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# Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks

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## Status of this Memo



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Abstract

This document provides a model of information needed by the routing and wavelength assignment (RWA) process in wavelength switched optical networks (WSONs). The purpose of the information described in this model is to facilitate constrained lightpath computation in WSONs. This model takes into account compatibility constraints between WSON signal attributes and network elements but does not include constraints due to optical impairments. Aspects of this information that may be of use to other technologies utilizing a GMPLS control plane are discussed.

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## 1. Introduction

The purpose of the following information model for WSONs is to facilitate constrained lightpath computation and as such is not a general purpose network management information model. This constraint is frequently referred to as the "wavelength continuity" constraint, and the corresponding constrained lightpath computation is known as the routing and wavelength assignment (RWA) problem. Hence the information model must provide sufficient topology and wavelength restriction and availability information to support this computation. More details on the RWA process and WSON subsystems and their properties can be found in [RFC6163]. The model defined here includes constraints between WSON signal attributes and network elements, but does not include optical impairments.

In addition to presenting an information model suitable for path computation in WSON, this document also highlights model aspects that may have general applicability to other technologies utilizing a GMPLS control plane. The portion of the information model applicable to other technologies beyond WSON is referred to as "general" to distinguish it from the "WSON-specific" portion that is applicable only to WSON technology.

## 2. Terminology

Refer to [RFC6163] for ROADM, RWA, Wavelength Conversion, WDM and WSON.

## 3. Routing and Wavelength Assignment Information Model

The following WSON RWA information model is grouped into four categories regardless of whether they stem from a switching subsystem or from a line subsystem:

o Node Information

o Link Information

o Dynamic Node Information

o Dynamic Link Information

Note that this is roughly the categorization used in [G.7715] section 7.

In the following, where applicable, the reduced Backus-Naur form (RBNF) syntax of [RBNF] is used to aid in defining the RWA information model.

### 3.1. Dynamic and Relatively Static Information

All the RWA information of concern in a WSON network is subject to change over time. Equipment can be upgraded; links may be placed in or out of service and the like. However, from the point of view of RWA computations there is a difference between information that can change with each successive connection establishment in the network and that information that is relatively static and independent of connection establishment. A key example of the former is link wavelength usage since this can change with connection setup/teardown and this information is a key input to the RWA process. Examples of relatively static information are the potential port connectivity of a WDM ROADM, and the channel spacing on a WDM link.

This document separates, where possible, dynamic and static information so that these can be kept separate in possible encodings and hence allowing for separate updates of these two types of information thereby reducing processing and traffic load caused by the timely distribution of the more dynamic RWA WSON information.

## 4. Node Information (General)

The node information described here contains the relatively static information related to a WSON node. This includes connectivity

constraints amongst ports and wavelengths since WSON switches can exhibit asymmetric switching properties. Additional information could include properties of wavelength converters in the node if any are present. In [Switch] it was shown that the wavelength connectivity constraints for a large class of practical WSON devices can be modeled via switched and fixed connectivity matrices along with corresponding switched and fixed port constraints. These connectivity matrices are included with the node information while the switched and fixed port wavelength constraints are included with the link information.

Formally,

<Node_Information> ::= <Node_ID> [<ConnectivityMatrix>...]

Where the Node_ID would be an appropriate identifier for the node within the WSON RWA context.

Note that multiple connectivity matrices are allowed and hence can fully support the most general cases enumerated in [Switch].

## 4.1. Connectivity Matrix

The connectivity matrix (ConnectivityMatrix) represents either the potential connectivity matrix for asymmetric switches (e.g. ROADMs and such) or fixed connectivity for an asymmetric device such as a multiplexer. Note that this matrix does not represent any particular internal blocking behavior but indicates which input ports and wavelengths could possibly be connected to a particular output port. Representing internal state dependent blocking for a switch or ROADM is beyond the scope of this document and due to its highly implementation dependent nature would most likely not be subject to standardization in the future. The connectivity matrix is a conceptual M by N matrix representing the potential switched or fixed connectivity, where M represents the number of input ports and N the number of output ports. This is a "conceptual" matrix since the matrix tends to exhibit structure that allows for very compact representations that are useful for both transmission and path computation.

Note that the connectivity matrix information element can be useful in any technology context where asymmetric switches are utilized.

