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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, particularly in cases where there are no or a limited number of wavelength converters available. This model currently does not include optical impairments.

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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. In particular this model has particular value in the cases where there are no or a limited number of wavelength converters available in the WSON. 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 does not currently include impairments however optical impairments can be accommodated by the general framework presented here.

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:

- Node Information

- Link Information

- Dynamic Node Information

- 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.

3.2. Node Information

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> [<SwitchedConnectivityMatrix>]
[<FixedConnectivityMatrix>], [<SRNG>] [<WavelengthConverterPool>]

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

3.2.1. Switched Connectivity Matrix

The switched connectivity matrix (SwitchConnectivityMatrix) represents the potential connectivity matrix for asymmetric switches (e.g. ROADMs and such). 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 its highly implementation dependent nature would not be subject to standardization. This is a conceptual M by N matrix representing the potential switched connectivity, where M represents the number of ingress ports and N the number of egress ports. We say this is a "conceptual" since this matrix tends to exhibit structure that allows for very compact representations that are useful for both transmission and path computation [Encode].

SwitchedConnectivityMatrix(i, j) = 0 or 1 depending on whether ingress port i can connect to egress port j for one or more wavelengths.

3.2.2. Fixed Connectivity Matrix

The fixed connectivity matrix (FixedConnectivityMatrix) represents the connectivity for asymmetric fixed devices or the fixed part of a "hybrid" device [Switch]. This is a conceptual M by N matrix, where M represents the number of ingress ports and N the number of egress ports. We say this is a "conceptual" since this matrix tends to exhibit structure that allows for very compact representations.

FixedConnectivityMatrix(i, j) = 0 or 1 depending on whether ingress port i is connected to egress port j for one or more wavelengths.

3.2.3. 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.

3.2.4. Wavelength Converter Pool

A WSON node may include wavelength converters. These are usually arranged into some type of pool to promote resource sharing. There are a number of different approaches used in the design of switches with converter pools. However, from the point of view of path computation we need to know the following:

1. The nodes that support 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.

To model point 2 above we can use a similar technique as used to model ROADMs and optical switches 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 wavelength converters are considered a scarce resource we will also want to our model to include as a minimum the usage state of individual wavelength 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.

We utilize a three stage model as shown schematically in Figure 1. In this model we assume N ingress ports (fibers), P wavelength converters, and M egress ports (fibers). Since not all ingress ports can necessarily reach the converter pool, the model starts with a wavelength pool ingress matrix WI(i,p) = {0,1} whether ingress port i can reach potentially reach wavelength converter p.

Since not all wavelength can necessarily reach all the converters or the converters may have limited input wavelength range we have a set of ingress port constraints for each wavelength converter. Currently we assume that a wavelength converter can only take a single

wavelength on input. We can model each wavelength converter ingress port constraint via a wavelength set mechanism.

Next we have a state vector WC(j) = {0,1} dependent upon whether wavelength converter j in the pool is in use. This is the only state kept in the converter pool model. This state is not necessary for modeling "fixed" transponder system, i.e., systems where there is no sharing. In addition, this state information may be encoded in a much more compact form depending on the overall connectivity structure [WC-Pool].

After that, we have a set of wavelength converter egress wavelength constraints. These constraints indicate what wavelengths a particular wavelength converter can generate or are restricted to generating due to internal switch structure.

Finally, we have a wavelength pool egress matrix WE(p,k) = {0,1} depending on whether the output from wavelength converter 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   |             +------+ WC #1  +-------+             | E2
     ----->|             |      +--------+       |             |----->
           | Wavelength  |                       |  Wavelength |
           | Converter   |      +--------+       |  Converter  |
           | Pool        +------+ WC #2  +-------+  Pool       |
           |             |      +--------+       |             |
           | Ingress     |                       |  Egress     |
           | Connection  |           .           |  Connection |
           | Matrix      |           .           |  Matrix     |
           |             |           .           |             |
           |             |                       |             |
      IN   |             |      +--------+       |             | EM
     ----->|             +------+ WC #P  +-------+             |----->
           |             |      +--------+       |             |
           +-------------+   ^               ^   +-------------+
                             |               |
                             |               |
                             |               |
                             |               |

