                    Generalized Labels for the Flexi-Grid in
              Lambda Switch Capable (LSC) Label Switching Routers

Abstract

   GMPLS supports the description of optical switching by identifying
   entries in fixed lists of switchable wavelengths (called grids)
   through the encoding of lambda labels. Work within the ITU-T Study
   Group 15 has defined a finer-granularity grid, and the facility to
   flexibly select different widths of spectrum from the grid. This
   document defines a new GMPLS lambda label format to support this
   flexi-grid.

   This document updates RFCs 3471 and 6205 by introducing a new label
   format.

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.

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1. Introduction

   As described in [RFC3945], GMPLS extends MPLS from supporting only
   Packet Switch Capable (PSC) interfaces and switching, to also support
   four new classes of interfaces and switching that include Lambda
   Switch Capable (LSC).

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

   Section 3.2.1.1 of [RFC3471] states that wavelength labels "only have
   significance between two neighbors": global wavelength semantics are
   not considered. [RFC6205] defines a standard lambda label format
   that has a global semantic and 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]. The terms
   DWDM and CWDM are defined in [G.671].

   A flexible-grid network selects its data channels as arbitrarily
   assigned pieces of the spectrum. Mixed bitrate transmission systems
   can allocate their channels with different spectral bandwidths so
   that the channels can be optimized for the bandwidth requirements of
   the particular bit rate and modulation scheme of the individual
   channels. This technique is regarded as a promising way to improve
   the network utilization efficiency and fundamentally reduce the cost
   of the core network.

   The "flexi-grid" has been developed within the ITU-T Study Group 15
   to allow selection and switching of pieces of the optical spectrum
   chosen flexibly from a fine-granularity grid of wavelengths with
   variable spectral bandwidth [G.694.1].

   [RFC3471] defines several basic label types including the lambda
   label. Section 3.2.1.1 of [RFC3471] states that wavelength labels
   "only have significance between two neighbors"; global wavelength
   semantics are not considered. In order to facilitate
   interoperability in a network composed of LSC equipment, [RFC6205]
   defines a standard lambda label format and is designated an update of
   RFC 3471.

   This document continues the theme of defining global semantics for
   the wavelength label by adding support for the flexi-grid. Thus,
   this document updates [RFC6205] and [RFC3471].

   This document relies on [G.694.1] for the definition of the optical
   data plane and does not make any updates to the work of the ITU-T.

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. Overview of Flexi-Grid

   [G.694.1] defines DWDM fixed grids. The latest version of that
   document extends the DWDM fixed grids to add support for flexible
   grids. The basis of the work is to allow a data channel to be formed
   from an abstract grid anchored at 193.1 THz and selected on a channel
   spacing of 6.25 GHz with a variable slot width measured in units of
   12.5 GHz. Individual allocations may be made on this basis from
   anywhere in the spectrum, subject to allocations not overlapping.

   [G.694.1] provides clear guidance on the support of flexible grid by
   implementations in Section 2 of Appendix I:

      The flexible DWDM grid defined in clause 7 has a nominal central
      frequency granularity of 6.25 GHz and a slot width granularity of
      12.5 GHz. However, devices or applications that make use of the
      flexible grid may not have to be capable of supporting every
      possible slot width or position. In other words, applications may
      be defined where only a subset of the possible slot widths and
      positions are required to be supported.

      For example, an application could be defined where the nominal
      central frequency granularity is 12.5 GHz (by only requiring
      values of n that are even) and that only requires slot widths as a
      multiple of 25 GHz (by only requiring values of m that are even).

   Some additional background on the use of GMPLS for flexible grids can
   be found in [RFC7698].

2.1. Composite Labels

   It is possible to construct an end-to-end connection as a composite
   of more than one flexi-grid slot. The mechanism used in GMPLS is
   similar to that used to support inverse multiplexing familiar in
   time-division multiplexing (TDM) and optical transport networks
   (OTNs). The slots in the set could potentially be contiguous or non-
   contiguous (only as allowed by the definitions of the data plane) and
   could be signaled as a single LSP or constructed from a group of
   LSPs. For more details, refer to Section 4.3.

   How the signal is carried across such groups of channels is out of
   scope for this document.

3. Fixed-Grid Lambda Label Encoding

   [RFC6205] defines an encoding for a global semantic for a DWDM label
   based on four fields:

   - Grid: used to select which grid the lambda is selected from.
      Values defined in [RFC6205] identify DWDM [G.694.1] and CWDM
      [G.694.2].

