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

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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 RFC 3471 and RFC 6205 by introducing a new label format.

Status of this Memo

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1. Introduction

As described in [RFC3945], GMPLS extends MPLS from supporting only Packet Switching 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 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]. 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]. This document updates the definition of GMPLS lambda labels provided in [RFC6205] to support the flexi-grid.

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 in that regard.

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 [FLEXFWRK].

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 (OTN). 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 lne 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 TSpec object and confirmed in the Flowspec object. The 'm' parameter that

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 [RFC4606], [RFC6344], [RFC7139]. The mechanism used for flexigrid 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 order of 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 out of 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 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. Firstly, systems that handle lambda labels as 32 bit quantities need to be updated to process the 64 bit labels described in this document even if the labels are treated as opaque quantities. Furthermore, although management systems that can handle lambda labels as defined in [RFC6205] can continue to process the fields defined in RFC 6205 as before, they have to handle new legal values of some of those fields (Grid = 3 and C.S. = 5), and they have to be aware of the new 'm' field.

6. Implementation Status

[RFC Editor Note: Please remove this entire seciton prior to publication as an RFC.]

This section records the status of known implementations of the protocol defined by this specification at the time of posting of this Internet-Draft, and is based on a proposal described in RFC 6982 [RFC6982]. The description of implementations in this section is intended to assist the IETF in its decision processes in progressing drafts to RFCs. Please note that the listing of any individual implementation here does not imply endorsement by the IETF. Furthermore, no effort has been spent to verify the information presented here that was supplied by IETF contributors. This is not intended as, and must not be construed to be, a catalog of available implementations or their features. Readers are advised to note that other implementations may exist.

According to RFC 6982, "this will allow reviewers and working groups to assign due consideration to documents that have the benefit of running code, which may serve as evidence of valuable experimentation and feedback that have made the implemented protocols more mature. It is up to the individual working groups to use this information as they see fit."

6.1. Centre Tecnologic de Telecomunicacions de Catalunya (CTTC)

Organization Responsible for the Implementation:
Centre Tecnologic de Telecomunicacions de Catalunya (CTTC)
Optical Networks and Systems Department

Implementation Name and Details:
ADRENALINE testbed
http://networks.cttc.es/experimental-testbeds/

Brief Description:
Experimental testbed implementation of GMPLS/PCE control plane.

Level of Maturity:
Implemented as extensions to a mature GMLPS/PCE control plane. It is limited to research / prototyping stages but it has been used successfully for more than the last five years.

Coverage:
Support for the 64 bit label as described version 07 of this document.
This affects mainly the implementation of RSVP-TE and PCEP protocols:

- Generalized Label Support
- Suggested Label Support
- Upstream Label Support
- ERO Label Subobjects and Explicit Label Control

It is expected that this implementation will evolve to follow the evolution of this document.

Licensing:
Proprietary

Implementation Experience:
Implementation of this document reports no issues.
General implementation experience has been reported in a number of journal papers. Contact Ramon Casellas for more information or see http://networks.cttc.es/publications/?search=GMPLS&research_area=optical-networks-systems

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Interoperability:
No report.

7. Security Considerations

[RFC6205] notes that the definition of a new label encoding does not introduce any new security considerations to [RFC3471] and [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].

8. IANA Considerations

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

8.1. Grid Subregistry

IANA is requested to allocate a new entry in this subregistry as follows:

Value	Grid	Reference
3	ITU-T Flex	[This.I-D]

8.2. DWDM Channel Spacing Subregistry

IANA is requested to allocate a new entry in this subregistry as follows:

Value	Channel Spacing (GHz)	Reference
5	6.25	[This.I-D]

9. Acknowledgments

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Very many thanks to Lou Berger for discussions of labels of more than 32 bits. Many thanks to Sergio Belotti and Pietro Vittorio Grandi for their support of this work. Thanks to Gabriele Galimberti for discussion of the size of the "m" field, and to Iftekhar Hussain for discussion of composite labels.

Special thanks to the Vancouver 2012 Pool Party for discussions and rough consensus: Dieter Beller, Ramon Casellas, Daniele Ceccarelli, Oscar Gonzalez de Dios, Iftekhar Hussain, Cyril Margaria, Lyndon Ong, Fatai Zhang, and Adrian Farrel.

10. References

10.1. Normative References

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[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.

[RFC6205] Otani, T., and Li, D., "Generalized Labels for Lambda-Switch-Capable (LSC) Label Switching Routers", RFC 6205, October 2011.

[G.694.1] ITU-T Recommendation G.694.1 (revision 2), "Spectral grids for WDM applications: DWDM frequency grid", February 2012.

10.2. Informative References

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

[RFC4606] Mannie, E., and Papadimitriou, D., "Generalized Multi-Protocol Label Switching (GMPLS) Extensions for Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Control", RFC 4606, August 2006.

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[RFC6344] Bernstein, G., Caviglia, D., Rabbat, R., and van Helvoort, H., "Operating Virtual Concatenation (VCAT) and the Link Capacity Adjustment Scheme (LCAS) with Generalized Multi-Protocol Label Switching (GMPLS)", RFC 6344, August 2011.

[RFC6982] Sheffer, Y. and A. Farrel, "Improving Awareness of Running Code: The Implementation Status Section", RFC 6982, July 2013.
[RFC Editor Note: This reference can be removed when Section 6 is removed]

[RFC7139] Zhang, F., Zhang, G., Belotti, S., Ceccarelli, D., and Pithewan, K., "GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks", RFC 7139, March 2014.

[G.671] ITU-T Recommendation G.671, "Transmission characteristics of optical components and subsystems", 2009.

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

[FLEXFWRK] O. Gonzalez de Dios, et al., "Framework and Requirements for GMPLS based control of Flexi-grid DWDM networks", draft-ogrcetal-ccamp-flexi-grid-fwk, work in progress.

[FLEXRSVP] Zhang, F., Gonzalez de Dios, O., and D. Ceccarelli, "RSVP-TE Signaling Extensions in support of Flexible Grid", draft-zhang-ccamp-flexible-grid-rsvp-te-ext, work in progress.

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 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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