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Framework for GMPLS Control of Flexible Grid Network
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Abstract

This document provides a framework for applying Generalized Multi-Protocol Label Switching (GMPLS) and the Path Computation Element (PCE) architecture to control the flexible grid network base on the Wavelength Switched Optical Networks (WSONs). GMPLS control of WSON which is addressed in RFC6163 is out of the scope of this document.

This document focuses on the topological elements changes and new path selection constraints that flexible grid technology takes. Impairments related technology is not covered in this document.

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1. Introduction

Flexible grid is a new DWDM application which is defined in the newest version of [G.694.1]. Compared to traditional fixed grid network, a flexible grid network can select its data channels with arbitrary slot width, and mainly be used to setup path with higher bitrates (e.g., 100G or 400G or higher). whereas traditional fixed grid DWDM technology always uses fixed slot width and is mainly used to setup path with lower bitrates signals. Flexible grid network is also a WDM-based optical network in which switching is performed selectively based on the center wavelength of optical channels ,which means flexible grid channels can be represented as a lambda capable switching LSP by center wavelength and slot width from the control plane perspective.

Wavelength Switched Optical Network (WSON) which is addressed in [RFC6163] is the application of Generalized Multi-Protocol Label Switching (GMPLS) [RFC3945] operation to traditional fixed grid WDM network. As flexible grid network is a new WDM network which evolves from traditional fixed grid network, GMPLS also can be used to operate flexible grid network. Similar to fixed grid network, flexible grid network is also 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, which have flexible grid characteristics. WSON specific descriptions are addressed in [RFC6163] and are out of the scope of this document. People who are interested in this document are supposed to be familiar with [RFC6163].

This document provides a framework for applying the GMPLS architecture and protocols [RFC3945] and the PCE architecture [RFC4655] to the control and operation of flexible grid networks. In order to help GMPLS and PCE use for flexible grid network, this document first focuses on the subsystems and characteristics information that flexible grid network brings and then modeled the characteristics information by GMPLS and PCE. This work will help facilitate the development of protocol solution models and protocol extensions within the GMPLS and PCE protocol families.

1.1. Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

2. Terminology

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

- Wavelength Range: [RFC6163] gives a description of this terminology.Wavelength range given a mapping between labels and the ITU-T grids, each range could be expressed in terms of a tuple, (lambda1, lambda2) or (freq1, freq2), where the lambdas or frequencies can be represented by 32-bit integers.

- Frequency slot: The definition in [G.694.1] is shown here. 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 of a frequency slot in a flexible grid.

3. Flexible Grid Networks

Wavelength Switched Optical Network (WSON) related documents cover the constraints information that needs to be considered in the process of path computation. Emergence of flexible grid DWDM technology raises some new characteristics and these new characteristics should be modeled by GMPLS and PCE from the perspective of contral plane in order to help path computation. This document mainly focus on the flexible grid subsystems' characteristics information and constraints information that impact the flexible grid path selection process (i.e. wavelength selection). Subsequent sections review and model flexible grid characteristics that need to be emphasized by control plane and these sections follow the sequence of the section addressed in [RFC6163].

3.1. Flexible Grid Network

As described in the newest version of [G.694.1], flexible DWDM grid allows frequency slots have a nominal central frequency (in THz) defined by: 193.1 + n x 0.00625 where n is a positive or negative integer including 0 and 0.00625 is the nominal central frequency granularity in THz and a slot width defined by: 12.5 x m where m is a positive integerand 12.5 is the slot width granularity in GHz. Any combination of frequency slots is allowed as long as no two frequency slots overlap.

3.2. WDM Links

According to the review of the newest version of [G.694.1], the nominal central frequencies for the flexible grid network are defined with a granularity of 6.25 GHz and the frequency slot widths are defined as a multiple of 12.5 GHz. A label representation which includes the information of central frequency and slot width is needed to provides a common label format to be used in signaling optical paths. The flexible grid labels can also be used to describe WDM links, ROADM ports, and wavelength converters for the purposes of path selection.

As described in section 3.1 of [RFC 6163], putting WDM over different types of fiber require significant engineering and a fairly limited range of wavelengths. Parameters that include wavelength range and channel spacing is needed to perform basic, impairment-unaware modeling of a WDM link.

- o Wavelength range: wavelength range can be used to give a mapping between labels and the flexible grid and each range could be expressed in terms of a tuple,(lambda1, lambda2) or (freq1, freq2). Maybe new label representation is needed to describe wavelength range.

- o Channel Spacing: since flexible grid can provide a granularity of 6.25GHz, this new channel spacing value needs to be added.

In addition to the wavelength range and channel spacing, indication SHOULD also be added to indicate the link support flexible grid DWDM technology.