   - C.S. (Channel Spacing): used to indicate the channel spacing.
      [RFC6205] defines values to represent spacing of 100, 50, 25, and
      12.5 GHz.

   - Identifier: a local-scoped integer used to distinguish different
      lasers (in one node) when they can transmit the same frequency
      lambda.

   - n: a two's-complement integer to take a positive, negative, or
      zero value. This value is used to compute the frequency as
      defined in [RFC6205] and based on [G.694.1]. The use of n is
      repeated here for ease of reading the rest of this document: in
      case of discrepancy, the definition in [RFC6205] is normative.

         Frequency (THz) = 193.1 THz + n * frequency granularity (THz)

      where the nominal central frequency granularity for the flexible
      grid is 0.00625 THz

4. Flexi-Grid Label Format and Values

4.1 Flexi-Grid Label Encoding

   This document defines a generalized label encoding for use in flexi-
   grid systems. As with the other GMPLS lambda label formats defined
   in [RFC3471] and [RFC6205], the use of this label format is known a
   priori. That is, since the interpretation of all lambda labels is
   determined hop by hop, the use of this label format requires that all
   nodes on the path expect to use this label format.

   For convenience, however, the label format is modeled on the fixed-
   grid label defined in [RFC6205] and briefly described in Section 3.

   Figure 1 shows the format of the Flexi-Grid Label. It is a 64-bit
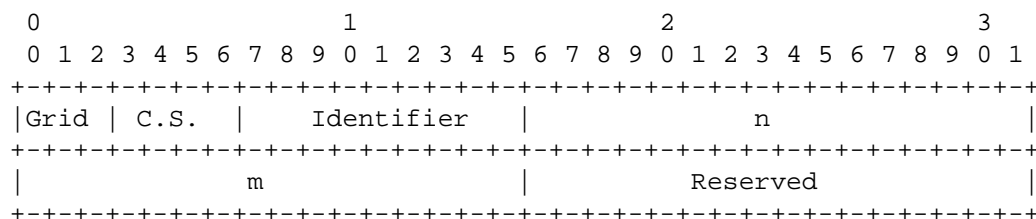   label.

```
 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                 |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             m                 |           Reserved            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

              Figure 1 : The Flexi-Grid Label Encoding

   This document defines a new Grid value to supplement those in
   [RFC6205]:

```
+----------+---------+
|   Grid   |  Value  |
+----------+---------+
|ITU-T Flex|    3    |
+----------+---------+
```

   Within the fixed-grid network, the C.S. value is used to represent
   the channel spacing, as the spacing between adjacent channels is
   constant. For the flexible-grid situation, this field is used to
   represent the nominal central frequency granularity.

   This document defines a new C.S. value to supplement those in
   [RFC6205]:

```
+------------+---------+
| C.S. (GHz) |  Value  |
+------------+---------+
|    6.25    |    5    |
+------------+---------+
```

   The meaning of the Identifier field is maintained from [RFC6205] (see
   also Section 3).

   The meaning of n is maintained from [RFC6205] (see also Section 3).

   The m field is used to identify the slot width according to the
   formula given in [G.694.1] as follows. It is a 16-bit integer value
   encoded in line format.

        Slot Width (GHz) = 12.5 GHz * m

   The Reserved field MUST be set to zero on transmission and SHOULD be
   ignored on receipt.

An implementation that wishes to use the flexi-grid label encoding
MUST follow the procedures of [RFC3473] and of [RFC3471] as updated
by [RFC6205]. It MUST set Grid to 3 and C.S. to 5. It MUST set
Identifier to indicate the local identifier of the laser in use as
described in [RFC6205]. It MUST also set n according to the formula
in Section 3 (inherited unchanged from [RFC6205]). Finally, the
implementation MUST set m as described in the formula stated above.

4.2. Considerations of Bandwidth

There is some overlap between the concepts of bandwidth and label in
many GMPLS-based systems where a label indicates a physical switching
resource. This overlap is increased in a flexi-grid system where a
label value indicates the slot width and so affects the bandwidth
supported by an LSP. Thus, the m parameter is both a property of the
label (i.e., it helps define exactly what is switched) and of the
bandwidth.

In GMPLS signaling [RFC3473], bandwidth is requested in the
SENDER_TSPEC object and confirmed in the FLOWSPEC object. The m
parameter, which is a parameter of the GMPLS flexi-grid label as
described above, is also a parameter of the flexi-grid Tspec and
Flowspec as described in [FLEXRSVP].

4.3. Composite Labels

The creation of a composite of multiple channels to support inverse
multiplexing is already supported in GMPLS for TDM and OTN (see
[RFC4606], [RFC6344], and [RFC7139]). The mechanism used for flexi-
grid is similar.

To signal an LSP that uses multiple flexi-grid slots, a "compound
label" is constructed. That is, the LABEL object is constructed from
a concatenation of the 64-bit Flexi-Grid Labels shown in Figure 1.
The number of elements in the label can be determined from the length
of the LABEL object. The resulting LABEL object is shown in Figure 2
including the object header that is not normally shown in
diagrammatic representations of RSVP-TE objects. Note that r is the
count of component labels, and this is backward compatible with the
label shown in Figure 1 where the value of r is 1.

The component labels MUST be presented in increasing order of the
value n. Implementations MUST NOT infer anything about the encoding
of a signal into the set of slots represented by a compound label
from the label itself. Information about the encoding MAY be handled
in other fields in signaling messages or through an out-of-band
system, but such considerations are outside the scope of this
document.

