alternate Marking feature instantiation. The M flag MUST be set by both PCC and PCE in order to support the Alternate Marking feature instantiation

Unassigned bits are considered reserved. They MUST be set to 0 on transmission and MUST be ignored on receipt.

Advertisement of the IFIT-CAPABILITY TLV implies support of IFIT methods (IOAM and/or Alternate Marking) as well as the objects, TLVs, and procedures defined in this document. It is worth mentioning that IOAM and Alternate Marking can be activated one at a time or can coexist; so it is possible to have only IOAM or only Alternate Marking enabled but they are recognized in general as IFIT capability.

The IFIT Capability Advertisement can imply the following cases:

- \* The PCEP protocol extensions for IFIT MUST NOT be used if one or both PCEP speakers have not included the IFIT-CAPABILITY TLV in their respective OPEN message.



Where:

Type: to be assigned by IANA.

Length: The Length field defines the length of the value portion in bytes as per RFC 5440 [RFC5440].

Value: This comprises one or more sub-TLVs.

The following sub-TLVs are defined in this document:

Type	Len	Name
1	8	IOAM Pre-allocated Trace Option
2	8	IOAM Incremental Trace Option
3	12	IOAM Directly Export Option
4	4	IOAM Edge-to-Edge Option
5	4	Enhanced Alternate Marking

Figure 3: Fig. 3 Sub-TLV Types of the IFIT-ATTRIBUTES TLV

#### 4.1. IOAM Sub-TLVs

In-situ Operations, Administration, and Maintenance (IOAM) [RFC9197] records operational and telemetry information in the packet while the packet traverses a path between two points in the network. In terms of the classification given in RFC 7799 [RFC7799] IOAM could be categorized as Hybrid Type 1. IOAM mechanisms can be leveraged where active OAM do not apply or do not offer the desired results.

For the SR use case, when SR policy enables IOAM, the IOAM header will be inserted into every packet of the traffic that is steered into the SR paths. Since this document aims to define the control plane, it is to be noted that a relevant document for the data plane is RFC 9486 [RFC9486] for Segment Routing over IPv6 data plane (SRv6).

##### 4.1.1. IOAM Pre-allocated Trace Option Sub-TLV

The IOAM tracing data is expected to be collected at every node that a packet traverses to ensure visibility into the entire path a packet takes within an IOAM domain. The preallocated tracing option will create pre-allocated space for each node to populate its information.



The format of IOAM pre-allocated trace option Sub-TLV is defined as follows:

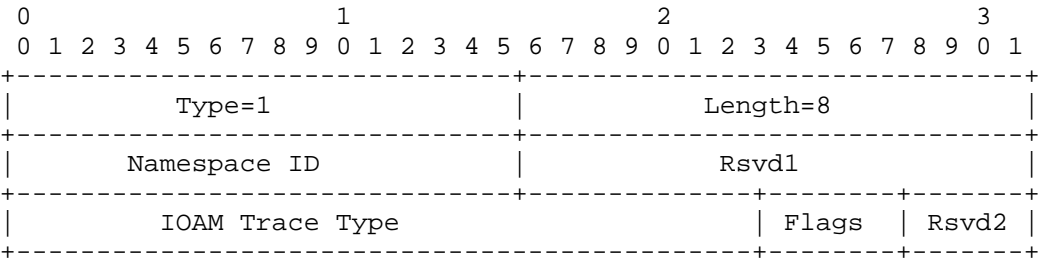


Figure 4: Fig. 4 IOAM Pre-allocated Trace Option Sub-TLV

Where:

- Type: 1 (to be assigned by IANA).
- Length: 8. It is the total length of the value field not including Type and Length fields.
- Namespace ID: A 16-bit identifier of an IOAM-Namespace. The definition is the same as described in section 4.4 of RFC 9197 [RFC9197].
- IOAM Trace Type: A 24-bit identifier which specifies which data types are used in the node data list. The definition is the same as described in section 4.4 of RFC 9197 [RFC9197].
- Flags: A 4-bit field. The definition is the same as described in RFC 9322 [RFC9322] and section 4.4 of RFC 9197 [RFC9197].
- Rsvd1: A 16-bit field reserved for further usage. It MUST be zero and ignored on receipt.
- Rsvd2: A 4-bit field reserved for further usage. It MUST be zero and ignored on receipt.

