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OSPF Extensions in Support of Routing and Wavelength Assignment (RWA) in Wavelength Switched Optical Networks (WSONs)

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Abstract

Wavelength switched optical networks (WSONs) are based on Wavelength Division Multiplexing (WDM) in which user traffic is carried by data channels of different optical wavelengths. In traditional WDM Networks, each wavelength path is statically configured. With the

deployment of Reconfigurable Optical Add-Drop Multiplexers (ROADMs), photonic cross-connects (PXCs), and tunable laser, WSONs have become more dynamic, and operators can flexibly set up wavelength paths to carry user traffic.

In WSONs where there are no or a limited number of switches capable of wavelength conversion paths must be set up subject to the "wavelength continuity" constraint. This leads to a path computation problem known as routing and wavelength assignment (RWA). In order to perform such computations, it is necessary to collect information about the available wavelengths within the network.

This document describes OSPF routing protocols extensions to support Wavelength Switched Optical Networks (WSON) under the control of Generalized MPLS (GMPLS).

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

Wavelength switched optical networks (WSONs) are based on Wavelength Division Multiplexing (WDM) in which user traffic is carried by data channels of different optical wavelengths. In traditional WDM Networks, each wavelength path is statically configured. With the deployment of Reconfigurable Optical Add-Drop Multiplexers (ROADMs), photonic cross-connects (PXCs), and tunable laser, WSONs have become more dynamic, and operators can flexibly set up wavelength paths to carry user traffic.

In WSONs where there are no or a limited number of switches capable of wavelength conversion paths must be set up subject to the "wavelength continuity" constraint. This leads to a path computation problem known as routing and wavelength assignment (RWA). In order to perform such computations, it is necessary to collect information about the available wavelengths within the network.

[WSON-Frame] provides a framework for applying GMPLS [RFC3945] and the Path Computation Element (PCE) architecture [RFC4655] to the control of WSONs to address the RWA problem. [WSON-Info] describes an information model that specifies the information needed at various points in a WSON in order to compute paths and establish Label Switched Paths (LSPs). Based on the information model of [WSON-Info], [WSON-Encode] provides efficient protocol-independent encodings of the information needed by the RWA process in a WSON. Such encodings can be used to extend GMPLS signaling and routing protocols.

Therefore, in order to enable GMPLS to control WSON networks, this document follows on from [WSON-Info], [WSON-Encode], and [WSON-IGP-Eval] to define extensions to the OSPF routing protocol to enhance the Traffic Engineering (TE) properties of GMPLS TE which are defined in [RFC3630], [RFC4202], and [RFC4203].

No consideration of optical impairment routing related information is included in this document.

2. Node Information

According to [WSON-Info] and [WSON-Encode], the node information about WSON nodes includes Node ID, connectivity matrix, wavelength converter pool information. Except for the Node ID which should comply with Routing Address described in [RFC3630], the other pieces of information are defined in this document.

[OSPF-Node] defines a new top TLV named the Node Attribute TLV which carries attributes related to a router/node. Connectivity matrix,

wavelength converter pool information are attributes associated with a WSON node, so this document defines the following sub-TLVs of Node Attribute TLV:

(1)Connectivity matrix sub-TLV

(2)Wavelength converter pool information sub-TLV

2.1. Connectivity Matrix

Unlike the packet and TDM networks whose switching devices are symmetric, the switching devices in a WSON are highly asymmetric. Therefore, it is necessary to identify which ingress ports and wavelengths can be connected to (the same wavelength on) a specific egress port. Detailed descriptions of the Connectivity Matrix can be found in the corresponding sections of [WSON-Info] and [WSON-Encode].

The Connectivity Matrix TLV is a sub-TLV (the type is TBD by IANA) of the Node Attribute TLV. The format of this sub-TLV is defined 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
| Connectivity  |              Reserved                         |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Link Set A #1                          |
:                               :                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                        Link Set B #1                          |
:                               :                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Additional Link set pairs as needed       |
:                     to specify connectivity                   :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type = TBD

Connectivity : 8 bits

The following values are currently defined. All other values are reserved and SHOULD be transmitted as zero and ignored on receipt.

0x01: Fixed Connectivity Matrix

Indicates that the switching element is a kind of fixed switching device, so the connectivity matrix represents the potential connectivity matrix. This applies to asymmetric fixed devices or to the fixed part of a "hybrid" device [Switch].

0x02: Switched Connectivity Matrix

Indicates that the switching element is a kind of switched device (e.g., ROADM or OXC). The connectivity matrix represents the potential connectivity matrix for an asymmetric switch.

Reserved: 24 bits

This field is reserved. It SHOULD be set to zero on transmission and MUST be ignored on receipt.

Link Set: At least one Link Set MUST be present. Multiple Link Sets MAY be present. Each one has variable length. The Link set is defined in Section 2.2.1..

2.1.1. Link Set

Link Set identifies a link group and is defined 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|    Action     |Dir|  Format   |   Num Links   |    Reserved   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Link Identifier 1                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
:                               :                               :
:                               :                               :
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                      Link Identifier N                        |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The Link Set is not a kind of sub-TLV and it is just a part of the Connectivity Matrix TLV. (Note that this construct may be reused in the Wavelength Converter Pool information in Section 2.3 in a future version of this document.)

