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Generalized Label for Super-Channel Assignment on Flexible Grid
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Abstract

To enable scaling of existing transport systems to ultra high data rates of 1 Tbps and beyond, next generation systems providing super-channel switching capability are currently being developed. To allow efficient allocation of optical spectral bandwidth for such high bit rate systems, International Telecommunication Union Telecommunication Standardization Sector (ITU-T) is extending the G.694.1 grid standard (termed "Fixed-Grid") to include flexible grid (termed "Flex-Grid") support (draft revised ITU-T G.694.1, revision 1.4, Oct 2011). This necessitates definition of new label format for the Flex-Grid. This document defines a super-channel label as a Super-Channel Identifier and an associated list of 12.5 GHz slices representing the optical spectrum of the super-channel. The label information can be encoded using a fixed length or variable length format. This label format can be used in GMPLS signaling and routing protocol to establish super-channel based optical label switched paths (LSPs).

Status of this Memo

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1. Introduction

Future transport systems are expected to support service upgrades to data rates of 1 Tbps and beyond. To scale networks beyond 100Gbps, multi-carrier super-channels coupled with advanced multi-level modulation formats and flexible channel spectrum bandwidth allocation schemes have become pivotal for future spectral efficient transport network architectures [1,2].

A super-channel represents an ultra high aggregate capacity channel containing multiple carriers which are co-routed through the network as a single entity from the source transceiver to the sink transceiver [3]. By multiplexing multiple carriers, modulating each carrier with multi-level advanced modulation formats (such as PM-QPSK, PM-8QAM, PM-16QAM), allocating an appropriate-sized flexible channel spectral bandwidth slot, and using a coherent receiver for detecting closely packed sub-carriers, a super-channel can support ultra high data rates in a spectrally efficient manner while maintaining required system reach. Figure 1 contrasts channel spectrum bandwidth allocation schemes for various bit rate optical paths on fixed-grid and flex-grid. ITU-T fixed-grid permits allocation of channel spectrum bandwidth in "single" fixed-sized slots (e.g., 50GHz, 100GHz etc) independent of the channel bit rate. In contrast, a flex-grid can allocate "arbitrary" size channel spectral bandwidth as an integer multiple of 12.5 GHz fine granularity slices. This means, a flex-grid can support multiple data rates channels (optical paths) in a spectrally efficient manner as it allocates appropriate-sized spectrum bandwidth slots, as opposed to fixed-sized slots. As in the examples in the figure, the optical spectrum slices assigned will be to a given super-channel in a contiguous manner. However, for flexibility in finding available optical spectrum on fragmented fibers and to reduce signaling message overhead, the two schemes proposed in this document also allow for identification of a split-spectrum super-channel with optical spectral slices that are non-contiguous, spread across multiple slots. Note that the channel capacity available on a given number of optical spectral slices depends on (among other factors) how many contiguous optical slots are used. The definition of the channel capacity available for a split-spectrum super-channel split across multiple slots of different widths is outside the scope of this document.

```
                                ITU-T G.694.1
                     Center frequency (f) = 193.1 THz

            n=-3     n=-2    n=-1    n=0    n=+1     n=+2

             ^        ^       ^       ^       ^       ^
       ...   |        |       |       |       |       |  ...
             |    |   |   |   |   |   |   |   |   |   |
             +--------+-------+-------+-------+-------+---
                                  <--   -->   <--   -->
                                    50 GHz      50 GHz

                      ^                       ^
                      | n=-2                  | n= +1
                      |                       |
                  +------+                +------+
                  |50 GHz|                |50 GHz|
                  +------+                +------+

             (10 Gbps channel)           (40Gbps channel)
             (a fixed 50GHz chunk)      (a fixed 50GHz chunk)

                                     (a)


                      ^       ^       ^       ^       ^       ^
                      |       |       |       |       |    + +|
                ...   |-|-|-|-|-|-|-|-| |+|+|+|+|+|+|+|+|+|1|1|   ...
                      |8|7|6|5|4|3|2|1|0|1|2|3|4|5|6|7|8|9|0|1|
                   ---+-------+-------+-------+-------+-------+---

                      ^                               ^       ^
                      |<--        200 GHz          -->|<-   ->|
                      |                               | 50GHz |
                      +-------------------------------+-------+
                      |     1 Tbps super-channel      |100Gbps|
                      |     16 slices of 12.5 GHz     |Channel|
                      |                               |4slices|
                      +-------------------------------+-------+


                                   (b)
```

Figure 1 ITU-T (a) 50 GHz fixed-grid (G.694.1) (b) 12.5 GHz granular flex-grid

2. Terminology

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. Motivation for Super-Channel Label

[RFC3471] defines new forms of MPLS "label" for the optical domain that are collectively referred to as a "generalized label". [RFC6205] defines a standard wavelength label based on ITU-T fixed-grids ([G.694.1] and [G.694.2]) for use by Lambda-Switch-Capable (LSC) LSRs.

