CCAMP Working Group
Internet-Draft
Intended status: Standards Track
Expires: April 13, 2016
October 16, 2015

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GMPLS OSPF-TE Extensions in support of Flexi-grid DWDM networks

draft-ietf-ccamp-flexible-grid-ospf-ext-03.txt

Abstract

This memo describes the OSPF-TE extensions in support of GMPLS control of networks that include devices that use the new flexible optical grid.

Status of this Memo

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Table of Contents

1. Introduction

[G.694.1] defines the Dense Wavelength Division Multiplexing (DWDM) frequency grids for Wavelength Division Multiplexing (WDM) applications. A frequency grid is a reference set of frequencies used to denote allowed nominal central frequencies that may be used for defining applications. The channel spacing is the frequency spacing between two allowed nominal central frequencies. All of the wavelengths on a fiber should use different central frequencies and occupy a fixed bandwidth of frequency.

Fixed grid channel spacing is selected from 12.5 GHz, 25 GHz, 50 GHz, 100 GHz and integer multiples of 100 GHz. But [G.694.1] also defines "flexible grids", also known as "flexi-grid". The terms "frequency slot" (i.e., the frequency range allocated to a specific channel and unavailable to other channels within a flexible grid) and "slot width" (i.e., the full width of a frequency slot in a flexible grid) are used to define a flexible grid.

[FLEX-FWK] defines a framework and the associated control plane requirements for the GMPLS based control of flexi-grid DWDM networks.

[RFC6163] provides a framework for GMPLS and Path Computation Element (PCE) control of Wavelength Switched Optical Networks (WSONs), and [WSON-OSPF] defines the requirements and OSPF-TE extensions in support of GMPLS control of a WSON.

[FLEX-SIG] describes requirements and protocol extensions for signaling to set up LSPs in networks that support the flexi-grid, and this document complements [FLEX-SIG] by describing the requirement and extensions for OSPF-TE routing in a flexi-grid network.

This draft compliments the efforts to provide extensions to Open Short Path First (OSPF) Traffic-Engineering (TE) protocol so as to support GMPLS control of flexi-grid networks.

2. Terminology

For terminology related to flexi-grid, please consult [FLEX-FWK] and [G.694.1].

2.1. Conventions Used in this Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC-2119 [RFC2119].

3. Requirements for Flexi-grid Routing

The architecture for establishing LSPs in a Spectrum Switched optical Network (SSON) is described in [FLEX-FWK].

A flexi-grid LSP occupies a specific frequency slot, i.e. a range of frequencies. The process of computing a route and the allocation of a frequency slot is referred to as RSA (Routing and Spectrum Assignment). [FLEX-FWK] describes three types of architectural approaches to RSA: combined RSA; separated RSA; and distributed SA. The first two approaches among them could be called "centralized SA" because the spectrum (frequency slot) assignment is performed by a single entity before the signaling procedure.

In the case of centralized SA, the assigned frequency slot is specified in the RSVP-TE Path message during the signaling process. In the case of distributed SA, only the requested slot width of the flexi-grid LSP is specified in the Path message, allowing the involved network elements to select the frequency slot to be used.

If the capability of switching or converting the whole optical spectrum allocated to an optical spectrum LSP is not available at nodes along the path of the LSP, the LSP is subject to the Optical "Spectrum Continuity Constraint", as described in [FLEX-FWK].

The remainder of this section states the additional extensions on the routing protocols in a flexi-grid network. That is, the additional information that must be collected and passed between nodes in the network by the routing protocols in order to enable correct path computation and signaling in support of LSPs within the network.

3.1. Available Frequency Ranges

In the case of flexi-grids, the central frequency steps from 193.1 THz with 6.25 GHz granularity. The calculation method of central frequency and the frequency slot width of a frequency slot are defined in [G.694.1], i.e., by using nominal central frequency n and the slot width m.

On a DWDM link, the allocated or in-use frequency slots must not overlap with each other. However, the border frequencies of two frequency slots may be the same frequency, i.e., the highest frequency of a frequency slot may be the lowest frequency of the next frequency slot.

```
                     Frequency Slot 1   Frequency Slot 2
                       +-----------+----------------------+
                       |           |                      |
      -9 -8 -7 -6 -5 -4 -3 -2 -1 0  1  2  3  4  5  6  7  8  9 10  11
   ...+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--...
                       ------------ ----------------------
                             ^                 ^
                Central F = 193.1THz    Central F = 193.1375 THz
                 Slot width = 25 GHz    Slot width = 50 GHz
```

Figure 1 - Two Frequency Slots on a Link

Figure 1 shows two adjacent frequency slots on a link. The highest frequency of frequency slot 1 denoted by n=2 is the lowest frequency of slot 2. In this example, it means that the frequency range from n=-2 to n=10 is occupied and is unavailable to other flexi-grid LSPs.

