

Internet Engineering Task Force (IETF)  
Request for Comments: 8363  
Category: Standards Track  
ISSN: 2070-1721

X. Zhang  
H. Zheng  
Huawei  
R. Casellas  
CTTC  
O. Gonzalez de Dios  
Telefonica  
D. Ceccarelli  
Ericsson  
May 2018

GMPLS OSPF-TE Extensions in Support of Flexi-Grid  
Dense Wavelength Division Multiplexing (DWDM) Networks

Abstract

The International Telecommunication Union Telecommunication standardization sector (ITU-T) has extended its Recommendations G.694.1 and G.872 to include a new Dense Wavelength Division Multiplexing (DWDM) grid by defining channel spacings, a set of nominal central frequencies, and the concept of the "frequency slot". Corresponding techniques for data-plane connections are known as "flexi-grid".

Based on the characteristics of flexi-grid defined in G.694.1 and in RFCs 7698 and 7699, this document describes the Open Shortest Path First - Traffic Engineering (OSPF-TE) extensions in support of GMPLS control of networks that include devices that use the new flexible optical grid.

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 7841.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at <https://www.rfc-editor.org/info/rfc8363>.

Copyright Notice

Copyright (c) 2018 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 (https://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
- 2. Terminology . . . . . 3
  - 2.1. Conventions Used in This Document . . . . . 4
- 3. Requirements for Flexi-Grid Routing . . . . . 4
  - 3.1. Available Frequency Ranges . . . . . 4
  - 3.2. Application Compliance Considerations . . . . . 5
  - 3.3. Comparison with Fixed-Grid DWDM Links . . . . . 6
- 4. Extensions . . . . . 7
  - 4.1. Interface Switching Capability Descriptor (ISCD) Extensions for Flexi-Grid . . . . . 7
    - 4.1.1. Switching Capability Specific Information (SCSI) . . . . . 8
    - 4.1.2. An SCSI Example . . . . . 10
  - 4.2. Extensions to the Port Label Restrictions Field . . . . . 11
- 5. IANA Considerations . . . . . 13
  - 5.1. New ISCD Switching Type . . . . . 13
  - 5.2. New SCSI Type . . . . . 13
- 6. Security Considerations . . . . . 13
- 7. References . . . . . 14
  - 7.1. Normative References . . . . . 14
  - 7.2. Informative References . . . . . 15
- Acknowledgments . . . . . 16
- Contributors . . . . . 16
- Authors' Addresses . . . . . 17

## 1. Introduction

[G.694.1] defines the Dense Wavelength Division Multiplexing (DWDM) frequency grids for Wavelength Division Multiplexing (WDM) applications. A frequency grid is a reference set of frequencies used to denote allowed nominal central frequencies that may be used for defining applications. The channel spacing is the frequency spacing between two allowed nominal central frequencies. All of the wavelengths on a fiber should use different central frequencies and occupy a fixed bandwidth of frequency.

Fixed-grid channel spacing ranges from one of 12.5 GHz, 25 GHz, 50 GHz, or 100 GHz to integer multiples of 100 GHz. But [G.694.1] also defines a "flexible grid", also known as "flexi-grid". The terms "frequency slot" (i.e., the frequency range allocated to a specific channel and unavailable to other channels within a flexible grid) and "slot width" (i.e., the full width of a frequency slot in a flexible grid) are used to define a flexible grid.

[RFC7698] defines a framework and the associated control-plane requirements for the GMPLS-based control of flexi-grid DWDM networks.

[RFC6163] provides a framework for GMPLS and Path Computation Element (PCE) control of Wavelength Switched Optical Networks (WSONs).

[RFC7688] defines the requirements and OSPF-TE extensions in support of GMPLS control of a WSON.

[RFC7792] describes requirements and protocol extensions for signaling to set up Label Switched Paths (LSPs) in networks that support the flexi-grid. This document complements [RFC7792] by describing the requirement and extensions for OSPF-TE routing in a flexi-grid network.

This document complements the efforts to provide extensions to the OSPF-TE protocol so as to support GMPLS control of flexi-grid networks.

## 2. Terminology

For terminology related to flexi-grid, please consult [RFC7698] and [G.694.1].

## 2.1. Conventions Used in This Document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

## 3. Requirements for Flexi-Grid Routing

The architecture for establishing LSPs in a Spectrum Switched Optical Network (SSON) is described in [RFC7698].

