           Generalized Labels for Lambda-Switching Capable Label Switching
                                  Routers

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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. However, [RFC3471]
   has defined that a wavelength label (section 3.2.1.1) "only has
   significance between two neighbors" and global wavelength continuity
   is not considered. In order to achieve interoperability in a network
   composed of next generation lambda switch-capable equipment, this
   document defines a standard lambda label format, being compliant
   with either [G.694.1](DWDM-grid) or [G.694.2](CWDM-grid). Moreover
   some consideration on how to ensure lambda continuity with RSVP-TE
   is provided. This document is a companion to the Generalized Multi-
   Protocol Label Switching (GMPLS) signaling. It defines the label
   format when Lambda Switching is requested in an all optical network.

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].

Table of Contents

1. Introduction

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

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    o Layer-2 Switch Capable (L2SC)

    o Time-Division Multiplex (TDM)

    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 a new generation of Lambda Switch Capable (LSC) equipment.
Technologies such as Reconfigurable Optical Add/Drop Multiplex (ROADM)
and Wavelength Cross-Connect (WXC) operate at the wavelength
switching level. As such, the wavelength is important information
that is necessary to set up a wavelength-based LSP appropriately and
the wavelength defined in [G.694.1] or [G.694.2] is widely utilized.

2. Assumed network model and related problem statement

Figure 1 depicts an all-optically switched network consisting of
different vendor's optical network domains. Vendor A's network
consists of ROADM or WXC, and vendor B's network consists of number
of photonic cross-connect (PXC) and Dense wavelength division
multiplexing (DWDM) multiplexer & demultiplexer, 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 LSP. It is also an
important constraint when conducting CSPF calculation for RSVP-TE
signaling. The way the Constrained Shortest Path First (CSPF) is
performed is outside the scope of this document.

It is needless to say, a 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 in detail the interconnection between Domain A
and Domain B.

```
                                    |
      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
```
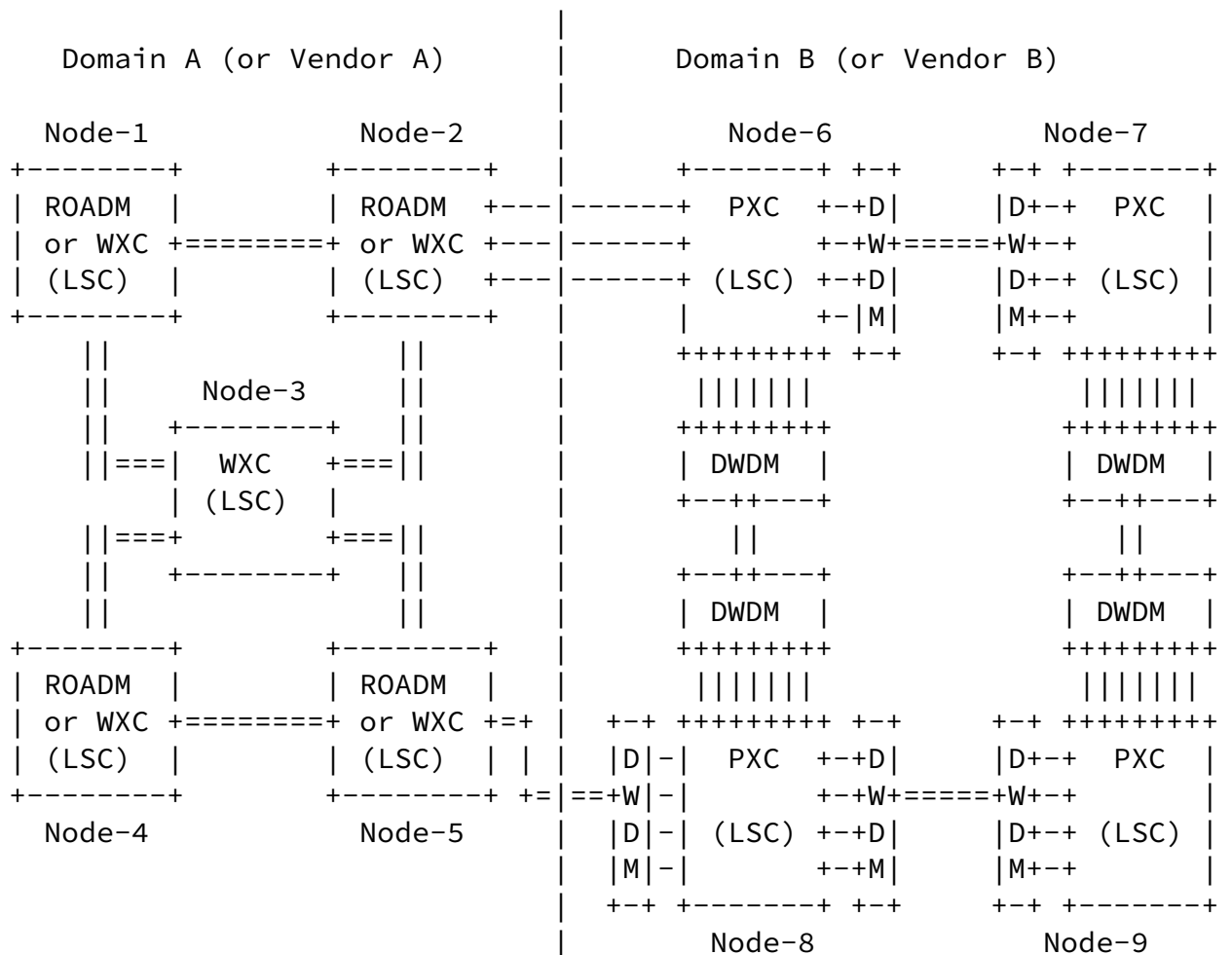
        Figure 1 Wavelength-based network model