                    Ingress wavelength    Egress wavelength
                    constraints for       constraints for
                    each converter        each converter
```

Figure 1 Schematic diagram of wavelength converter pool model.

Formally we can specify the model as:

<WavelengthConverterPool> ::= <IngressPoolMatrix>
<IngressPoolConstraints> [<WCPoolState>] <EgressPoolConstraints>
<PoolEgressMatrix>

Note that except for <WCPoolState> all the other components of <WavelengthConverterPool> are relatively static. In addition <WCPoolState> is a relatively small structure compared potentially to the others and hence in a future revision of this document maybe moved to a new section on dynamic node information.

3.2.4.1. OEO Wavelength Converter Info

An OEO based wavelength converter can be characterized by an input wavelength set and an output wavelength set. In addition any constraints on the signal formats and rates accommodated by the converter must be described. Such a wavelength converter can be modeled by:

<OEOWavelengthConverterInfo> ::= <RegeneratorType> [<BitRateRange>] [<AcceptableSignals>]

Where the RegeneratorType is used to model an OEO regenerator. Regenerators are usually classified into three types [G.sup39]. Level 1 provides signal amplification, level 2 amplification and pulse shaping, and level 3 amplification, pulse shaping and timing regeneration. Level 2 regenerators can have a restricted bit rate range, while level 3 regenerators can also be specialized to a particular signal type.

BitRateRange: indicates the range of bit rates that can be accommodated by the wavelength converter.

AcceptableSignals: is a list of signals that the wavelength converter can handle. This could be fairly general for Level 1 and Level 2 regenerators, e.g., characterized by general signal properties such as modulation type and related parameters, or fairly specific signal types for Level 3 based regenerators.

3.3. Link Information

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. 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 route protocols and new information that maybe needed by the RWA process.

```
<LinkInfo> ::=  <LinkID> [<AdministrativeGroup>] [<InterfaceCapDesc>]
[<Protection>] [<SRLG>]... [<TrafficEngineeringMetric>]
[<MaximumBandwidthPerChannel>] <[SwitchedPortWavelengthRestriction>]
[<FixedPortWavelengthRestriction>]
```

3.3.1. Link ID

```
<LinkID> ::=  <LocalLinkID> <LocalNodeID> <RemoteLinkID>
<RemoteNodeID>
```

Here we can generally identify a link via a combination of local and remote node identifiers along with the corresponding local and remote link identifiers per [RFC4202, RFC4203, RFC5307]. Note that reference [RFC3630] provides other ways to identify local and remote link ends in the case of numbered links.

3.3.2. 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.

3.3.3. 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.

3.3.4. 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.

3.3.5. 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.

3.3.6. 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...

3.3.7. Maximum Bandwidth Per Channel

TBD: Need to check if we still want this.

3.3.8. Switched and Fixed Port Wavelength Restrictions

Switch and fixed port wavelength restrictions (SwitchedPortWavelengthRestriction, FixedPortWavelengthRestriction) model the wavelength restrictions that various optical devices such as OXCs, ROADMs, and waveband mulitplexers may impose on a port. This plays an important role in fully characterizing a WSON switching device [Switch]. The SwitchedPortWavelengthRestriction is used with ports specified in the SwitchedConnectivityMatrix while the FixedPortWavelengthRestriction is used with ports specified in the FixedConnectivityMatrix. Reference [Switch] gives an example where both switch and fixed connectivity matrices are used and both types of constraints occur on the same port.

<SwitchedPortWavelengthRestriction> ::= <port wavelength restriction>

<FixedPortWavelengthRestriction> ::= <port wavelength restriction>

<port wavelength restriction> ::= <RestrictionKind>
<RestrictionParameters> <WavelengthSet>

<RestrictionParameters> ::= <MaxNumChannels> [<OthersTBD>]...

Where WavelengthSet is a conceptual set of wavelengths, MaxNumChannels is the number of channels permitted on the port, and RestrictionKind can take the following values and meanings:

SIMPLE: Simple wavelength selective restriction. Max number of channels indicates the number of wavelengths permitted on the port and the accompanying wavelength set indicates the permitted values.

WAVEBAND1:   Waveband device with a tunable center frequency and passband. In this case the maximum number of channels indicates the maximum width of the waveband in terms of the channels spacing given in the wavelength set. The corresponding wavelength set is 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.

For example, if the port is a "colored" drop port of a ROADM then the value of RestrictionKind = SIMPLE for a simple wavelength selective restriction, the MaxNumberOfChannels = 1, and the wavelength restriction is just a wavelength set consisting of a single member corresponding to the frequency of the permitted wavelength. See [Switch] for a complete waveband example.

3.4. Dynamic Link Information

By dynamic information we mean information that is subject to change on a link with subsequent connection establishment or teardown. Currently for WSON the only information we currently envision is wavelength availability and wavelength in use for shared backup purposes.

```
<DynamicLinkInfo> ::=  <LinkID> <AvailableWavelengths>
[<SharedBackupWavelengths>]
```

Where

```
<LinkID> ::= <LocalLinkID> <LocalNodeID> <RemoteLinkID>
<RemoteNodeID>
```

AvailableWavelengths is a set of wavelengths available on the link.

SharedBackupWavelengths is a set of wavelengths currently used for shared backup protection on the link. An example usage of this information in a WSON setting is given in [Shared].

3.5. Dynamic Node Information

Dynamic node information is used to hold information for a node that can change frequently. Currently only wavelength converter pool information is included as a possible (but not required) information sub-element.

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

Where NodeID is a node identifier and the exact form of the wavelength converter pool status information is TBD.

4. 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.

5. IANA Considerations

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

6. Acknowledgments

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

7. References

7.1. Normative References

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