Hence, in order to clearly show which LSPs can be supported and what frequency slots are unavailable, the available frequency ranges MUST be advertised by the routing protocol for the flexi-grid DWDM links. A set of non-overlapping available frequency ranges MUST be disseminated in order to allow efficient resource management of flexi-grid DWDM links and RSA procedures which are described in Section 4.8 of [FLEX-FWK].

3.2. Application Compliance Considerations

As described in [G.694.1], devices or applications that make use of the flexi-grid may not be capable of supporting every possible slot width or position (i.e., central frequency). In other words, applications or implementations may be defined where only a subset of the possible slot widths and positions are required to be supported.

For example, an application could be defined where the nominal central frequency granularity is 12.5 GHz (by only requiring values of n that are even) and that only requires slot widths as a multiple of 25 GHz (by only requiring values of m that are even).

Hence, in order to support all possible applications and implementations the following information should be advertised for a flexi-grid DWDM link:

o Chanel Spacing (C.S.): as defined in [FLEX-LBL] and for flexi-grid, is set to 5 to denote 6.25GHz.

o Central frequency granularity: a multiplier of C.S..

o Slot width granularity: a multiplier of 2*C.S..

o Slot width range: two multipliers of the slot width granularity, each indicate the minimal and maximal slot width supported by a port respectively.

The combination of slot width range and slot width granularity can be used to determine the slot widths set supported by a port.

3.3. Comparison with Fixed-grid DWDM Links

In the case of fixed-grid DWDM links, each wavelength has a pre-defined central frequency and each wavelength maps to a pre-defined central frequency and the usable frequency range is implicit by the channel spacing. All the wavelengths on a DWDM link can be identified with an identifier that mainly convey its central frequency as the label defined in [RFC6205], and the status of the wavelengths (available or not) can be advertised through a routing protocol.

Figure 2 shows a link that supports a fixed-grid with 50 GHz channel spacing. The central frequencies of the wavelengths are pre-defined by values of "n" and each wavelength occupies a fixed 50 GHz frequency range as described in [G.694.1].

```
     W(-2)  |    W(-1)  |    W(0)   |    W(1)   |     W(2)  |
...---------+-----------+-----------+-----------+-----------+----...
      |   50 GHz  |  50 GHz    |  50 GHz    |   50 GHz  |

    n=-2        n=-1        n=0         n=1         n=2
...---+-----------+-----------+-----------+-----------+----------...
                              ^
                 Central F = 193.1THz
```

Figure 2 - A Link Supports Fixed Wavelengths with 50 GHz Channel Spacing

Unlike the fixed-grid DWDM links, on a flexi-grid DWDM link the slot width of the frequency slot is flexible as described in section 3.1. That is, the value of m in the following formula [G.694.1] is uncertain before a frequency slot is actually allocated for a flexi-grid LSP.

Slot Width (GHz) = 12.5GHz * m

For this reason, the available frequency slot/ranges need to be advertised for a flexi-grid DWDM link instead of the specific "wavelengths" points that are sufficient for a fixed-grid link. Moreover, thus advertisement is represented by the combination of Central Frequency Granularity and Slot Width Granularity.

4. Extensions

As described in [FLEX-FWK], the network connectivity topology constructed by the links/nodes and node capabilities are the same as for WSON, and can be advertised by the GMPLS routing protocols (refer to section 6.2 of [RFC6163]). In the flexi-grid case, the available frequency ranges instead of the specific "wavelengths" are advertised for the link. This section defines the GMPLS OSPF-TE extensions in support of advertising the available frequency ranges for flexi-grid DWDM links.

4.1. ISCD Extensions for Flexi-grid

Value	Type
152 (TBA by IANA)	Flexi-Grid-LSC capable

Switching Capability and Encoding values MUST be used as follows:

Switching Capability = Flexi-Grid-LSC

Encoding Type = lambda [as defined in RFC3471]

When Switching Capability and Encoding fields are set to values as stated above, the Interface Switching Capability Descriptor MUST be interpreted as in [RFC4203] with the optional inclusion of one or more Switching Capability Specific Information sub-TLVs.

