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**OSPF Extensions for Routing Constraint Encoding in Flexible-Grid
Networks
draft-wangl-ccamp-ospf-ext-constraint-flexi-grid-02**

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. In such environments, Network elements (such as nodes and Optical-to-Electronic/Electronic-to-Optical sub-systems) and links may impose additional routing constraints such as available frequency range, flexible-grid ability and slot width range on ports/links, asymmetric switch connectivity, signal processing limitations of each OE/OE system, and so on. 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 the requirements of RSA, and then 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

Center Frequency Granularity (CFG): The minimum step by which the center frequency of optical bandwidth can be increased or decreased.

.

frequency grid: A frequency grid is a reference set of frequencies used to denote allowed nominal central frequencies that may be used for defining applications.

Frequency slot: The frequency range allocated to a slot and unavailable to other slots within a flexible grid. A frequency slot is defined by its nominal central frequency and its slot width [[G.694.1v2](#)].

[Editor's note: according to ITU-T WP3 Q12 interim meeting [ITU-T WD12R2], one or multiple Optical Channels may be transported over a

single frequency slot. If this viewpoint is accepted, the following definitions are needed:

Single-Channel Frequency Slot: a frequency slot associated with a single optical channel signal (that carries a single OCh payload).

Multi-Channel Frequency Slot: a frequency slot associated with multiple optical channel signals (i.e. multiple OChs).]

Frequency Slot Channel: a topological construct that represents a piece of spectrum supported by a concatenation of media elements (fiber, amplifiers, filters..). This term is used to identify the end-to-end physical layer entity with its corresponding (one or more) frequency slots local at each link.

GMPLS: Generalized Multi-Protocol Label Switching.

Lowest/Highest frequency: the lowest/highest frequency of a frequency slot.

OCH: Optical Channel

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.

Slot width: The full width of a frequency slot in a flexible grid [[G.694.1v2](#)].

Slot Width Granularity (SWG): the minimum step by which the optical filter bandwidth of ROADM can be increased or decreased. Accordingly, $SWG \text{ (GHz)} = 2 * CFG \text{ (GHz)}$.

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 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 (WSN) [[I-D.ietf-ccamp-general-constraint-encode](#)]. The spectrum availability constraint is studied in several drafts [[I-D.li-ccamp-flexible-grid-label](#)] [[I-D.zhang-ccamp-flexible-grid-ospf-ext](#)] [[I-D.dhillon-ccamp-super-channel-ospf-ext](#)], and could be represented by Label-set extensions. However, these extensions are not complete, so we reorganize the Flexible-Grid label-set according to WSON definition. In addition, Flexible-Grid ability constraint (including grid type and slot width granularity/range) and optical signal compatibility constraint are also necessary for efficient RSA, but few document takes these into account. we will describe the requirements and encodings of such constraints in this draft.