A flexi-grid LSP occupies one or multiple specific frequency slots. The process of computing a route and the allocation of a frequency slot is referred to as "RSA" (Routing and Spectrum Assignment). [RFC7698] describes three types of architectural approaches to RSA: combined RSA, separated RSA, and routing and distributed SA. The first two approaches could be called "centralized SA" because the spectrum (frequency slot) assignment is performed by a single entity before the signaling procedure.

In the case of centralized SA, the assigned frequency slot is specified in the RSVP-TE Path message during the signaling process. In the case of routing and distributed SA, only the requested slot width of the flexi-grid LSP is specified in the Path message, allowing the involved network elements to select the frequency slot to be used.

If the capability of switching or converting the whole optical spectrum allocated to an optical spectrum LSP is not available at nodes along the path of the LSP, the LSP is subject to the Optical "Spectrum Continuity Constraint", as described in [RFC7698].

The remainder of this section states the additional extensions on the routing protocols in a flexi-grid network.

### 3.1. Available Frequency Ranges

In the case of flexi-grids, the central frequency steps from 193.1 THz with 6.25 GHz granularity. The calculation method of central frequency and the frequency slot width of a frequency slot are defined in [G.694.1], i.e., by using nominal central frequency  $n$  and the slot width  $m$ .



Hence, in order to support all possible applications and implementations, the following information SHOULD be advertised for a flexi-grid DWDM link:

- o Channel Spacing (C.S.): as defined in [RFC7699] for flexi-grid, is set to 5 to denote 6.25 GHz.
- o Central frequency granularity: a multiplier of C.S.
- o Slot width granularity: a multiplier of 2\*C.S.
- o Slot width range: two multipliers of the slot width granularity, each indicating the minimal and maximal slot width supported by a port, respectively.

The combination of slot width range and slot width granularity can be used to determine the slot widths set supported by a port.

### 3.3. Comparison with Fixed-Grid DWDM Links

In the case of fixed-grid DWDM links, each wavelength has a predefined central frequency. Each wavelength maps to a predefined central frequency, and the usable frequency range is implicit by the channel spacing. All the wavelengths on a DWDM link can be identified with an identifier that mainly conveys its central frequency as the label defined in [RFC6205]; the status of the wavelengths (available or not) can be advertised through a routing protocol.

Figure 2 shows a link that supports a fixed-grid with 50 GHz channel spacing. The central frequencies of the wavelengths are predefined by values of "n", and each wavelength occupies a fixed 50 GHz frequency range as described in [G.694.1].

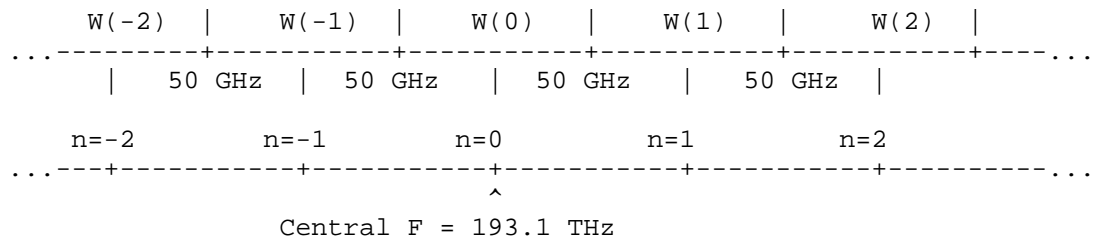


Figure 2: A Link Supports Fixed Wavelengths with 50 GHz Channel Spacing

Unlike the fixed-grid DWDM links, on a flexi-grid DWDM link, the slot width of the frequency slot is flexible, as described in Section 3.1. That is, the value of  $m$  in the following formula from [G.694.1] is uncertain before a frequency slot is actually allocated for a flexi-grid LSP.

$$\text{Slot Width (in GHz)} = 12.5\text{GHz} * m$$

For this reason, the available frequency slots (or ranges) are advertised for a flexi-grid DWDM link instead of the specific "wavelength" points that are sufficient for a fixed-grid link. Moreover, this advertisement is represented by the combination of central frequency granularity and slot width granularity.