4.1.2. IOAM Incremental Trace Option Sub-TLV

The incremental tracing option contains a variable node data fields where each node allocates and pushes its node data immediately following the option header.

The format of IOAM incremental trace option Sub-TLV is defined as follows:

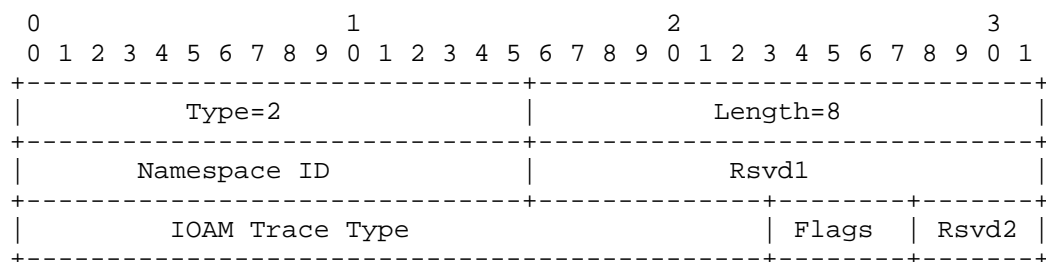


Figure 5: Fig. 5 IOAM Incremental Trace Option Sub-TLV

Where:

Type: 2 (to be assigned by IANA).

Length: 8. It is the total length of the value field not including Type and Length fields.

All the other fields definition is the same as the pre-allocated trace option Sub-TLV in the previous section.

#### 4.1.1.3. IOAM Directly Export Option Sub-TLV

IOAM directly export option is used as a trigger for IOAM data to be directly exported to a collector without being pushed into in-flight data packets.

The format of IOAM directly export option Sub-TLV is defined as follows:

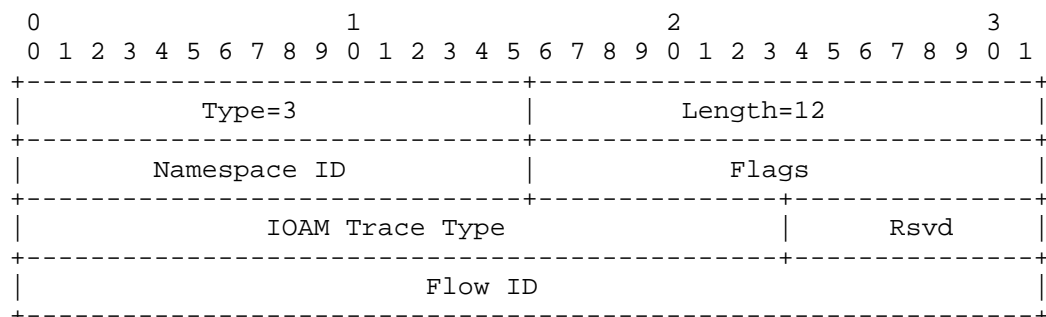


Figure 6: Fig. 6 IOAM Directly Export Option Sub-TLV

Where:

Type: 3 (to be assigned by IANA).

Length: 12. It is the total length of the value field not including Type and Length fields.

Namespace ID: A 16-bit identifier of an IOAM-Namespace. The definition is the same as described in section 4.4 of RFC 9197 [RFC9197].

IOAM Trace Type: A 24-bit identifier which specifies which data types are used in the node data list. The definition is the same as described in section 4.4 of RFC 9197 [RFC9197].

Flags: A 16-bit field. The definition is the same as described in section 3.2 of RFC 9326 [RFC9326].

Flow ID: A 32-bit flow identifier. The definition is the same as described in section 3.2 of RFC 9326 [RFC9326].

Rsvd: A 4-bit field reserved for further usage. It MUST be zero and ignored on receipt.

#### 4.1.4. IOAM Edge-to-Edge Option Sub-TLV

The IOAM edge to edge option is to carry data that is added by the IOAM encapsulating node and interpreted by IOAM decapsulating node.

