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OSPF Extensions for Routing Constraint Encoding in Flexible-Grid Networks
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Abstract

In Flexible-Grid networks, network elements and links may impose additional routing constraints, which cannot be ignored in Routing and Spectrum Assignment (RSA) process. This document describes the requirements of such constraints, and then provides efficient encodings to specify how the information is carried.

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1. Introduction

Flexible-Grid technique breaks the rigid nature of traditional DWDM wavelength Grid, and enables flexible allocation of optical spectrum resources to accommodate ultra-high data rate traffic. Currently, there are several IETF draft addressing GMPLS routing and signaling extension to support Flexible-Grid DWDM Networks, such as [I-D.farrkingel-ccamp-flexigrid-lambda-label][I-D.li-ccamp-flexible-grid-label][I-D.zhang-ccamp-flexible-grid-requirements][I-D.zhang-ccamp-flexible-grid-rsvp-te-ext][I-D.zhang-ccamp-flexible-grid-ospf-ext][I-D.hussain-ccamp-super-channel-label][I-D.dhillon-ccamp-super-channel-ospfte-ext][I-D.zhangj-ccamp-flexi-grid-ospf-te-ext]. However, all these documents mainly focus on Label/Label-set extensions and spectrum consecutiveness/continuity constraints in Flexible-Grid Networks, but ignore other aspects of RSA problem. In fact, Network elements (such as nodes and Optical-to-Electronic/Electronic-to-Optical sub-systems) and links may impose additional routing constraints such as flexible-grid ability/range limitations on ports, asymmetric switch connectivity, and signal processing limitations of each OE/EO system. Without considering these constraints, it cannot be guaranteed to obtain available results in RSA process especially for network scenarios with various Flexible-Grid and Fixed-Grid elements, which leads to inefficient routing and high blocking probability of end-to-end paths.

This document describes and encodes the constraints imposed by network elements and links, which could be carried in OSPF Messages to flood to each node for efficient RSA. In addition, such information could be conveyed by other mechanisms to a Path Computation Element (PCE). Note that, impairment-related constraints are not considered here.

2. 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 [RFC2119].

3. Terminologies

GMPLS: Generalized Multi-Protocol Label Switching

LSP: Label Switched Path

ROADM: Reconfigurable Optical Add-Drop Multiplexer

RSA: Routing and spectrum assignment

Slice: the basic slot unit, and the slot width of one slice is equal to slot width granularity

WSON: Wavelength Switched Optical Networks [RFC6163]

WSS: Wavelength Selective Switch

4. Requirements of Routing Constraint for RSA in Flexible-Grid Networks

In Flexible-Grid network, there is one key problem: how to route and allocate spectrum resources for each end-to end optical channel, so to fulfill their requirements in an efficient way? To address this problem, some constraints must be taken into consideration, which are listed as follows.

-Spectrum availability constraint.

-Flexible-Grid supporting ability constraint.

-Asymmetric switch connectivity constraint.

-Optical signal compatibility constraint.

-Other constraints.

The asymmetric switch connectivity constraint in Flexible-Grid network could be well addressed by Connectivity matrix sub-TLV used in Wavelength Switched Optical Networks (WSON) [I-D.ietf-ccamp-general-constraint-encode]. The spectrum availability constraint is studied in several drafts, and could be represented by Label-set extensions of [I-D.li-ccamp-flexible-grid-label][I-D.zhang-ccamp-flexible-grid-ospf-ext][I-D.dhillon-ccamp-super-channel-ospfte-ext]. However, these extensions are not complete, so we reorganize the Flexible-Grid label-set according to WSON definition. In addition, this document also takes the constraints imposed by network ports and OE/EO subsystems into consideration.