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```
+---------------------------------------------------------------+
|          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 |=====             |
|          |   |                 |        |   |                |
|          +---+                 |        +---+                |
+---------------------------------------------------------------+
```
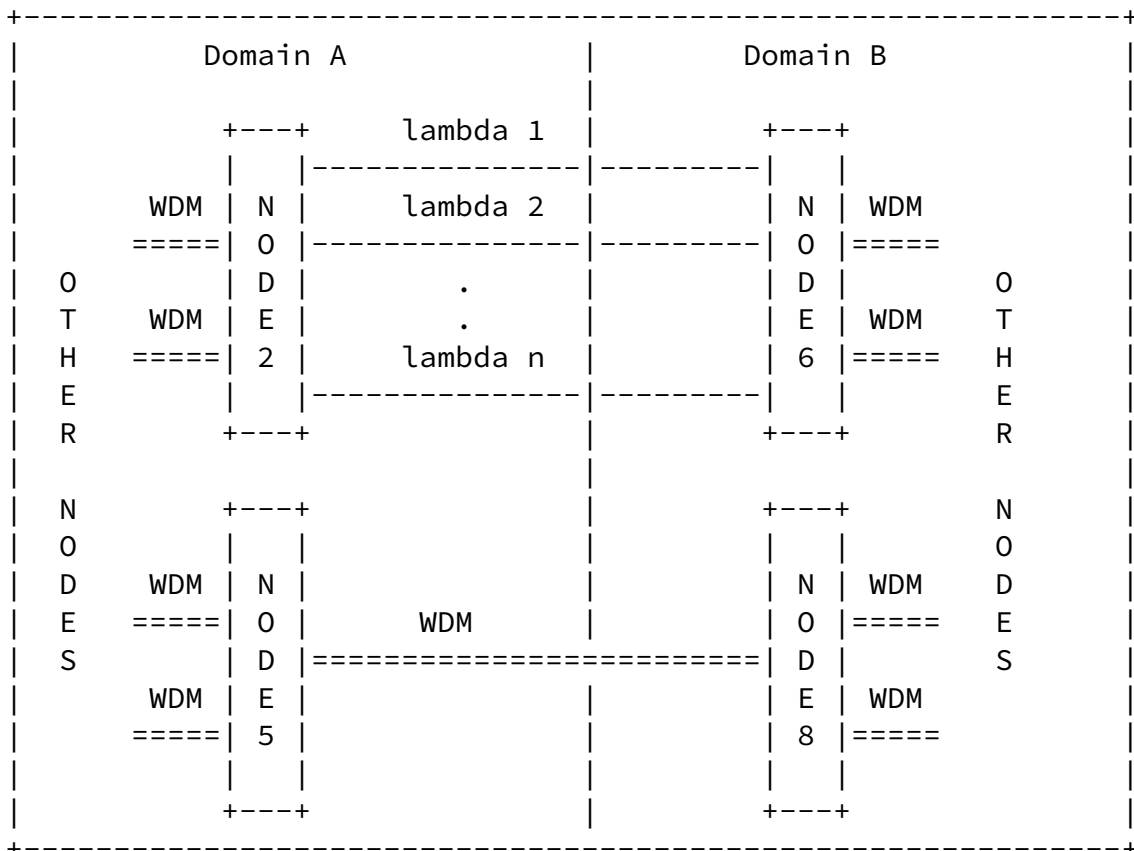
       Figure 2 Interconnecting details between two domains

    In the scenario of Figure 1, consider the setting up of a
    bidirectional LSP from ingress switch 1 to egress switch 9. In order

to satisfy wavelength continuity constraint, a fixed wavelength
(lambda 1) needs to be used in domain A and domain B. A Path message
will be used for the signaling, the PATH message must contain the
upstream label and a label set object; both containing the same
lambda. The label set object is made by only one sub channel that
must be same as the upstream label. The path setup will continue
downstream to switch 9 by configuring each lambda switch based on the
wavelength label. This label allows the correct switching of lambda
switches and the label contents needs to be used over the inter-
domain. As same above, the path setup will continue downstream to
switch 9 by configuring lambda switch based on multiple wavelength
labels. If the node has a tunable wavelength transponder, the tuning
wavelength is considered as a part of 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 and 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. As identical wavelength information, the ITU-T
frequency grid specified in [G.694.1] for Dense WDM (DWDM) and
wavelength information in [G.694.2] for Coarse WDM (CWDM) are used by
LSRs and should be followed as a wavelength label.

3. Label Related Formats

To deal with the widening scope of MPLS into the optical and time
domains, several new forms of "label" have been defined in [RFC3471].
This section contains clarifications for the Wavelength label based
on [G.694.1] or [G.694.2] and Label Set definition specific for LSC
LSRs.

3.1. Wavelength Labels

In section 3.2.1.1 of [RFC3471], a Wavelength label is defined to
have significance between two neighbors, and the receiver may need to
convert the received value into a value that has local significance.

LSC equipment uses multiple wavelengths controlled by a single

control channel. In such case, the label indicates the wavelength to
be used for the LSP. This document proposes to standardize the
wavelength label. As an example of wavelength values, the reader is
referred to [G.694.1] which lists the frequencies from the ITU-T DWDM
frequency grid. The same can be done for CWDM technology by using
the wavelength defined in [G.694.2]. In that sense, we can call
wavelength labels.

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 the other example of the case of the ITU-T CWDM grid, the spacing