Action: 8 bits

The following values are currently defined. All other values are reserved.

0x01: Inclusive List

Indicates that one or more link identifiers are included in the Link Set. Each identifies a separate link that is part of the set.

0x02: Inclusive Range

Indicates that the Link Set defines a range of links. It contains two link identifiers. The first identifier indicates the start of the range (inclusive). The second identifier indicates the end of the range (inclusive). All links with numeric values between the bounds are considered to be part of the set. A value of zero in either position indicates that there is no bound on the corresponding portion of the range. Note that the Action field could be set to 0x02(Inclusive Range) only when unnumbered link identifier is used.

Directionality of the Link Set (Dir): 2 bits

The following values are currently defined. All other values are reserved.

0x01: Bidirectional

Indicates that the links in the Link Set are bidirectional.

0x02: Incoming

Indicates that the links in the Link Set are from the incoming direction with respect to the node advertising the information.

0x03: Outgoing

Indicates that the links in the Link Set are to the outgoing direction with respect to the node advertising the information.

Format: 6 bits

This field identifies the format of the link identifier. The following values are currently defined. All other values are reserved.

0x01: Link Local Identifier with IPv4 address

Indicates that the links in the Link Set are identified by link local identifiers which are IPv4 numbered. All link local identifiers are supplied in the context of the advertising node.

0x02: Link Local Identifier with unnumbered interface

Indicates that the links in the Link Set are identified by link local identifiers which are unnumbered interface IDs. All link local identifiers are supplied in the context of the advertising node.

Num Links: 8 bits

This field indicates the total number of the links in the Link Set.

Reserved: 8 bits

This field is reserved. It MUST be set to zero on transmission and MUST be ignored on receipt.

Link Identifier: 32 bits for each link

If the Format field is set to 0x01 (Link Local Identifier with IPv4 address), the link identifier is the interface IP address used to identify the incoming or outgoing port corresponding to the link. The format of the Link Identifier should comply with the format of the Local/Remote Interface IP Address described in [RFC3630].

If the Format field is set to 0x02 (Link Local Identifier with unnumbered interface), the link identifier is unnumbered.

An example about Connectivity Matrix representation could be referred to the Section 3.2 of [WSON-Encode].

2.2. Wavelength Converter Pool Information

TBD.

3. Link Information

The most common link sub-TLVs are already defined in [RFC3630], [RFC4203]. For example, Link ID, Administrative Group, Interface Switching Capability Descriptor (ISCD), Link Protection Type, Shared Risk Link Group Information (SRLG), and Traffic Engineering Metric.

For WSONs, per [WSON-Info] and [WSON-Encode], the following additional link sub-TLVs are defined in this document.

(1) WSON Port Wavelength Restrictions sub-TLV

(2) Wavelength Availability sub-TLV

(3) Shared Backup Wavelengths sub-TLV

3.1. WSON Port Wavelength Restrictions

In WSONs, there may be wavelength restrictions on a link or port. For example, a WSON link might only be able to support switching some specific wavelengths. These restrictions are distributed by OSPF to be convenient for wavelength path computation.

The WSON Port Wavelength Restrictions TLV is a sub-TLV (the type is TBD by IANA) of the Link TLV. The format of this sub-TLV is defined 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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |RestrictionKind|T|  Reserved   |       MaxNumChannels          |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |                     Wavelength Set                            |
  |                      (variable)                               |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type = TBD

RestrictionKind: 8 bits

The following values are currently defined. All other values are reserved.

0x01: Simple wavelength selective restriction

In this case, MaxNumChannels indicates the maximum number of wavelengths permitted on the port, and the accompanying Wavelength Set indicates the specific permitted wavelengths.

0x02: Waveband device with a tunable center frequency and passband.

In this case, MaxNumChannels indicates the maximum width of the waveband in terms of the channels spacing given in the Wavelength Set. The corresponding wavelength set is used to indicate the overall tuning range. Specific center frequency tuning information can be obtained from dynamic channel in use information.

MaxNumChannels indicates the maximum number of channels supported on the port/waveband dependent on the setting of the RestrictionKind field.

Wavelength Set information is carried as defined in Section 3.4 of [WSON-Encode].

3.2. Wavelength Availability Information

The requirements for a global semantic for wavelength labels and the corresponding standardized wavelength label can be found in [Lambda-Labels].

Because the wavelength continuity along the wavelength Label Switched Path (LSP) should be ensured without wavelength conversion or with wavelength conversion at some switches along the path, the information about wavelength availability and wavelength connectivity is very important when computing a wavelength LSP. For example, if the wavelength label range [lambda 1, lambda 5] of fiber 1 can be connected to the same wavelength label range of fiber 2, but only lambda 3 is available on fiber 2 because other wavelength labels are occupied, lambda 3 must be selected on fiber 1.