#### 4. Extensions

The network-connectivity topology constructed by the links and/or nodes and node capabilities are the same as for WSON, as described in [RFC7698], and they can be advertised by the GMPLS routing protocols using Opaque Link State Advertisements (LSAs) [RFC3630] in the case of OSPF-TE [RFC4203] (refer to Section 6.2 of [RFC6163]). In the flexi-grid case, the available frequency ranges, instead of the specific "wavelengths", are advertised for the link. This section defines the GMPLS OSPF-TE extensions in support of advertising the available frequency ranges for flexi-grid DWDM links.

##### 4.1. Interface Switching Capability Descriptor (ISCD) Extensions for Flexi-Grid

This section defines a new value for the Switching Capability field of the ISCD with a value of 152 and type name Flexi-Grid-LSC.

Value	Name
-----	-----
152	Flexi-Grid-LSC

Switching Capability and Encoding values MUST be used as follows:

Switching Capability = Flexi-Grid-LSC

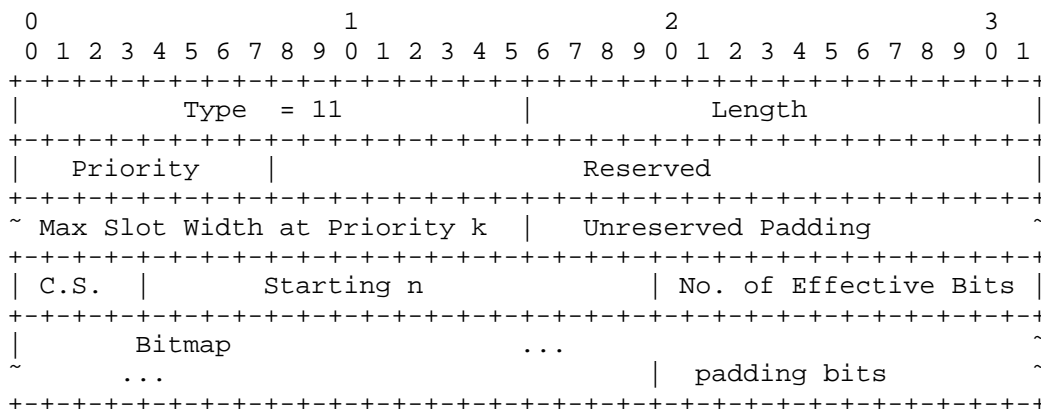
Encoding Type = lambda (as defined in [RFC3471])

When the Switching Capability and Encoding fields are set to values as stated above, the ISCD is interpreted as in [RFC4203] with the optional inclusion of one or more Switching Capability Specific Information (SCSI) sub-TLVs.

As the "Max LSP Bandwidth at priority x" (x from 0 to 7) fields in the generic part of the ISCD [RFC4203] are not meaningful for flexi-grid DWDM links, the values of these fields MUST be set to zero and MUST be ignored. The SCSI as defined below provides the corresponding information for flexi-grid DWDM links.

4.1.1. Switching Capability Specific Information (SCSI)

[RFC8258] defines a Generalized SCSI for the ISCD. This document defines the Frequency Availability Bitmap as a new type of the Generalized SCSI TLV. The technology-specific part of the flexi-grid ISCD includes the available frequency-spectrum resource as well as the information regarding max slot widths per priority. The format of this flexi-grid SCSI, the Frequency Availability Bitmap sub-TLV, is depicted in the following figure:



Type (16 bits): The type of this sub-TLV (11).

Length (16 bits): The length of the value field of this sub-TLV in octets.

Priority (8 bits): A bitmap used to indicate which priorities are being advertised. The bitmap is in ascending order, with the leftmost bit representing priority level 0 (i.e., the highest) and the rightmost bit representing priority level 7 (i.e., the lowest). A bit is set (1) corresponding to each priority represented in the sub-TLV and clear (0) for each priority not represented in the sub-TLV. At least one priority level MUST be advertised. If only one priority level is advertised, it MUST be at priority level 0.

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



Max Slot Width at Priority k (16 bits): This field indicates maximal frequency slot width supported at a particular priority level, up to 8. This field is set to max frequency slot width supported in the unit of 2\*C.S., for a particular priority level. One field MUST be present for each bit set in the Priority field, and each present field is ordered to match the Priority field. Fields MUST be present for priority levels that are indicated in the Priority field.

Unreserved Padding (16 bits): The Padding field is used to ensure the 32-bit alignment of Max Slot Width at Priority k. When k is an odd number, the Unreserved Padding field MUST be included. When k is an even number, the Unreserved Padding field MUST be omitted. This field MUST be set to 0 and MUST be ignored on receipt.

