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Impairment Constraints for Routing in All-Optical Networks

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1. Status of this Memo

2. Abstract

In the not too distant future, signals carried between two endpoints will be transmitted in an all-optical domain over a multi-hop path. Such transparent networks consist of photonic switches, optical add/drop multiplexers, optical amplifiers, optical regenerators, and fiber. Signaling for such routes needs to account for optical impairments in the path. This draft discusses a number of optical parameters and proposes optical constraints as enhancements to the routing protocols (for a subset of the parameters).

3. Introduction

Recently, a lot of work has been done to use the Generalized MPLS control plane [ABB01] to dynamically provision resources and to provide network survivability using protection and restoration techniques for all-optical networks. The optical networks presently being deployed may be called "opaque" ([TGN98]) - each link is optically isolated by transponders doing O/E/O conversions from other links. These transponders are quite expensive and they also constrain the rapid evolution to new services - for example, they tend to be bit rate and format specific. Thus there are strong motivators to introduce "domains of transparency" - all-optical networks. Such _transparent_ networks consist of photonic switches, optical add/drop multiplexers, optical amplifiers, optical regenerators, and fiber.

Current proposals on routing protocol extensions (see [KRB01a] and [KRB01b]) consider opaque networks where all routes have adequate signal quality. Here, we consider all-optical networks. In order to take full advantages of potential cost and operational efficiencies offered by the all-optical networks, we assume that a domain of transparency may be too large to ensure that all potential routes have adequate signal quality for all connections. In order to obtain paths for the connections, physical impairments of various links in the all-optical network need to be accounted for. Our goal is to understand the impacts of the various types of impairments in this environment and to recommend a practical set of parameters that need to be accounted for. This necessitates enhancing the routing protocols to advertise the selected attributes which are necessary to compute constrained shortest paths.

The organization of the remainder of this document is as follows. In Section 4, we discuss the various optical parameters that may need to be announced. Furthermore, we outline the TLVs for the (specifically for the OSPF and IS-IS routing protocols) parameters that are to be flooded into the routing database.

4. Optical Parameters

In this section, we identify the various attributes that are potential candidates for being flooded using the routing protocols. We are only concerned with the impairments that may have impacts on possible routes chosen through a transparent network. According to the requirements specified in [CST00], we account for two key linear impairments, namely Polarization Mode Dispersion (PMD) and Optical Signal to Noise Ratio (OSNR). There are other performance related parameters, e.g., modulator extinction ratio, jitter, Q-factor, etc outlined in [CBD00], that need to be taken into account when designing the transmission system. These parameters are either not route dependent, or implicitly reflected by the PMD and OSNR constraints or included in the OSNR margin described in section 4.3.

4.1. Polarization Mode Dispersion (PMD)

PMD management requires that the time-average differential group delay (DGD) between two orthogonal state of polarizations, tau be less than a fraction a of the bit duration, T = 1/B, where B is the bit rate. The value of a depends on three major factors, 1) margin allocated to PMD, e.g., 1dB; 2) targeting outage probability, e.g., 4x10-5; 3) sensitivity of receiver to DGD. A typical value for a is 0.1[ITU].

Assume that the transparent segment consists of K links, with each link k having a PMD value of tau(k). The PMD value of a link tau(k) is a function of the length and fiber PMD parameter of each fiber span on the link. The constraint on overall path PMD becomes the sum of squares of the PMD parameter across all links to be less than a^2/B^2. Hence, for routing constraint checking purposes regarding PMD, the only link dependent information that needs to be propagated or is tau(k)^2 (the square of the polarization mode dispersion).

In OSPF, the PMD parameter is represented as a sub-TLV of the Link TLV in the Traffic Engineering LSA, with type 15. The length of the sub-TLV is four-octets and specifies the square of the polarization mode dispersion (in IEEE floating point format, the unit being pico seconds squared). The format of the PMD sub-TLV is as shown:

```
 0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|  Type = 15                    |         Length = 4            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Polarization Mode Dispersion Square                |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In IS-IS, we enhance the sub-TLVs for the extended IS reachability TLV. The length of the PMD sub-TLV is four-octets and specifies the square of the polarization mode dispersion (in IEEE floating point format, the unit being pico seconds squared). Specifically, we add the following sub-TLV:

Sub-TLV type	Length(in bytes)	Name
21	4	PMD Type

4.2 Optical Signal to Noise Ratio (OSNR)

Amplifier Spontaneous Emission (ASE) degrades the signal to noise ratio. An acceptable optical SNR level (SNRmin) which depends on the bit rate, transmitter-receiver technology (e.g., FEC), and margins allocated for other impairments, needs to be maintained at the receiver. Vendors currently provide OTS engineering rules defining maximum span length and number of spans that ensure that all routes meet this requirement. For larger transparent domains, more detailed OSNR computations will be needed to determine whether the OSNR level on a given all-optical service or restoration route has acceptable OSNR.

Assume P is the average optical power launched at the transmitter, and each link k generates noise power N(k). The OSNR constraint for path computation becomes the sum of the noise power across all links in the path must be less than P/ SNRmin.

In OSPF, the Noise parameter is represented as a sub-TLV of the Link TLV in the Traffic Engineering LSA, with type 16. The length of the sub-TLV is four-octets and specifies the noise power (in IEEE floating point format, the unit being dBm). The format of the Noise sub-TLV is as shown:

```
  0                   1                   2                   3
  0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |  Type = 16                     |         Length = 4            |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
 |                      Noise Parameter                           |
 +-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

In IS-IS, we enhance the sub-TLVs for the extended IS reachability TLV. The length of the noise sub-TLV is four-octets and specifies the noise power of the link (in IEEE floating point format, the unit being dBm). Specifically, we add the following sub-TLV:

```
     Sub-TLV type  Length(in bytes)   Name
        21           4              Noise parameter Type
```

4.3 OSNR Margin and Receiver OSNR requirements

As an additional constraint, a network-wide margin on the OSNR accounts for a number of other additional parameters that are not spelled out explicitly in the above TLVs. For example, other major impairments are:

1. Polarization-Dependent Loss (PDL): It is required that the total PDL on the path to be within some acceptable limit, typically 1dB margin in OSNR.
2. Chromatic Dispersion: In general, this impairment can be adequately (but not optimally) compensated for on a per-link basis, and/or at system initial setup time.
3. Crosstalk: Since crosstalk in the system affects Q, it can be factored in with some margin in Q. As a result, one can increase the OSNR requirement by some modified margin.
4. Nonlinear Impairments: One could assume that nonlinear impairments are bounded and increase the required OSNR level by X dB, where X for performance reasons would be limited to 1 or 2 dB, consequently setting a limit on the maximum number of spans. For the approach described here to be useful, it is desirable for this span limit to be longer than that imposed by the constraints which can be treated explicitly.

Furthermore, it is assumed that all nodes in the network have a table of the minimum value of the OSNR required to transmit

information at a specified bit rate for a given transceiver technology (e.g. FEC).

5. Security Considerations

The enhancements do not introduce any additional security considerations.

6. Acknowledgments

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7. References

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