As indicated in [RFC6163], this information is relatively statically for a particular link as changes to these properties generally require hardware upgrades. Such information may be used locally during wavelength assignment via signaling.

3.3. Optical Transmitters and Receivers

Similar to WSON, flexible grid WDM optical systems make use of coupled optical transmitters and receivers to setup LSC LSP. In the case of an optical network without wavelength converters, an optical path needs to be routed from source transmitter to sink receiver and must use a single wavelength. Flexible grid brings some new characteristics to transmitters and receivers compare to traditional fixed grid characteristics like "Tunable", "Tuning range", "Tuning time" and "Spectral characteristics and stability" which are addressed in [RFC6163] for fixed grid. This section examines the new

characteristics that would impact optical transmitters and receivers in the process of control plane path computation. Modeling parameters for flexible grid optical transmitters and receivers from the control plane perspective are:

- o Tuning range: As described in [RFC6163], this is the frequency or wavelength range over which the optics can be tuned. (lambda1, lambda2) or (freq1, freq2) can be used to represent the wavelength range, where lambda1 and lambda2 or freq1 and freq2 are the labels representing the lower and upper bounds in wavelength. As nominal central frequencies can't be figured out before the path setup in flexible grid network and flexible grid label may be different from fixed grid label, "Tuning range" may be encode with some different format from traditional fixed grid technology.

- o Slot width: this parameter indicates slot width needed by a transmitter or receiver and SHOULD be considered in the process of path computation.

When an end-to-end LSC LSP needs be setup, operator first sends a path setup command which convey some characteristics information of the LSP, such as bitrates, to the source node. Path setup request is sent to path computation element to computes an end-to-end LSC LSP with specific slot width information, which bases on the bitrates and modulation format that transceiver and receiver support.

3.4. Optical Signals in Flexible Grid Network

Similar to the fixed grid swithing (e.g., WSON), the fundamental unit of switching in flexible grid is also a "wavelength". The transmitters and receivers in these networks will deal with one wavelength at a time, while the switching systems themselves can deal with multiple wavelengths at a time. Key non-impairment-related parameters which are listed in [RFC6163] are shown below:

- o (a) Minimum channel spacing (GHz)

- o (b) Minimum and maximum central frequency

- o (c) Bitrates/Line coding (modulation) of optical tributary signals

As described in [RFC6163], (a) and (b) are considered properties of the link and restrictions on the GMPLS Labels while (c) is a property of the "signal". For the purposes of modeling the flexible grid, new parameters which are related to the properities of the link and

restrictions and property of "signal" SHOULD be considered:

o (d) Minimum and Maximum Slot Width

o (e) Slot Width

(d) is considered properties of the link and restrictions on the GMPLS Labels, and description can be found in the following section. (e) is a property of the "signal" and this property is determined by the transmitter and may be changed if signal traverse an OEO.

3.4.1. Optical Tributary Signals

In [RFC6163], "optical tributary signal classes" are characterized by a modulation format and bitrates range and both of them are key parameters in characterizing the optical tributary signal. Note that, with advances in technology, optical tributary signal classes that support flexible grid would be added.

For optical tributary signals in flexible grid, bitrates range and modulation format are still two key parameters, as a single wavelength with central frequency and slot width used by a signal sent from transmitter can be deduced from these two parameters base on the available wavelength and slot width range from the source to the destination.

3.4.2. WSON Signal Characteristics

Description about WSON signal characteristics in [RFC6163] also can be applied to this document. Fundamental unit of switching in flexible grid network is also "wavelength". WSON signal characteristics like optical tributary signal class (modulation format), forward error correction (FEC), central frequency (wavelength), bitrates and general protocol identifier (G-PID) are still used in flexible grid network in the process of path computation and some more modulation formats and FECs may be added to describe flexible grid network signal characteristics.

Except the parameter that have been included in [RFC6163], the parameter slot width is also needed here to specify the slot width that signal occupies.

3.5. ROADMs, OXCs, Splitters, Combiners, and FOADMs

This section mainly focuses on optical devices such as ROADMs, Optical Cross-Connects (OXCs), splitters, combiners, and Fixed

Optical Add/Drop Multiplexers (FOADMs) which can be used in flexible grid network and examines their parameters of these devices that can be used in the process of control plane path computation.