Here a general use scenario of Flexible-Grid Network is given to illustrate these requirements.

```
                 +----+A-E2    B-I1+----+B-E2    C-I1+----+
                 | A  |----------->| B  |----------->| C  |
                 |    |<-----------|    |<-----------|    |
                 +----+A-I2    B-E1+----+B-I2    C-E1+----+
                   O|                O|                O|
               A-I1||A-E1        B-I3||B-E3        C-I2||C-E2
                   ||                ||                ||
                   ||                ||                ||
                   ||                ||                ||
                   ||                ||                ||
               D-E1||D-I1        E-E3||E-I3        F-E2||F-I2
                   |O                |O                |O
                 +----+D-E2    E-I1+----+E-E2    F-I1+----+
                 | D  |----------->| E  |----------->| F  |
                 |    |<-----------|    |<-----------|    |
                 +----+D-I2    E-E1+----+E-I2    F-E1+----+
```

Figure 1. A sample network with both Fixed-Grid and Flexible-Grid elements

```
         Tributary Side:        E5 I5 E6 I6
                                O |   O |
                                | |   | |
                                | O   | O
                         +-----------------------+
                         |+-----+         +-----+|
         Line side-1 --->||Split|         |WSS-2||---> Line side-2
         Input (I1)      |+-----+         +-----+|     Output (E2)
         Line side-1 <---||WSS-1|         |Split||<--- Line side-2
         Output  (E1)    |+-----+         +-----+|     Input (I2)
                         |         ROADM         |
                         |+-----+         +-----+|
         Line side-3 --->||Split|         |WSS-4||---> Line side-4
         Input (I3)      |+-----+         +-----+|     Output (E4)
         Line side-3 <---||WSS-3|         |Split||<--- Line side-4
         Output (E3)     |+-----+         +-----+|     Input (I4)
                         +-----------------------+
                                | O   | O
                                | |   | |
                                O |   O |
         Tributary Side:        E7 I7 E8 I8
```

Figure 2. A ROADM Composed of WSSs and splitters (Internal connections are not presented)

Figure 1 shows the network topology, while Figure 2 shows the architecture of nodes. The ROADM of Figure 2 is composed of WSSs and splitters. I1~4/E1~4 are line-side input/output ports, while I5~8/E5~8 are tributary-side add/drop ports to/from line-side 1~4 respectively. The configuration of each line-side output port is shown as follows:

Node	Node-Type	Ports	Type	Granularity	Min width	Max width
A	Flex	A-E1	Flex	25GHz	50GHz	300GHz
		A-E2	Flex	12.5GHz	50GHz	300GHz
B	Mixed	B-E1	Flex	12.5GHz	50GHz	200GHz
		B-E2	Fixed	50GHz	50GHz	50GHz
		B-E3	Flex	12.5GHz	50GHz	200GHz
C	Fixed	C-E1	Fixed	50GHz	50GHz	50GHz
		C-E2	Fixed	50GHz	50GHz	50GHz
D	Flex	D-E1	Flex	25GHz	50GHz	300GHz
		D-E2	Flex	25GHz	50GHz	300GHz
E	Flex	E-E1	Flex	25GHz	50GHz	300GHz
		E-E2	Flex	12.5Ghz	50GHz	200GHz
		E-E3	Flex	12.5GHz	50GHz	200GHz
F	Mixed	F-E1	Flex	12.5GHz	50GHz	200GHz
		F-E2	Fixed	50GHz	50GHz	50GHz

The granularity denotes the slot width granularity. The Min-width and Max-width denote the slot width range. There are three types of nodes: Node A, node D and node E are Flexible-Grid ROADMs, which only consist of Flexible-Grid elements; Node C is a Fixed-Grid ROADM, which only consists of Fixed-Grid elements; Node B and Node F are Mixed-Grid ROADMs, which consist of both Flexible-Grid and Fixed-Grid Elements. Both Flexible-Grid ROADM and Mixed-Grid ROADM can support

Flexible-Grid LSPs to accommodate ultra-high data rate traffic such as beyond 100G. In addition, the Fixed-Grid ROADM can be smoothly updated to Mixed-Grid ROADM by adding Flexible-Grid ports. With appropriate RSA, the network is able to support both Fixed-Grid services and Flexible-Grid services in an efficient way.

