Regeneration Algorithms

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Overview

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2. Impairment-aware Metrics
3. Regeneration Strategies
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Factors Affecting Regeneration

Factors Affecting Regeneration

1. Optical Fiber Impairments for Propagation Distance
   - Linear impairments (Attenuation, dispersion)
   - Nonlinear impairments (Stimulated scattering, Kerr effects)
2. Network Element Effects on Cascadability
   - Filtering (Attenuation, distortion)
   - Switching leakage (Crosstalk)
   - Polarization-dependent loss
   - Dispersion
3. Transmission System Design
   - Amplification type (EDFA, Raman)
   - Fiber type (NDSF, NZ-DSF, DSF, SMF, heterogeneous)
   - Channel spacing (10, 25, 50, 100 GHz, mixed)
   - Modulation format (OOK, DPSK, DQPSK, DP-QPSK, mixed)
   - Transmission technology (Coherent, incoherent, mixed)
   - Compensation technology (FEC, DCF, EDC, DSP)
   - Operational problems (Splicing, aging)

Regeneration Rules

Regenerate a connection if

1. OSNR is below N
2. accumulated dispersion is above D
3. accumulated PMD is above P
4. number of network elements optically bypassed is greater than E

Note that

1. Consider a margin for aging, splicing, son on.
2. The regeneration rules may be vendor-specific.
3. Sometimes, several rules should be satisfied.
4. The rules thresholds may depend on network traffic and situation.

Impairment-aware Metrics

Link Noise Figure

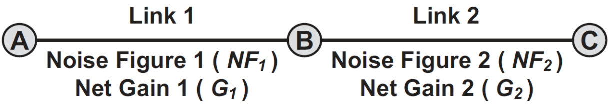

Figure: Two consecutive long-haul links, each with their respective NFs and net gains. In long-haul communications with inline amplifiers, the received OSNR determine the signal quality, BER, and optical reach.

1. Link noise figure: $NF_{Link} = \frac{OSNR_{LinkBegin}}{OSNR_{LinkEnd}}$
2. Friis noise figure formula: $NF_{tot} = NF_1 + \frac{NF_2 - 1}{G_1} + \frac{NF_3 - 1}{G_1 G_2} + \cdots$
3. Unit gain assumption: $NF_{tot} \approx NF_1 + NF_2 + NF_3 + \cdots$

Element Noise Figure

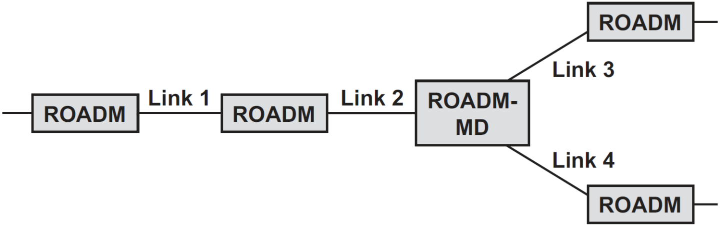

Figure: The NF of each link needs to be adjusted to account for the NF of the network elements at either end of the link. For example, the NF of Link 2 (25 dB) is incremented by half of the NF of a ROADM (16 dB) and half of the NF of a ROADM-MD (17 dB) as $10^{\frac{25}{10}} + 10^{\frac{13}{10}} + 10^{\frac{14}{10}} = 361.3$. Now, a shortest path algorithm with the metric of noise figure can be run to find the routes. To determine where regeneration is required for the routed paths, based on accumulated noise, one adds up the NF on a link-by-link basis. Regeneration must occur before the total NF grows to a certain threshold.

Other Metrics

Cohesive impairment-aware routing with a metric composed of

- Noise, dispersion, and optical bypass
  - Noise figure-limited optical reach (nominally $L = 2000$ km)
  - Chromatic dispersion-limited optical reach (nominally $L = 3000$ km for coherent transmission with EDC and $L = 600$ km for incoherent transmission without DCF)
  - Polarization-mode dispersion-limited optical reach (nominally $L = 10000$ km for coherent transmission with EDC and $L = 2000$ km for incoherent transmission without DCF)
  - Optical bypass-limited optical reach (nominally $L = 2000$ km for 8 optical bypasses with a typical bypass inter distance of 250 km in a backbone network)
- Noise, dispersion, optical bypass, crosstalk, nonlinear effects
  - Quality factor
  - Quality transmission
  - Quality penalty

Regeneration Strategies

Islands of Transparency

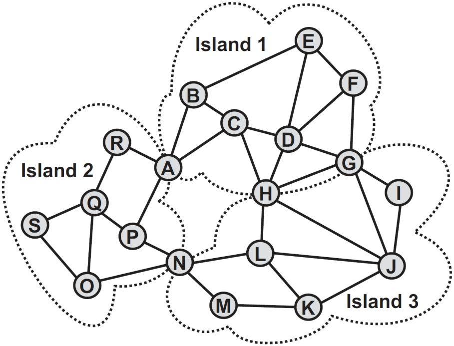

Figure: This network is partitioned into three islands of transparency. Any traffic within an island does not need regeneration. Any traffic between islands does require regeneration. The boundary nodes have hybrid architecture. Here, no calculation for regeneration sites is required. The islands are isolated due to hybrid architecture. Island isolation allows a heterogeneous network and facilitates network upgrade. This strategy may lead to unnecessary regeneration and extra cost. Partitioning the network into islands needs heuristic algorithms. A simple idea to find islands is to select a mesh and try to extend to its neighboring meshes as long as regeneration is not require.