<ConnectivityMatrix> ::= <MatrixID> <ConnType> <Matrix>

Where

<MatrixID> is a unique identifier for the matrix.

<ConnType> can be either 0 or 1 depending upon whether the connectivity is either fixed or switched.

<Matrix> represents the fixed or switched connectivity in that Matrix(i, j) = 0 or 1 depending on whether input port i can connect to output port j for one or more wavelengths.

## 5. Node Information (WSON specific)

As discussed in [RFC6163] a WSON node may contain electro-optical subsystems such as regenerators, wavelength converters or entire switching subsystems. The model present here can be used in characterizing the accessibility and availability of limited resources such as regenerators or wavelength converters as well as WSON signal attribute constraints of electro-optical subsystems. As such this information element is fairly specific to WSON technologies.

A WSON node may include regenerators or wavelength converters arranged in a shared pool. As discussed in [RFC6163] this can include OEO based WDM switches as well. There are a number of different approaches used in the design of WDM switches containing regenerator or converter pools. However, from the point of view of path computation the following need to be known:

1. The nodes that support regeneration or wavelength conversion.

2. The accessibility and availability of a wavelength converter to convert from a given input wavelength on a particular input port to a desired output wavelength on a particular output port.

3. Limitations on the types of signals that can be converted and the conversions that can be performed.

Since resources tend to be packaged together in blocks of similar devices, e.g., on line cards or other types of modules, the fundamental unit of identifiable resource in this document is the "resource block". A resource block may contain one or more resources. A resource is the smallest identifiable unit of processing allocation. One can group together resources into blocks if they have similar characteristics relevant to the optical system being modeled, e.g., processing properties, accessibility, etc.

This leads to the following formal high level model:

<Node_Information> ::= <Node_ID> [<ConnectivityMatrix>...]
[<ResourcePool>]

Where

<ResourcePool> ::= <ResourceBlockInfo>...
[<ResourceAccessibility>...] [<ResourceWaveConstraints>...]
[<RBPoolState>]

First the accessibility of resource blocks is addressed then their properties are discussed.

5.1. Resource Accessibility/Availability

A similar technique as used to model ROADMs and optical switches can be used to model regenerator/converter accessibility. This technique was generally discussed in [RFC6163] and consisted of a matrix to indicate possible connectivity along with wavelength constraints for links/ports. Since regenerators or wavelength converters may be considered a scarce resource it is desirable that the model include, if desired, the usage state (availability) of individual regenerators or converters in the pool. Models that incorporate more state to further reveal blocking conditions on input or output to particular converters are for further study and not included here.

The three stage model is shown schematically in Figure 1 and Figure 2. The difference between the two figures is that Figure 1 assumes that each signal that can get to a resource block may do so, while in Figure 2 the access to sets of resource blocks is via a shared fiber which imposes its own wavelength collision constraint. The representation of Figure 1 can have more than one input to each resource block since each input represents a single wavelength signal, while in Figure 2 shows a single multiplexed WDM input or output, e.g., a fiber, to/from each set of block.

This model assumes N input ports (fibers), P resource blocks containing one or more identical resources (e.g. wavelength converters), and M output ports (fibers). Since not all input ports can necessarily reach each resource block, the model starts with a resource pool input matrix RI(i,p) = {0,1} whether input port i can reach potentially reach resource block p.

Since not all wavelengths can necessarily reach all the resources or the resources may have limited input wavelength range the model has a set of relatively static input port constraints for each resource. In addition, if the access to a set of resource blocks is via a shared fiber (Figure 2) this would impose a dynamic wavelength

availability constraint on that shared fiber. The resource block input port constraint is modeled via a static wavelength set mechanism and the case of shared access to a set of blocks is modeled via a dynamic wavelength set mechanism.

Next a state vector RA(j) = {0,...,k} is used to track the number of resources in resource block j in use. This is the only state kept in the resource pool model. This state is not necessary for modeling "fixed" transponder system or full OEO switches with WDM interfaces, i.e., systems where there is no sharing.

After that, a set of static resource output wavelength constraints and possibly dynamic shared output fiber constraints maybe used. The static constraints indicate what wavelengths a particular resource block can generate or are restricted to generating e.g., a fixed regenerator would be limited to a single lambda. The dynamic constraints would be used in the case where a single shared fiber is used to output the resource block (Figure 2).