If the wavelength availability information is not known by the node performing the path computation, then the computation can only be performed at the level of TE links, and wavelength assignment must be resolved locally by the switches on a hop-by-hop basis enhanced by signaling protocol mechanisms used to negotiate label selection. However, this case may be very inefficient in the signaling protocol, and can easily lead to blocking problems where a path is selected for which there is no suitable wavelength availability, unless some or all of the switches along the path are capable of full wavelength conversion. In the general case of limited or no wavelength conversion, information on wavelength availability is essential to perform efficient and accurate path computation.

It is possible to consider reporting the statuses of each wavelength on a link using implicit wavelength identification based on the link-local knowledge of wavelengths supported and a well-known sequence. However, this information would be of no use in a wider context (i.e., away from the link ends). On the other hand, if the standardized label format described in [Lambda-Labels] is used to identify every wavelength when its status is reported, the wavelength information will be a little larger (or the order of one wavelength label per status advertised). This may have a significant affect on the total information advertised in a network because a WSON link often supports many wavelengths (e.g., 80 or 160 wavelength systems).

To minimize the size of information, a bitmap wavelength set is defined in [WSON-Encode] to indicate the wavelength availability information for a fiber, i.e., only one bit is used to indicate the

status of a certain wavelength (the wavelength is either available or not available).

Note that there are five approaches for Wavelength Set which is used to represent the wavelength availability information described in Section 3.4 of [WSON-Encode]. Considering that the continuity of the available or unavailable wavelength set can be scattered for the dynamic wavelength availability, so it may burden the routing to reorganize the wavelength set information when the Inclusive (/Exclusive) List (/Range) approaches are used to represent wavelength availability information. Therefore, it is RECOMMENDED that only the Bitmap Set be used for representation wavelength availability information as follows.

The Wavelength Availability TLV is a sub-TLV (the type is TBD by IANA) of the Link TLV. The format of this sub-TLV is defined 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
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |          Num Wavelengths      |          Reserved             |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |Grid |  C.S. |      Reserved    |     n  for lowest frequency    |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |    Bit Map Double-word #1 (Lowest frequency channels)         |
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  :                                                               :
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
  |Bit Map Double-word #N (Highest frequency channels)|Padded bits|
  +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Type = TBD

The three fields (Grid, C.S. and n) are defined in [Lambda-Label].

Num Wavelengths: 8 bits

Indicates the number of the wavelengths represented by the bit map.

Each bit in the bit map represents a particular frequency with a value of 1/0 indicating whether the frequency is available or not. Bit position zero represents the lowest frequency, while each succeeding bit position represents the next frequency a channel spacing (C.S.) above the previous. The values of the bit map are defined as follows:

1 = Available

0 = Assigned (in use, or failed, or administratively down, or under testing)

The valid length of the bit map is clearly Num Wavelengths bits, but the bit map should be padded to make the whole number of the bits in bitmap be the time of 32 bits so that the TLV is a multiple of four bytes. Padded bit SHOULD be set to 0 and MUST be ignored.

Bits that do not represent wavelengths (i.e., those in positions (Num Wavelengths - 1) and beyond) SHOULD be set to zero and MUST be ignored.

3.3. Shared Backup Wavelengths

TBD.

4. Procedures for Routing Flooding

The advertisement for the node attributes SHOULD comply with the procedures described in [OSPF-Node].

In the WSON networks, the node information can be classified as two kinds: one is static information comparatively such as Node ID, Connectivity Matrix information; the other is dynamic information such as Wavelength Converter Pool Status information. For the static node information, the router announces the static node information in the node attribute TLV which could be advertised during the node starts or periodically for some configurable time (e.g., per hour or several hours). For the dynamic node information, the router announces this information in the separate node attribute TLV which SHOULD be advertised during node starts or when the corresponding node information is changed.

For the WSON link information, the procedures for the routing flooding SHOULD comply with [RFC3630], [RFC4203] and the other existing family standards, and there is no extended process for the link attributes advertisement, except that some link sub-TLVs are defined in this document.

Note that as with other TE information, an implementation SHOULD take measures to avoid rapid and frequent updates of routing information that could cause the routing network to become swamped. A threshold mechanism MAY be applied such that updates are only flooded when a

number of changes have been made to the wavelength availability information within a specific time. Such mechanisms MUST be configurable if they are implemented.

5. Security Considerations

This document does not introduce any further security issues other than those discussed in [RFC 3630], [RFC 4203].

6. IANA Considerations

[RFC3630] says that the top level Types in a TE LSA and Types for sub-TLVs for each top level Types must be assigned by Expert Review, and must be registered with IANA.

IANA is requested to allocate new Types for the sub-TLVs as defined in Sections 2.1, 3.1, and 3.2 as follows:

6.1. Node Information

This document introduces the following sub-TLV of Node Attribute TLV (Value TBD, see [OSPF-Node])

Type	sub-TLV
TBD	Connectivity matrix

6.2. Link Information

This document introduces the following sub-TLV of TE Link TLV (Value 2)

Type	sub-TLV
TBD	WSON Port Wavelength Restrictions
TBD	Wavelength Availability

7. References

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TBD.

Intellectual Property