Designated Regeneration Sites

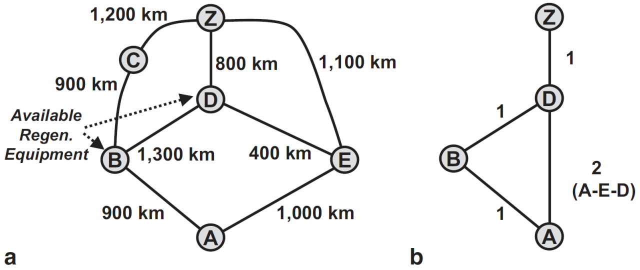

Figure: Here, a subset of the nodes are designated as regeneration sites. The regeneration sites may have O-E-O or ROADM architecture. The routing process can take into account the limited number of regeneration sites using reachability graph. Traffic streams or network topology can be used for designating the regeneration sites. Using traffic stream approach, the node is designated for regeneration based on the number of traffic streams that become feasible with regeneration allowed at that site. The idea in network topology approach is finding connected dominating sets. A connected dominating set S is a subset of the topology graph nodes such that all nodes not in S are directly connected to at least one of the nodes in S.

Designated Regeneration Sites

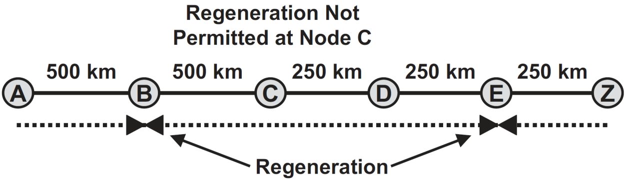

Figure: Assume that the optical reach is 1000 km. A connection between Nodes A and Z is ideally regenerated in just Node C. However, because it is assumed that regeneration is not permitted at this site, the connection is regenerated at both Nodes B and E instead. So, this strategy may lead to extra regeneration and cost. Further, the full regeneration capacity may not be utilized, especially for the O-E-O architecture. On the other hand, regeneration may limit the number of add/drop ports in the regeneration sites. This strategy leads to streamlined equipment pre-deployment.

Selective Regeneration

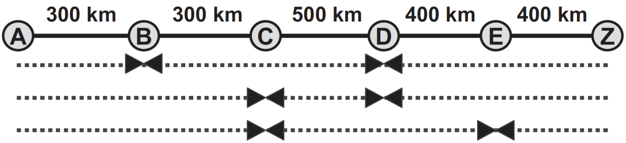

Figure: In the selective regeneration strategy, any node can be selected for regeneration based on a per-connection basis. Here, there may be several options for a regeneration placement. Assume that the optical reach is 1,000 km, and assume that regeneration is permitted at any node. A connection between Nodes A and Z can be regenerated at Nodes B and D, at Nodes C and D, or at Nodes C and E. Factors such as available equipment, sub-connections, wavelength conversion, and OSNR margin may impact on the selection of an option. This strategy may lead to long-time connection setup due to its online per-connection decision style.

Regeneration Architectures

Back-to-Back WDM Transponders

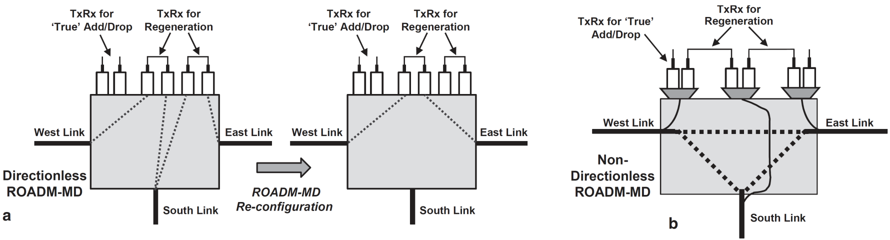

Figure: Regeneration via back-to-back transponders (TxRx's) that are interconnected by a patch cable and provide 3R (reamplification, reshaping, and retiming). a The directionless ROADM-MD allows any transponder pair to access any two network links. The left-hand side shows regeneration between the East/South links and the South/West links. After the ROADM-MD is reconfigured, the right-hand side shows regeneration between the East/West links. b In the nondirectionless ROADM-MD, the transponders are tied to a particular network link; thus, in this example, regeneration is possible only between the East/South and South/West links.