Finally, to complete the model, a resource pool output matrix RE(p,k) = {0,1} depending on whether the output from resource block p can reach output port k, may be used.

```
     I1   +-------------+                       +-------------+ O1
    ----->|             |      +--------+       |             |----->
     I2   |             +------+ Rb #1  +-------+             | O2
    ----->|             |      +--------+       |             |----->
          |             |                       |             |
          | Resource    |      +--------+       |  Resource   |
          | Pool        +------+        +-------+  Pool       |
          |             |      + Rb #2  +       |             |
          | Input       +------+        +-------|  Output     |
          | Connection  |      +--------+       |  Connection |
          | Matrix      |           .           |  Matrix     |
          |             |           .           |             |
          |             |           .           |             |
     IN   |             |      +--------+       |             | OM
    ----->|             +------+ Rb #P  +-------+             |----->
          |             |      +--------+       |             |
          +-------------+   ^               ^   +-------------+
                            |               |
                            |               |
                            |               |
                            |               |

                   Input wavelength      Output wavelength
                   constraints for       constraints for
                   each resource         each resource
```

Figure 1 Schematic diagram of resource pool model.

```
 I1   +-------------+                       +-------------+ O1
----->|             |      +--------+       |             |----->
 I2   |             +======+ Rb #1  +-+     +             | O2
----->|             |      +--------+ |     |             |----->
      |             |                 |=====|             |
      | Resource    |      +--------+ |     |  Resource   |
      | Pool        |    +-+ Rb #2  +-+     |  Pool       |
      |             |    | +--------+       +             |
      | Input       |====|                  |  Output     |
      | Connection  |    | +--------+       |  Connection |
      | Matrix      |    +-| Rb #3  |=======|  Matrix     |
      |             |      +--------+       |             |
      |             |          .            |             |
      |             |          .            |             |
      |             |          .            |             |
 IN   |             |      +--------+       |             | OM
----->|             +======+ Rb #P  +=======+             |----->
      |             |      +--------+       |             |
      +-------------+   ^               ^   +-------------+
                        |               |
                        |               |
                        |               |
            Single (shared) fibers for block input and output

             Input wavelength           Output wavelength
             availability for           availability for
             each block input fiber     each block output fiber
```

Figure 2 Schematic diagram of resource pool model with shared block accessibility.

Formally the model can be specified as:

<ResourceAccessibility ::= <PoolInputMatrix> <PoolOutputMatrix>

<ResourceWaveConstraints> ::= <InputWaveConstraints>
<OutputOutputWaveConstraints>

<RBPoolState> ::=<ResourceBlockID> <NumResourcesInUse>
[<InAvailableWavelengths>] [<OutAvailableWavelengths>]
[<RBPoolState>]

Note that except for <RBPoolState> all the other components of <ResourcePool> are relatively static. Also the <InAvailableWavelengths> and <OutAvailableWavelengths> are only used in the cases of shared input or output access to the particular block. See the resource block information in the next section to see how this is specified.

### 5.2. Resource Signal Constraints and Processing Capabilities

The wavelength conversion abilities of a resource (e.g. regenerator, wavelength converter) were modeled in the <OutputWaveConstraints> previously discussed. As discussed in [RFC6163] the constraints on an electro-optical resource can be modeled in terms of input constraints, processing capabilities, and output constraints:

<ResourceBlockInfo> ::= <ResourceBlockSet> [<InputConstraints>] [<ProcessingCapabilities>] [<OutputConstraints>]

Where <ResourceBlockSet> is a list of resource block identifiers with the same characteristics. If this set is missing the constraints are applied to the entire network element.

The <InputConstraints> are signal compatibility based constraints and/or shared access constraint indication. The details of these constraints are defined in section 5.3.

<InputConstraints> ::= <SharedInput> [<OpticalInterfaceClassList>] [<ClientSignalList>]

The <ProcessingCapabilities> are important operations that the resource (or network element) can perform on the signal. The details of these capabilities are defined in section 5.3.

<ProcessingCapabilities> ::= [<NumResources>] [<RegenerationCapabilities>] [<FaultPerfMon>] [<VendorSpecific>]

The <OutputConstraints> are either restrictions on the properties of the signal leaving the block, options concerning the signal properties when leaving the resource or shared fiber output constraint indication.