C.S. (4 bits): As defined in [RFC7699]; it is currently set to 5.

Starting n (16 bits): As defined in [RFC7699]. This value denotes the starting point of the nominal central frequency of the frequency availability bitmap sub-TLV.

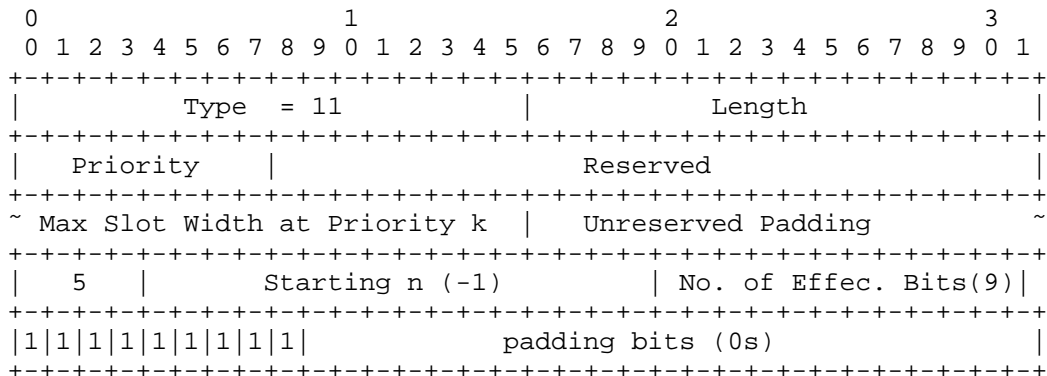
No. of Effective Bits (12 bits): Indicates the number of effective bits in the Bitmap field.

Bitmap (variable): Indicates whether or not a basic frequency slot, characterized by a nominal central frequency and a fixed m value of 1, is available for flexi-grid LSP setup. The first nominal central frequency is the value of starting n; subsequent nominal central frequencies are implied by the position in the bitmap. Note that setting to 1 indicates that the corresponding central frequency is available for a flexi-grid LSP with m=1 and setting to 0 indicates the corresponding central frequency is unavailable. Note that a centralized SA process will need to extend this to high values of m by checking a sufficiently large number of consecutive basic frequency slots that are available.

padding bits (variable): Padded after the Bitmap to make it a multiple of four bytes, if necessary. Padding bits MUST be set to 0 and MUST be ignored on receipt.

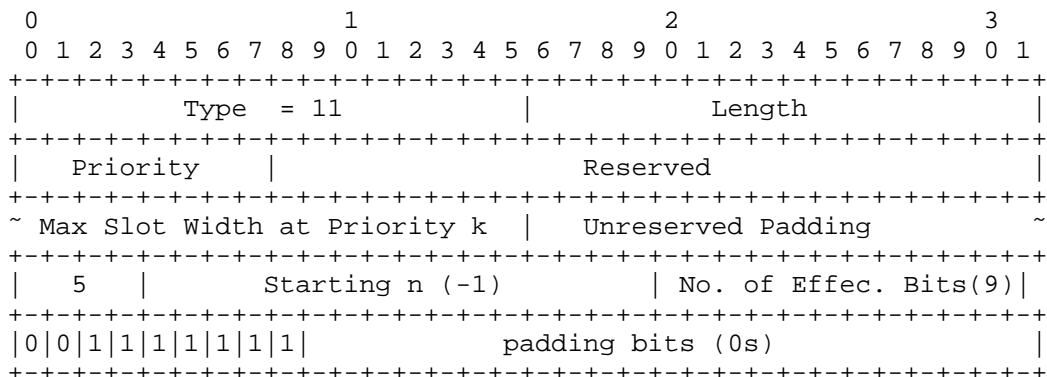
An example is provided in Section 4.1.2.





