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Generalized Labels for Lambda-Switch-Capable (LSC) Label Switching Routers

Abstract

Technology in the optical domain is constantly evolving, and, as a consequence, new equipment providing lambda switching capability has been developed and is currently being deployed.

Generalized MPLS (GMPLS) is a family of protocols that can be used to operate networks built from a range of technologies including wavelength (or lambda) switching. For this purpose, GMPLS defined a wavelength label as only having significance between two neighbors. Global wavelength semantics are not considered.

In order to facilitate interoperability in a network composed of next generation lambda-switch-capable equipment, this document defines a standard lambda label format that is compliant with the Dense Wavelength Division Multiplexing (DWDM) and Coarse Wavelength Division Multiplexing (CWDM) grids defined by the International Telecommunication Union Telecommunication Standardization Sector. The label format defined in this document can be used in GMPLS signaling and routing protocols.

1. Introduction

As described in [RFC3945], GMPLS extends MPLS from supporting only Packet Switching Capable (PSC) interfaces and switching to also supporting four new classes of interfaces and switching:

o Layer-2 Switch Capable (L2SC)

o Time-Division Multiplex (TDM) Capable

o Lambda Switch Capable (LSC)

o Fiber Switch Capable (FSC)

A functional description of the extensions to MPLS signaling needed to support new classes of interfaces and switching is provided in [RFC3471].

This document presents details that are specific to the use of GMPLS with LSC equipment. Technologies such as Reconfigurable Optical Add/Drop Multiplex (ROADM) and Wavelength Cross-Connect (WXC) operate

at the wavelength switching level. [RFC3471] states that wavelength labels "only have significance between two neighbors" (Section 3.2.1.1); global wavelength semantics are not considered. In order to facilitate interoperability in a network composed of LSC equipment, this document defines a standard lambda label format, which is compliant with both the Dense Wavelength Division Multiplexing (DWDM) grid [G.694.1] and the Coarse Wavelength Division Multiplexing (CWDM) grid [G.694.2].

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. Assumed Network Model and Related Problem Statement

Figure 1 depicts an all-optical switched network consisting of different vendors' optical network domains. Vendor A's network consists of ROADM or WXC, and Vendor B's network consists of a number of Photonic Cross-Connects (PXCs) and DWDM multiplexers and demultiplexers. Otherwise, both vendors' networks might be based on the same technology.

In this case, the use of standardized wavelength label information is quite significant to establish a wavelength-based Label Switched Path (LSP). It is also an important constraint when calculating the Constrained Shortest Path First (CSPF) for use by Generalized Multi-Protocol Label Switching (GMPLS) Resource ReserVation Protocol - Traffic Engineering (RSVP-TE) signaling [RFC3473]. The way the CSPF is performed is outside the scope of this document.

Needless to say, an LSP must be appropriately provisioned between a selected pair of ports not only within Domain A but also over multiple domains satisfying wavelength constraints.

Figure 2 illustrates the interconnection between Domain A and Domain B in detail.

```
                                  |
      Domain A (or Vendor A)      |      Domain B (or Vendor B)
                                  |
     Node-1            Node-2     |         Node-6            Node-7
   +--------+        +--------+   |      +-------+ +-+     +-+ +-------+
   | ROADM  |        | ROADM  +---|------+  PXC  +-+D|     |D+-+  PXC  |
   | or WXC +========+ or WXC +---|------+       +-+W+=====+W+-+       |
   | (LSC)  |        | (LSC)  +---|------+ (LSC) +-+D|     |D+-+ (LSC) |
   +--------+        +--------+   |      |       +-|M|     |M+-+       |
       ||                ||       |      +++++++++ +-+     +-+ +++++++++
       ||     Node-3     ||       |       |||||||               |||||||
       ||   +--------+   ||       |      +++++++++             +++++++++
       ||===|  WXC   +===||       |      | DWDM  |             | DWDM  |
            | (LSC)  |            |      +--++---+             +--++---+
       ||===+        +===||       |         ||                    ||
       ||   +--------+   ||       |      +--++---+             +--++---+
       ||                ||       |      | DWDM  |             | DWDM  |
   +--------+        +--------+   |      +++++++++             +++++++++
   | ROADM  |        | ROADM  |   |       |||||||               |||||||
   | or WXC +========+ or WXC +=+ |  +-+ +++++++++ +-+     +-+ +++++++++
   | (LSC)  |        | (LSC)  | | |  |D|-|  PXC  +-+D|     |D+-+  PXC  |
   +--------+        +--------+ +=|==+W|-|       +-+W+=====+W+-+       |
     Node-4            Node-5     |  |D|-| (LSC) +-+D|     |D+-+ (LSC) |
                                  |  |M|-|       +-+M|     |M+-+       |
                                  |  +-+ +-------+ +-+     +-+ +-------+
                                  |        Node-8            Node-9
```

