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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.

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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.

On a DWDM link, the allocated or in-use frequency slots do not overlap with each other. However, the border frequencies of two frequency slots may be the same frequency, i.e., the upper bound of a frequency slot and the lower bound of the directly adjacent frequency slot are the same.

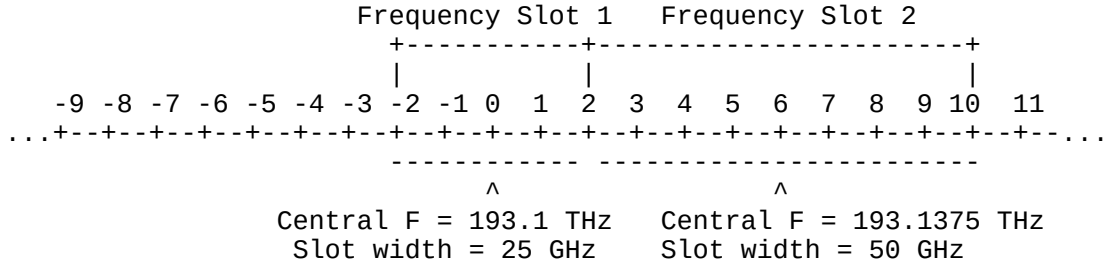


Figure 1: Two Frequency Slots on a Link

Figure 1 shows two adjacent frequency slots on a link. The highest frequency of frequency slot 1 denoted by n=2 is the lowest frequency of slot 2. In this example, it means that the frequency range from n=-2 to n=10 is unavailable to other flexi-grid LSPs. Available central frequencies are advertised for m=1, which means that for an available central frequency n, the frequency slot from central frequency n-1 to central frequency n+1 is available.

Hence, in order to clearly show which frequency slots are available and can be used for LSP establishment and which frequency slots are unavailable, the availability of frequency slots is advertised by the routing protocol for the flexi-grid DWDM links. A set of non-overlapping available frequency ranges is disseminated in order to allow efficient resource management of flexi-grid DWDM links and RSA procedures, which are described in Section 4.8 of [RFC7698].

3.2. Application Compliance Considerations

As described in [G.694.1], devices or applications that make use of the flexi-grid may not be capable of supporting every possible slot width or position (i.e., central frequency). In other words, applications or implementations 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 the same application only requires slot widths as a multiple of 25 GHz (by only requiring values of m that are even).

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

- Channel Spacing (C.S.): as defined in [RFC7699] for flexi-grid, is set to 5 to denote 6.25 GHz.
- Central frequency granularity: a multiplier of C.S.
- Slot width granularity: a multiplier of 2*C.S.
- 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].

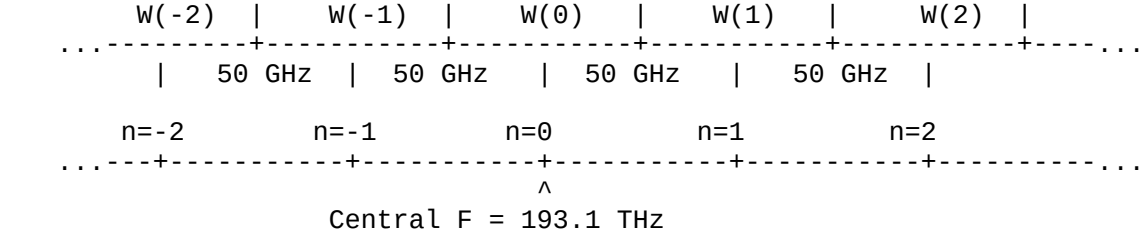


Figure 2: A Link Supports Fixed Wavelengths with 50 GHz Channel Spacing

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.

