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Expires: August 17, 2017   February 17, 2017

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

draft-ietf-ccamp-flexible-grid-ospf-ext-09.txt

Abstract

   The International Telecommunication Union Telecommunication
   Standardization Sector (ITU-T) has extended its Recommendations
   G.694.1 and G.872 to include a new Dense Wavelength Division
   Multiplexing (DWDM) grid by defining a set of nominal central
   frequencies, channel spacings, and the concept of the "frequency
   slot". Corresponding techniques for data-plane connections are known
   as flexi-grid.

   Based on the characteristics of flexi-grid defined in G.694.1, RFC
   7698 and 7699, this document describes the OSPF-TE extensions in
   support of GMPLS control of networks that include devices that use
   the new flexible optical grid.

   The list of current Internet-Drafts can be accessed at
   http://www.ietf.org/ietf/1id-abstracts.txt.

   The list of Internet-Draft Shadow Directories can be accessed at
   http://www.ietf.org/shadow.html.

  This Internet-Draft will expire on August 17, 2017.

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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 ranges from 12.5 GHz, 25 GHz, 50 GHz, 100
   GHz to 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.

   [RFC7698] 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 [RFC7688] defines the requirements and OSPF-TE
   extensions in support of GMPLS control of a WSON.

   [RFC7792] describes requirements and protocol extensions for
   signaling to set up LSPs in networks that support the flexi-grid,
   and this document complements [RFC7792] by describing the
   requirement and extensions for OSPF-TE routing in a flexi-grid
   network.

   This document complements 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 [RFC7698] 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 [RFC7698].

A flexi-grid LSP occupies a specific frequency slot, i.e., a
frequency range. The process of computing a route and the
allocation of a frequency slot is referred to as RSA (Routing and
Spectrum Assignment). [RFC7698] 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 [RFC7698].

The remainder of this section states the additional extensions on
the routing protocols in a flexi-grid 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 do not
overlap with each other. However, the border frequencies of two
frequency slots may be the same frequency, i.e., the upper bound of
a frequency slot and the lower bound of the directly adjacent

   frequency slot are the same.

                      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 unavailable to other flexi-grid LSPs. Available
   central frequencies are advertised for m=1, which means that for an
   available central frequency n, the frequency slot from central
   frequency n-1 to central frequency n+1 is available.

   Hence, in order to clearly show which LSPs can be supported and what
   frequency slots are unavailable, the available frequency ranges are
   advertised by the routing protocol for the flexi-grid DWDM links. A
   set of non-overlapping available frequency ranges are disseminated
   in order to allow efficient resource management of flexi-grid DWDM
   links and RSA procedures which are described in Section 4.8 of
   [RFC7698].

