CCAMP Working Group   Xian Zhang
Internet-Draft   Haomian Zheng
Intended status: Standards Track   Huawei
                                                   Ramon Casellas
                                                             CTTC
                                              O. Gonzalez de Dios
                                                       Telefonica
                                                     D. Ceccarelli
                                                         Ericsson
Expires: April 13, 2016   October 16, 2015

        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

      This Internet-Draft is submitted to IETF in full conformance with
      the provisions of BCP 78 and BCP 79.

      Internet-Drafts are working documents of the Internet Engineering
      Task Force (IETF), its areas, and its working groups. Note that
      other groups may also distribute working documents as Internet-
      Drafts.

      Internet-Drafts are draft documents valid for a maximum of six
      months   and may be updated, replaced, or obsoleted by other
      documents at any   time. It is inappropriate to use Internet-Drafts
      as reference   material or to cite them other than as "work in
      progress."

      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 April 13, 2016.

   Copyright Notice

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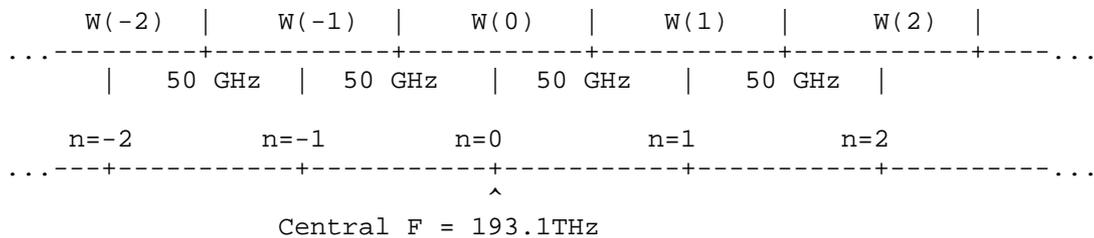
   Figure 2 - A Link Supports Fixed Wavelengths with 50 GHz Channel
                                Spacing

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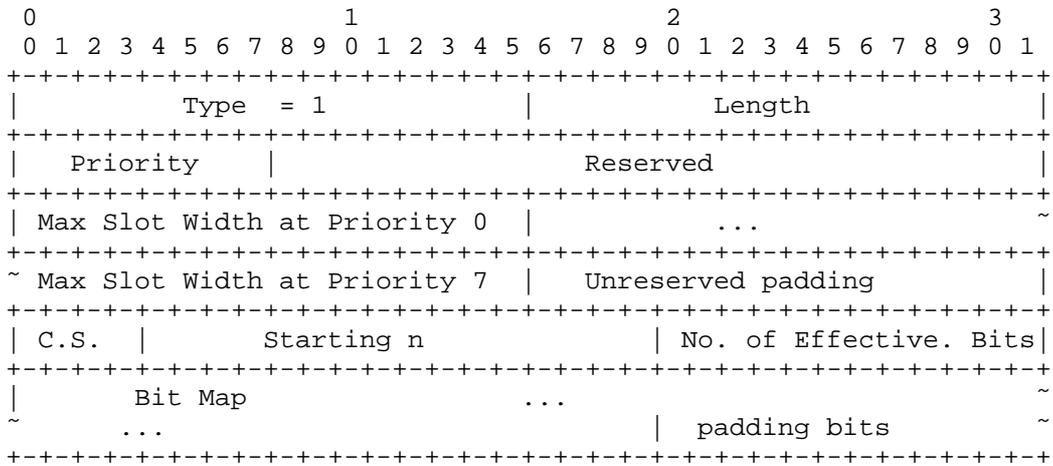
Type (16 bits): The type of this sub-TLV and is set to 1.

