Information Model for Impaired Optical Path Validation
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Abstract

This document provides an information model for the optical impairment characteristics of optical network elements for use in GMPLS/PCE control plane protocols and mechanisms. This information model supports Impairment Aware Routing and Wavelength Assignment (IA-RWA) in optical networks in which path computation and optical path validation are essential components. This is not a general network management information model.

This model is based on ITU-T defined optical network element characteristics as given in ITU-T recommendation G.680 and related specifications. This model is intentionally compatible with a previous impairment free optical information model used in optical path computations and wavelength assignment.

Conventions used in this document

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in RFC-2119 [RFC2119].

Table of Contents

1. Introduction....................................................3
2. Optical Impairment Information Model........................3
   2.1. Network Element Wide Parameters..............................4
   2.2. Per Port Parameters........................................4
   2.3. Port to Port Parameters..................................5
   2.4. Frequency Dependent Parameters............................5
3. Encoding Considerations........................................6
4. Usage of Parameters in Optical Path Validation.................6
5. Security Considerations.........................................7
6. IANA Considerations...............................................7
7. Conclusions.....................................................7
8. Acknowledgments................................................7
APPENDIX A: Distributed Impairment Accumulation Model...........8
   A.1. Distributed Computation of OSNR............................9
   A.2. Distributed Computation of Residual Dispersion............10
   A.3. Distributed Computation of PMD............................10
   A.4. Distributed Computation of PDL...........................11
APPENDIX B: Optical Parameters.................................12
   B.1. Parameters for NEs without optical amplifiers...........12
   B.2. Additional parameters for NEs with optical amplifiers....14
References.....................................................................16
   8.1. Normative References........................................16
   8.2. Informative References......................................16
Author’s Addresses..................................................17
Intellectual Property Statement.................................17
Disclaimer of Validity..............................................18

1. Introduction

Impairments in optical networks can be accounted for in a number of ways as discussed in reference [Imp-Frame]. This document provides an information model for path validation in optical networks utilizing approximate computations. The definitions, characteristics and usage of the optical parameters that form this model are based on ITU-T recommendation G.680 [G.680]. This impairment related model is intentionally compatible with the impairment free model of reference [RWA-Info]. Although this document focuses on the optical impairment parameters from a control plane point of view, Appendix B provides a list of optical parameter definitions from ITU-T G.680 and related documents.

This document only covers the links and network elements. The end system models (i.e., transmitter and receiver models based on the interfaces defined in G.698.1 and G.698.2) are subject to further study.

2. Optical Impairment Information Model

The definitions of optical impairment parameters of network elements and examples of their use can be found in [G.680] and related documents (also see Appendix B). From an information modeling and control plane perspective, one basic aspect of a given parameter is the scope of its applicability within a network element. In particular we need to know which parameters will (a) apply to the network element as a whole, (b) can vary on a per port basis for a network element, and (c) can vary based on ingress to egress port pairs. A second orthogonal aspect of impairment parameters is whether a parameter exhibits a strong frequency variation over the optical frequencies supported by the subnetwork.
2.1. Network Element Wide Parameters

Based on the definitions in [G.680] and related documents the following parameters apply to the network element as a whole. At most one of these parameters is required per network element.

1. Channel frequency range (GHz, Max, Min)
2. Channel insertion loss deviation (dB, Max)
3. Ripple (dB, Max)
4. Channel chromatic dispersion (ps/nm, Max, Min)
5. Differential group delay (ps, Max)
6. Polarization dependent loss (dB, Max)
7. Reflectance (passive component) (dB, Max)
8. Reconfigure time/Switching time (ms, Max, Min)
9. Channel uniformity (dB, Max)
10. Channel addition/removal (steady-state) gain response (dB, Max, Min)
11. Transient duration (ms, Max)
12. Transient gain increase (dB, Max)
13. Transient gain reduction (dB, Max)
14. Multichannel gain-change difference (inter-channel gain-change difference) (dB, Max)
15. Multichannel gain tilt (inter-channel gain-change ratio) (dB, Max)

2.2. Per Port Parameters

The following optical parameters may exhibit per port dependence, hence may be specified at most once for each port of the network element.

