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Routing and Wavelength Assignment Information Model for Wavelength Switched Optical Networks

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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 [WSON-Frame]. 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. We refer to the information model applicable to other technologies beyond WSON as "general" to distinguish from the "WSON-specific" model that is applicable only to WSON technology.

1.1. Revision History

1.1.1. Changes from 01

Added text on multiple fixed and switched connectivity matrices.

Added text on the relationship between SRNG and SRLG and encoding considerations.

Added clarifying text on the meaning and use of port/wavelength restrictions.

Added clarifying text on wavelength availability information and how to derive wavelengths currently in use.

1.1.2. Changes from 02

Integrated switched and fixed connectivity matrices into a single "connectivity matrix" model. Added numbering of matrices to allow for wavelength (time slot, label) dependence of the connectivity. Discussed general use of this node parameter beyond WSON.

Integrated switched and fixed port wavelength restrictions into a single port wavelength restriction of which there can be more than one and added a reference to the corresponding connectivity matrix if there is one. Also took into account port wavelength restrictions in the case of symmetric switches, developed a uniform model and specified how general label restrictions could be taken into account with this model.

Removed the Shared Risk Node Group parameter from the node info, but left explanation of how the same functionality can be achieved with existing GMPLS SRLG constructs.

Removed Maximum bandwidth per channel parameter from link information.

1.1.3. Changes from 03

Removed signal related text from section 3.2.4 as signal related information is deferred to a new signal compatibility draft.

Removed encoding specific text from Section 3.3.1 of version 03.

1.1.4. Changes from 04

Removed encoding specific text from Section 4.1.

Removed encoding specific text from Section 3.4.

1.1.5. Changes from 05

Renumbered sections for clarity.

Updated abstract and introduction to encompass signal compatibility/generalization.

Generalized Section on wavelength converter pools to include electro optical subsystems in general. This is where we added signal compatibility modeling.

1.1.6. Changes from 06

Simplified information model for WSON specifics, by combining similar fields and introducing simpler aggregate information elements.

2. Terminology

CWDM: Coarse Wavelength Division Multiplexing.

DWDM: Dense Wavelength Division Multiplexing.

FOADM: Fixed Optical Add/Drop Multiplexer.

ROADM: Reconfigurable Optical Add/Drop Multiplexer. A reduced port count wavelength selective switching element featuring ingress and egress line side ports as well as add/drop side ports.

RWA: Routing and Wavelength Assignment.

Wavelength Conversion. The process of converting an information bearing optical signal centered at a given wavelength to one with "equivalent" content centered at a different wavelength. Wavelength conversion can be implemented via an optical-electronic-optical (OEO) process or via a strictly optical process.

WDM: Wavelength Division Multiplexing.

Wavelength Switched Optical Network (WSON): A WDM based optical network in which switching is performed selectively based on the center wavelength of an optical signal.

3. Routing and Wavelength Assignment Information Model

We group the following WSON RWA information model 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 we use, where applicable, the reduced Backus-Naur form (RBNF) syntax of [RBNF] 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 on the time scales 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.

In this document we will separate, 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. We include these connectivity matrices with our node information the switched and fixed port wavelength constraints 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 ingress 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 it's 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 ingress ports and N the number of egress ports. We say this is a "conceptual" matrix since this matrix tends to exhibit structure that allows for very compact representations that are useful for both transmission and path computation [Encode].

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

ConnectivityMatrix(i, j) ::= <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 potentially switched.

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

4.2. Shared Risk Node Group

SRNG: Shared risk group for nodes. The concept of a shared risk link group was defined in [RFC4202]. This can be used to achieve a desired "amount" of link diversity. It is also desirable to have a similar capability to achieve various degrees of node diversity. This is explained in [G.7715]. Typical risk groupings for nodes can include those nodes in the same building, within the same city, or geographic region.

Since the failure of a node implies the failure of all links associated with that node a sufficiently general shared risk link group (SRLG) encoding, such as that used in GMPLS routing extensions can explicitly incorporate SRNG information.

5. Node Information (WSON specific)

As discussed in [WSON-Frame] 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. We refer to regenerator block or wavelength converter block as resource block.

A WSON node may include regenerators or wavelength converters arranged in a shared pool. As discussed in [WSON-Frame] 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 we need to know the following:

1. The nodes that support regeneration or wavelength conversion.

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

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

This leads to the following formal high level model:

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

Where

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

First we will address the accessibility of resource blocks then we will discuss their properties.

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 [WSON-Frame] 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 we will also want to our model to include as a minimum the usage state (availability) of individual regenerators or converters in the pool. Models that incorporate more state to further reveal blocking conditions on ingress or egress to particular converters are for further study and not included here.

The three stage model as shown schematically in Figure 1. In this model we assume N ingress ports (fibers), P resource blocks containing one or more identical resources (e.g. wavelength converters), and M egress ports (fibers). Since not all ingress ports can necessarily reach each resource block, the model starts with a resource pool ingress matrix RI(i,p) = {0,1} whether ingress 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 we have a set of ingress port constraints for each resource. Currently we assume that a resource with a resource block can only take a single wavelength on input. We can model each resource block ingress port constraint via a wavelength set mechanism.