4.1.1. Switching Capability Specific Information (SCSI)

The technology specific part of the Flexi-grid ISCD should include the available frequency spectrum resource as well as the max slot widths per priority information. The format of this flex-grid SCSI, the frequency available bitmap TLV, is depicted in the following figure:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Type  = 1            |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Priority    |                  Reserved                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Max Slot Width at Priority 0  |           ...                 ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~ Max Slot Width at Priority 7  |   Unreserved padding          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| C.S.  |       Starting n              | No. of Effective. Bits|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       Bit Map                 ...                             ~
~      ...                              |  padding bits         ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type (16 bits): The type of this sub-TLV and is set to 1.

Length (16 bits): The length of the value field of this sub-TLV.

Priority (8 bits): A bitmap used to indicate which priorities are being advertised. The bitmap is in ascending order, with the leftmost bit representing priority level 0 (i.e., the highest) and the rightmost bit representing priority level 7 (i.e., the lowest). A bit MUST be set (1) corresponding to each priority represented in the sub-TLV, and MUST NOT be set (0) when the corresponding priority is not represented. At least one priority level MUST be advertised that, unless overridden by local policy, SHALL be at priority level 0.

Max Slot Width (16 bits): This field indicates maximal frequency slot width supported at a particular priority level. This field MUST be set to max frequency slot width supported in the unit of 2.C.S., for a particular priority level. One field MUST be present for each bit set in the Priority field, and is ordered to match the Priority field. Fields MUST NOT be present for priority levels that are not indicated in the Priority field.

Unreserved Padding (16 bits): The Padding field is used to ensure the 32 bit alignment of Max Slot Width fields. When present the Unreserved Padding field is 16 bits (2 byte) long. When the number of priorities is odd, the Unreserved Padding field MUST be included. When the number of priorities is even, the Unreserved Padding MUST be omitted.

C.S. (4 bits): As defined in [FLEX-LBL] and it is currently set to 5.

Starting n (16 bits): as defined in [FLEX-LBL] and this value denotes the starting nominal central frequency point of the frequency availability bitmap sub-TLV.

Number of Effective Bits (12 bits): Indicates the number of effective bits in the Bit Map field.

Bit Map (variable): Indicates whether a basic frequency slot, characterized by a nominal central frequency and a fixed m value of 1, is available or not for flexi-grid LSP setup. The first nominal central frequency is the value of starting n and with the subsequent ones implied by the position in the bitmap. Note that when setting to 1, it means that the corresponding central frequency is available for a flexi-grid LSP with m=1. Note that a centralized SA process will need to extend this to high values of m by checking a sufficient large number of consecutive basic frequency slots that are available.

Padding Bits (variable): Added after the Bit Map to make it a multiple of four bytes if necessary. Padding bits MUST be set to 0 and MUST be ignored on receipt.

The Reserved field MUST be set to zero on transmission and SHOULD be ignored on receipt.

The starting n MAY be set to the lowest possible nominal central frequency supported by the link. An example is provided in the next section.

4.1.2. An SCSI Example

Figure 3 shows an example of the available frequency spectrum resource of a flexi-grid DWDM link.

```
   -9 -8 -7 -6 -5 -4 -3 -2 -1 0  1  2  3  4  5  6  7  8  9 10  11
...+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--...
                        |--Available Frequency Range--|
```

Figure 3 - Flexi-grid DWDM Link Example

The symbol "+" represents the allowed nominal central frequency. The symbol "--" represents a central frequency granularity of 6.25 GHz, as currently be standardized in [G.694.1]. The number on the top of the line represents the "n" in the frequency calculation formula

(193.1 + n * 0.00625). The nominal central frequency is 193.1 THz when n equals zero.

