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Requirements for GMPLS Control of Flexible Grids

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Abstract

A new flexible grid of DWDM is being developed within the ITU-T Study Group 15 to allow more efficient spectrum allocation. This

memo describes the requirements of GMPLS control of flexible grid DWDM networks.

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](#)].

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1. Introduction

[G.694.1v1] defines the DWDM frequency grids for 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, i.e. the frequency spacing between two allowed nominal central frequencies could be 12.5 GHz, 25 GHz, 50 GHz, 100 GHz and integer multiples of 100 GHz as defined in [G.694.1v1]. The frequency spacing of the channels on a fiber is fixed.

The speed of the optical signal becomes higher and higher with the advancement of the optical technology. In the near future, high-speed signals (beyond 100 Gbit/s or even 400 Gbit/s) will be deployed in optical networks. These signals may not be accommodated in the channel spacing specified in [G.694.1v1]. On the other hand, 'mixed rate' scenarios will be commonplace, and bandwidth requirements of the optical signals with different speed will probably be quite different. As a consequence, when the optical signals with different speed are mixed to be transmitted on a fiber, the frequency allocation needs to be more flexible to promote the efficiency.

An updated version of [G.694.1v1] will be consented in December 2011 in support of flexible grids. The terms 'frequency slot (the frequency range allocated to a channel and unavailable to other channels within a flexible grid)' and 'slot width' (the full width of a frequency slot in a flexible grid) are introduced to address flexible grid. A channel is represented as a LSC (Lambda Switching Capable) LSP in the control plane and it means a LSC LSP should occupy a frequency slot on each fiber it traverses. In the case of flexible grid, different LSC LSPs may have different slot widths on a fiber, i.e. the slot width is flexible on a fiber.

WSO related documents are being developed currently with the focus of the GMPLS control of fixed grid optical networks. This document describes the new characteristics of flexible grids and analyses the requirements of GMPLS control for the new 'flexible grid' based optical transmission.

2. Terminology

Flexible Grid: a new WDM frequency grid defined with the aim of allowing flexible optical spectrum management, in which the Slot Width of the frequency ranges allocated to different channels are flexible (variable sized).

Frequency Range: a frequency range is defined by a lowest frequency and a highest frequency.

Frequency Slot: The frequency range allocated to a channel and unavailable to other channels within a flexible grid. A frequency slot is defined by its nominal central frequency and its slot width.

Slot Width: the full width (in Hz) of a frequency slot in a flexible grid. A slot width can be expressed as a multiple (m) of a basic slot width (e.g. 12.5 GHz)

SSON: Spectrum-Switched Optical Network. An optical network in which a data plane connection is switched based on an optical spectrum frequency slot of a variable (flexible) slot width, rather than based on a fixed grid. Note that a wavelength switched optical network (WSON) can be seen as a particular case of SSON in which all slot widths are equal and depend on the used channel spacing.

LSC SS-LSP or flexi-LSP (Lambda Switch Capable Spectrum-Switched Label Switched Path): a control plane construct that represents a data plane connection in which the switching involves a frequency slot of a variable (flexible) slot width. The mapped client signal is transported over the frequency slot, using spectrum efficient modulations such as Coherent Optical Orthogonal Frequency Division Multiplexing (CO-OFDM) and Forward Error Correction (FEC) techniques. Although still in the scope of LSC, the term flexi-LSP is used, when needed, to differentiate from regular WSON LSP in which switching is based on a nominal wavelength.

3. Characteristics of Flexible Grid

Per [[G.FLEXIGRID](#)], a flexible grid is defined for the DWDM system. Compared with the fixed grids (i.e. traditional DWDM), flexible grid has a smaller granularity for the central frequency and the slot width of the LSC LSPs is more flexible on a fiber.

3.1. Central Frequency

According to the definition of flexible DWDM grid in [[G.FLEXIGRID](#)], the step granularity for the central frequency of flexible grid is 6.25 GHz. The allowed nominal central frequencies are calculated as in the case of flexible grid:

$$\text{Central Frequency} = 193.1 \text{ THz} + n * 0.00625 \text{ THz}$$

Where 193.1 THz is ITU-T 'anchor frequency' for transmission over the C band and n is a positive or negative integer including 0.

3.2. Slot Width

A slot width is defined by:

12.5 GHz * m, where m is a positive integer.

Note that, when flexi-grid is supported on a fiber or DWDM link, the slot width of different flexi-LSPs may be different.

4. Impact on WSON

Wavelength Switched Optical Networks (WSONs) are constructed from subsystems that include Wavelength Division Multiplexing (WDM) links, tunable transmitters and receivers, Reconfigurable Optical Add/Drop Multiplexers (ROADMs), wavelength converters, and electro-optical network elements. WSON framework is described in [RFC6163]. The introduced flexible grid brings some changes on WSON.