Slot Width (in GHz) = 12.5GHz * 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

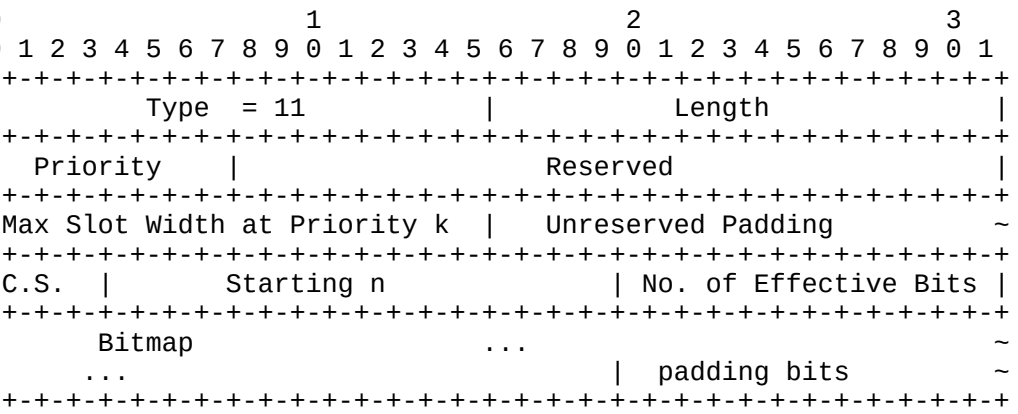
Encoding Type = lambda (as defined in [RFC3471])

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.

4.1.2. An SCSI Example

Figure 3 shows an example of the available frequency spectrum resource of a flexi-grid DWDM link.

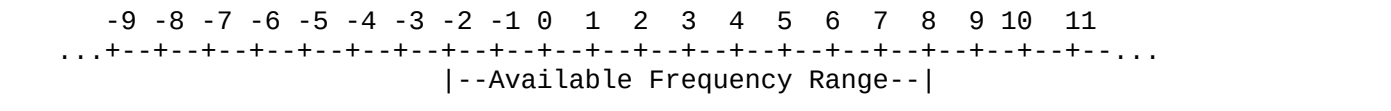
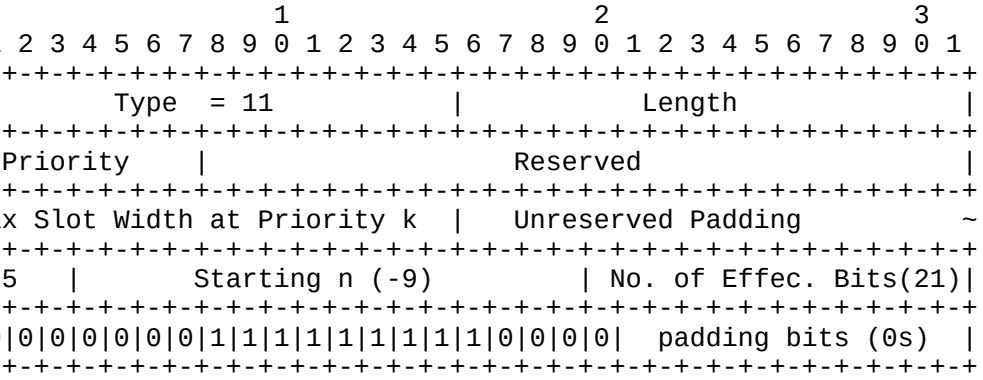