In this example, it is assumed that the lowest nominal central frequency supported is n= -9 and the highest is n=11. Note they cannot be used as a nominal central frequency for setting up a LSP, but merely as the way to express the supported frequency range. Using the encoding defined in Section 4.1.1, the relevant fields to express the frequency resource availability can be filled as below:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|          Type  = 1            |           Length              |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Priority    |                   Reserved                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Max Slot Width at Priority 0  |          ...                  ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~ Max Slot Width at Priority 7  |   Unreserved padding          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   5   |       Starting n (-9)         | No. of Effec. Bits(21)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|0|0|0|0|0|0|0|0|1|1|1|1|1|1|1|1|1|0|0|0|0|  padding bits (0s)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In the above example, the starting n is selected to be the lowest nominal central frequency, i.e. -9. Note other starting n values can be chosen and for example, the first available nominal central frequency (a.k.a., the first available basic frequency slot) can be chosen and the SCSI will be expressed as the following:

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Type  = 1            |           Length              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Priority    |                  Reserved                     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Max Slot Width at Priority 0  |           ...                 ~
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    ~ Max Slot Width at Priority 7  |   Unreserved padding          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   5   |       Starting n (-1)         | No. of Effec. Bits(9)|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |1|1|1|1|1|1|1|1|1|            padding bits (0s)                |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

This denotes that other than the advertised available nominal central frequencies, the other nominal central frequencies within the whole frequency range supported by the link are not available for path computation use.

If a LSP with slot width (m) equal to 1 is set up using this link, say using n= -1, then the SCSI information is updated to be the following:

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |          Type  = 1            |           Length              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   Priority    |                  Reserved                     |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    | Max Slot Width at Priority 0  |           ...                 ~
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    ~ Max Slot Width at Priority 7  |   Unreserved padding          |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |   5   |       Starting n (-1)         | No. of Effec. Bits(9)|
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |0|0|1|1|1|1|1|1|1|            padding bits (0s)                |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

4.2. Extensions to Port Label Restriction sub-TLV

As described in Section 3.2, a port that supports flexi-grid may support only a restricted subset of the full flexible grid. The Port Label Restriction sub-TLV is defined in [RFC7579]. It can be used to describe the label restrictions on a port and is carried in the top-level Link TLV as specified in [RFC7580]. A new restriction type, the flexi-grid Restriction Type, is defined here to specify the restrictions on a port to support flexi-grid.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| MatrixID      | RstType = 5 | Switching Cap |   Encoding    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  C.S. |     C.F.G     |    S.W.G      |     Reserved          |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|      Min Slot Width           |        Reserved               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

MatrixID (8 bits): As defined in [RFC7579].

RstType (Restriction Type, 8 bits): Takes the value of 5 to indicate the restrictions on a port to support flexi-grid.

Switching Cap (Switching Capability, 8 bits): As defined in [RFC7579], MUST be consistent with the one specified in ISCD as described in Section 4.1.

Encoding (8 bits): As defined in [RFC7579], must be consistent with the one specified in ISCD as described in Section 4.1.

C.S. (4 bits): As defined in [FLEX-LBL] and for flexi-grid is 5 to denote 6.25GHz.

C.F.G (Central Frequency Granularity, 8 bits): A positive integer. Its value indicates the multiple of C.S., in terms of central frequency granularity.

S.W.G (Slot Width Granularity, 8 bits): A positive integer. Its value indicates the multiple of 2*C.S., in terms of slot width granularity.

Min Slot Width (16 bits): A positive integer. Its value indicates the multiple of 2*C.S. (GHz), in terms of the supported minimal slot width.

The Reserved field MUST be set to zero on transmission and SHOULD be ignored on receipt.

5. IANA Considerations

5.1. New Switching Type

Upon approval of this document, IANA will make the assignment in the "Switching Types" section of the "GMPLS Signaling Parameters" registry located at http://www.iana.org/assignments/gmpls-sig-parameters:

Value	Name	Reference
152 (*)	Flexi-Grid-LSC capable	[This.I-D]

(*) Suggested value

5.2. New Sub-TLV

This document defines one new sub-TLV that are carried in the Interface Switching Capability Descriptors [RFC4203] with Signal Type Flexi-Grid-LSC capable.

Upon approval of this document, IANA will create and maintain a new sub-registry, the "Types for sub-TLVs of Flexi-Grid-LSC capable SCSI (Switch Capability-Specific Information)" registry under the "Open Shortest Path First (OSPF) Traffic Engineering TLVs" registry, see http://www.iana.org/assignments/ospf-traffic-eng-tlvs/ospf-traffic-eng-tlvs.xml, with the sub-TLV types as follows:

This document defines new sub-TLV types as follows:

Value	Sub-TLV	Reference
0	Reserved	[This.I-D]
1	Frequency availability bitmap	[This.I-D]

6. Implementation Status

[RFC Editor Note: Please remove this entire section prior to publication as an RFC.]