<OutputConstraints> := <SharedOutput> [<OpticalInterfaceClassList>][<ClientSignalList>]

5.3. Compatibility and Capability Details

5.3.1. Shared Input or Output Indication

As discussed in the previous section and shown in Figure 2 the input or output access to a resource block may be via a shared fiber. The <SharedInput> and <SharedOutput> elements are indicators for this condition with respect to the block being described.

5.3.2. Optical Interface Class List

<OpticalInterfaceClassList> ::= <OpticalInterfaceClass> ...

The Optical Interface Class is a unique number that identifies all information related to optical characteristics of a physical interface. The class may include other optical parameters related to other interface properties. A class always includes signal compatibility information.

The content of each class is out of the scope of this draft and can be defined by other entities (e.g. ITU, optical equipment vendors, etc.).

Since even current implementation of physical interfaces may support different optical characteristics, a single interface may support multiple interface classes. Which optical interface class is used among all the ones available for an interface is out of the scope of this draft but is an output of the RWA process.

5.3.3. Acceptable Client Signal List

The list is simply:

< ClientSignalList>::=[<G-PID>]...

Where the Generalized Protocol Identifiers (G-PID) object represents one of the IETF standardized G-PID values as defined in [RFC3471] and [RFC4328].

5.3.4. Processing Capability List

The ProcessingCapabilities were defined in Section 5.2.

The processing capability list sub-TLV is a list of processing functions that the WSON network element (NE) can perform on the signal including:

1. Number of Resources within the block

2. Regeneration capability

3. Fault and performance monitoring

4. Vendor Specific capability

Note that the code points for Fault and performance monitoring and vendor specific capability are subject to further study.

## 6. Link Information (General)

MPLS-TE routing protocol extensions for OSPF and IS-IS [RFC3630], [RFC5305] along with GMPLS routing protocol extensions for OSPF and IS-IS [RFC4203, RFC5307] provide the bulk of the relatively static link information needed by the RWA process. However, WSON networks bring in additional link related constraints. These stem from WDM line system characterization, laser transmitter tuning restrictions, and switching subsystem port wavelength constraints, e.g., colored ROADM drop ports.

In the following summarize both information from existing GMPLS route protocols and new information that maybe needed by the RWA process.

```
<LinkInfo> ::=  <LinkID> [<AdministrativeGroup>]
[<InterfaceCapDesc>] [<Protection>] [<SRLG>...]
[<TrafficEngineeringMetric>] [<PortLabelRestriction>...]
```

Note that these additional link characteristics only applies to line side ports of WDM system or add/drop ports pertaining to Resource Pool (e.g., Regenerator or Wavelength Converter Pool). The advertisement of input/output tributary ports is not intended here.

### 6.1. Administrative Group

AdministrativeGroup: Defined in [RFC3630]. Each set bit corresponds to one administrative group assigned to the interface.  A link may belong to multiple groups. This is a configured quantity and can be used to influence routing decisions.

### 6.2. Interface Switching Capability Descriptor

InterfaceSwCapDesc: Defined in [RFC4202], lets us know the different switching capabilities on this GMPLS interface. In both [RFC4203] and [RFC5307] this information gets combined with the maximum LSP bandwidth that can be used on this link at eight different priority levels.

### 6.3. Link Protection Type (for this link)

Protection: Defined in [RFC4202] and implemented in [RFC4203, RFC5307]. Used to indicate what protection, if any, is guarding this link.

### 6.4. Shared Risk Link Group Information

SRLG: Defined in [RFC4202] and implemented in [RFC4203, RFC5307]. This allows for the grouping of links into shared risk groups, i.e., those links that are likely, for some reason, to fail at the same time.

### 6.5. Traffic Engineering Metric

TrafficEngineeringMetric: Defined in [RFC3630]. This allows for the identification of a data channel link metric value for traffic engineering that is separate from the metric used for path cost computation of the control plane.

Note that multiple "link metric values" could find use in optical networks, however it would be more useful to the RWA process to assign these specific meanings such as link mile metric, or probability of failure metric, etc...