A new label format for super-channels assignment on flex-grid is needed because the existing label formats (such as the waveband switching label defined in RFC3471 and the wavelength label defined in RFC6205) either lack necessary fields to carry required flex-grid related information (e.g., channel spacing) or do not allow signaling of arbitrary flexible-size optical spectral bandwidth in an efficient manner (e.g., in terms of integer multiple of fine granularity 12.5GHz slices). For example,

- o Waveband switching label format (defined in section 3.3.1 of RFC3471) lacks fields to carry necessary information to support flex-grid.

- o Wavelength label allows signaling of single fixed-size optical spectrum bandwidth slot only.

- o Wavelength label does not allow signaling of arbitrary flexible-size optical spectrum bandwidth needed for super-channels assignment on flex-grid.

3.1. Flex-Grid Slice Numbering

Given a slice spacing value (e.g., 0.0125 THz) and a slice number "n", the slice left edge frequency can be calculated as follows:

Slice Left Edge Frequency (THz)= 193.1 THz + n*slice spacing (THz).

Where "n" is a two's-complement integer (i.e., positive, negative, or 0) and "slice spacing" is 0.0125 THz conforming to ITU-T Flex-

Grid. (Note: in the future, if necessary the slice numbering scheme will be updated in accordance with the Flex-Grid.)

Figure 2 shows an example using the slice number scheme described earlier.

3.2. Super-Channel Label

In order to setup an optical path manually or dynamically, we need a way to identify and reserve resources (i.e., signal optical spectral bandwidth for the super-channels) along the optical path. For this purpose, this document defines a super-channel label to cover the cases of split-spectrum super-channels as well, such that the label consists of a Super-Channel Identifier and an associated list of contiguous or non-contiguous set of 12.5 GHz slices representing arbitrary size optical spectrum of the super-channels (Note: in the future, slice granularity could be 6.25 GHz.)

```
                  (n=0 is 193.1 THz)

           n=-2    n=-1    n=0    n=+1     n=+2

            ^       ^       ^       ^       ^
            |       |       |       |       |
      ...   |-|-|-|-|-|-|-|-| |+|+|+|+|+|+|+|  ...
            |8|7|6|5|4|3|2|1|0|1|2|3|4|5|6|7|
         ---+-------+-------+-------+-------+---
              ^                        ^
              |                        |
              |                        |
              +------------------------+
              | A super-channel with   |
              | Spectral BW = 150 GHz |
              |(12 slices of 12.5 GHz)|
              |                        |
              | n_start= -7            |
              | n_end  = +4            |
              |                        |
              | (see label encoding    |
              |  format for details)   |
              +------------------------+
```

Figure 2 flex-grid example of the proposed slice numbering scheme.

3.2.1. Super-Channel Label Encoding Format

This section describes two options (option A and B) for encoding the super-channel label by making extensions to the waveband switching label[RFC3471] and wavelength label [RFC6205] formats.

o Option A: Encode super-channel label as a list of start and end slice numbers corresponding to N groups, each consisting of contiguous slices with each group denoted by its starting and ending slice number (e.g., "n_start_1" and "n_end_1" represent contiguous slices in group#1, "n_start 2" and "n_end 2" in group#2, ..., "n_start N" and "n_end N" in group#N).

```
    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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |    Super-Channel Id (16-bit)  |Grid | S.S.  | Reserved (9-bit)|
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  | Reserved (16-bit)             |  Number of Entries(16-bit)    |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |n_start_1(contiguous group #1) | n_end_1(contiguous group #1)  |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |n_start_2(contiguous group #2)  | n_end_2(contiguous group #2) |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                                                               |
  |                          ...                                  |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |n_start_N (contiguous group #N)  | n_end_N (contiguous group#N |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Super-Channel Id: 16 bits

This field represents a logical identifier for a super-channel or split-spectrum super-channel. To disambiguate waveband switching and super-channel label applications, we propose to rename the Waveband Identifier (32-bit) as a Super-Channel Identifier (16-bit).

Grid: 3 bits

This field indicates the Grid type. The value for Grid should be set to xx (to be assigned by IANA) for the ITU-T flex-grid.

```
+----------------+---------+
|   Grid         |  Value  |
+----------------+---------+
| Reserved       |    0    |
```

ITU-T DWDM	1
ITU-T CWDM	2
ITU-T Flex-Grid	xx (TBD)
Future use	3 - 7

S.S. (slice spacing): 4 bits

This field should be set to a value of 4 to indicate 12.5 GHz in both labels.

S.S. (GHz)	Value
Reserved	0
100	1
50	2
25	3
12.5	4
Future use	5 - 15

Number of Entries: 16-bit

This field represents the number of 32-bit entries in the super-channel label (i.e., number of slots with contiguous slices). For example, in the case of a super-channel with contiguous optical spectrum, this field should have a value of 1 (indicating one slot of contiguous slices).

n_start_i (i=1,2,...N): 16 bits

n_end_i (i=1,2,...N): 16 bits

A super-channel with contiguous spectrum or a split-spectrum super-channel with non-contiguous optical spectrum can be represented by N slots of slices where two adjacent slots can be contiguous or non-contiguous, however each slot contains contiguous slices. Each slot

is denoted by n_start_i (which indicates the lowest or starting 12.5 GHz slice number of the slot) and n_end_i (which indicates the highest or ending 12.5 GHz slice number of the slot). "n_start_i" and "n_end_i" are two's-complement integers that can take either a positive, negative, or zero value.

o Option B: Encode super-channel label as a first slice number of the grid (denoted as "n_start of Grid") plus the entire list of slices in the grid as a Bitmap