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

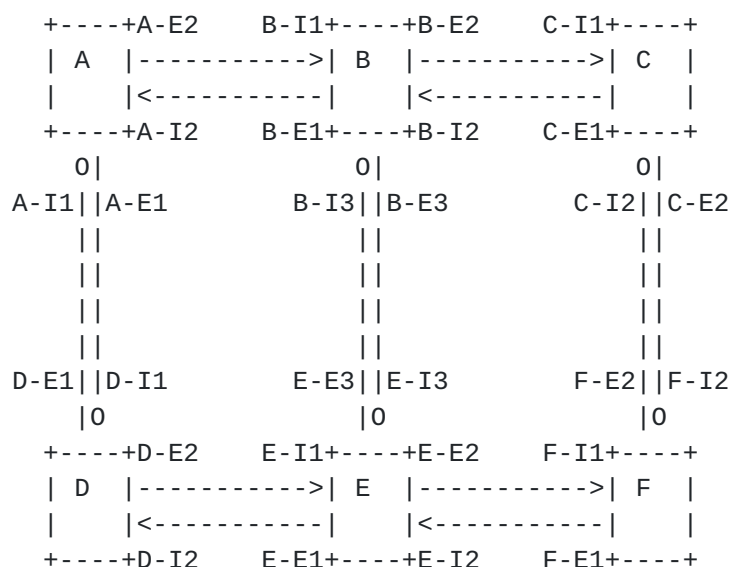


Figure 1. A sample network with both Fixed-Grid and Flexible-Grid elements

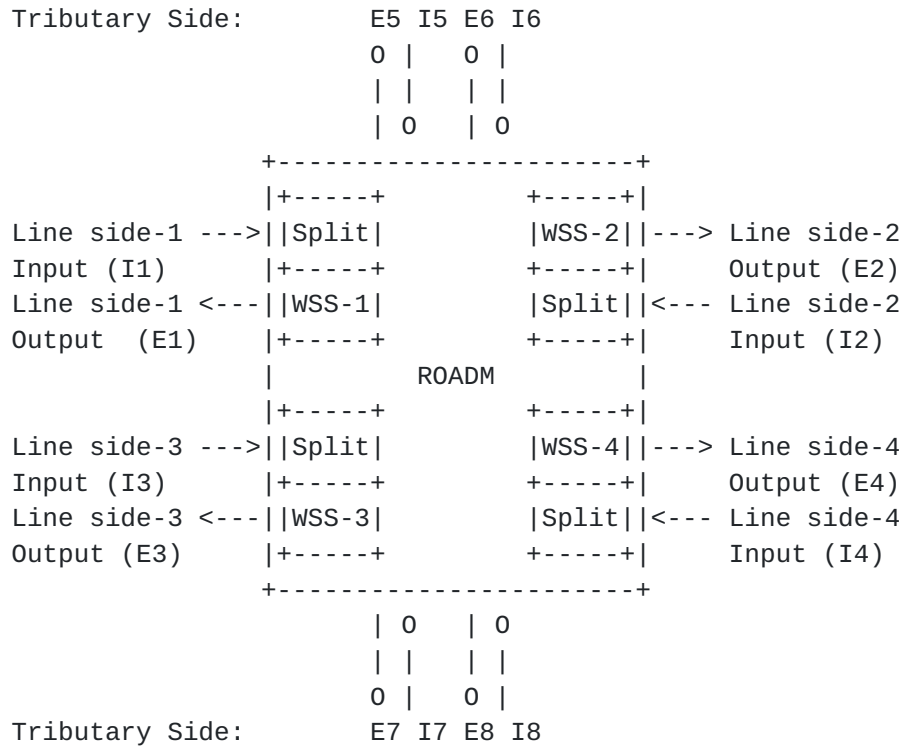


Figure 2. A ROADM Composed of WSSs and splitters (Internal connections are not presented)

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	200GHz
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 LSPs and Flexible-Grid LSPs 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 150GHz 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. Flexible-Grid Ability Constraint

Flexible-Grid ability may include the grid type (Fixed-Grid or Flexible-Grid) and slot width granularity/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.694.1v2](#)], 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 Flexible-Grid 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.

In addition, The slot width granularity of network elements may impact the spectral efficiency. For example, when a Flexible-Grid LSP request from node A to node E with 87.5GHz slot width arrives, 100GHz Slot width must be assigned for the route A->D->E due to 25GHz slot width granularity, which performs poor in spectral efficiency.

Furthermore, Although Flexible-Grid technology may offer full backwards compatibility with the standard ITU-T DWDM grids, it is a cost-efficient way to consider Flexible-Grid Ability constraints in RSA process for Fixed-Grid requirements. For example, in the network of figure 1, when a Fixed-Grid 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 necessary 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.

In addition, for each Flexible-Grid Label Switch Path, the required slot width is determined by the attribution of optical signal. However, a client only requests "data rate" as its traffic parameter but do not care "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

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 is meaningless on the label set, however, in order to keep the integrity of labels and avoid misunderstanding, it is set to default value: $m = (\text{slot width granularity})/12.5\text{GHz}$.

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

Lowest frequency _{k} = (central frequency _{k start}) - (slot width granularity)/2

= (193.1 + $n_{k\text{start}}$ * C.S.) - C.S.

= (193.1 + ($n_{k\text{start}}$ - 1) * C.S.) THz;

Highest frequency _{k} = (central frequency _{k end}) + (slot width granularity)/2

= (193.1 + $n_{k\text{end}}$ * C.S.) + C.S.

= (193.1 + ($n_{k\text{end}}$ + 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:

$$\text{Lowest frequency}_k = (\text{central frequency_start}) + (K - 1) * (\text{slot width granularity})/2$$

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

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

$$\text{Highest frequency}_k = \text{Low frequency}_k + C.S.$$

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

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. Flexible-Grid Ability and Switching Capability Constraint

To accommodate the feature of Flexible-Grid Ability and switching capability 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  | Switching Cap. | Encoding  |
+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+---+
| Grid | C.S.  | S|M|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 0xFF 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: GRID_ABILITY.

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. the reason is explained later in this document.

"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 ROADM 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 GRID_ABILITY 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.

A new switching capability is defined here: 151, Spectrum Switch Capable (SSC). When the switching capability is SSC, the field S indicates the signal-layer switch capability (1-support, 0-not), while the field M indicates the media-layer switch capability (1-support, 0-not).

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 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
+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
|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/regenenerator 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/E0 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.

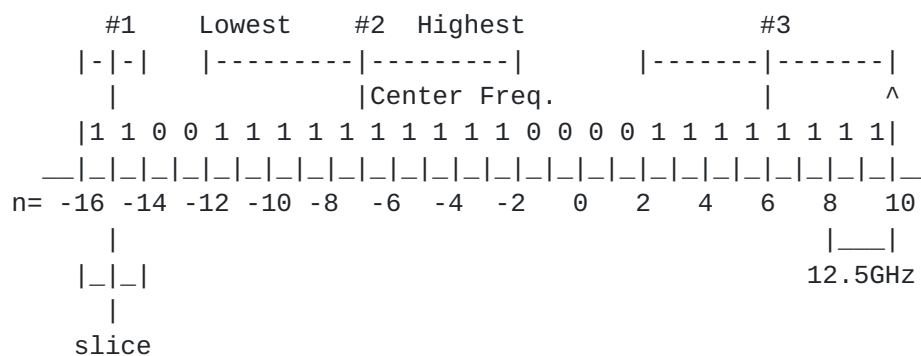


Figure 3. Spectral resource state of link AB

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 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	2	3	4	5	6	7	8	9
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 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	2	3	4	5	6	7	8	9										
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 follows:

[illegible]

6.2. Example of Flexible-Grid Ability Constraint Encoding

Taking the network of figure 1 as an example, the Flexible-Grid 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 Flexible-Grid 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 Flexible-Grid 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 types: optical 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

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