4.1. Label set

In Flexible-Grid networks, the spectrum assignment is not a local matter due to spectral consecutiveness and continuity constraints, so it is needed to get the information of which slice may or may not be used on each link and node port along the path in RSA process. For example, in the network of Figure 1, when a LSP request from node A to node E with 50GHz slot width and route A->B->E arrives, the label restriction of input port A-I6, output port E-E7, switch port A-E2, B-I1, B-E3, E-I3 and spectrum availability of link AB, BE must be got for the spectrum assignment. All the information is described by the label set objects which is decided by the label format. The generalized label for the flexible grid can be referred to [I-D.farrkingel-ccamp-flexigrid-lambda-label] including central frequency and slot width information.

As specified in [I-D.li-ccamp-flexible-grid-label] in section 4.1, this kind of label format is backward compatible to support the traditional 5 ways of wavelength label set encoding [I-D.ietf-ccamp-general-constraint-encode].

o 1. Inclusive list

o 2. Exclusive list

o 3. Inclusive range

o 4. Exclusive range

o 5. Bitmap set

It can be seen that these 5 types of representations can be easily inherited by incorporating the new flexible label into the object. Note that in the procedure of flooding, any combination of the 5 types of label sets is feasible.

4.2. Port Flexible-Grid Supporting Ability Constraint

Flexible-Grid supporting ability may include the type (Fixed-Grid or Flexible-Grid), center frequency granularity and slot width range. This information can be seen as the attribution of network ports with relations to links or nodes. The RSA requirements of such fields are

listed as follows:

Firstly, Flexible-Grid WSSs of different companies or product-types may have different slot width granularity and range, which may be a subset of possible values specified by ITU-T [G.694.1], so it should be taken into consideration in RSA process to avoid invalid route selection. For example, in the network of Figure 1, when a LSP request from node A to node E with 250GHz slot width arrives, only the optical channel with a route A->D->E is able to carry the traffic due to the slot width range limitations on other ports.

Secondly, Fixed-Grid ports/links cannot support Flexible-Grid LSPs with high slot width requirements, so it is necessary to distinguish Fixed-Grid ports/links from Flexible-Grid ports/links. For example, in the network of Figure 1, when a LSP request from node B to Node F with 150GHz slot width arrives, the route B->C->F may be selected without considering Flexible-Grid Supporting Ability constraints. Even if there are free consecutive and continuous spectrum resources along the route, the optical channel cannot be setup successfully due to the limitation of Fixed-Grid ports/links.

Thirdly, Although Flexible-Grid technology may offer full backwards compatibility with the standard ITU-T DWDM grids, it is a cost-efficient way to consider port Flexible-Grid Supporting Ability constraints in RSA process for Fixed-Grid requirements. For example, in the network of figure 1, when a LSP request from node B to node F with 50GHz slot width arrives, it is a better route of B->C->F than the route B->E->F, because that flexible-Grid WSSs are more expensive than fixed-grid ones, and routing fixed-Grid requests on fixed-Grid elements could leave the Flexible-Grid elements and related spectrum resources to subsequent high data rate traffic.

4.3. **Optical Signal Compatibility Constraint**

Optical Signal Compatibility Constraint includes the signal processing ability (for example, data rate, FEC and modulation format) and modulation-related minimum slot width for each Optical-to-Electronic (OE)/Electronic-to-Optical (EO) subsystem. The RSA requirements of such fields are listed as follows:

Firstly, as described in [I-D.ietf-ccamp-rwa-wson-encode], OE/EO subsystems may be limited to process only certain types of optical signal in WSON or Flexible-Grid networks, so it is needed to get sufficient information characterizing OE/EO elements in RSA process to determine the signal compatibility along the path. Examples of such subsystems include transponders, regenerators and so on.