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--|
```
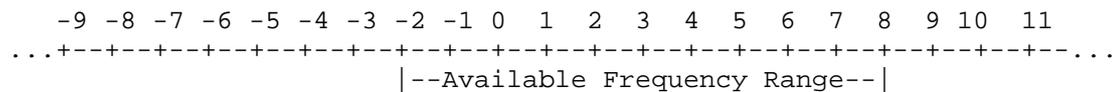
                 Figure 3 - Flexi-grid DWDM Link Example

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)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
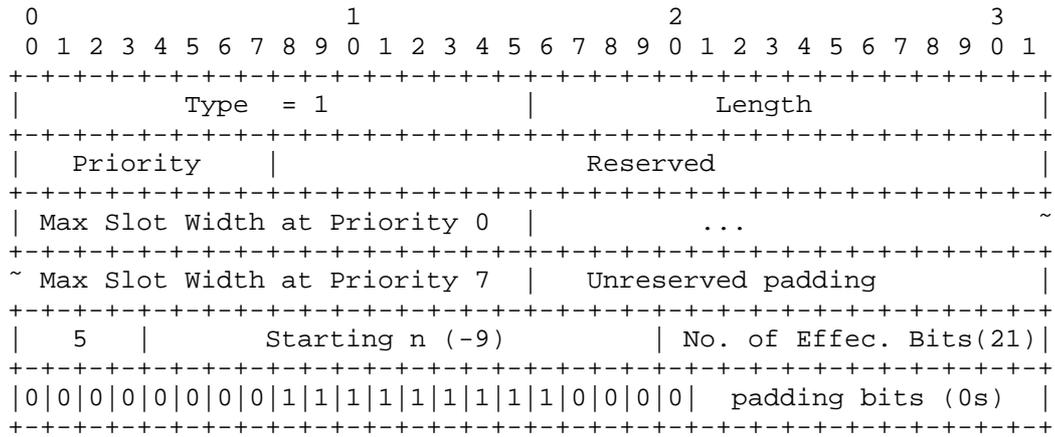
In the above example, the starting n is selected to be the lowest
nominal central frequency, i.e. -9. Note other starting n values can
be chosen and for example, the first available nominal central
frequency (a.k.a., the first available basic frequency slot) can be
chosen and the SCSI will be expressed 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)                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
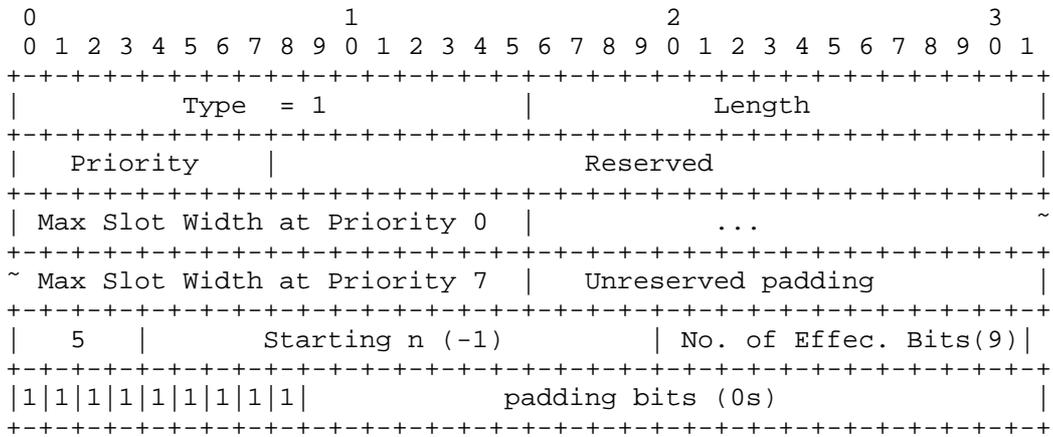
This denotes that other than the advertised available nominal
central frequencies, the other nominal central frequencies within
the whole frequency range supported by the link are not available
for path computation use.

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)                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
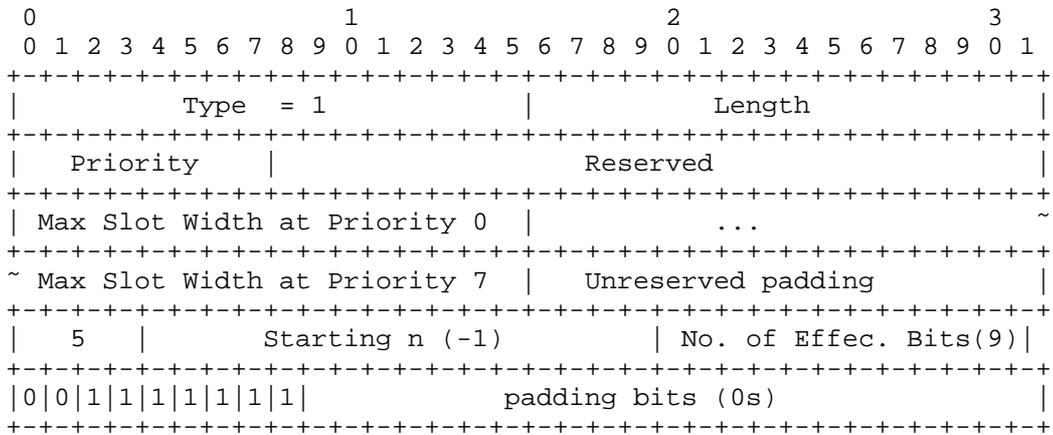
4.2. Extensions to Port Label Restriction sub-TLV

   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             |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
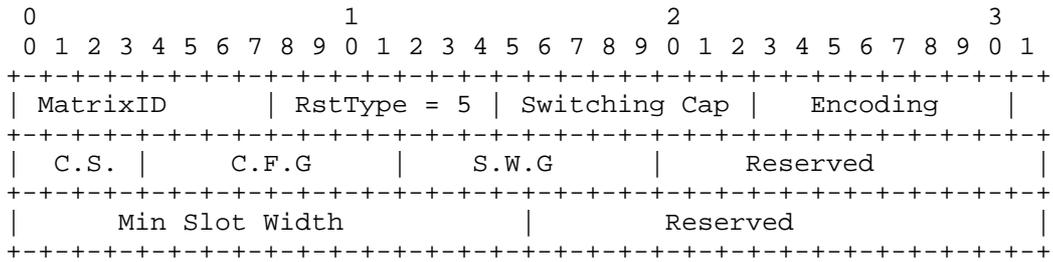
   MatrixID (8 bits): As defined in [RFC7579].

   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.

9. Contributors' Addresses

   Adrian Farrel
   Old Dog Consulting
   Email: adrian@olddog.co.uk

   Fatai Zhang
   Huawei Technologies
   Email: zhangfatai@huawei.com

    Lei Wang,
    ZTE
    Email: wang.lei31@zte.com.cn

    Guoying Zhang,
    China Academy of Telecom Research
    Email: zhangguoying@ritt.cn

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.

Authors' Addresses

Xian Zhang
Huawei Technologies
Email: zhang.xian@huawei.com

Haomian Zheng
Huawei Technologies
Email: zhenghaomian@huawei.com

Ramon Casellas, Ph.D.
CTTC
Spain
Phone: +34 936452916
Email: ramon.casellas@cttc.es

Oscar Gonzalez de Dios
Telefonica Investigacion y Desarrollo
Emilio Vargas 6
Madrid,   28045
Spain
Phone: +34 913374013
Email: ogondio@tid.es

Daniele Ceccarelli
Ericsson
Via A. Negrone 1/A
Genova - Sestri Ponente
Italy

Email: daniele.ceccarelli@ericsson.com