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in RFC 6982[RFC6982]. The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to RFC 6982, "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit.

6.1. Centre Tecnologic de Telecomunicacions de Catalunya (CTTC)

Organization Responsible for the Implementation: CTTC - Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Optical Networks and Systems Department, http://wikiona.cttc.es.

Implementation Name and Details: ADRENALINE testbed, http://networks.cttc.es/experimental-testbeds/

Brief Description: Experimental testbed implementation of GMPLS/PCE control plane.

Level of Maturity: Implemented as extensions to a mature GMLPS/PCE control plane. It is limited to research / prototyping stages but it has been used successfully for more than the last five years.

Coverage: Support for the 64 bit label [FLEC-LBL] for flexi-grid as described in this document, with available label set encoded as bitmap.

It is expected that this implementation will evolve to follow the evolution of this document.

Licensing: Proprietary

Implementation Experience: Implementation of this document reports no issues. General implementation experience has been reported in a number of journal papers. Contact Ramon Casellas for more information or see http://networks.cttc.es/publications/?search=GMPLS&research_area=optical-networks-systems

Contact Information: Ramon Casellas: ramon.casellas@cttc.es

Interoperability: No report.

7. Acknowledgments

This work was supported in part by the FP-7 IDEALIST project under grant agreement number 317999.

This work was supported in part by NSFC Project 61201260.

8. Security Considerations

This document extends [RFC4203] and [RFC7580] to carry flex-grid specific information in OSPF Opaque LSAs. This document does not introduce any further security issues other than those discussed in [RFC3630], [RFC4203]. To be more specific, the security mechanisms described in [RFC2328] which apply to Opaque LSAs carried in OSPF still apply. An analysis of the OSPF security is provided in [RFC6863] and applies to the extensions to OSPF in this document as well.

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10. References

10.1. Normative References

[RFC2119] S. Bradner, "Key words for use in RFCs to indicate requirements levels", RFC 2119, March 1997.

[G.694.1] ITU-T Recommendation G.694.1 (revision 2), "Spectral grids for WDM applications: DWDM frequency grid", February 2012.

[RFC7579] Bernstein, G., Lee, Y., Li, D., and W. Imajuku, "General Network Element Constraint Encoding for GMPLS Controlled Networks", RFC 7579, June 2015.

[RFC7580] F. Zhang, Y. Lee, J. Han, G. Bernstein and Y. Xu, "OSPF-TE Extensions for General Network Element Constraints ", RFC 7580, June 2015.

[RFC6205] T. Otani and D. Li, "Generalized Labels for Lambda-Switch-Capable (LSC) Label Switching Routers", RFC 6205, March 2011.

[FLEX-LBL] King, D., Farrel, A. and Y. Li, "Generalized Labels for the Flexi-Grid in Lambda Switch Capable (LSC) Label Switching Routers", draft-ietf-ccamp-flexigrid-lambda-label, work in progress.

10.2. Informative References

[RFC6163] Y. Lee, G. Bernstein and W. Imajuku, "Framework for GMPLS and Path Computation Element (PCE) Control of Wavelength Switched Optical Networks (WSONs)", RFC 6163, April 2011.

[FLEX-SIG] F.Zhang et al, "RSVP-TE Signaling Extensions in support of Flexible-grid", draft-ietf-ccamp-flexible-grid-rsvp-te-ext, work in progress.

[FLEX-FWK] Gonzalez de Dios, O., Casellas R., Zhang, F., Fu, X., Ceccarelli, D., and I. Hussain, "Framework and Requirements for GMPLS based control of Flexi-grid DWDM networks', draft-ietf-ccamp-flexi-grid-fwk, work in progress.

[WSON-OSPF] Y. Lee and G. Bernstein, "GMPLS OSPF Enhancement for Signal and Network Element Compatibility for Wavelength Switched Optical Networks ", draft-ietf-ccamp-wson-signal-compatibility-ospf, work in progress.

[RFC2328] Moy, J., "OSPF Version 2", STD 54, RFC 2328, April 1998.

[RFC6863] Hartman, S. and D. Zhang, "Analysis of OSPF Security According to the Keying and Authentication for Routing Protocols (KARP) Design Guide", RFC 6863, March 2013.

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