1. Total input power range (dBm, Max, Min)
2. Channel input power range (dBm, Max, Min)
3. Channel output power range (dBm, Max, Min)
4. Input reflectance (dB, Max) (with amplifiers)
5. Output reflectance (dB, Max) (with amplifiers)
6. Maximum reflectance tolerable at input (dB, Min)
7. Maximum reflectance tolerable at output (dB, Min)
8. Maximum total output power (dBm, Max)

2.3. Port to Port Parameters

The following optical parameters may exhibit a port-to-port dependence and hence may be specified at most once for each ingress/egress port pair of the network element.

1. Insertion loss (dB, Max, Min)
2. Isolation, adjacent channel (dB, Min)
3. Isolation, non-adjacent channel (dB, Min)
4. Channel extinction (dB, Min)
5. Channel signal-spontaneous noise figure (dB, Max)
6. Channel gain (dB, Max, Min)

2.4. Frequency Dependent Parameters

Many of the previously mentioned parameters can exhibit significant frequency dependence over the range of wavelength supported by a subnetwork. In reference [G.680] parameters denoted as related to "channel" could exhibit significant frequency variation that would need to be encoded efficiently. These parameters may include:

1. Channel insertion loss deviation (dB, Max)
2. Channel chromatic dispersion (ps/nm, Max, Min)
3. Channel uniformity (dB, Max)
4. Insertion loss (dB, Max, Min)
5. Channel extinction (dB, Min)
6. Channel signal-spontaneous noise figure (dB, Max)

7. Channel gain (dB, Max, Min)

Finalization of this list is TBD and will need liaison with ITU-T.

3. Encoding Considerations

The units for the various parameters include GHz, dB, dBm, ms, ps, and ps/nm. These are typically expressed as floating point numbers. Due to the measurement limitations inherent in these parameters single precision floating point, e.g., 32 bit IEEE floating point, numbers should be sufficient.

For realistic optical network elements per port and port-to-port parameters typically only assume a few values. For example, the channel gain of a ROADM is usually specified in terms of input to drop, add to output, and input to output. This implies that many port and port-to-port parameters could be efficiently specified, stored and transported by making use of the Link Set Sub-TLV and Connectivity Matrix Sub-TLV of reference [Encode].

For parameters that vary with frequency we have the following options:

1. Explicit parameter list with associated frequencies: Here we would give the parameter and frequencies it applies to. We would need as many of these parameter/frequency pairs as necessary to cover all the frequencies and parameters. This could get large for a high channel count system with strong frequency dependencies in some parameters.

2. Provide "standardized" general interpolation formulas and parameters for use over an entire frequency range or sub-range.

3. Use parameter specific interpolation formulas based on ITU-T and other standards. For example in reference [G.650.1]Annex A equations and fitting coefficients are given for chromatic dispersion interpolation. Such formulas may be valid over an entire frequency range or a sub-range.

4. Usage of Parameters in Optical Path Validation

Given an optical path and the optical characteristics of each network element along the path we can then use these characteristics to
validate the path. We envision that these parameters will be made available via some mechanism to the entity which validates optical paths. Refer to [Imp-Frame] for architectural options in which impairment validation for an optical path is defined.

Sections 9 and 10 of G.680 give techniques and formulas for use in calculating the impact of a cascade of network elements such as occurs along an optical signal path. These range from relatively simple bounds on the sum of uncompensated chromatic dispersion (residual dispersion) to more elaborate formulas for overall optical signal to noise ratio (OSNR) computations based on multiple parameters including noise factor.

To further aid understanding and use of these optical parameters Appendix I of [G.680] provides example parameter values for different network element types and appendix II provides examples of computations involving the cascades of network elements along a path.

5. Security Considerations

This document defines an information model for impairments in optical networks. If such a model is put into use within a network it will by its nature contain details of the physical characteristics of an optical network. Such information would need to be protected from intentional or unintentional disclosure.

6. IANA Considerations

This draft does not currently require any consideration from IANA.

7. Conclusions

The state of standardization of optical device characteristics has matured from when initial IETF work concerning optical impairments was investigated in [RFC4054]. Relatively recent ITU-T recommendations provide a standardized based of optical characteristic definitions and parameters that control plane technologies such as GMPLS and PCE can make use of in performing optical path validation. The enclosed information model shows how readily such ITU-T optical work can be utilized within the control plane.