```
     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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |  Super-Channel Id (16-bit)    |Grid | S.S.  | Reserved (9-bit)|
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   | n_start of Grid (16-bit)      |Num of Slices in Grid (16-bit) |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |Bitmap Word #1(first set of 32 slices from the left most edge) |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |Bitmap Word #2 (next set of 32 contiguous slice numbers)       |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                                                               |
                              ...
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |Bitmap Word #N(last set of 32 contiguous slice numbers)        |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Where:

Super-Channel Id, Grid, and S.S fields are same as described earlier in option A.

n_start of Grid: 16-bit

This field indicates the first slice number in Grid for the band being referenced (i.e., the start of the left most edge of the Grid).

Num of Slices in Grid: 16-bit

This field represents the total number of slices in the band. The value in this field determines the number of 32-bitmap words required for the grid.

Bit map (Word): 32-bit

Each bit in the 32-bitmap word represents a particular slice with a value of 1 or 0 to indicate whether for that slice reservation is required (1) or not (0). Bit position zero in the first word represents the first slice in the band (Grid) and corresponds to the value indicated in the "n_start of Grid" field.

Both options allow efficient encoding of a super-channel label with contiguous and non-contiguous slices. Option B yields a fixed length format while option A a variable length format. Option B is relatively simpler, more flexible, however, might be less compact than option A for encoding a single super-channel with contiguous optical spectrum. In contrast, option A provides a very compact representation for super-channels with contiguous optical spectrum, however, might be less flexible in encoding split-spectrum super-channels with arbitrary non-contiguous set of slices.

3.2.2. LSP Encoding and Switching Type in Generalized Label Request

For requesting a super-channel label in a Generalized Label Request defined in section 3.1.1 of RFC3471, this document proposes to use LSP Encoding Type = Lambda (as defined in RFC4328) and Switching Type = Super-Channel-Switch-Capable(SCSC) (as defined in [6]).

4. Security Considerations

<Add any security considerations>

5. IANA Considerations

IANA needs to assign a new Grid field value to represent ITU-T Flex-Grid.

6. References

6.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC3471] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description", RFC 3471, January 2003.

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

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

6.2. Informative References

[1] Gringeri, S., Basch, B. Shukla,V. Egorov, R. and Tiejun J. Xia, "Flexible Architectures for Optical Transport Nodes and Networks", IEEE Communications Magazine, July 2010, pp. 40-50

[2] M. Jinno et. al., "Spectrum-Efficient and Scalable Elastic Optical Path Network: Architecture, Benefits and Enabling Technologies", IEEE Comm. Mag., Nov. 2009, pp. 66-73.

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[4] ITU-T Recommendation G.694.1, "Spectral grids for WDM applications: DWDM frequency grid", June 2002

[5] [4] "Finisar to Demonstrate Flexgrid(TM) WSS Technology at ECOC 2010", press release.

[6] Abinder D., Iftekhar, Rajan, "OSPFTE extension to support GMPLS for Flex Grid", draft-dhillon-ccamp-super-channel-ospfte-ext-00.txt, October 2011.

7. Acknowledgments

<Add any acknowledgements>

Appendix A. Super-Channel Label Format Example

Suppose node A and Node Z are super-channel switching capable and node A receives a request for establishing a 1 Tbps optical LSP from itself to node Z. Assume the super-channel requires a "contiguous" spectral bandwidth of 200 GHz with left-edge frequency of 191.475 THz for the left-most 12.5 GHz slice and left-edge frequency of 191.6625 THz for the right-most slice. This means n_start = (191.475 - 193.1)/0.0125 = -130 and n_end = (191.6625 - 193.1)/0.0125 = -115 (i.e. we need 16 slices of 12.5 GHz starting from slice number -130 and ending at slice number -115).

Node A signals the LSP via a Path message including a super-channel label format encoding option A defined in section 3.3:

```
       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
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |  Super-Channel Id (16-bit)    |Grid | S.S.  | Reserved (9-bit)|
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     | Reserved (16-bit)             | Number of Entries(16-bit)     |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
     |n_start_1 (contiguous group #1) | n_end_1(contiguous group #1) |
     +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Where:

Super-Channel Id = 1 : super-channel number 1

Number of Entries: 1

Grid = xx : ITU-T Flex-Grid

S.S. = 4 : 12.5 GHz Slice Spacing

n_start_1 = -130 : left-most 12.5 GHz slice number for slot 1

n_end_1 = -115 : Right-most 12.5 GHz slice number for slot 1

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