The format of IOAM edge-to-edge option Sub-TLV is defined as follows:

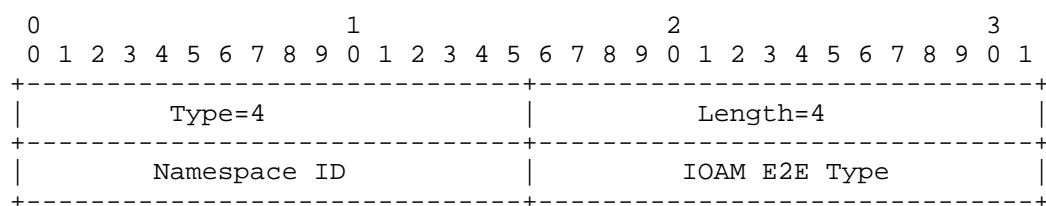


Figure 7: Fig. 7 IOAM Edge-to-Edge Option Sub-TLV

Where:

Type: 4 (to be assigned by IANA).

Length: 4. It is the total length of the value field not including Type and Length fields.

Namespace ID: A 16-bit identifier of an IOAM-Namespace. The definition is the same as described in section 4.6 of RFC 9197 [RFC9197].

IOAM E2E Type: A 16-bit identifier which specifies which data types are used in the E2E option data. The definition is the same as described in section 4.6 of RFC 9197 [RFC9197].

#### 4.2. Enhanced Alternate Marking Sub-TLV

The Alternate Marking [RFC9341] technique is an hybrid performance measurement method, per RFC 7799 [RFC7799] classification of measurement methods. Because this method is based on marking consecutive batches of packets. It can be used to measure packet loss, latency, and jitter on live traffic.

For the SR use case, since this document aims to define the control plane, it is to be noted that a relevant document for the data plane is RFC 9343 [RFC9343] for Segment Routing over IPv6 data plane (SRv6).

The format of Enhanced Alternate Marking (EAM) Sub-TLV is defined as follows:

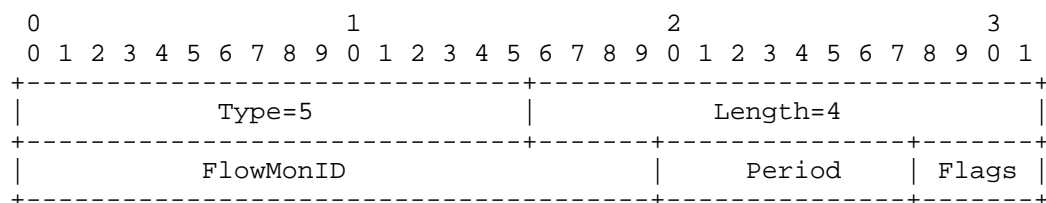


Figure 8: Fig. 8 Enhanced Alternate Marking Sub-TLV

Where:

Type: 5 (to be assigned by IANA).

Length: 4. It is the total length of the value field not including Type and Length fields.

FlowMonID: A 20-bit identifier to uniquely identify a monitored flow within the measurement domain. The definition is the same as described in section 5.3 of RFC 9343 [RFC9343]. It is to be noted that PCE also needs to maintain the uniqueness of FlowMonID as described in RFC 9343 [RFC9343].

Period: Time interval between two alternate marking period. The unit is second.

Flags: A 4-bits field. Two flags are currently assigned:

H: A flag indicating that the measurement is Hop-By-Hop.

E: A flag indicating that the measurement is End-to-End.

Unassigned bits MUST be set to zero on transmission and ignored on receipt.

## 5. PCEP Messages

### 5.1. The PCInitiate Message

A PCInitiate message is a PCEP message sent by a PCE to a PCC to trigger LSP instantiation or deletion RFC 8281 [RFC8281].

For the PCE-initiated LSP with the IFIT feature enabled, IFIT-ATTRIBUTES TLV MUST be included in the LSPA object with the PCInitiate message.

The Routing Backus-Naur Form (RBNF) definition of the PCInitiate message RFC 8281 [RFC8281] is unchanged by this document.

### 5.2. The PCUpd Message

A PCUpd message is a PCEP message sent by a PCE to a PCC to update the LSP parameters RFC 8231 [RFC8231].

For PCE-initiated LSPs with the IFIT feature enabled, the IFIT-ATTRIBUTES TLV MUST be included in the LSPA object with the PCUpd message. The PCE can send this TLV to direct the PCC to change the IFIT parameters.

The RBNF definition of the PCUpd message RFC 8231 [RFC8231] is unchanged by this document.

### 5.3. The PCRpt Message

The PCRpt message RFC 8231 [RFC8231] is a PCEP message sent by a PCC to a PCE to report the status of one or more LSPs.