Figure 1. Wavelength-Based Network Model

```
   +-------------------------------------------------------------+
   |          Domain A             |        Domain B             |
   |                               |                             |
   |           +---+     lambda 1  |         +---+               |
   |           |   |---------------|---------|   |               |
   |       WDM | N |     lambda 2  |         | N | WDM           |
   |      =====| O |---------------|---------| O |=====          |
   |  O        | D |        .      |         | D |        O      |
   |  T    WDM | E |        .      |         | E | WDM    T      |
   |  H   =====| 2 |     lambda n  |         | 6 |=====   H      |
   |  E        |   |---------------|---------|   |        E      |
   |  R        +---+               |         +---+        R      |
   |                               |                             |
   |  N        +---+               |         +---+        N      |
   |  O        |   |               |         |   |        O      |
   |  D    WDM | N |               |         | N | WDM    D      |
   |  E   =====| O |      WDM      |         | O |=====   E      |
   |  S        | D |=========================| D |        S      |
   |       WDM | E |               |         | E | WDM           |
   |      =====| 5 |               |         | 8 |=====          |
   |           |   |               |         |   |               |
   |           +---+               |         +---+               |
   +-------------------------------------------------------------+
```

Figure 2. Interconnecting Details between Two Domains

In the scenario of Figure 1, consider the setting up of a bidirectional LSP from ingress switch (Node-1) to egress switch (Node-9) using GMPLS RSVP-TE. In order to satisfy wavelength continuity constraints, a fixed wavelength (lambda 1) needs to be used in Domain A and Domain B. A Path message will be used for signaling. The Path message will contain an Upstream_Label object and a Label_Set object, both containing the same value. The Label_Set object shall contain a single sub-channel that must be the same as the Upstream_Label object. The Path setup will continue downstream to egress switch (Node-9) by configuring each lambda switch based on the wavelength label. If a node has a tunable wavelength transponder, the tuning wavelength is considered a part of the wavelength switching operation.

Not using a standardized label would add undue burden on the operator to enforce policy as each manufacturer may decide on a different representation; therefore, each domain may have its own label formats. Moreover, manual provisioning may lead to misconfiguration if domain-specific labels are used.

Therefore, a wavelength label should be standardized in order to allow interoperability between multiple domains; otherwise, appropriate existing labels are identified in support of wavelength availability. Containing identical wavelength information, the ITU-T DWDM frequency grid specified in [G.694.1] and the CWDM wavelength information in [G.694.2] are used by Label Switching Routers (LSRs) and should be followed for wavelength labels.

3. Label-Related Formats

To deal with the widening scope of MPLS into the optical switching and time division multiplexing domains, several new forms of "label" have been defined in [RFC3471]. This section contains a definition of a wavelength label based on [G.694.1] or [G.694.2] for use by LSC LSRs.

3.1. Wavelength Labels

Section 3.2.1.1 of [RFC3471] defines wavelength labels: "values used in this field only have significance between two neighbors, and the receiver may need to convert the received value into a value that has local significance".

We do not need to define a new type as the information stored is either a port label or a wavelength label. Only the wavelength label needs to be defined.