The concept of WSON is extended to SSON, to highlight that such subsystems are extended with flexible and/or elastic capabilities (i.e. flexi-grid). Note that, when modeling SSONs, a WSON can be seen as a particular case of SSON where all LSC LSP use a fixed (and equal) slot width which depends on the used channel spacing.

Transceivers may be able to fully leverage flexible optical channels with advanced modulation formats, and ROADMs may need to be extended to allow flexible spectrum switching, based in, for example, Spectrum Selective Switches (SSS).

4.1. Fiber Links

The nominal (central) frequencies for the flexible grid are defined with a granularity of 6.25 GHz and the allocated frequency slot widths are defined as a multiple of 12.5 GHz. The fiber link for flexible grid can be modeled as shown in figure 1.

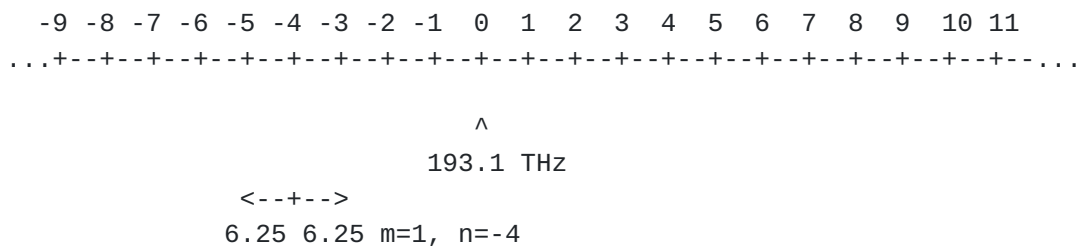


Figure 1 Fiber link model for flexible grid

The symbol '+' represents the allowed nominal central frequency. The symbol '--' represents a 6.25 GHz frequency unit. The number on the top of the line represents the 'n' in the frequency calculation formula. The nominal central frequency is 193.1 THz when n equals zero.

Because the resource allocated to each flexi-LSP is a frequency range on a fiber link, the following information is needed as parameters to perform resource allocation for the LSPs:

- o Available frequency ranges: The set or union of frequency ranges that are not allocated (i.e., available or unused) to flexi-LSPs crossing the DWDM link. The relative grouping and distribution of available frequency ranges in a fiber is usually referred to as 'fragmentation' and it is common design criterion for optical resource control and management.

4.2. Optical Transmitters and Receivers

In WSON, the optical transmitter is the wavelength source and the optical receiver is the wavelength sink of the WDM system. In each direction, the wavelength used by the transmitter and receiver along a path shall be consistent if there is no wavelength converter in the path.

In the case of flexible grids, the central frequency utilized by a transmitter or receiver may be fixed or tunable. The slot width needed by different transmitters or receivers may be different. Hence, the changes introduced by flexible grid on fundamental modeling parameters for optical transmitters and receivers from the control plane perspective are:

- o Available central frequencies: The set of central frequencies which can be used by an optical transmitter or receiver.
- o Slot width: The slot width needed by a transmitter or receiver.

Similarly, information on transmitters and receivers capabilities, in regard to signal processing is needed to perform efficient RSA, much like in WSON [[WSON-ENCODE](#)]. Additional modeling parameters are:

- o Supported Input/Output Modulation formats and spectral efficiency and reach, as well as Input/Output client signals.
- o Supported FEC techniques.

5. Routing and Spectrum Assignment

A LSC flexi-LSP occupies a frequency slot, i.e. a range of frequency, on each link the LSP traverses. The route computation and frequency slot assignment could be called RSA (Routing and Spectrum Assignment).

Similar to fixed grids network, if there is no (available) wavelength converter in an optical network, a flexible grid LSC LSP (flexi-LSP) resource allocation will be subject to the 'wavelength continuity constraint', which is described as [section 4 of \[RFC6163\]](#).

Because of the high cost of the wavelength converters, an optical network is generally deployed with limited or without wavelength converters (sparse translucent optical network). Hence, the wavelength/spectrum continuity constraint should always be considered, and the possibility of wavelength conversion will not be taking into account during the RSA process. When available, information regarding spectrum conversion capabilities at the optical nodes MAY be used by RSA mechanisms

The RSA should determine a route and frequency slot for a flexi-LSP. Note that the mapping between client signals data rates (10, 40, 100... Gbps) and optical slot widths (which are dependent on modulation formats and other physical layer parameters) is out of the scope of the document. The frequency slot can be deduced from the central frequency and slot width parameters as follows:

Lowest frequency = (central frequency) - (slot width)/2;

Highest frequency = (central frequency) + (slot width)/2.