For PCE-initiated LSPs RFC 8281 [RFC8281], the PCC creates the LSP using the attributes communicated by the PCE and the local values for the unspecified parameters. After the successful instantiation of the LSP, the PCC automatically delegates the LSP to the PCE and generates a PCRpt message to provide the status report for the LSP.

The RBNF definition of the PCRpt message RFC 8231 [RFC8231] is unchanged by this document.

For both PCE-initiated and PCC-initiated LSPs, when the LSP is instantiated the IFIT methods are applied as specified for the corresponding data plane. RFC 9486 [RFC9486] and RFC 9343 [RFC9343] are the relevant documents for Segment Routing over IPv6 data plane (SRv6).

## 6. Application to SR Policy

RFC 8664 [RFC8664] and RFC 9603 [RFC9603] specify extensions to the Path Computation Element Communication Protocol (PCEP) that allow a stateful PCE to compute and initiate Traffic-Engineering (TE) paths, as well as a Path Computation Client (PCC) to request a path subject to certain constraints and optimization criteria in SR networks both for SR-MPLS and SRv6.

IFIT attributes, here defined as TLVs for the LSPA object, complement both RFC 8664 [RFC8664], RFC 9603 [RFC9603] and RFC 9862 [RFC9862].

It is worth mentioning that, at the moment, the IFIT methods (IOAM and Alternate Marking) are more mature for SRv6 compared to SR-MPLS. The reference documents are RFC 9486 [RFC9486] and RFC 9343 [RFC9343] for SRv6.

A PCC or PCE sets the IFIT-CAPABILITY TLV in the Open message during the PCEP initialization phase to indicate that it supports the IFIT procedures.

RFC 9862 [RFC9862] defines the PCEP extension to support Segment Routing Policy Candidate Paths and in this regard the SRPAG Association object is introduced.

The Examples of PCC Initiated SR Policy with single or multiple candidate-paths and PCE Initiated SR Policy with single or multiple candidate-paths are reported in RFC 9862 [RFC9862].

In case of PCC Initiated SR Policy, PCC sends PCReq message to the PCE, encoding the SRPAG ASSOCIATION object and IFIT-ATTRIBUTES TLV via the LSPA object. This is valid for both single and multiple candidate-paths. Finally PCE returns the path in PCRep message, and echoes back the SRPAG object that were used in the computation and IFIT LSPA TLVs too. Additionally, PCC sends PCRpt message to the PCE, including the LSP object and the SRPAG ASSOCIATION object and IFIT-ATTRIBUTES TLV via the LSPA object. Then PCE computes path and finally PCE updates the SR policy candidate path's ERO using PCUpd message considering the IFIT LSPA TLVs too.

In case of PCE Initiated SR Policy, PCE sends PCInitiate message, containing the SRPAG Association object and IFIT-ATTRIBUTES TLV via the LSPA object. This is valid for both single and multiple candidate-paths. Then PCC uses the color, endpoint and preference from the SRPAG object to create a new candidate path considering the IFIT LSPA TLVs too. Finally PCC sends a PCRpt message back to the PCE to report the newly created Candidate Path. The PCRpt message contains the SRPAG Association object and IFIT-ATTRIBUTES information.

The procedure of enabling/disabling IFIT is simple, indeed the PCE can update the IFIT-ATTRIBUTES of the LSP by sending subsequent Path Computation Update Request (PCUpd) messages. PCE can update the IFIT-ATTRIBUTES of the LSP by sending Path Computation State Report (PCRpt) messages.

## 7. IANA Considerations

This document defines the new IFIT-CAPABILITY TLV and IFIT-ATTRIBUTES TLV.

### 7.1. PCEP TLV Type Indicators

IANA is requested to make the assignment from the "PCEP TLV Type Indicators" subregistry of the "Path Computation Element Protocol (PCEP) Numbers" registry as follows:

Value	Description	Reference
TBD1	IFIT-CAPABILITY TLV	This document
TBD2	IFIT-ATTRIBUTES TLV	This document

### 7.2. IFIT-CAPABILITY TLV Flags field

This document specifies the IFIT-CAPABILITY TLV 32-bits Flags field. IANA is requested to create a registry to manage the value of the IFIT-CAPABILITY TLV's Flags field within the "Path Computation Element Protocol (PCEP) Numbers" registry.