Secondly, for each Label Switch Path, the required slot width is

determined by the attribution of optical signal. Generally, a client requests "data rate" as its traffic parameter but not "slot width", so it is needed to establish the mapping relations between data-rate/modulation-format and slot width, which should be reflected in optical signal compatibility constraint. For example, in the network of Figure 1, when a LSP request from node A to Node E with 100Gbit/s data rate arrives, and both the transmitter of node A and the responder of node E support optical tributary signal class DP-QPSK 100G with the same FEC and corresponding slot width 50GHz, the minimum slot width required by this connection should be 50GHz (without the consideration of impairments and regeneration).

5. Encoding

5.1. Label Set

The general format for a label set is in accordance with that in [I-D.ietf-ccamp-general-constraint-encode],with a new flag G (1bit) representing the grid type of label sets(1~Flexible-Grid DWDM; 0~Fixed-Grid DWDM):

```
    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
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |G| Act.|    Num Labels         |          Length               |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                         start Label                           |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   |                         start Label(continue)                 |
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
   :     Additional fields as necessary per action                 :
   :                                                               :
   +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

the label format is in accordance with that in [I-D.farrkingel-ccamp-flexigrid-lambda-label].

In the case of Inclusive/Exclusive label lists (0/1), the label set format is given as follows:

```
       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |1| 0or1| Num Labels (not used) |          Length               |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         First Label                           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         First Label(continue)                 |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      :                                                               :
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         Last  Label                           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |                         Last  Label(continue)                 |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Note that one label set may contain multiple labels. The lowest/ highest frequency of the K-th label is calculated as follows:

Lowest frequency_k = (central frequency_k) - (slot width_k)/2

= (193.1 + n_k * C.S.) - (2 * C.S. * m_k)/2

= (193.1 + (n_k - m_k) * C.S.) THz;

Highest frequency_k = Lowest frequency_k + slot width_k

= (193.1 + (n_k + m_k) * C.S.) THz;

In the case of Inclusive/Exclusive label ranges (2/3), the label set format is given as follows:

```
     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
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |1| 2or3| Num Labels(not used)  |             Length            |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Start Label #1                             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Start Label #1(continue)                   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     End Label #1                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     End Label #1(continue)                    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    :                                                               :
    :                                                               :
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Start Label #n                             |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                    Start Label #n(continue)                   |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     End Label #n                              |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
    |                     End Label #n(continue)                    |
    +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Note that one label set may contain multiple label ranges. The value of m in start/end label has no effect on the label set, however, in order to keep the integrity of labels and avoid misunderstanding, it is set to default value: m = (slot width granularity)/12.5GHz.

The lowest/highest frequency of the K-th label range is calculated as follows:

Lowest frequency_k = (central frequency_kstart) - (slot width granularity)/2

= (193.1 + n_kstart * C.S.) - C.S.

= (193.1 + (n_kstart - 1) * C.S.) THz;

Highest frequency_k = (central frequency_kend) + (slot width granularity)/2

= (193.1 + n_kend * C.S.) + C.S.

= (193.1 + (n_kend + 1) * C.S.) THz;

In the case of bitmap (4), the label set format is given as follows:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|1|  4  |   Num Labels          |             Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Start Label                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                         Start Label(continue)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Bit Map Word #1 (Lowest numerical labels)                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                                                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Bit Map Word #N (Highest numerical labels)                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Based on [I-D.ietf-ccamp-general-constraint-encode], Num labels denote the number of slices represented by the bit map; where the slice denotes the basic slot unit, and the slot width of one slice is equal to the slot width granularity. As there may exist some situations that the unused bandwidth between two occupied bandwidth is odd times of the central frequency granularity (not integral times of the slot with granularity), two bits are needed to represent a single slice. Each bit in the bit map represents a particular label of half a slice with a value of 1/0 indicating whether the part is in the set or not. Bit position zero and one represent the lowest slice and corresponds to the start label. The lowest/highest frequency of label range represented by bit position K is calculated as follows:

Lowest frequency_k = (central frequency_start) + (K - 1) * (slot width granularity)/2

= (193.1 + n_start * C.S.) + (K - 1) * C.S.

= 193.1 + (n_start + K -1) * C.S.;

Highest frequency_k = Low frequency_k + C.S.

= 193.1 + (n_start + K) * C.S.

The size of the bit map is (2 * Num Label) bits, but the bit map is padded out to a full multiple of 32 bits so that the TLV is a multiple of four bytes. "Bits that do not represent labels (i.e., those in positions) and beyond SHOULD be set to zero and MUST be

ignored" [I-D.ietf-ccamp-general-constraint-encode].

5.2. Port Flexible-Grid Supporting Ability Constraint

To accommodate the feature of port Flexible-Grid Supporting Ability constraint, we extend the Port Label Restriction sub-TLV defined in [I-D.ietf-ccamp-general-constraint-encode] for Flexible-Grid networks:

```
 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   |        Reserved               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid | C.S.  |    Reserved     |  Min-Width    |   Max-Width   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In WSON network, Matrix ID is used to represent "either the value in the corresponding Connectivity Matrix sub-TLV or takes the value OxFF to indicate the restriction applies to the port regardless of any Connectivity Matrix"[I-D.ietf-ccamp-general-constraint-encode]. RstType is used to represent the restriction type. This document defines a new RstType value to express the port Flexible-Grid Supporting Ability constraint in Flexible-Grid networks:

5: PORT_ATTRIBUTION.

The meaning of Grid and C.S. is defined in [I-D.farrkingel-ccamp-flexigrid-lambda-label], which is shown as follows:

Grid	Value
Reserved	0
ITU-T DWDM	1
ITU-T CWDM	2
Flexible DWDM	3
Any	4(TBA)
Future use	5-7

+---------------+-------+

C.S. (GHz)	Value
Reserved	0
100	1
50	2
25	3
12.5	4
6.25	5 (TBA)
Future use	6 ~ 15

A new Grid type "Any" is defined.

"Within the fixed grid network, the C.S. value is used to represent the channel spacing, as the spacing between adjacent channels is constant. While for flexible grid situation, this field should be used to represent central frequency granularity."[I-D.farrkingel-ccamp-flexigrid-lambda-label] Accordingly the slot width granularity is twice of the C.S..

Min-Width/Max-Width: 8bits, unsigned integer. Min-Width/Max-Width denotes the minimum/maximum slot width that the port supports, which is an inherent attribution of the network elements. The formula is shown as follows:

Minimum Slot Width (GHz) = 12.5GHz * Min-Width;

Maximum Slot Width (GHz) = 12.5GHz * Max-Width;

For flexible-Grid ports (Grid = 3), the possible values of slot width are within the range [Minimum Slot Width, Maximum Slot Width] and with the slot width granularity of 2 * C.S.; for Fixed-Grid ports (Grid = 1 or 2), Min-Width/Max-Width is meaningless and padded with 0. For any port with Grid type "any", it means that the port support any Grid type, any slot width granularity and any slot width range,

so C.S. and Min-Width/Max-Width are meaningless and padded with 0.. One example of such port is A-I1, which is comprised of optical splitter.

Note that, the similar field of Min-Width/Max-Width is also included in object "BW sub-TLV" proposed by [I-D.dhillon-ccamp-super-channel-ospfte-ext]. However, BW sub-TLV is mainly used to present the available label set, so it belongs to dynamic information according to [RFC6163] and should be flooded frequently whenever the link state changes (for example, after the setup/teardown of the path traversing the link). In this document, the Port Label Restriction sub-TLV with PORT_ATTRIBUTION type is regarded as relatively static information, as changes to these properties such as Grid, C.S. and Min-Width/Max-Width require hardware upgrades. It is more suitable to carry such information separated from available label set in order to alleviate unnecessary flooding.