Hence, when a route is computed (by the routing assignment process or subprocess, RA) the spectrum assignment process (SA) should determine the central frequency for a flexi-LSP based on the slot width and available central frequencies information of the transmitter and receiver, and the available frequency ranges information of the links that the route traverses.

Figure 2 shows two LSC LSPs that traverse a link.

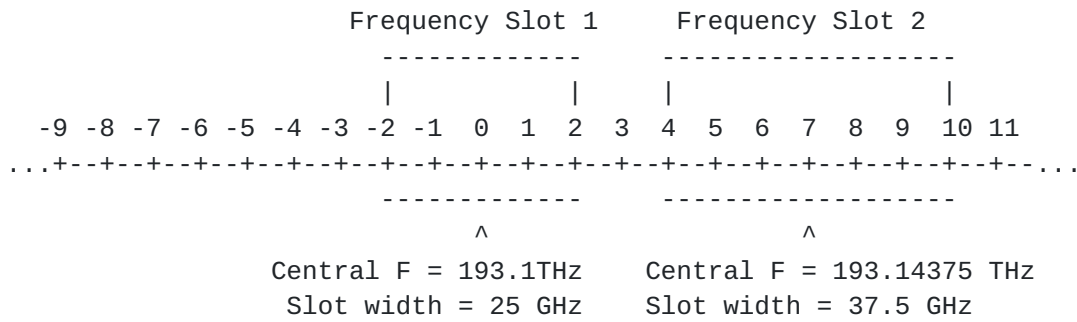


Figure 2 Two LSC LSPs traverse a Link

The two wavelengths shown in figure 2 have the following meaning:

Flexi-LSP 1: central frequency = 193.1 THz, slot width = 25 GHz. It means the frequency slot [193.0875 THz, 193.1125 THz] is assigned to this LSC LSP.

Flexi-LSP 2: central frequency = 193.14375 THz, slot width = 37.5 GHz. It means the frequency slot [193.125 THz, 193.1625 THz] is assigned to this LSC LSP.

Note that the frequency slots of two LSC flexi-LSPs on a fiber MUST NOT overlap with each other.

5.1. Architecture Approaches to RSA

Similar to RWA for fixed grids, different ways of performing RSA in conjunction with the control plane can be considered. The approaches included in this document are provided for reference purposes only, other possible options could also be deployed.

5.1.1. Combined RSA (R&SA)

In this case, a computation entity performs both routing and frequency slot assignment. The computation entity should have the detailed network information, e.g. connectivity topology constructed by nodes/links information, available frequency ranges on each link, node capability, etc.

The computation entity could reside on the following elements, which depends on the implementation:

- o PCE: PCE get the detailed network information and implement the RSA algorithm for RSA requests from the PCCs.

- o Ingress node: Ingress node gets the detailed network information through routing protocol and implements the RSA algorithm when a LSC LSP request is received.

5.1.2. Separated RSA (R+SA)

In this case, routing computation and frequency slot assignment are performed by different entities. The first entity computes the routes and provides them to the second entity; the second entity assigns the frequency slot.

The first entity should get the connectivity topology to compute the proper routes; the second entity should get the available frequency ranges of the links and nodes' capabilities information to assign the spectrum.

5.1.3. Routing and Distributed SA (R+DSA)

In this case, one entity computes the route but the frequency slot assignment is performed hop-by-hop in a distributed way along the route. The available central frequencies which meet the wavelength continuity constraint should be collected hop by hop along the route. This procedure can be implemented by the GMPLS signaling protocol.

The GMPLS signaling procedure is similar to the one described in [section 4.1.3 of \[RFC6163\]](#) except that the label set should specify the available central frequencies that meet the slot width requirement of the LSC LSP, i.e. the frequency slot which is determined by the central frequency and slot width MUST NOT overlap with the existing LSC LSPs.

6. Requirements of GMPLS Control

According to the different architecture approaches to RSA some additional requirements have to be considered for the GMPLS control.

6.1. Routing

In the case of combined RSA architecture, the computation entity needs to get the detailed network information, i.e. connectivity topology, node capabilities and available frequency ranges of the links. Route computation is performed based on the connectivity topology and node capabilities; spectrum assignment is performed based on the available frequency ranges of the links. The computation entity may get the detailed network information by the GMPLS routing protocol.

Compared with [\[RFC6163\]](#), except wavelength-specific availability information, the connectivity topology and node capabilities are the same as WSON, which can be advertised by GMPLS routing protocol (refer to [section 6.2 of \[RFC6163\]](#)). This section analyses the necessary changes on link information brought by flexible grids.