between different channels was defined to be 20nm, so we need to pass
the wavelength value in nm in this case. Examples of CWDM wavelengths
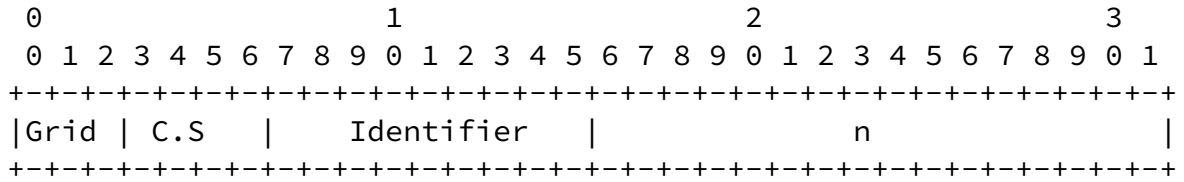are 1471, 1491, etc. nm.

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 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 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 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.

(4) n: 16 bits

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

3.3. CWDM Wavelength Label

For the case of CWDM, the information carried in a Wavelength label
is:

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```
     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
DWDM case.

(1) Grid: 3 bits

The value for grid is set to 2 for 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 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.

(4) n: 16 bits

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

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
as above needs to be defined.

4. Security Considerations

This document introduces no new security considerations to [RFC3473].
GMPLS security is described in section 11 of [RFC3471] and refers to
[RFC3209] for RSVP-TE.

5. IANA Considerations

This document has no actions for IANA.

6. Acknowledgments

The authors would like to thank Adrian Farrel, Lou Berger, Lawrence
Mao, Zafar Ali and Daniele Ceccarelli for the discussion and their
comments.

7. References

7.1. Normative References

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          Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC3209] Awduche, D., Berger, L., Gan, D., Li, T., Srinivasan, V.,
          and G. Swallow, "RSVP-TE: Extensions to RSVP for LSP
          Tunnels", RFC 3209, December 2001.

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

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

   [RFC3945] Mannie, E., Ed., "Generalized Multiprotocol 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.

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9. Appendix A. DWDM Example

   Considering the network displayed in figure 1 it is possible to show
   an example of LSP set up 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 50Ghz 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 4.2:


```
 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   |R|  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

10. Appendix B. CWDM Example

   The network displayed in figure 1 can be used also 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 20nm channel spacing and
   is to established using wavelength equal to 1331 nm.

Node 4 signals the LSP via a Path message including a Wavelength
Label structured as defined in section 4.3:

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```
 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   |R|  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