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GMPLS OSPF-TE Extensions in support of Flexible Grid

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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.

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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.

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-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 both routing and spectrum (frequency slot) assignment are performed by centralized entity before the signaling procedure.

In the case of centralized SA, the assigned frequency slot is specified in the Path message during LSP setup. In the case of distributed SA, the 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 flexi-LSP are defined in [G.694.1].

On a DWDM link, the 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-LSPs.

Hence, in order to clearly show which LSPs can be supported and what frequency slots are unavailable, the available frequency ranges should be advertised by the routing protocol for the flexi-grid DWDM links. A set of non-overlapping available frequency ranges should be disseminated in order to allow efficient resource management of flexi-grid DWDM links and RSA procedures which are described in section 5.8 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 Central frequency granularity: a multiplier of 6.25 GHz.

o Slot width granularity: a multiplier of 12.5 GHz.

o Slot width range: two multipliers of 12.5GHz, 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 has the same frequency range (i.e., there is a uniform channel spacing). Hence all the wavelengths on a DWDM link can be identified uniquely simply by giving it an identifier (such as the central wavelength [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 are flexible as described in section 3.1. That is, the value of m in the formula is uncertain before a frequency slot is actually allocated. For this reason, the available frequency slot/ranges need to be advertised for a flexi-grid DWDM link instead of the specific "wavelengths" that are sufficient for a fixed-grid link.

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 for Flexi-grid

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

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.

4.2. Available Labels Set Sub-TLV

As described in section 3.1, the available frequency ranges other than the available frequency slots should be advertised for the flexi-grid DWDM links. The label encoding defined in [FLEX-LBL] is used to encode the label field in Available Labels Set sub-TLV [GEN-Encode].

4.2.1. Inclusive/Exclusive Label Range

The inclusive/exclusive label ranges format of the Available Labels Set sub-TLV defined in [GEN-ENCODE] can be used for specifying the frequency ranges of the flexi-grid DWDM links.

Note that multiple Available Labels Set sub-TLVs may be needed if there are multiple discontinuous frequency ranges on a link.

4.2.2. Inclusive/Exclusive Label Lists

The inclusive/exclusive label lists format of Available Labels Set sub-TLV defined in [GEN-ENCODE] can be used for specifying the available central frequencies of flexi-grid DWDM links.

4.2.3. Bitmap

The bitmap format of Available Labels Set sub-TLV defined in [GEN-ENCODE] can be used for specifying the available central frequencies of the flexi-grid DWDM links.

Each bit in the bit map represents a particular central frequency with a value of 1/0 indicating whether the central frequency is in the set or not. Bit position zero represents the lowest central frequency and corresponds to the base label, while each succeeding bit position represents the next central frequency logically above the previous.

4.3. 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 [GEN-ENCODE] and [GEN-OSPF]. It can be used to describe the label restrictions on a port. 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 = TBA |            Reserved           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |     C.F.G     |     S.W.G     |   Min Width   |   Max Width   |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

MatrixID (8 bits): As defined in [GEN-ENCODE].

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

C.F.G (Central Frequency Granularity, 8 bits): A positive integer. Its value indicates the multiple of 6.25 GHz in terms of central frequency granularity.

S.W.G (Slot Width Granularity, 8 bits): A positive integer. Its value indicates the multiple of 12.5 GHz in terms of slot width granularity.

Min Width (8 bits): A positive integer. Its value indicates the multiple of 12.5 GHz in terms of the supported minimal slot width.

Max Width (8 bits): A positive integer. Its value indicates the multiple of 12.5 GHz in terms of the supported maximal slot width.

4.4. Examples for Available Label Set Sub-TLV

Figure 3 shows an example of available frequency range 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

The symbol '+' represents the allowed nominal central frequency. The symbol "--" represents a 6.25 GHz frequency unit. 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.

Assume that the central frequency granularity is 6.25GHz, the label set can be encoded as follows:

Inclusive Label Range:

- o Start Slot = -2;
- o End Slot = 8.

The available central frequencies (-1, 0, 1, 2, 3, 4, 5, 6, 7) can be deduced by the Inclusive Label Range, because the Central Frequency Granularity is 6.25 GHz.

Inclusive Label Lists:

- o List Entry 1 = slot -1;
- o List Entry 2 = slot 0;
- o List Entry 3 = slot 1;
- o List Entry 4 = slot 2;
- o List Entry 5 = slot 3;
- o List Entry 6 = slot 4;
- o List Entry 7 = slot 5;
- o List Entry 8 = slot 6;
- o List Entry 9 = slot 7.

Bitmap:

- o Base Slot = -1;
- o Bitmap = 111111111(padded out to a full multiple of 32 bits)

5. IANA Considerations

[GEN-OSPF] defines the Port label Restriction sub-TLV of OSPF TE Link TLV. It also creates a registry of values of the Restriction Type field of that sub-TLV

IANA is requested to assign a new value from that registry as follows:

Value	Meaning	Reference
TBD	Flexi-grid restriction	[This.I-D]

6. Implementation Status

[RFC Editor Note: Please remove this entire seciton 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 [FLEX-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

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8. Security Considerations

This document does not introduce any further security issues other than those discussed in [RFC3630], [RFC4203].

9. References

9.1. 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", June 2012.

[GEN-ENCODE] Bernstein, G., Lee, Y., Li, D., and W. Imajuku, "General Network Element Constraint Encoding for GMPLS Controlled Networks", draft-ietf-ccamp-general-constraint-encode, work in progress.

[GEN-OSPF] Fatai Zhang, Y. Lee, Jianrui Han, G. Bernstein and Yunbin Xu, " OSPF-TE Extensions for General Network Element Constraints ", draft-ietf-ccamp-gmpls-general-constraints-ospf-te, work in progress.

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

9.2. 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-zhang-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-ogrcetal-cammp-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.

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