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 Channel Spacing (C.S.): as defined in [RFC7699] 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 conveys 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
```
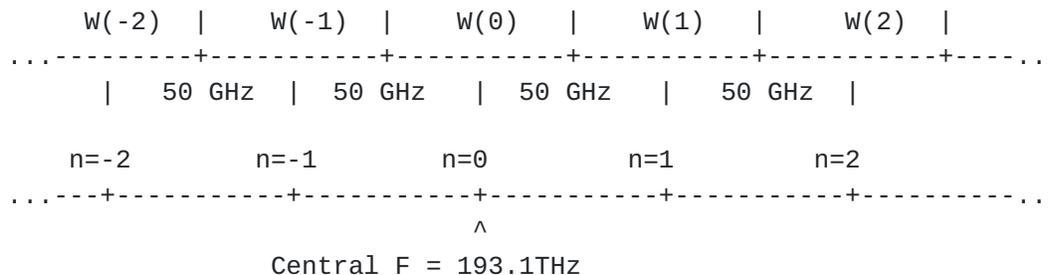
               Figure 2 - A Link Supports Fixed Wavelengths with 50 GHz Channel
                                  Spacing

   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 are advertised
   for a flexi-grid DWDM link instead of the specific "wavelengths"
   points that are sufficient for a fixed-grid link. Moreover, this
   advertisement is represented by the combination of Central Frequency
   Granularity and Slot Width Granularity.

4. Extensions

   As described in [RFC7698], 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 using
   opaque LSAs [RFC3630] in the case of OSPF-TE [RFC4203] (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

Switching Capability and Encoding values MUST be used as follows:

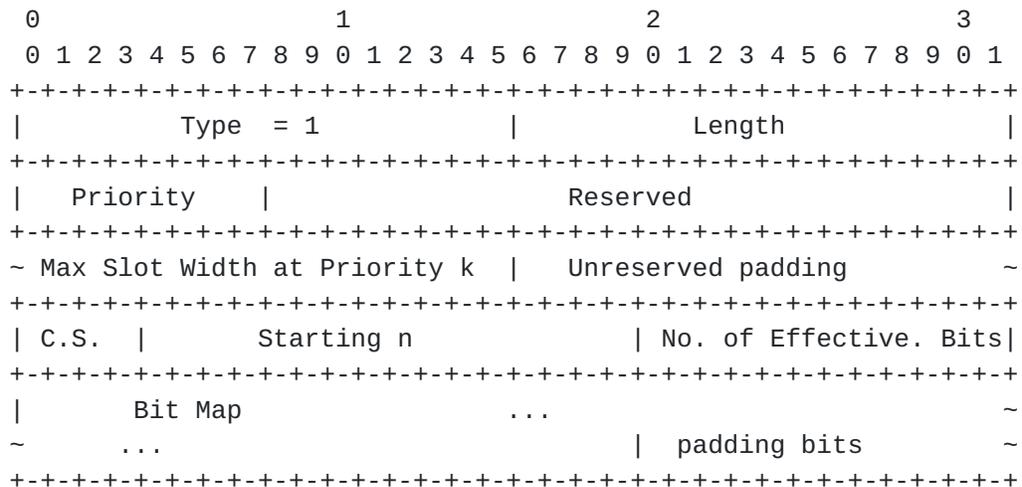   Switching Capability = Flexi-Grid-LSC

              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 is
interpreted as in [RFC4203] with the optional inclusion of one or
more Switching Capability Specific Information sub-TLVs.

As the "Max LSP Bandwidth at priority x" (x from 0 to 7) fields in
the generic part of the Interface Switching Capability Descriptor
[RFC4203] are not meaningful for flexi-grid DWDM links, the values
of these fields MUST be set to zero and MUST be ignored. The
Switching Capability Specific Information (SCSI) as defined below
provides the corresponding information for flexi-grid DWDM links.

4.1.1. Switching Capability Specific Information (SCSI)

The technology specific part of the Flexi-grid ISCD includes 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 k  |   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, in
octets.

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 is set (1) corresponding to each priority
represented in the sub-TLV, and clear (0) for each priority not
represented in the sub-TLV.   At least one priority level MUST be
advertised. If only one priority level is advertised, it MUST be at
priority level 0.

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

Max Slot Width at priority k(16 bits): This field indicates maximal
frequency slot width supported at a particular priority level, up to
8. This field is 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 be present for priority
levels that are 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 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. This field MUST be set to 0 and MUST be
ignored on receipt.

C.S. (4 bits): As defined in [[RFC7699](RFC7699)] and it is currently set to 5.

Starting n (16 bits): as defined in [[RFC7699](RFC7699)] 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; and when setting to 0, it means the
corresponding central frequency is unavailable. 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): Padded 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.

An example is provided in section 4.1.2.

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,
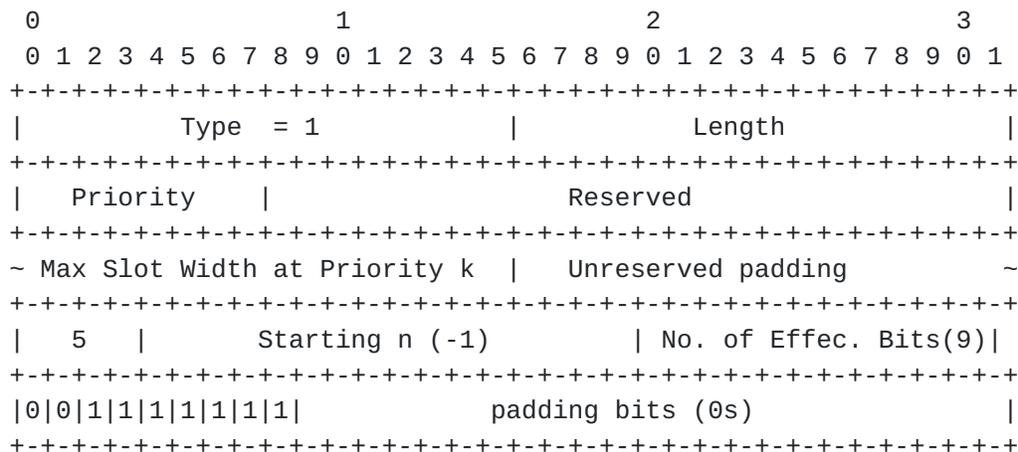but merely as the way to express the supported frequency range.
Using the encoding defined in Section 4.1.1, the relevant fields to
express the frequency resource availability can be filled as below:

```
  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 k  |   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. It is observed from the bit map
that n = -1 to 7 can be used to set up LSPs. Note other starting n
values can be chosen to represent the bit map, 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 k  |   Unreserved padding        ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   5   |      Starting n (-1)       | No. of Effec. Bits(9)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1|1|1|1|1|1|1|1|1|            padding bits (0s)             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
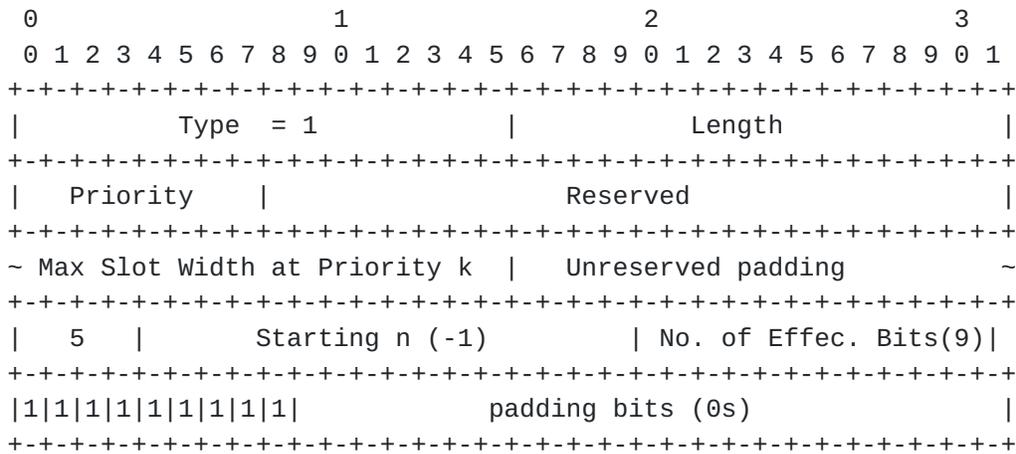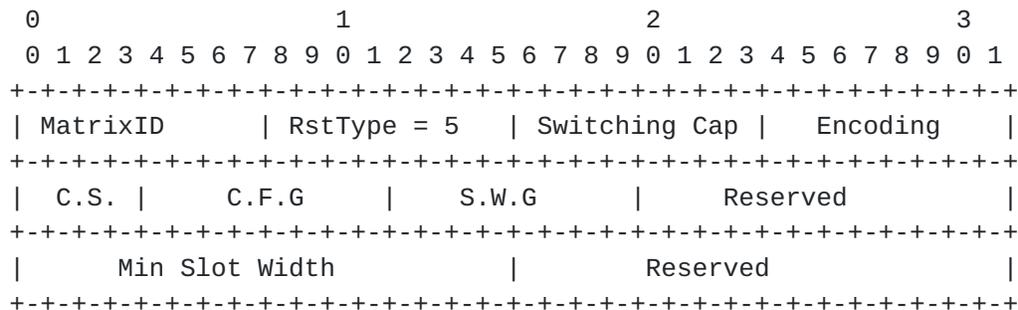
This denotes that other than the advertised available nominal
central frequencies, the other nominal central frequencies within
the whole frequency range supported by the link are not available
for flexi-grid LSP set up.

If a LSP with slot width m equals 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 k  |   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 field 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 [RFC7699] 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   [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.

Upon approval of this document, IANA will create and maintain a new
sub-registry, the "Types for sub-TLVs of Flexi-Grid-LSC 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 7942. 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 7942, "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 [RFC7699] 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

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.

9. Contributors' Addresses

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