Back-to-Back WDM Transponders

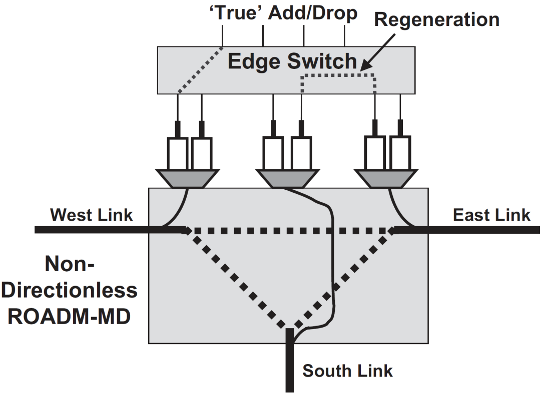

Figure: An edge switch regeneration provides flexibility at a node with a non-directionless ROADM-MD. Any transponder can be used for either "true" add/drop or regeneration; any regeneration direction through the node is supported.

Regenerator Cards

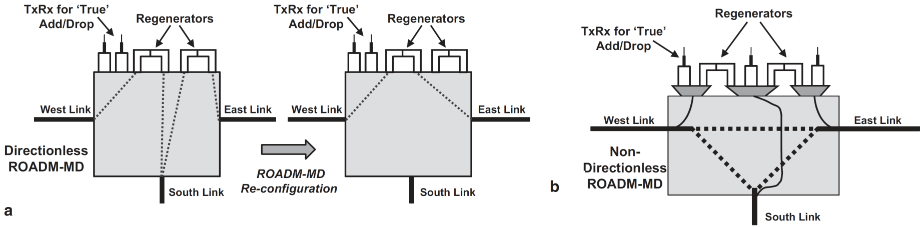

Figure: Regenerator cards with 3R used in conjunction with a directionless ROADM-MD. By reconfiguring the ROADM-MD, a regenerator card can be used for regeneration between different combinations of links. b Regenerator used in conjunction with a non-directionless ROADM-MD. In the configuration shown, regeneration is supported only between the East/South links and the South/West links.

Regenerator Cards

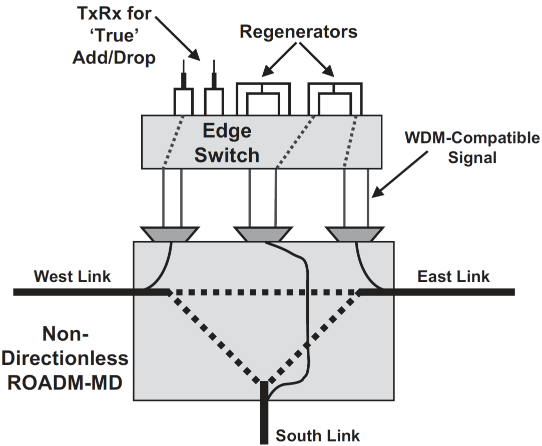

Figure: With an edge switch used in combination with regenerator cards, four ports on the switch are utilized for each regeneration. Additionally, the edge switch must be capable of switching a WDM-compatible signal (e.g., the switch could be a MEMS-based fiber cross-connect).

Regenerator Cards

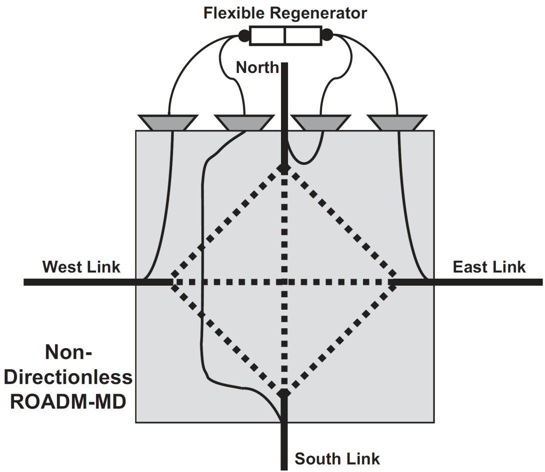

Figure: A degree-four non-directionless ROADM-MD combined with a flexible regenerator that allows regeneration in either the East/West, East/South, North/West, or North/South directions. An optical backplane can be used to eliminate complex cabling.

All-Optical Regeneration

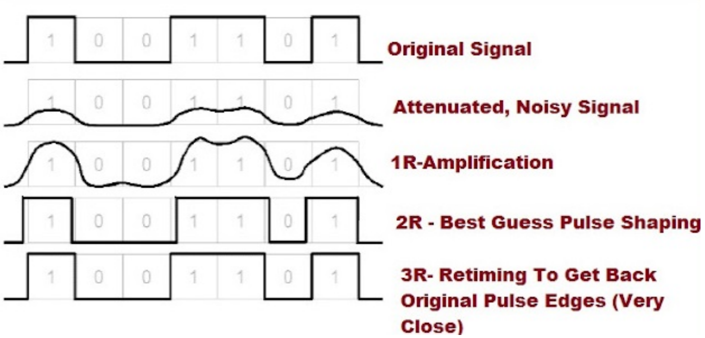

Figure: All optical regenerators provide only 2R regeneration, i.e., reamplification and reshaping, as opposed to 3R, which includes retiming as well. Thus, a combination of all-optical and electronic regeneration may be needed.

The End