LSC equipment uses multiple wavelengths controlled by a single control channel. In such a case, the label indicates the wavelength to be used for the LSP. This document defines a standardized wavelength label format. For examples of wavelength values, refer to [G.694.1], which lists the frequencies from the ITU-T DWDM frequency grid. For CWDM technology, refer to the wavelength values defined in [G.694.2].

Since the ITU-T DWDM grid is based on nominal central frequencies, we need to indicate the appropriate table, the channel spacing in the grid, and a value n that allows the calculation of the frequency. That value can be positive or negative.

The frequency is calculated as such in [G.694.1]:

    Frequency (THz) = 193.1 THz + n * channel spacing (THz)

Where "n" is a two's-complement integer (positive, negative, or 0) and "channel spacing" is defined to be 0.0125, 0.025, 0.05, or 0.1 THz. When wider channel spacing such as 0.2 THz is utilized, the combination of narrower channel spacing and the value "n" can provide

proper frequency with that channel spacing. Channel spacing is not utilized to indicate the LSR capability but only to specify a frequency in signaling.

For other cases that use the ITU-T CWDM grid, the spacing between different channels is defined as 20 nm, so we need to express the wavelength value in nanometers (nm). Examples of CWDM wavelengths in nm are 1471, 1491, etc.

The wavelength is calculated as follows:

    Wavelength (nm) = 1471 nm + n * 20 nm

Where "n" is a two's-complement integer (positive, negative, or 0). The grids listed in [G.694.1] and [G.694.2] are not numbered and change with the changing frequency spacing as technology advances, so an index is not appropriate in this case.

3.2. DWDM Wavelength Label

For the case of lambda switching of DWDM, the information carried in a wavelength label is:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid | C.S.  |    Identifier   |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

(1) Grid: 3 bits

The value for Grid is set to 1 for the ITU-T DWDM grid as defined in [G.694.1].

Grid	Value
Reserved	0
ITU-T DWDM	1
ITU-T CWDM	2
Future use	3 - 7

(2) C.S. (channel spacing): 4 bits

DWDM channel spacing is defined as follows.

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

(3) Identifier: 9 bits

The Identifier field in lambda label format is used to distinguish different lasers (in one node) when they can transmit the same frequency lambda. The Identifier field is a per-node assigned and scoped value. This field MAY change on a per-hop basis. In all cases but one, a node MAY select any value, including zero (0), for this field. Once selected, the value MUST NOT change until the LSP is torn down, and the value MUST be used in all LSP-related messages, e.g., in Resv messages and label Record Route Object (RRO) subobjects. The sole special case occurs when this label format is used in a label Explicit Route Object (ERO) subobject. In this case, the special value of zero (0) means that the referenced node MAY assign any Identifier field value, including zero (0), when establishing the corresponding LSP. When a non-zero value is assigned to the Identifier field in a label ERO subobject, the referenced node MUST use the assigned value for the Identifier field in the corresponding LSP-related messages.

(4) n: 16 bits

n is a two's-complement integer to take either a positive, negative, or zero value. This value is used to compute the frequency as shown above.

3.3. CWDM Wavelength Label

For the case of lambda switching of CWDM, the information carried in a wavelength label is:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid | C.S.  |    Identifier   |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

The structure of the label in the case of CWDM is the same as that of the DWDM case.

(1) Grid: 3 bits

The value for Grid is set to 2 for the ITU-T CWDM grid as defined in [G.694.2].

Grid	Value
Reserved	0
ITU-T DWDM	1
ITU-T CWDM	2
Future use	3 - 7

(2) C.S. (channel spacing): 4 bits

CWDM channel spacing is defined as follows.

C.S. (nm)	Value
Reserved	0
20	1
Future use	2 - 15

(3) Identifier: 9 bits

The Identifier field in lambda label format is used to distinguish different lasers (in one node) when they can transmit the same frequency lambda. The Identifier field is a per-node assigned and scoped value. This field MAY change on a per-hop basis. In all cases but one, a node MAY select any value, including zero (0), for this field. Once selected, the value MUST NOT change until the LSP

is torn down, and the value MUST be used in all LSP-related messages, e.g., in Resv messages and label RRO subobjects. The sole special case occurs when this label format is used in a label ERO subobject. In this case, the special value of zero (0) means that the referenced node MAY assign any Identifier field value, including zero (0), when establishing the corresponding LSP. When a non-zero value is assigned to the Identifier field in a label ERO subobject, the referenced node MUST use the assigned value for the Identifier field in the corresponding LSP-related messages.