### 6.6. Port Label Restrictions

Port label restrictions could be applied generally to any label types in GMPLS by adding new kinds of restrictions. Wavelength is a type of label.

Port label (wavelength) restrictions (PortLabelRestriction) model the label (wavelength) restrictions that the link and various optical devices such as OXCs, ROADMs, and waveband multiplexers may impose on a port. These restrictions tell us what wavelength may or may not be used on a link and are relatively static. This plays an important role in fully characterizing a WSON switching device [Switch]. Port wavelength restrictions are specified relative to the port in general or to a specific connectivity matrix (section 4.1.

Reference [Switch] gives an example where both switch and fixed connectivity matrices are used and both types of constraints occur on the same port.

```
<PortLabelRestriction> ::= <MatrixID> <RestrictionType>
            <Restriction parameters list>

<Restriction parameters list> ::=
      <Simple label restriction parameters> |
      <Channel count restriction parameters> |
      <Label range restriction parameters> |
      <Simple+channel restriction parameters> |
      <Exclusive label restriction parameters>

<Simple label restriction parameters> ::= <LabelSet> ...

<Channel count restriction parameters> ::= <MaxNumChannels>

<Label range restriction parameters> ::=
      <MaxLabelRange> (<LabelSet> ...)

<Simple+channel restriction parameters> ::=
      <MaxNumChannels> (<LabelSet> ...)

<Exclusive label restriction parameters> ::= <LabelSet> ...
```

Where

MatrixID is the ID of the corresponding connectivity matrix (section 4.1.

The RestrictionType parameter is used to specify general port restrictions and matrix specific restrictions. It can take the following values and meanings:

SIMPLE_LABEL: Simple label (wavelength) set restriction; The label set parameter is required.

CHANNEL_COUNT: The number of channels is restricted to be less than or equal to the Max number of channels parameter (which is required).

LABEL_RANGE: Used to indicate a restriction on a range of labels that can be switched. For example, a waveband device with a tunable center frequency and passband. This constraint is characterized by the MaxLabelRange parameter which indicates the maximum range of the labels, e.g., which may represent a waveband in terms of channels. Note that an additional parameter can be used to indicate the overall tuning range. Specific center frequency tuning information can be obtained from dynamic channel in use information. It is assumed that both center frequency and bandwidth (Q) tuning can be done without causing faults in existing signals.

SIMPLE LABEL & CHANNEL COUNT: In this case, the accompanying label set and MaxNumChannels indicate labels permitted on the port and the maximum number of labels that can be simultaneously used on the port.

LINK LABEL_EXCLUSIVITY: A label (wavelength) can be used at most once among a given set of ports. The set of ports is specified as a parameter to this constraint.

Restriction specific parameters are used with one or more of the previously listed restriction types. The currently defined parameters are:

LabelSet is a conceptual set of labels (wavelengths).

MaxNumChannels is the maximum number of channels that can be simultaneously used (relative to either a port or a matrix).

LinkSet is a conceptual set of ports.

MaxLabelRange indicates the maximum range of the labels.

For example, if the port is a "colored" drop port of a ROADM then there are two restrictions: (a) CHANNEL_COUNT, with MaxNumChannels = 1, and (b) SIMPLE_WAVELENGTH, with the wavelength set consisting of a single member corresponding to the frequency of the permitted wavelength. See [Switch] for a complete waveband example.

This information model for port wavelength (label) restrictions is fairly general in that it can be applied to ports that have label restrictions only or to ports that are part of an asymmetric switch and have label restrictions. In addition, the types of label restrictions that can be supported are extensible.

