            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.

Status of This Memo

   This is an Internet Standards Track document.

   This document is a product of the Internet Engineering Task Force
   (IETF). It represents the consensus of the IETF community. It has
   received public review and has been approved for publication by the
   Internet Engineering Steering Group (IESG). Further information on
   Internet Standards is available in Section 2 of RFC 5741.

   Information about the current status of this document, any errata,
   and how to provide feedback on it may be obtained at
   http://www.rfc-editor.org/info/rfc6205.

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
                                  |
```
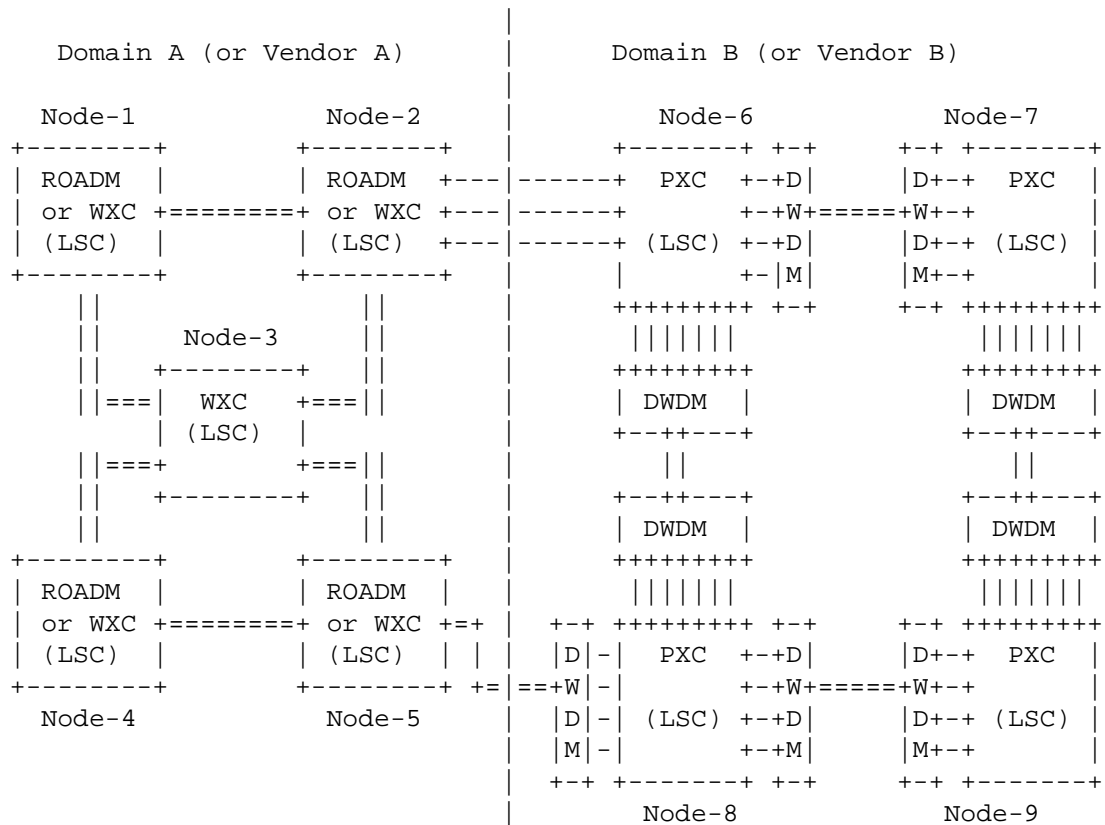
        Figure 1. Wavelength-Based Network Model
```
```

```
+--------------------------------------------------------------+
|          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 |=====            |
|          |   |                  |       |   |                |
|          +---+                  |       +---+                |
+--------------------------------------------------------------+
```
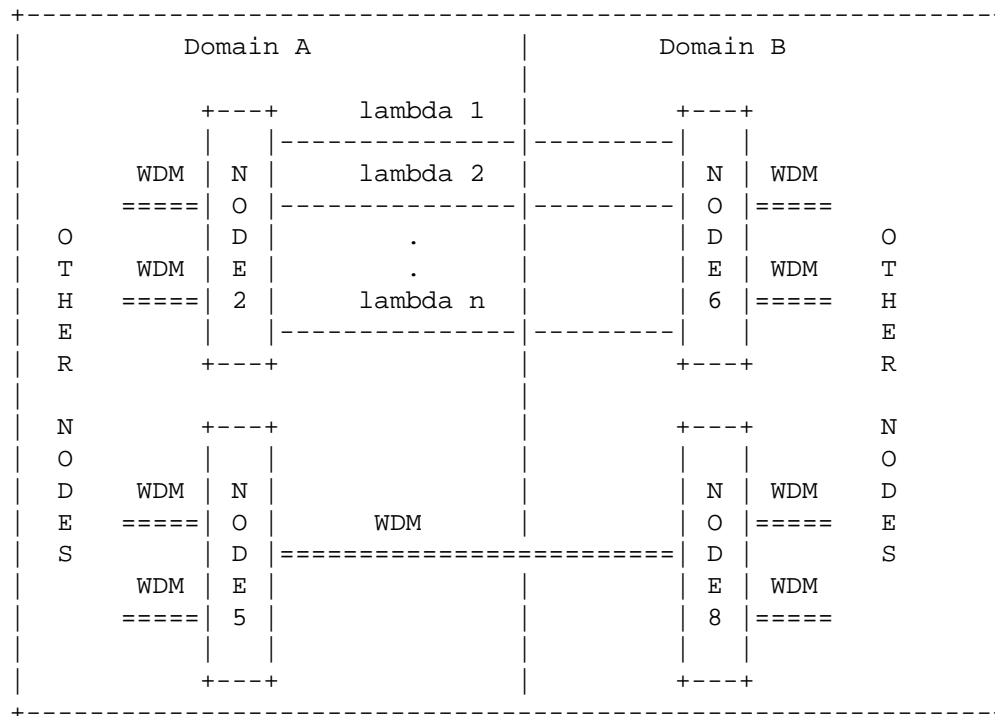
        Figure 2. Interconnecting Details between Two Domains

   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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   comments.

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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