8. Acknowledgments

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APPENDIX A: Distributed Impairment Accumulation Model

In reference [Imp-Frame] an alternative impairment aware RWA control plane based on distributed impairment validation was discussed. In such a scheme the preceding impairment information model would not be distributed via a link state IGP, instead a set of impairment parameters would be computed along the proposed path and a final decision on whether the path is viable would be made based on these accumulated impairment parameters. It should be noted that these accumulated impairment parameters are estimated at each node along the path and not measured.

When signaling a path we think of the "nodes" as being the switching nodes along the path. In the case of optical impairments the properties of the links (WDM line systems) are just as important as the properties of the nodes. In the following we will assume that the switching nodes (GMPLS nodes) will act on behalf of all the line systems corresponding to their egress ports. In particular this implies that some how these nodes will obtain the line system impairment information.

![Diagram of an optical network with line systems, PXCs, ROADMs, and multiplexers.](image)

In Figure 1 we show an example system from appendix II of [G.680]. This diagram shows the DWDM line systems including amplifiers, BA = booster amplifier, LA = line amplifier. For distributed impairment validation we would group the line systems with their preceding nodes as shown for computational purposes.

Section 9 of ITU-T G.680 [G.680] shows how various impairment parameters accumulate and this suggests that the following parameters or subset thereof could be used in distributed impairment estimation:

- Optical Signal to Noise Ratio (OSNR)
- Residual Dispersion (chromatic)
For each of the above the units and accumulation procedure needs to be defined. In the following we suggest units and procedures for the above for which computation of cascaded elements are suitably defined in [G.680]. Note: ONE = Optical Network Element.

A.1. Distributed Computation of OSNR

Section 9.1 of ITU-T G.680 gives several equivalent formulas for the estimation of OSNR. For distributed impairment validation the following formula from [G.680] is convenient:

\[ \text{OSNR}_{\text{out}} = -10\log(\text{Term1} + \text{Term2}) \]

Where

\[ \text{Term1} = 10^{-\left(\text{OSNR}_{\text{in}}/10\right)} \], and
\[ \text{Term2} = 10^{-\left((P_{\text{in}}-NF-10\log(h\cdot v\cdot vr))/10\right)} \]

and we have the following additional definitions:

- \( \text{OSNR}_{\text{out}} \) is the output optical signal to noise ratio in dB of the ONE
- \( \text{OSNR}_{\text{in}} \) is the input optical signal to noise ratio in dB of the ONE
- \( P_{\text{in}} \) is the channel power (dBm) at the input port of the ONE
- \( NF \) is the noise figure (dB) of the relevant path through the ONE
- \( h \) is Planck’s constant (in mJ\*s to be consistent with \( P_{\text{in}} \) in dBm)
- \( v \) is the optical frequency in Hz
- \( vr \) is the reference bandwidth in Hz (usually the frequency equivalent of 0.1nm)

From the previous formula, a distributed computation of OSNR requires knowing the \( \text{OSNR}_{\text{in}} \) and the \( P_{\text{in}} \) based on computations from the previous node along the path. The noise figure, \( F \), is something that...
the current node performing the computation would know along with the
frequency, \( v \), and the reference bandwidth \( v_r \) (TBD: confirm with ITU-
T).

The control plane will need to distribute the following information
from node to node along the path:

- \( \text{OSNR}_{\text{in}} \) (this is the accumulated OSNR along the path)(dB)
- \( P_{\text{in}} \) (this is the estimated power into the next node)(dBm)

The input power would be calculated by the previous node by taking
into account gain and attenuation on the link between the nodes.

A.2. Distributed Computation of Residual Dispersion

The residual dispersion for a path is required to be bounded, in
particular from [G.680] equation 9-4:

\[
\text{Min } RD < \text{Residual Dispersion} < \text{Max } RD
\]

Where Min RD and Max RD are the minimum and maximum tolerable
residual dispersion for a particular transmitter/receiver
combination.

The residual dispersion for a cascade of network elements can be
computed by [G.680] equation 9-5:

\[
\text{Residual dispersion} = \sum(\text{fiber dispersion}) + \sum(\text{DCM dispersion}) + \sum(\text{ONE dispersion})
\]

Where DCM dispersion is from Dispersion Compensation Modules (DCM),
and ONE dispersion is due to optical network elements.