### 6.6.1. Port-Wavelength Exclusivity Example

Although there can be many different ROADM or switch architectures that can lead to the constraint where a lambda (label) maybe used at most once on a set of ports Figure 3 shows a ROADM architecture based on components known as a Wavelength Selective Switch (WSS)[OFC08]. This ROADM is composed of splitters, combiners, and WSSes. This ROADM has 11 output ports, which are numbered in the diagram. Output ports 1-8 are known as drop ports and are intended to support a single wavelength. Drop ports 1-4 output from WSS #2, which is fed from WSS #1 via a single fiber. Due to this internal structure a constraint is placed on the output ports 1-4 that a lambda can be only used once over the group of ports (assuming uni-cast and not multi-cast operation). Similarly the output ports 5-8 have a similar constraint due to the internal structure.

```
                               |               A
                               v            10 |
                           +-------+        +-------+
                           | Split |        |WSS  6 |
                           +-------+        +-------+
        +----+              | | | |          | | | |
        | W  |              | | | |          | | | +-------+   +----+
        | S  |--------------+ | | |    +-----+ | +----+    |   | S  |
      9 | S  |----------------|---|----|-------|------|----|---| p  |
     <--|    |----------------|---|----|-------|----+ |    +---| l  |<
        | 5  |--------------+ |   |    | +-----+    | |     +--| i  |
        +----+              | |   |    | |   +------|-|-----|--| t  |
                   +--------|-+   +----|-|---|------|----+  |  +----+
        +----+     |        |          | |   |      | |  |  |
        | S  |-----|--------|----------+ |   |      | |  |  |  +----+
        | p  |-----|--------|------------|---|------|----|--|--| W  |
     -->| l  |-----|-----+  | +----------+   |      | |  +--|--| S  |11
        | i  |---+ |     |  | | +------------|------|-------|--| S  |->
        | t  |   | |     |  | | |            |      | | +---|--|    |
        +----+   | | +---|--|-|-|------------|------|-|-|---+  | 7  |
                 | | |   +--|-|-|--------+ | |      | | |      +----+
                 | | |      | | |        | | |      | | |
                +------+   +------+     +------+   +------+
                | WSS 1|   | Split|     | WSS 3|   | Split|
                +--+---+   +--+---+     +--+---+   +--+---+
                   |          A            |          A
                   v          |            v          |
                +-------+  +--+----+    +-------+  +--+----+
                | WSS 2 |  | Comb. |    | WSS 4 |  | Comb. |
                +-------+  +-------+    +-------+  +-------+
                1|2|3|4|    A A A A     5|6|7|8|    A A A A
                 v v v v    | | | |      v v v v    | | | |
```

Figure 3 A ROADM composed from splitter, combiners, and WSSs.

## 7. Dynamic Components of the Information Model

In the previously presented information model there are a limited number of information elements that are dynamic, i.e., subject to change with subsequent establishment and teardown of connections. Depending on the protocol used to convey this overall information model it may be possible to send this dynamic information separate from the relatively larger amount of static information needed to characterize WSON's and their network elements.

7.1. Dynamic Link Information (General)

For WSON links wavelength availability and wavelengths in use for shared backup purposes can be considered dynamic information and hence are grouped with the dynamic information in the following set:

```
<DynamicLinkInfo> ::=  <LinkID> <AvailableLabels>
[<SharedBackupLabels>]
```

AvailableLabels is a set of labels (wavelengths) currently available on the link. Given this information and the port wavelength restrictions one can also determine which wavelengths are currently in use. This parameter could potential be used with other technologies that GMPLS currently covers or may cover in the future.

SharedBackupLabels is a set of labels (wavelengths) currently used for shared backup protection on the link. An example usage of this information in a WSON setting is given in [Shared]. This parameter could potential be used with other technologies that GMPLS currently covers or may cover in the future.

Note that the above does not dictate a particular encoding or placement for available label information. In some routing protocols it may be advantageous or required to place this information within another information element such as the interface switching capability descriptor (ISCD). Consult routing protocol specific extensions for details of placement of information elements.

7.2. Dynamic Node Information (WSON Specific)

Currently the only node information that can be considered dynamic is the resource pool state and can be isolated into a dynamic node information element as follows:

```
<DynamicNodeInfo> ::=  <NodeID> [<ResourcePool>]
```

## 8. Security Considerations

This document discussed an information model for RWA computation in WSONs. Such a model is very similar from a security standpoint of the information that can be currently conveyed via GMPLS routing protocols.  Such information includes network topology, link state and current utilization, and well as the capabilities of switches and routers within the network.  As such this information should be protected from disclosure to unintended recipients.  In addition,

the intentional modification of this information can significantly affect network operations, particularly due to the large capacity of the optical infrastructure to be controlled. A general discussion on security in GMPLS networks can be found in [RFC5920].

## 9. IANA Considerations

This informational document does not make any requests for IANA action.

## 10. Acknowledgments

This document was prepared using 2-Word-v2.0.template.dot.

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