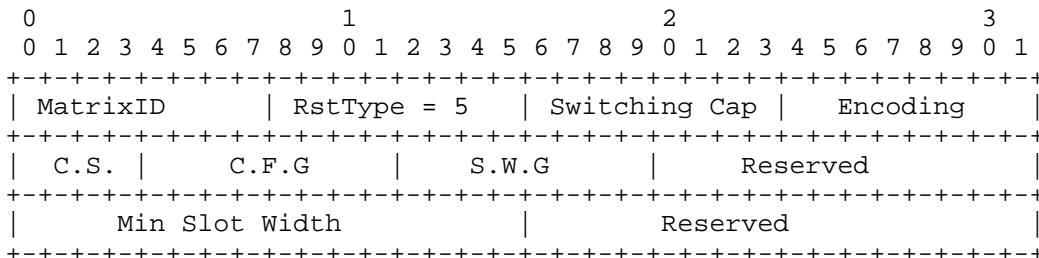
This encoding denotes that, other than the advertised available nominal central frequencies, the other nominal central frequencies within the whole frequency range supported by the link are not available for flexi-grid LSP setup.

If an LSP with slot width m equal to 1 is set up using this link, say using n=-1, then the SCSI information is updated to be the following:



#### 4.2. Extensions to the Port Label Restrictions Field

As described in Section 3.2, a port that supports flexi-grid may support only a restricted subset of the full flexible grid. The Port Label Restrictions field is defined in [RFC7579]. It can be used to describe the label restrictions on a port and is carried in the top-level Link TLV as specified in [RFC7580]. A new restriction type, the flexi-grid Restriction Type, is defined here to specify the restrictions on a port to support flexi-grid.



MatrixID (8 bits): As defined in [RFC7579].

RstType (Restriction Type, 8 bits): Takes the value of 5 to indicate the restrictions on a port to support flexi-grid.

Switching Cap (Switching Capability, 8 bits): As defined in [RFC7579], MUST be consistent with the one specified in ISCD as described in Section 4.1.

Encoding (8 bits): As defined in [RFC7579], MUST be consistent with the one specified in ISCD as described in Section 4.1.

C.S. (4 bits): As defined in [RFC7699]. For flexi-grid, it is 5 to denote 6.25 GHz.

C.F.G (Central Frequency Granularity, 8 bits): A positive integer. Its value indicates the multiple of C.S., in terms of central frequency granularity.

S.W.G (Slot Width Granularity, 8 bits): A positive integer. Its value indicates the multiple of 2\*C.S., in terms of slot width granularity.

Min Slot Width (16 bits): A positive integer. Its value indicates the multiple of 2\*C.S. (in GHz), in terms of the supported minimal slot width.

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

## 5. IANA Considerations

### 5.1. New ISCD Switching Type

IANA has made the following assignment in the "Switching Types" sub-registry of the "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry located at <https://www.iana.org/assignments/gmpls-sig-parameters>:

Value	Name	Reference
-----	-----	-----
152	Flexi-Grid-LSC	RFC 8363

### 5.2. New SCSI Type

This document defines a new generalized SCSI sub-TLV that is carried in the Interface Switching Capability Descriptors [RFC4203] when the Switching Type is set to Flexi-Grid-LSC.

IANA has made the following assignment in the "Generalized SCSI (Switching Capability Specific Information) TLV Types" sub-registry [RFC8258] of the "Generalized Multi-Protocol Label Switching (GMPLS) Signaling Parameters" registry located at <https://www.iana.org/assignments/gmpls-sig-parameters>:

Value	SCSI-TLV	Switching Type	Reference
-----	-----	-----	-----
11	Frequency Availability Bitmap	152	RFC 8363

## 6. Security Considerations

This document extends [RFC4203] and [RFC7580] to carry flexi-grid-specific information in OSPF Opaque LSAs. This document does not introduce any further security issues other than those discussed in [RFC3630] and [RFC4203]. To be more specific, the security mechanisms described in [RFC2328], which apply to Opaque LSAs carried in OSPF, still apply. An analysis of the OSPF security is provided in [RFC6863] and applies to the extensions to OSPF in this document as well.