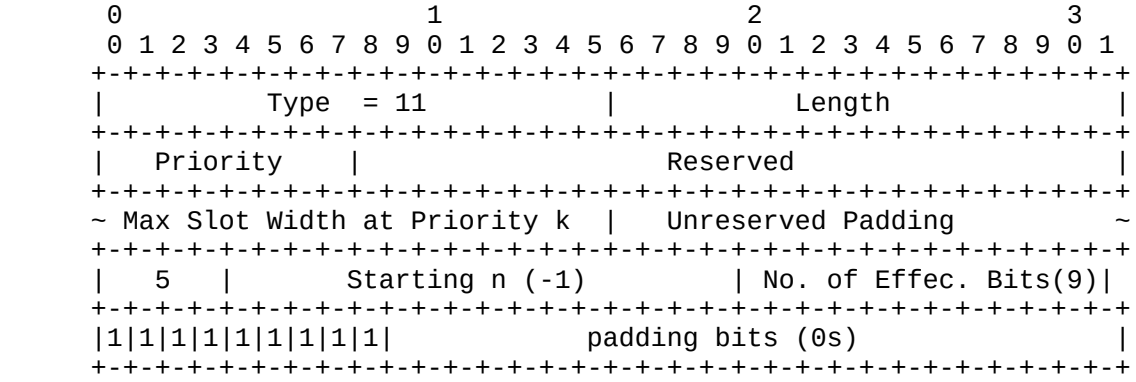
Figure 3: Flexi-Grid DWDM Link Example

The symbol "+" represents the allowed nominal central frequency. The symbol "--" represents a central frequency granularity of 6.25 GHz, which is currently standardized in [G.694.1]. The number on the top of the line represents the "n" in the frequency calculation formula (193.1 + n * 0.00625). The nominal central frequency is 193.1 THz when n equals zero.

In this example, it is assumed that the lowest nominal central frequency supported is n=-9 and the highest is n=11. Note they cannot be used as a nominal central frequency for setting up an LSP, but merely as the way to express the supported frequency range. Using the encoding defined in Section 4.1.1, the relevant fields to express the frequency resource availability can be filled as below:

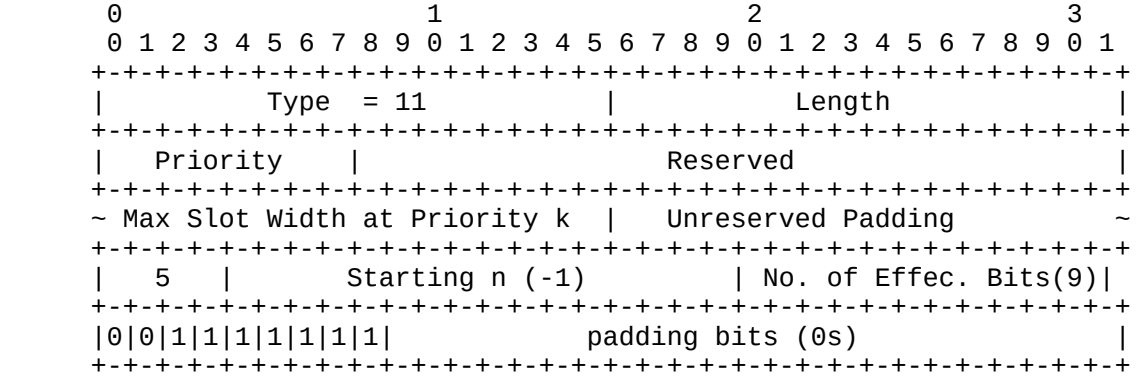


In the above example, the starting n is selected to be the lowest nominal central frequency, i.e., -9. It is observed from the bitmap that n=-1 to 7 can be used to set up LSPs. Note other starting n values can be chosen to represent the bitmap; for example, the first available nominal central frequency (a.k.a., the first available basic frequency slot) can be chosen, and the SCSI will be expressed as the following:



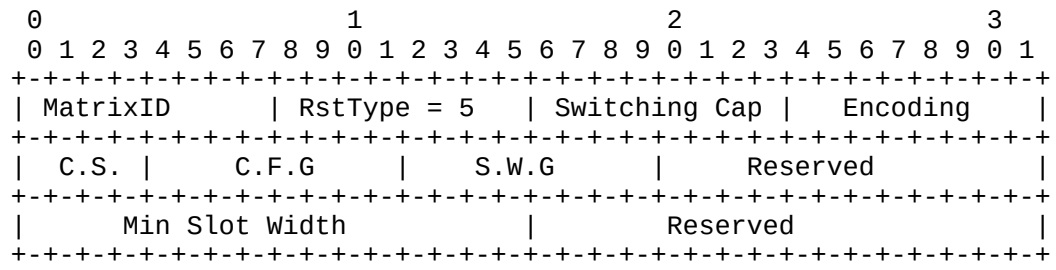
This encoding denotes that, other than the advertised available nominal central frequencies, the other nominal central frequencies within the whole frequency range supported by the link are not available for flexi-grid LSP setup.

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

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7.2. Informative References

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