New values are to be assigned by Standards Action RFC 8126 [RFC8126]. Each bit should be tracked with the following qualities:

- \* Bit number (count from 0 as the most significant bit)
- \* Flag Name
- \* Reference

IANA is requested to set 5 new bits in the IFIT-CAPABILITY TLV Flags Field registry, as follows:

Bit no.	Flag Name	Reference
0-26	Unassigned	This document
27	P: IOAM Pre-allocated Trace Option flag	This document
28	I: IOAM Incremental Trace Option flag	This document
29	D: IOAM Directly Export Option flag	This document
30	E: IOAM Edge-to-Edge Option	This document
31	M: Alternate Marking Flag	This document

### 7.3. IFIT-ATTRIBUTES Sub-TLV

This document also specifies the IFIT-ATTRIBUTES sub-TLVs. IANA is requested to create an "IFIT-ATTRIBUTES Sub-TLV Types" subregistry within the "Path Computation Element Protocol (PCEP) Numbers" registry.

IANA is requested to set the Registration Procedure for this registry to read as follows:

Range	Registration Procedure
0-65503	IETF Review
65504-65535	Experimental Use

This document defines the following types:



Type	Description	Reference
0	Reserved	This document
1	IOAM Pre-allocated Trace Option	This document
2	IOAM Incremental Trace Option	This document
3	IOAM Directly Export Option	This document
4	IOAM Edge-to-Edge Option	This document
5	Enhanced Alternate Marking	This document
6-65503	Unassigned	This document
65504-65535	Experimental Use	This document

#### 7.4. Enhanced Alternate Marking Sub-TLV Flags field

This document specifies the Enhanced Alternate Marking Sub-TLV 4-bits Flags field. IANA is requested to create a registry to manage the value of the Enhanced Alternate Marking Sub-TLV's Flags field within the "Path Computation Element Protocol (PCEP) Numbers" registry.

New values are to be assigned by Standards Action RFC 8126 [RFC8126]. Each bit should be tracked with the following qualities:

- \* Bit number (count from 0 as the most significant bit)
- \* Flag Name
- \* Reference

IANA is requested to set 2 new bits in the IFIT-CAPABILITY TLV Flags Field registry, as follows:

Bit no.	Flag Name	Reference
3	H: Hop-By-Hop flag	This document
2	E: End-to-End flag	This document
0-1	Unassigned	

## 7.5. PCEP Error Codes

This document defines a new Error-value for PCErr message of Error-Type 19 (Invalid Operation). IANA is requested to allocate a new Error-value within the "PCEP-ERROR Object Error Types and Values" subregistry of the "Path Computation Element Protocol (PCEP) Numbers" registry as follows:

Error-Type	Meaning	Error-value	Reference
19	Invalid Operation	TBD3: IFIT capability not advertised	This document

## 8. Security Considerations

This document defines the new IFIT-CAPABILITY TLV and IFIT Attributes TLVs, which do not add any substantial new security concerns beyond those already discussed in RFC 8231 [RFC8231] and RFC 8281 [RFC8281] for stateful PCE operations. As per RFC 8231 [RFC8231], it is RECOMMENDED that these PCEP extensions only be activated on authenticated and encrypted sessions across PCEs and PCCs belonging to the same administrative authority, using Transport Layer Security (TLS) RFC 8253 [RFC8253], as per the recommendations and best current practices in BCP 195 RFC 7525 [RFC7525] (unless explicitly set aside in RFC 8253 [RFC8253]).

Implementation of IFIT methods (IOAM and Alternate Marking) are mindful of security and privacy concerns, as explained in RFC 9197 [RFC9197] and Alternate Marking [RFC9341]. Anyway incorrect IFIT parameters in the IFIT-ATTRIBUTES sub-TLVs SHOULD NOT have an adverse effect on the LSP as well as on the network, since it affects only the operation of the telemetry methodology.

IFIT data MUST be propagated in a limited domain in order to avoid malicious attacks and solutions to ensure this requirement are respectively discussed in RFC 9197 [RFC9197] and RFC 9343 [RFC9343].

IFIT methods (IOAM and Alternate Marking) are applied within a controlled domain where the network nodes are locally administered. A limited administrative domain provides the network administrator with the means to select, monitor and control the access to the network, making it a trusted domain also for the PCEP extensions defined in this document.

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