```
 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
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|   Object Length (4 + 8r)      | Class-Num (16)|  C-Type (2)   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid | C.S. |    Identifier    |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             m                 |            Reserved           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
~                                                               ~
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Grid | C.S. |    Identifier    |              n                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|             m                 |            Reserved           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```
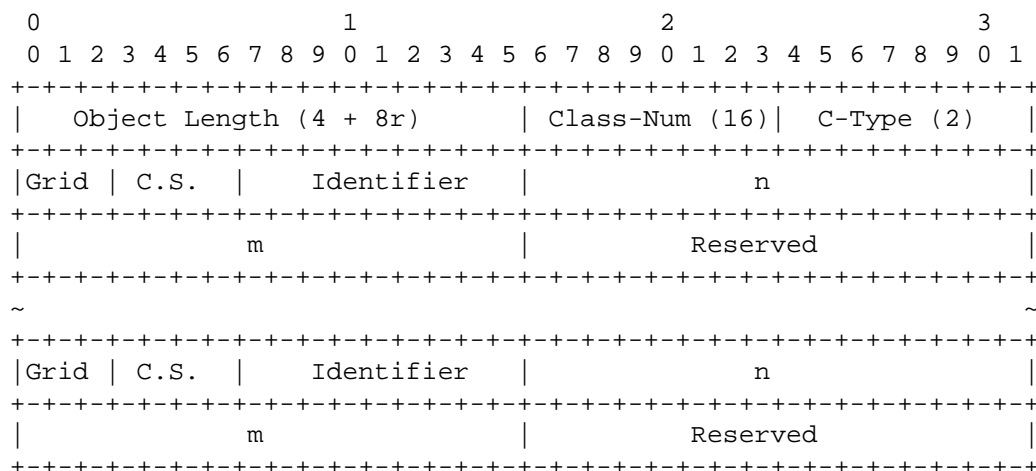
       Figure 2 : A Compound Label for Virtual Concatenation

   Note that specific rules must be applied as follows:

   - Grid MUST show "ITU-T Flex" value 3 in each component label.
   - C.S. MUST have the same value in each component label.
   - Identifier in each component label may identify different physical
      equipment.
   - Values of n and m in each component label define the slots that
      are concatenated.

   At the time of writing, [G.694.1] only supports only groupings of
   adjacent slots (i.e., without intervening unused slots that could be
   used for other purposes) of identical width (same value of m), and
   the component slots must be in increasing order of frequency (i.e.,
   increasing order of the value n). The mechanism defined here MUST
   NOT be used for other forms of grouping unless and until those forms
   are defined and documented in Recommendations published by the ITU-T.

   Note further that while the mechanism described here naturally means
   that all component channels are corouted, a composite channel can
   also be achieved by constructing individual LSPs from single flexi-
   grid slots and managing those LSPs as a group. A mechanism for
   achieving this for TDM is described in [RFC6344], but is out of scope
   for discussion in this document because the labels used are normal,
   single-slot labels and require no additional definitions.

5. Manageability and Backward Compatibility Considerations

   This section briefly considers issues of manageability and backward
   compatibility.

5.1. Control-Plane Backward Compatibility

   Labels are carried in two ways in GMPLS: for immediate use on the
   next hop and for use at remote hops.