Next we have a state vector RA(j) = {0,...,k} which tells us 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, we have a set of resource egress wavelength constraints. These 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.

Finally, we have a resource pool egress matrix RE(p,k) = {0,1} depending on whether the output from resource block p can reach egress port k. Examples of this method being used to model wavelength converter pools for several switch architectures from the literature are given in reference [WC-Pool].

```
      I1   +-------------+                       +-------------+ E1
     ----->|             |      +--------+       |             |----->
      I2   |             +------+ Rb #1  +-------+             | E2
     ----->|             |      +--------+       |             |----->
           |             |                       |             |
           | Resource    |      +--------+       |  Resource   |
           | Pool        +------+        +-------+  Pool       |
           |             |      + Rb #2  +       |             |
           | Ingress     +------+        +-------|  Egress     |
           | Connection  |      +--------+       |  Connection |
           | Matrix      |           .           |  Matrix     |
           |             |           .           |             |
           |             |           .           |             |
      IN   |             |      +--------+       |             | EM
     ----->|             +------+ Rb #P  +-------+             |----->
           |             |      +--------+       |             |
           +-------------+   ^               ^   +-------------+
                             |               |
                             |               |
                             |               |
                             |               |

                    Ingress wavelength    Egress wavelength
                    constraints for       constraints for
                    each resource         each resource
```

Figure 1 Schematic diagram of resource pool model.

Formally we can specify the model as:

<ResourceBlockAccessibility ::= <PoolIngressMatrix>
<PoolEgressMatrix>

[<ResourceWaveConstraints> ::= <IngressWaveConstraints>
<EgressWaveConstraints>

<ResourcePoolState> ::=(<ResourceBlockID><NumResourcesInUse>)...

Note that except for <ResourcePoolState> all the other components of <ResourcePool> are relatively static.

5.2. Resource Signal Constraints and Processing Capabilities

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

<ResourceBlockInfo> ::=
([<ResourceSet>]<InputConstraints><ProcessingCapabilities><OutputConstraints>)*

Where <ResourceSet> 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. The details of these constraints are defined in section 5.3.

<InputConstraints> ::= <ModulationTypeList> <FECTypeList>
<BitRateRange> <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 resource or network element or options concerning the signal properties when leaving the resource or network element.

<OutputConstraints> := <ModulationTypeList><FECTypeList>

5.3. Compatibility and Capability Details

5.3.1. Modulation Type List

Modulation type, also known as optical tributary signal class, comes in two distinct flavors: (i) ITU-T standardized types; (ii) vendor specific types. The permitted modulation type list can include any mixture of standardized and vendor specific types.

```
<modulation-list>::=
[<STANDARD_MODULATION>|<VENDOR_MODULATION>]...
```

Where the STANDARD_MODULATION object just represents one of the ITU-T standardized optical tributary signal class and the VENDOR_MODULATION object identifies one vendor specific modulation type.

5.3.2. FEC Type List

Some devices can handle more than one FEC type and hence a list is needed.

```
<fec-list>::= [<FEC>]
```

Where the FEC object represents one of the ITU-T standardized FECs defined in [G.709], [G.707], [G.975.1] or a vendor-specific FEC.

5.3.3. Bit Rate Range List

Some devices can handle more than one particular bit rate range and hence a list is needed.

```
<rate-range-list>::= [<rate-range>]...

<rate-range>::=<START_RATE><END_RATE>
```

Where the START_RATE object represents the lower end of the range and the END_RATE object represents the higher end of the range.

5.3.4. Acceptable Client Signal List

The list is simply:

```
<client-signal-list>::=[<GPID>]...
```

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

5.3.5. Processing Capability List

We have defined ProcessingCapabilities in Section 5.2 as follows:

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

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>]

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 definition of one additional link metric value for traffic engineering separate from the IP link state routing protocols link metric. 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 (Wavelength) Restrictions

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. Such restrictions could be applied generally to other label types in GMPLS by adding new kinds of restrictions.

```
<PortLabelRestriction> ::= [<GeneralPortRestrictions>...]
[<MatrixSpecificRestrictions>...]
```

<GeneralPortRestrictions> ::= <RestrictionType>
[<RestrictionParameters>]

<MatrixSpecificRestriction> ::= <MatrixID> <RestrictionType>
[<RestrictionParameters>]

<RestrictionParameters> ::= [<LabelSet>...] [<MaxNumChannels>]
[<MaxWaveBandWidth>]

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_WAVELENGTH: Simple wavelength set restriction; The wavelength 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).

WAVEBAND1:   Waveband device with a tunable center frequency and passband. This constraint is characterized by the MaxWaveBandWidth parameters which indicates the maximum width of the waveband in terms of channels. Note that an additional wavelength set 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.

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).

MaxWaveBandWidth is the maximum width of a tunable waveband switching device.

For example, if the port is a "colored" drop port of a ROADM then we have 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.

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 we can isolate 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 we 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.

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> [<ResourcePoolState>]
```

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.

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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