(4) n: 16 bits

n is a two's-complement integer. This value is used to compute the wavelength as shown above.

4. Security Considerations

This document introduces no new security considerations to [RFC3471] and [RFC3473]. For a general discussion on MPLS and GMPLS-related security issues, see the MPLS/GMPLS security framework [RFC5920].

5. IANA Considerations

IANA maintains the "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry. IANA has added three new subregistries to track the codepoints (Grid and C.S.) used in the DWDM and CWDM wavelength labels, which are described in the following sections.

5.1. Grid Subregistry

Initial entries in this subregistry are as follows:

Value	Grid	Reference
0	Reserved	[RFC6205]
1	ITU-T DWDM	[RFC6205]
2	ITU-T CWDM	[RFC6205]
3-7	Unassigned	[RFC6205]

New values are assigned according to Standards Action.

5.2. DWDM Channel Spacing Subregistry

Initial entries in this subregistry are as follows:

Value	Channel Spacing (GHz)	Reference
0	Reserved	[RFC6205]
1	100	[RFC6205]
2	50	[RFC6205]
3	25	[RFC6205]
4	12.5	[RFC6205]
5-15	Unassigned	[RFC6205]

New values are assigned according to Standards Action.

5.3. CWDM Channel Spacing Subregistry

Initial entries in this subregistry are as follows:

Value	Channel Spacing (nm)	Reference
0	Reserved	[RFC6205]
1	20	[RFC6205]
2-15	Unassigned	[RFC6205]

New values are assigned according to Standards Action.

6. Acknowledgments

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7. References

7.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC3471] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description", RFC 3471, January 2003.

[RFC3473] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Extensions", RFC 3473, January 2003.

[RFC3945] Mannie, E., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Architecture", RFC 3945, October 2004.

7.2. Informative References

[G.694.1] ITU-T Recommendation G.694.1, "Spectral grids for WDM applications: DWDM frequency grid", June 2002.

[G.694.2] ITU-T Recommendation G.694.2, "Spectral grids for WDM applications: CWDM wavelength grid", December 2003.

[RFC5920] Fang, L., Ed., "Security Framework for MPLS and GMPLS Networks", RFC 5920, July 2010.

Appendix A. DWDM Example

Considering the network displayed in Figure 1, it is possible to show an example of LSP setup using the lambda labels.

Node 1 receives the request for establishing an LSP from itself to Node 9. The ITU-T grid to be used is the DWDM one, the channel spacing is 50 Ghz, and the wavelength to be used is 193,35 THz.

Node 1 signals the LSP via a Path message including a wavelength label structured as defined in Section 3.2:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid |  C.S. |   Identifier    |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Where:

Grid = 1 : ITU-T DWDM grid

C.S. = 2 : 50 GHz channel spacing

n   = 5 :

Frequency (THz) = 193.1 THz + n * channel spacing (THz)

193.35 (THz) = 193.1 (THz) + n* 0.05 (THz)

n = (193.35-193.1)/0.05 = 5

Appendix B. CWDM Example

The network displayed in Figure 1 can also be used to display an example of signaling using the wavelength label in a CWDM environment.

This time, the signaling of an LSP from Node 4 to Node 7 is considered. Such LSP exploits the CWDM ITU-T grid with a 20 nm channel spacing and is established using a wavelength equal to 1331 nm.

Node 4 signals the LSP via a Path message including a wavelength label structured as defined in Section 3.3:

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid |  C.S. |    Identifier     |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Where:

Grid = 2 : ITU-T CWDM grid

C.S. = 1 : 20 nm channel spacing

n = -7 :

Wavelength (nm) = 1471 nm + n * 20 nm

1331 (nm) = 1471 (nm) + n * 20 nm

n = (1331-1471)/20 = -7

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