Although the residual dispersion formula is a relatively simple
linear formula [G.680] indicates two possible methods for its
evaluation (a) Worst-case upper and lower bounds, or (b) Statistical
approach. In case (a) two parameters would need to be accumulated
along the path a worst case upper and lower bound. In case (b) some
type of statistical information would be needed in [G.680] mean and
standard deviation are used under a Gaussian assumption.

A.3. Distributed Computation of PMD

The accumulated impact of line system and ONE polarization mode
dispersion can be estimated via the formula [G.680] equation (9-6):
DGDmax_link = (DGDmxf^2 + S^2*sum_i(PMDc_i^2))^(1/2)

where

DGDmax_link is the max link DGD (ps)

DGDmxf is the max concatenated optical fiber cable DGD (ps)

S is the Maxwell adjustment factor(Table 9-2 of [G.680])

PMDc_i is the PMD value for the ith component (ps)

Under a distributed computation approach the above could be computed by keeping track of DGDmxf and the running sum of PMDc_i^2. The Maxwell adjustment factor and final square root can be applied at the final node in the path. [Question for Q6: does DGDMaxf^2 need to be accumulated over the different link segments?]

A.4. Distributed Computation of PDL

See section 9.3.2 of [G.680]
APPENDIX B: Optical Parameters

The following provides an annotated list of optical characteristics from ITU-T recommendation G.680 [G.680] for use in optical path impairment computations. For each parameter we specify the units to be used, whether minimum or maximum values are used, and whether the parameters applies to the optical network element as a whole, on a per port basis or on a port-to-port pair basis.

Not all these parameters will apply to all devices. The main differentiation in G.680 comes from those network elements that include or do not include optical amplifiers.

B.1. Parameters for NEs without optical amplifiers

Channel frequency range (GHz, Max, Min): [G.671] The frequency range within which a DWDM device is required to operate with a specified performance. For a particular nominal channel central frequency, fnomi, this frequency range is from fimin = (fnomi - dfmax) to fimax = (fnomi + dfmax), where dfmax is the maximum channel central frequency deviation. Nominal channel central frequency and maximum channel central frequency deviation are defined in ITU-T Rec. G.692.

Insertion loss (dB, Port-Port, Max, Min): [G.671] It is the reduction in optical power between an input and output port of a WDM device in decibels (dB).

Channel insertion loss deviation (dB, Max): [G.671] This is the maximum variation of insertion loss at any frequency within the channel frequency range (DWDM devices) or channel wavelength range (CWDM and WWDM devices).

Ripple (dB, Max): [G.671] For WDM devices and tuneable filters, the peak-to-peak difference in insertion loss within a channel frequency (or wavelength) range.

Channel chromatic dispersion (ps/nm, Max, Min): [G.650.1] Change of the group delay of a light pulse for a unit fibre length caused by a unit wavelength change.

Differential group delay (ps, Max): [G.671] Polarization Mode Dispersion (PMD) is usually described in terms of a Differential Group Delay (DGD), which is the time difference between the principal States of Polarization (SOPs) of an optical signal at a particular wavelength and time.
Polarization dependent loss (dB, Max): [G.671] Maximum variation of insertion loss due to a variation of the state of polarization (SOP) over all SOPs.

Reflectance (dB, Max): [G.671] The ratio of reflected power Pr to incident power, Pi at a given port of a passive component, for given conditions of spectral composition, polarization and geometrical distribution.

Isolation, adjacent channel (dB, Min, Port-Port): [G.671] The adjacent channel isolation (of a WDM device) is defined to be equal to the unidirectional (far-end) isolation of that device with the restriction that x, the isolation wavelength number, is restricted to the channels immediately adjacent to the (channel) wavelength number associated with port o.

Isolation, non-adjacent channel (dB, Min, Port-Port): [G.671] The non-adjacent channel isolation (of a WDM device) is defined to be equal to the unidirectional (far-end) isolation of that device with the restriction that x, the isolation wavelength number, is restricted to each of the channels not immediately adjacent to the (channel) wavelength number associated with port o.