3.5.1. Reconfigurable Optical Add/Drop Multiplexers, OXCs and FOADM

```
         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 1: ROADM

A picture is shown here to facilitate the description of ROADM. ROADM is composed of WSSes (wavelength selective switch) and splitters which are used massively in current WDM network. WSS can be used to select the wavelength on the line side output port and splitter can be used on the line side input port to split the income wavelength.

Switched connectivity matrix is needed to show whether a wavelength on input port can be connected to an output port internal.

Besides the switched connectivity matrix which is applied to line side port and tributary side port included in [RFC6163], new wavelength restriction of the line side port on a ROADM which are brought by flexible grid are considered below:

o (a) Available wavelength range:

This parameter indicates the available wavelength that can be allocated to a LSP. (lambda1, lambda2) or (freq1, freq2) can be used to represent the available wavelength range.

o (b) Maximum/Minimum slot width that a port support

This is an inherent attribution of the network subsystems, like WSS, and can be treated as port label restriction. Requirements and descriptions about the restrictions information can be found in [draft-wangl-ccamp-ospf-ext-constraint-flexi-grid]. For flexible grid subsystems' ports, 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. (Channel Spacing). The combination of C.S. and [Minimum Slot Width, Maximum Slot Width] can represent any slot width that ROADM support.

o (c) Wavelength Range allocation

The whole wavelength that ROADM support can be partitioned into several wavelength ranges, and one wavelength range can only be used for paths setup with the specific bit rate and/or modulation format. The advertisement of this restrictions information will help reduce fragments in flexible grid network. Requirements related description can be found in [draft-wang-ccamp-flexible-grid-wavelength-range-ospf-te]. This is an optional requirement.

These restrictions information can also be applied to fixed optical Add/Drop Multiplexers.

3.5.2. Splitters and Combiners

Nothing is new except switched connectivity matrix and this has been addressed in [RFC6163].

3.6. Electro-Optical Systems

Some words can be found in [RFC6163]. OEO switches, wavelength converters, and regenerators all share a similar property: they can be more or less "transparent" to an "optical signal" depending on their functionality and/or implementation. Properties can be applied to flexible grid, and these properties can satisfy path computation without taking any new characteristics into consideration. Modeling of OEO switches, wavelength converters and regenerators can also be applied to flexible grid.

Regenerator can be used to restore signal quality. Bitrates range and modulation formats that the regenerator support need to be taken into consideration to help path computation, whereas slot width do not (May be someone will talk about slot width). If one regenerator is designed to handle signal with specific bitrates and modulation formats, then it would support the corresponding slot width because slot width can be derived by modulation format and bitrates. Even if the slot width is changed by the electro-optical systems due to the change of modulation format, the slot width that has already changed may not be explicitly specified because bitrates and modulation format are explicitly specified.

4. Routing and wavelength Assignment in flexible grid network

This section briefly describes the constraints information of routing and wavelength assignment in the flexible grid network. Similar to WSON, the input to basic RWA in flexible grid network are the requested optical path's source and destination, the network topology, the locations and capabilities of any wavelength converters, the wavelengths available on each optical link and port label constraints information such as slot width range that a port support and wavelength range partition information by bitrates and/or modulation formats. The output that provided by RWA in flexible grid network are an explicit route through ROADMs, a wavelength for optical transmitter, the slot width that this wavelength occupies, and a set of locations (generally associated with ROADMs or switches) where wavelength conversion is to occur and the new wavelength to be used on each component link after that point in the route.Similar to WSON, an optical flexible grid path that from source to destination also must use a single wavelength that is available along that path without "colliding" with a wavelength used by any other optical path that may share an optical fiber.

In [RFC6163], three different ways of performing RWA in conjunction with the control plane are shown here:

1) Combined RWA

2) Separated R and WA (R + WA)

3) Routing and Distributed WA (R + DWA)

These ways can also be applied to flexible grid control plane path computation. Related description about these three architectures can be found in section 4.1 of [RFC6163].

5. GMPLS and PCE Control

Flexible grid brings some new characteristics to WDM network, and consequently WSON would add some extensions or change in order to control the flexible grid network. Extensions to GMPLS signaling, routing and PCE are described in this section.

5.1. Extension to GMPLS Signaling

Support for WSON signaling exists in [RFC3471], [RFC4328] and [draft-ietf-ccamp-wson-signaling]. However, a number of practical issues arise in the identification of wavelengths and signals in wavelength assignment in flexible grid.

A mapping between label and wavelength is needed to simplify the characterization of WDM links and WSON devices. The mapping like the one described in [draft-farrkingel-ccamp-flexigrid-lambda-label] provides label and wavelength mapping for communication between PCE and WSON PCCs. Different LSP may occupy different slot width if paths have different bitrates and modulation format in flexible grid network. So in the flexible grid network, not only central frequency is needed, but also slot width SHOULD be included to identify a channel in the process of path setup in flexible grid network.

