

Internet Engineering Task Force (IETF)  
Request for Comments: 7699  
Updates: 3471, 6205  
Category: Standards Track  
ISSN: 2070-1721

A. Farrel  
D. King  
Old Dog Consulting  
Y. Li  
Nanjing University  
F. Zhang  
Huawei Technologies  
November 2015

## 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.

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/rfc7699>.

## Copyright Notice

Copyright (c) 2015 IETF Trust and the persons identified as the document authors. All rights reserved.

This document is subject to BCP 78 and the IETF Trust's Legal Provisions Relating to IETF Documents (<http://trustee.ietf.org/license-info>) in effect on the date of publication of this document. Please review these documents carefully, as they describe your rights and restrictions with respect to this document. Code Components extracted from this document must include Simplified BSD License text as described in Section 4.e of the Trust Legal Provisions and are provided without warranty as described in the Simplified BSD License.

## Table of Contents

1. Introduction . . . . .	3
1.1. Conventions Used in This Document . . . . .	4
2. Overview of Flexi-Grid . . . . .	4
3. Fixed-Grid Lambda Label Encoding . . . . .	5
4. Flexi-Grid Label Format and Values . . . . .	5
4.1. Flexi-Grid Label Encoding . . . . .	5
4.2. Considerations of Bandwidth . . . . .	7
4.3. Composite Labels . . . . .	7
5. Manageability and Backward Compatibility Considerations . . . . .	9
5.1. Control-Plane Backward Compatibility . . . . .	9
5.2. Manageability Considerations . . . . .	9
6. Security Considerations . . . . .	10
7. IANA Considerations . . . . .	10
7.1. Grid Subregistry . . . . .	10
7.2. DWDM Channel Spacing Subregistry . . . . .	11
8. References . . . . .	11
8.1. Normative References . . . . .	11
8.2. Informative References . . . . .	11
Appendix A. Flexi-Grid Example . . . . .	13
Acknowledgments . . . . .	14
Contributors . . . . .	14
Authors' Addresses . . . . .	14

## 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.

$$\text{Frequency (THz)} = 193.1 \text{ THz} + n * \text{frequency granularity (THz)}$$

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

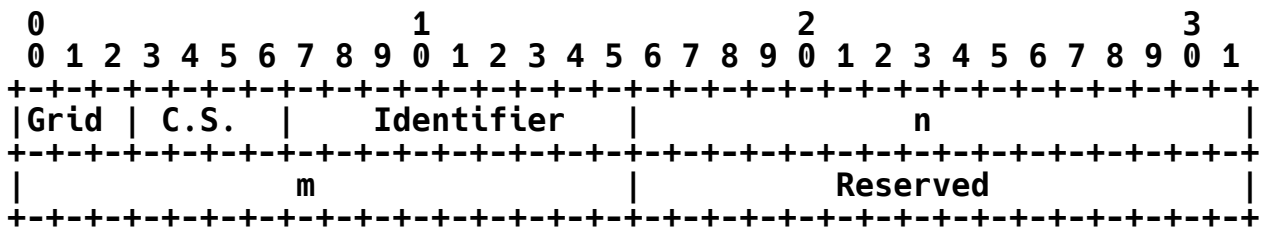
### 4. Flexi-Grid Label Format and Values

#### 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.



### 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.

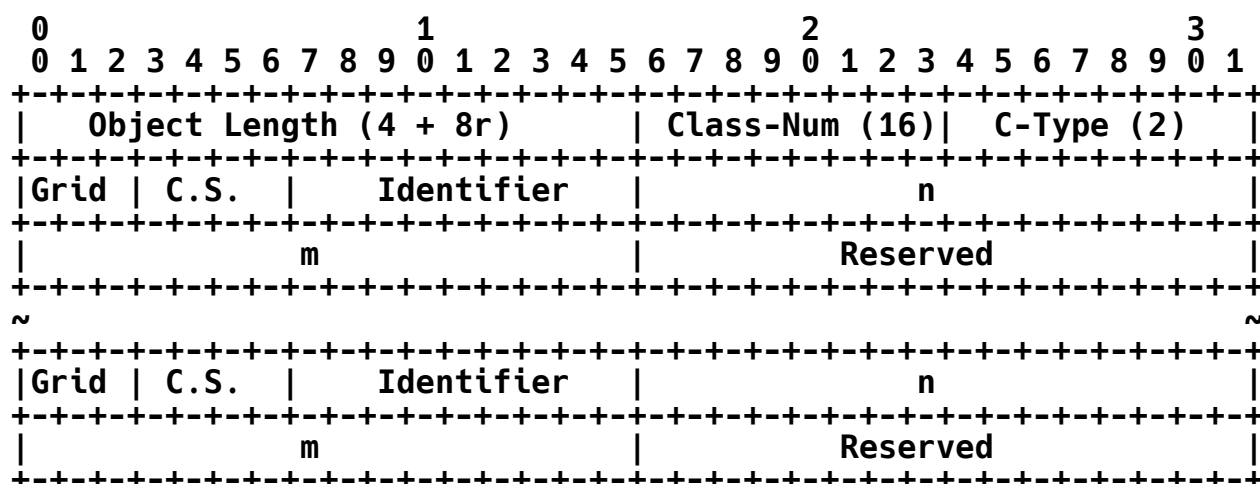


Figure 2 : A Compound Label for Virtual Concatenation

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 transitting 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 these 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

- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<http://www.rfc-editor.org/info/rfc2119>>.
- [RFC3471] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Functional Description", RFC 3471, DOI 10.17487/RFC3471, January 2003, <<http://www.rfc-editor.org/info/rfc3471>>.
- [RFC3473] Berger, L., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Resource ReserVation Protocol-Traffic Engineering (RSVP-TE) Extensions", RFC 3473, DOI 10.17487/RFC3473, January 2003, <<http://www.rfc-editor.org/info/rfc3473>>.
- [RFC6205] Otani, T., Ed., and D. Li, Ed., "Generalized Labels for Lambda-Switch-Capable (LSC) Label Switching Routers", RFC 6205, DOI 10.17487/RFC6205, March 2011, <<http://www.rfc-editor.org/info/rfc6205>>.
- [G.694.1] International Telecommunication Union, "Spectral grids for WDM applications: DWDM frequency grid", ITU-T Recommendation G.694.1, February 2012, <<https://www.itu.int/rec/T-REC-G.694.1/en>>.

### 8.2. Informative References

- [RFC3945] Mannie, E., Ed., "Generalized Multi-Protocol Label Switching (GMPLS) Architecture", RFC 3945, DOI 10.17487/RFC3945, October 2004, <<http://www.rfc-editor.org/info/rfc3945>>.

- [RFC4606] Mannie, E. and D. Papadimitriou, "Generalized Multi-Protocol Label Switching (GMPLS) Extensions for Synchronous Optical Network (SONET) and Synchronous Digital Hierarchy (SDH) Control", RFC 4606, DOI 10.17487/RFC4606, August 2006, <<http://www.rfc-editor.org/info/rfc4606>>.
- [RFC5920] Fang, L., Ed., "Security Framework for MPLS and GMPLS Networks", RFC 5920, DOI 10.17487/RFC5920, July 2010, <<http://www.rfc-editor.org/info/rfc5920>>.
- [RFC6344] Bernstein, G., Ed., Caviglia, D., Rabbat, R., and H. van Helvoort, "Operating Virtual Concatenation (VCAT) and the Link Capacity Adjustment Scheme (LCAS) with Generalized Multi-Protocol Label Switching (GMPLS)", RFC 6344, DOI 10.17487/RFC6344, August 2011, <<http://www.rfc-editor.org/info/rfc6344>>.
- [RFC7139] Zhang, F., Ed., Zhang, G., Belotti, S., Ceccarelli, D., and K. Pithewan, "GMPLS Signaling Extensions for Control of Evolving G.709 Optical Transport Networks", RFC 7139, DOI 10.17487/RFC7139, March 2014, <<http://www.rfc-editor.org/info/rfc7139>>.
- [RFC7698] Gonzalez de Dios, O., Ed., Casellas, R., Ed., Zhang, F., Fu, X., Ceccarelli, D., and I. Hussain, "Framework and Requirements for GMPLS-Based Control of Flexi-Grid Dense Wavelength Division Multiplexing (DWDM) Networks", RFC 7698, DOI 10.17487/RFC7698, November 2015, <<http://www.rfc-editor.org/info/rfc7698>>.
- [G.671] International Telecommunication Union, "Transmission characteristics of optical components and subsystems", ITU-T Recommendation G.671, February 2012, <<https://www.itu.int/rec/T-REC-G.671/en>>.
- [G.694.2] International Telecommunication Union, "Spectral grids for WDM applications: CWDM wavelength grid", ITU-T Recommendation G.694.2, December 2003, <<https://www.itu.int/rec/T-REC-G.694.2/en>>.
- [FLEXRSVP] Zhang, F., Zhang, X., Farrel, A., Gonzalez de Dios, O., and D. Ceccarelli, "RSVP-TE Signaling Extensions in support of Flexible Grid", Work in Progress, draft-ietf-ccamp-flexible-grid-rsvp-te-ext-03, August 2015.

## 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

## Acknowledgments

This work was supported in part by the FP-7 IDEALIST project under grant agreement number 317999.

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. Robert Sparks, Carlos Pignataro, and Paul Wouters provided review comments during IETF Last Call.

The Vancouver 2012 Pool Party drove early discussions and rough consensus. It comprised: Dieter Beller, Ramon Casellas, Daniele Ceccarelli, Oscar Gonzalez de Dios, Iftekhar Hussain, Cyril Margaria, Lyndon Ong, Fatai Zhang, and Adrian Farrel.

## Contributors

Zhang Fei  
Huawei Technologies  
Email: zhangfei7@huawei.com

Ramon Casellas  
CTTC  
Email: ramon.casellas@cttc.es

## Authors' Addresses

Adrian Farrel  
Old Dog Consulting  
Email: adrian@olddog.co.uk

Daniel King  
Old Dog Consulting  
Email: daniel@olddog.co.uk

Yao Li  
Nanjing University  
Email: wsliguotou@hotmail.com

Fatai Zhang  
Huawei Technologies  
Email: zhangfatai@huawei.com