Note: [G.671] In a WDM device able to separate k wavelengths (w1, w2, ..., wk) radiation coming from one input port into k output ports, each one nominally passing radiation at one specific wavelength only. The unidirectional (far-end) isolation is a measure of the part of the optical power at each wavelength exiting from the port at wavelengths different from the nominal wavelength relative to the power at the nominal wavelength.

Channel extinction (dB, Min, Port-Port): [G.671] Within the operating wavelength range, the difference (in dB) between the maximum insertion loss for the non-extinguished (non-blocked) channels and the minimum insertion loss for the extinguished (blocked) channels.

Reconfigure time (ms, Max, Min): [G.680] The reconfigure time (of an ROADM) is the elapsed time measured from the earliest point that the actuation energy is applied to reconfigure the ONE to the time when the channel insertion loss for all wanted channels has settled to within 0.5 dB of its final steady state value and all other parameters of the device (e.g., isolation and channel extinction) are within the allowed limits.

Switching time (for PXC) (ms, Max, Min): [G.671] The elapsed time it takes the switch to turn path io on or off from a particular initial...
state, measured from the time the actuation energy is applied or removed.

Channel uniformity (dB, Max): [G.671] The difference (in dB) between the powers of the channel with the most power (in dBm) and the channel with the least power (in dBm). This applies to a multichannel signal across the operating wavelength range.

B.2. Additional parameters for NEs with optical amplifiers

Total input power range (dBm, Max, Min, Port): [G.661] The range of optical power levels at the input for which the corresponding output signal optical power lies in the specified output power range, where the OA performance is ensured.

Channel input power range (dBm, Max, Min, Port): see above.

Channel output power range (dBm, Max, Min, Port): [G.661] The range of optical power levels at the output of the OA for which the corresponding input signal power lies in the specified input power range, where the OA performance is ensured.

Channel signal-spontaneous noise figure (dB, Max, Port-Port) [G.661] The signal-spontaneous beat noise contribution to the noise figure, expressed in dB.

Input reflectance (dB, Max, Port): [G.661] The maximum fraction of incident optical power, at the operating wavelength and over all states of input light polarization, reflected by the OA from the input port, under nominal specified operating conditions, expressed in dB.

Output reflectance (dB, Max, Port): [G.661] The fraction of incident optical power at the operating wavelength reflected by the OA from the output port, under nominal operating conditions, expressed in dB.

Maximum reflectance tolerable at input (dB, Min, Port): [G.661] The maximum fraction of power, expressed in dB, exiting the optical input port of the OA which, when reflected back into the OA, allows the device to still meet its specifications.

Maximum reflectance tolerable at output (dB, Min, Port): [G.661] The maximum fraction of power, expressed in dB, exiting the optical output port of the OA which, when reflected back into the OA, allows the device to still meet its specifications.
Maximum total output power (dBm, Max, Port): [G.661] The highest signal optical power at the output that can be obtained from the OA under nominal operating conditions.

Channel addition/removal (steady-state) gain response (dB, Max, Min): [G.661] For a specified multichannel configuration, the steady-state change in channel gain of any one of the channels due to the addition/removal of one or more other channels, expressed in dB.

Transient duration (ms, Max): [G.661] The time period from the addition/removal of a channel to the time when the output power level of that or another channel reaches and remains within ± N dB from its steady-state value.

Transient gain increase (dB, Max): [G.661] For a specified multichannel configuration, the maximum change in channel gain of any one of the channels due to the addition/removal of one or more other channels during the transient period after channel addition/removal, expressed in dB.

Transient gain reduction (dB, Max): see above.

Channel gain (dB, Max, Min, Port-Port): [G.661] Gain for each channel (at wavelength \( w_j \)) in a specified multichannel configuration, expressed in dB.

Multichannel gain-change difference (inter-channel gain-change difference) (dB, Max): [G.661] For a specified channel allocation, the difference of change in gain in one channel with respect to the change in gain of another channel for two specified sets of channel input powers, expressed in dB.

Multichannel gain tilt (inter-channel gain-change ratio)(dB, Max): [G.661] The ratio of the changes in gain in each channel to the change in gain at a reference channel as the input conditions are varied from one set of input channel powers to a second set of input channel powers, expressed in dB per dB.
8.1. Normative References


8.2. Informative References


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