GMPLS Signaling should be able to convey the central frequency and slot width information that a LSC LSP occupies. If the slot width is changed due to the change of modulation format, signaling should also be able to express this. Except methods that are specified in [draft-farrkingel-ccamp-flexigrid-lambda-label], [draft-hussain-ccamp-super-channel-label] and [draft-zhang-ccamp-flexible-grid-rsvp-te-ext] also provide methods to carry central frequency and slot width information in the process of signaling.

Note: extension to GMPLS signaling SHOULD be compatible with current signaling protocol.

5.2. Extension to GMPLS Routing

The following subsystem's properties are needed by IGP to minimally characterize WSON, also these properties are needed to characterize flexible grid control plane. This section addresses the constraints information needed to model flexible grid from the control plane perspective base on the Wavelength Switched Optical Network (WSON).

1) WDM link properties (allowed wavelengths)

2) Optical transmitters (wavelength range)

3) ROADM/FOADM properties (connectivity matrix, port wavelength restrictions)

4) Wavelength converter properties (per network element, may change if a common limited shared pool is used)

Here 1, 2 and 3 are re-considered in the flexible grid network.

5.2.1. Available Wavelength Range

Wavelengths available on WDM link and port of optical transmitters are advertised through routing protocol, the wavelengths available information can be used by path computation element to compute a suitable end-to-end LSP. As different flexible grid channels always have different slot widths and channels' central frequency position and slot width can't be decided in advance, so mapping between label and wavelength may not be able to use the representation similar to [RFC6205] to represent every channel. Maybe new label formats and representation of wavelength available are needed in routing protocol to transfer IGP information between nodes and PCEs. Extensions to label set field SHOULD be able to represent the wavelength available validly in flexible grid network. Allowed wavelengths on WDM link and wavelength range on optical transmitters neede to adapt to this change.[draft-dhillon-ccamp-super-channel-ospfte-ext], [draft-wangl-ccamp-ospf-ext-constraint-flexi-grid] and [draft-zhang-ccamp-flexible-grid-ospf-ext] give some different methods to represent the available wavelengths.

5.2.2. Port Label Restriction

Some new ROADM/FOADM properties brought by flexible grid need to be advertised by routing protocol in order to help path computation. In the section 3, properties of ROADM/FOADM are described as the port label restrictions information.

The first one, maximum/minimum slot width supported on one port need to be advertised. This slot width constraint information of a port (i.e., available slot width range of a WSS) SHOULD be known by path computation element in order to compute a suitable path. According to [draft-wangl-ccamp-ospf-ext-constraint-flexi-grid], combination of C.S. and [Minimum Slot Width, Maximum Slot Width] can represent any slot width that ROADM support. LMP can be run between two neighbor nodes to negotiate these attributes and related extension can be found in [draft-li-ccamp-grid-property-lmp]. This is optional

because routing protocol can also be used to deal with it.

The second one, wavelength range allocation information of ROADM/ FOADM needs to be advertised through routing protocol. Grouping of wavelength of the same bitrates and/or modulation formats would help reduce fragments. Channels in the same wavelength range with the same bitrates looks almost like fixed grid technology, and they won't generate much fragment in the path setup and release because every channel use the same slot width. Requirements of wavelength range allocation and protocol extensions can be found in [draft-wang-ccamp-flexible-grid-wavelength-range-ospf-te].

5.3. Optical Path Computation and Implications for PCE

Extensions to PCEP can be found in [draft-lee-pce-wson-rwa-ext] base on Wavelength Switched Optical Network. Emergence of flexible grid brings some extension to current draft. PCEP SHOULD be able to support flexible grid path computation.

5.3.1. Optical Path Constraints and Electro-Optical Element Signal Compatibility

Flexible grid may not change the computation architectures of WSON, but new constraints information SHOULD be taken into consideration in the process of path computation. According to the description in [RFC6163], when requesting a path computation to PCE, the PCC should be able to indicate:

1) The G-PID type of an LSP

2) The signal attributes at the transmitter and receiver.

And the PCE should be able to respond to the PCC with the following:

1) The conformity of the requested optical characteristics associated with the resulting LSP with the source, sink, and NE along the LSP.

2) Additional LSP attributes modified along the path.

3) Slot width of the LSP. This should be respond to the PCC as flexible grid channels always have different slot widths. Slot width information may be contained in the wavelength object which is carried in PCRep message from PCE to PCC.

5.3.2. Discovery of RWA-Capable PCEs

Not all PCEs within a domain would necessarily need the capability of flexible grid path computation. Therefore, it would be useful to indicate that a PCE has the ability to deal with flexible grid via the discovery mechanisms being established for PCE discovery in [RFC5088]. Extensions to [RFC5088] are needed to achieve this goal.

5.3.3. Use of GCO

Though GCO is able to reduce the fragment of the wavelength or spectrum, it is hard to be implemented in the network, because GCO would involve massive LSPs and distrub current service. As fragment can be reduced through early wavelength or spectrum allocation planning, GCO maybe avoided.

6. Security Considerations

TBD

7. References

7.1. Normative References

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