Other port label restrictions have no difference with that in [I-D.ietf-ccamp-general-constraint-encode].

5.3. Optical Signal Compatibility Constraint

To accommodate the feature of Optical Signal Compatibility Constraint, we extend the Modulation Type sub-TLV defined in [I-D.ietf-ccamp-rwa-wson-encode] for Fixed-Grid networks:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|S|I|        Modulation ID         |          Length            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|       m       |   Possible additional modulation parameters   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:   the modulation ID                                           :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The meaning of S, I and Modulation ID is in accordance with that of [I-D.ietf-ccamp-rwa-wson-encode].

This document adds a new field "m" (8bit) to represent the minimum slot width requirement for corresponding Modulation ID:

Minimum Slot Width = 12.5GHz * m.

Note that the modulation type sub-TLV may contain multiple modulation

IDs, which means the transmitter/responder/transponder support multiple data rate/modulation format.

This sub-TLV establishes mapping relations between data rate/ modulation format (Modulation ID) and slot width. In addition, it also provides the signal processing ability for each OE/EO element in the network. However, FEC may impact the value of m, but it is not discussed here and leaved for further study. New values of Modulation ID should be defined for ultra-high speed transmission, but it depends on transmission technique and not specified in this document.

Other signal compatibility constraints have no difference with that in [I-D.ietf-ccamp-rwa-wson-encode].

6. Encoding Example

6.1. Example of Label Set Encoding

Taking the network of figure 1 as an example, the available spectral resource of link AB is shown in figure 3.

```
            #1    Lowest    #2  Highest               #3
          |-|-|   |---------|---------|       |-------|-------|
            |               |Center Freq.             |       ^
          |1 1 0 0 1 1 1 1 1 1 1 1 1 1 0 0 0 0 1 1 1 1 1 1 1 1|
        __|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|__
      n= -16 -14 -12 -10 -8   -6   -4   -2    0   2   4   6   8   10
            |                                             |___|
          |_|_|                                          12.5GHz
            |
          slice
```

Figure 3. Spectral resource state of link AB

In figure 3, the spectral resource is from 193.1THz - 16 * 6.25GHz to 193.1THz + 10 * 6.25GHz. For label list type, the label set format is given as followsGBPo

```
        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
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |1|  0  | Num Labels(not used)  |             Length(28)        |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |  3  |C.S.(5)|    Identifier   |              n(-15)           |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |       m(1)    |                  Reserved                     |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |  3  |C.S.(5)|    Identifier   |              n(-7)            |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |       m(5)    |                  Reserved                     |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |  3  |C.S.(5)|    Identifier   |              n(6)             |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
       |       m(4)    |                  Reserved                     |
       +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

For label range type, the label set format is given as followsGBPo

```
       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |1|  2  | Num Labels(not used)  |             Length(52)        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(-15)           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(-15)           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(-11)           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(-3)            |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(3)             |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(9)             |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

For bitmap type, the label set format is given as followsGBPo

```
       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |1|  4  | Num Labels(26)        |             Length(16)        |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |  3  |C.S.(5)|    Identifier   |              n(-15)           |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |       m(1)    |                  Reserved                     |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |1|1|0|0|1|1|1|1|1|1|1|1|1|1|0|0|0|0|1|1|1|1|1|1|1|1|0|0|0|0|0|0|
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

6.2. Example of Port Flexible-Grid Supporting Ability Constraint Encoding

Taking the network of figure 1 as an example, the port Flexible-Grid supporting ability constraint of A-E1 can be encoded as follows:

```
 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(0xff)| RstType(5)    |        Reserved               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  3  |C.S.(5)|    Reserved     |  Min-Width(4) | Max-Width(16) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The port port Flexible-Grid supporting ability constraint of A-E2 can be encoded as follows:

```
 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(0xff)| RstType(5)    |        Reserved               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  3  |C.S.(4)|    Reserved     |  Min-Width(4) | Max-Width(24) |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The port Flexible-Grid supporting ability constraint of B-E2 can be encoded as follows:

```
 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(0xff)| RstType(5)    |        Reserved               |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  1  |C.S.(2)|    Reserved     |  Min-Width(0) | Max-Width(0)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

6.3. Example of Signal Compatibility Encoding

Assuming an optical transmitter can support the following modulation typesGBPooptical tributary signal class DP-QPSK 100G (minimum slot width: 50GHz); optical tributary signal class DP-BPSK 100G (minimum slot width: 100GHz). The Modulation Type sub-TLV is given as follows:

```
       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
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |1|0|       DP-QPSK 100G        |             Length(8)         |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |      m(4)     |   Possible additional modulation parameters   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |1|0|       DP-BPSK 100G        |             Length(8)         |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
      |      m(8)     |   Possible additional modulation parameters   |
      +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

7. Security Considerations

8. IANA Considerations

TBD.

9. References

9.1. Normative References

[G.694.1] ITU-T Recommendation G.694.1, "Spectral grids for WDM apllications: DWDM frequency grid", November 2011.

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

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

9.2. Informative References

[I-D.dhillon-ccamp-super-channel-ospfte-ext]
Dhillon, A., Hussain, I., Rao, RJ., and M. Sosa, "OSPFTE extension to support GMPLS for Flex Grid", October 2011.

[I-D.farrkingel-ccamp-flexigrid-lambda-label]
Farrel, A., King, D., Li, Y., Zhang, F., and R. Casellas, "Generalized Labels for the Flexi-Grid in Lambda-Switch-Capable (LSC) Label Switching Routers", October 2011.

[I-D.hussain-ccamp-super-channel-label]

Hussain, I., Dhillon, A., Pan, Z., Sosa, M., Basch, B., Liu, S., and A-G. Malis, "Generalized Label for Super-Channel Assignment on Flexible Grid", October 2011.

[I-D.ietf-ccamp-general-constraint-encode]
Bernstein, G., Lee, Y., Li, D., Imajuku, W., and JR. Han, "General Network Element Constraint Encoding for GMPLS Controlled Networks", May 2011.

[I-D.ietf-ccamp-rwa-wson-encode]
Bernstein, G., Lee, Y., Li, D., Imajuku, W., and JR. Han, "Routing and Wavelength Assignment Information Encoding for Wavelength Switched Optical Networks", October 2011.

[I-D.li-ccamp-flexible-grid-label]
Li, Y., Zhang, F., and R. Casellas, "Flexible Grid Label Format in Wavelength Switched Optical Network", July 2011.

[I-D.zhang-ccamp-flexible-grid-ospf-ext]
Zhang, FT., Zi, XB., Casellas, R., Gonzales-de-Dios, O., and D. Ceccarelli, "GMPLS OSPF-TE Extensions in support of Flexible-Grid in DWDM Networks", October 2011.

[I-D.zhang-ccamp-flexible-grid-requirements]
Zhang, FT., Zi, XB., Gonzales-de-Dios, O., and R. Casellas, "Requirements for GMPLS Control of Flexible Grids", October 2011.

[I-D.zhang-ccamp-flexible-grid-rsvp-te-ext]
Zhang, FT., Gonzales-de-Dios, O., and D. Ceccarelli, "RSVP-TE Signaling Extensions in support of Flexible Grid", October 2011.

[I-D.zhangj-ccamp-flexi-grid-ospf-te-ext]
Zhang, J., Zhao, YL., and ZY. Yu, "OSPF-TE Protocol Extension for Constraint-aware RSA in Flexi-Grid Networks", October 2011.

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