## 7. References

### 7.1. Normative References

- [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>>.
- [RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <<https://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, <<https://www.rfc-editor.org/info/rfc3471>>.
- [RFC4203] Kompella, K., Ed. and Y. Rekhter, Ed., "OSPF Extensions in Support of Generalized Multi-Protocol Label Switching (GMPLS)", RFC 4203, DOI 10.17487/RFC4203, October 2005, <<https://www.rfc-editor.org/info/rfc4203>>.
- [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, <<https://www.rfc-editor.org/info/rfc6205>>.
- [RFC7579] Bernstein, G., Ed., Lee, Y., Ed., Li, D., Imajuku, W., and J. Han, "General Network Element Constraint Encoding for GMPLS-Controlled Networks", RFC 7579, DOI 10.17487/RFC7579, June 2015, <<https://www.rfc-editor.org/info/rfc7579>>.
- [RFC7580] Zhang, F., Lee, Y., Han, J., Bernstein, G., and Y. Xu, "OSPF-TE Extensions for General Network Element Constraints", RFC 7580, DOI 10.17487/RFC7580, June 2015, <<https://www.rfc-editor.org/info/rfc7580>>.
- [RFC7699] Farrel, A., King, D., Li, Y., and F. Zhang, "Generalized Labels for the Flexi-Grid in Lambda Switch Capable (LSC) Label Switching Routers", RFC 7699, DOI 10.17487/RFC7699, November 2015, <<https://www.rfc-editor.org/info/rfc7699>>.
- [RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <<https://www.rfc-editor.org/info/rfc8174>>.

- [RFC8258] Ceccarelli, D. and L. Berger, "Generalized SCSI: A Generic Structure for Interface Switching Capability Descriptor (ISCD) Switching Capability Specific Information (SCSI)", RFC 8258, DOI 10.17487/RFC8258, October 2017, <<https://www.rfc-editor.org/info/rfc8258>>.

## 7.2. Informative References

- [RFC2328] Moy, J., "OSPF Version 2", STD 54, RFC 2328, DOI 10.17487/RFC2328, April 1998, <<https://www.rfc-editor.org/info/rfc2328>>.
- [RFC3630] Katz, D., Kompella, K., and D. Yeung, "Traffic Engineering (TE) Extensions to OSPF Version 2", RFC 3630, DOI 10.17487/RFC3630, September 2003, <<https://www.rfc-editor.org/info/rfc3630>>.
- [RFC6163] Lee, Y., Ed., Bernstein, G., Ed., and W. Imajuku, "Framework for GMPLS and Path Computation Element (PCE) Control of Wavelength Switched Optical Networks (WSONs)", RFC 6163, DOI 10.17487/RFC6163, April 2011, <<https://www.rfc-editor.org/info/rfc6163>>.
- [RFC6863] Hartman, S. and D. Zhang, "Analysis of OSPF Security According to the Keying and Authentication for Routing Protocols (KARP) Design Guide", RFC 6863, DOI 10.17487/RFC6863, March 2013, <<https://www.rfc-editor.org/info/rfc6863>>.
- [RFC7688] Lee, Y., Ed. and G. Bernstein, Ed., "GMPLS OSPF Enhancement for Signal and Network Element Compatibility for Wavelength Switched Optical Networks", RFC 7688, DOI 10.17487/RFC7688, November 2015, <<https://www.rfc-editor.org/info/rfc7688>>.
- [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, <<https://www.rfc-editor.org/info/rfc7698>>.
- [RFC7792] Zhang, F., Zhang, X., Farrel, A., Gonzalez de Dios, O., and D. Ceccarelli, "RSVP-TE Signaling Extensions in Support of Flexi-Grid Dense Wavelength Division Multiplexing (DWDM) Networks", RFC 7792, DOI 10.17487/RFC7792, March 2016, <<https://www.rfc-editor.org/info/rfc7792>>.

## Acknowledgments

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

This work was supported in part by NSFC Project 61201260.

## Contributors

Adrian Farrel  
Juniper Networks

Email: afarrel@juniper.net

Fatai Zhang  
Huawei Technologies

Email: zhangfatai@huawei.com

Lei Wang  
Beijing University of Posts and Telecommunications

Email: wang.lei@bupt.edu.cn

Guoying Zhang  
China Academy of Information and Communication Technology

Email: zhangguoying@rictt.cn



## Authors' Addresses

Xian Zhang  
Huawei Technologies

Email: zhang.xian@huawei.com

Haomian Zheng  
Huawei Technologies

Email: zhenghaomian@huawei.com

Ramon Casellas, Ph.D.  
CTTC  
Spain

Phone: +34 936452916  
Email: ramon.casellas@cttc.es

Oscar Gonzalez de Dios  
Telefonica Investigacion y Desarrollo  
Emilio Vargas 6  
Madrid, 28045  
Spain

Phone: +34 913374013  
Email: oscar.gonzalezdedios@telefonica.com

Daniele Ceccarelli  
Ericsson  
Via A. Negrone 1/A  
Genova - Sestri Ponente  
Italy

Email: daniele.ceccarelli@ericsson.com