   It is an assumption of GMPLS that both ends of a link know what label
   types are supported and only use appropriate label types. If a label
   of an unknown type is received, it will be processed as if it was of
   a known type since the Label Object and similar label-carrying
   objects do not contain a type identifier. Thus, the introduction of
   a flexi-grid label in this document does not change the compatibility
   issues, and a legacy node that does not support the new flexi-grid
   label should not expect to receive or handle such labels. If one is
   incorrectly used in communication with a legacy node, it will attempt
   to process it as an expected label type with a potentially poor
   outcome.

   It is possible that a GMPLS message transiting a legacy node will
   contain a flexi-grid label destined for or reported by a remote node.
   For example, an LSP that transits links of different technologies
   might record flexi-grid labels in a Record Route Object that is
   subsequently passed to a legacy node. Such labels will not have any
   impact on legacy implementations except as noted in the manageability
   considerations in the next section.

5.2. Manageability Considerations

   This document introduces no new elements for management. That is,
   labels can continue to be used in the same way by the GMPLS protocols
   and where those labels were treated as opaque quantities with local
   or global significance, no change is needed to the management
   systems.

   However, this document introduces some changes to the nature of a
   label that may require changes to management systems. Although
   Section 3.2 of [RFC3471] makes clear that a label is of variable
   length according to the type and that the type is supposed to be
   known a priori by both ends of a link, a management system is not
   guaranteed to be updated in step with upgrades or installations of
   new flexi-grid functionality in the network.

But, an implementation expecting a 32-bit lambda label would not fail
ungracefully because the first 32 bits follow the format of
[RFC6205]. It would look at theses labels and read but not recognize
the new grid type value. It would then give up trying to parse the
label and (presumably) the whole of the rest of the message.

The management system can be upgraded in two steps:

- Firstly, systems that handle lambda labels as 32-bit quantities
   need to be updated to handle the increased length (64 bits) of
   labels as described in this document. These "unknown" 64-bit
   labels could be displayed as opaque 64-bit quantities and still
   add a lot of value for the operator (who might need to parse the
   label by hand). However, an implementation that already supports
   lambda labels as defined in [RFC6205] can safely continue to
   process the first 32 bits and display the fields defined in RFC
   6205 as before, leaving just the second 32 bits as opaque data.

- Second, a more sophisticated upgrade to a management system would
   fully parse the flexi-grid labels and display them field by field
   as described in this document.

6. Security Considerations

   [RFC6205] notes that the definition of a new label encoding does not
   introduce any new security considerations to [RFC3471] or [RFC3473].
   That statement applies equally to this document.

   For a general discussion on MPLS and GMPLS-related security issues,
   see the MPLS/GMPLS security framework [RFC5920].

7. IANA Considerations

   IANA maintains the "Generalized Multi-Protocol Label Switching
   (GMPLS) Signaling Parameters" registry that contains several
   subregistries.

7.1. Grid Subregistry

   IANA has allocated a new entry in this subregistry as follows:

   Value   Grid   Reference
   -----   ------------------------   ----------
     3   ITU-T Flex   RFC 7699

7.2. DWDM Channel Spacing Subregistry

   IANA has allocated a new entry in this subregistry as follows:

   Value   Channel Spacing (GHz)   Reference
   -----   ------------------------   ----------
     5   6.25   RFC 7699

8. References

8.1. Normative References

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Appendix A. Flexi-Grid Example

   Consider a fragment of an optical LSP between node A and node B using
   the flexible grid. Suppose that the LSP on this hop is formed:

   - using the ITU-T Flexi-Grid
   - the nominal central frequency of the slot is 193.05 THz
   - the nominal central frequency granularity is 6.25 GHz
   - the slot width is 50 GHz.

   In this case, the label representing the switchable quantity that is
   the flexi-grid quantity is encoded as described in Section 4.1 with
   the following parameter settings. The label can be used in signaling
   or in management protocols to describe the LSP.

      Grid = 3 : ITU-T Flexi-Grid

      C.S. = 5 : 6.25 GHz nominal central frequency granularity

      Identifier = local value indicating the laser in use

      n = -8 :

          Frequency (THz) = 193.1 THz + n * frequency granularity (THz)

          193.05 (THz) = 193.1 (THz) + n * 0.00625 (THz)

          n = (193.05 - 193.1) / 0.00625 = -8

      m = 4 :

          Slot Width (GHz) = 12.5 GHz * m

          50 (GHz) = 12.5 (GHz) * m

          m = 50 / 12.5 = 4

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