[6.1.1. Available Frequency Ranges of DWDM Links](#)

In the case of flexible grids, channel central frequencies span from 193.1 THz towards both ends of the spectrum with 6.25 GHz granularity. Different LSC LSPs could make use of different slot widths on the same link. Hence, the available frequency ranges should be advertised.

[6.1.2. Tunable Optical Transmitters and Receivers](#)

The slot width of a LSC LSP is determined by the transmitter and receiver. The transmitters and receivers could be mapped to ADD/DROP interfaces in WSON. Hence, the slot width of an ADD/DROP interface should be advertised.

The central frequency of a transmitter or receiver could be fixed or tunable. Hence, the available central frequencies should be advertised.

[6.2. Signaling](#)

Compared with [\[RFC6163\]](#), except identifying the resource (i.e., fixed wavelength for WSON and frequency resource for flexible grids), the other signaling requirements (e.g., unidirectional or bidirectional, with or without converters) are the same as WSON described in the [section 6.1 of \[RFC6163\]](#).

In the case of routing and distributed SA, GMPLS signaling can be used to allocate the frequency slot to a LSC LSP. This brings the following changes to the GMPLS signaling.

[6.2.1. Slot Width Requirement](#)

In order to allocate a proper frequency slot for a LSC LSP, the signaling should specify the slot width requirement of a LSC LSP. Then the intermediate nodes can collect the acceptable central frequencies that meet the slot width requirement hop by hop.

The tail node also needs to know the slot width of a LSC LSP to assign the proper frequency resource. Hence, the slot width

requirement should be specified in the signaling message when a LSC LSP is being set up.

6.2.2. Frequency Slot Representation

The frequency slot can be determined by the two parameters, which are central frequency and slot width as described in [section 5](#). Hence, the signaling messages should be able to specify the central frequency and slot width of a LSC LSP.

6.3. PCE

[WSON-PCE] describes the architecture and requirements of PCE for WSON. In the case of flexible grid, RSA instead of RWA is used for routing and frequency slot assignment. Hence PCE should implement RSA for flexible grids. The architecture and requirements of PCE for flexible grids are similar to what is described in [\[WSON-PCE\]](#). This section describes the changes brought by flexible grids.

6.3.1. RSA Computation Type

A PCEP request within a PCReq message MUST be able to specify the computation type of the request:

- o Combined RSA: Both of the route and frequency slot should be provided by PCE.
- o Routing Only: Only the route is requested to be provided by PCE.

The PCEP response within a PCRep Message MUST be able to specify the route and the frequency slot assigned to the route.

RSA in SSON MAY include the check of signal processing capabilities, which MAY be provided by the IGP. A PCC should be able to indicate additional restrictions for such signal compatibility, either on the endpoint or any given link (such as regeneration points).

A PCC MUST be able to specify whether the PCE MUST also assign a Modulation list and / or a FEC list, as defined in [\[WSON-ENCODE\]](#) and [\[WSON-PCE\]](#).

A PCC MUST be able to specify whether the PCE MUST or SHOULD include or exclude specific modulation formats and FEC mechanisms.

In the case where a valid path is not found, the response MUST be able to specify the reason (e.g., no route, spectrum not found, etc.)

6.3.2. RSA path re-optimization request/reply

For a re-optimization request, the PCEP request MUST provide the path to be re-optimized and include the following options:

- o Re-optimize the path keeping the same frequency slot.
- o Re-optimize spectrum keeping the same path.
- o Re-optimize allowing both frequency slot and the path to change.

The corresponding PCEP response for the re-optimized request MUST provide the Re-optimized path and frequency slot.

In case the path is not found, the response MUST include the reason (e.g., no route, frequency slot not found, both of route and frequency slot not found, etc.)

6.3.3. Frequency Constraints

PCE for flexible grids should consider the following constraints brought by the transmitters and receivers:

- o Available central frequencies: The set of central frequencies that can be used by an optical transmitter or receiver.
- o Slot width: The slot width needed by a transmitter or receiver.

This constraints may be provided by the requester (PCC) in PCReq or reside within the PCE's TEDB which stores the transponder's capabilities.

PCC may also specify the frequency constraints for policy reasons. In this case, the constraints should be specified in the PCReq message sent to the PCE. In any case, PCE will compute the route and assign the frequency slot to meet the constraints specified in the PCReq message. Then return the result to the PCC.

7. Security Considerations

This document does not introduce any further security issues other than those described in [[RFC6163](#)] and [[RFC5920](#)].

8. References

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- [WSO-PCE] Y. Lee, G. Bernstein, Jonas Martensson, T. Takeda and T. Tsuritani, "PCEP Requirements for WSON Routing and Wavelength Assignment", [draft-ietf-pce-wson-routing-wavelength-05](#), July 2011.
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