A Novel Segment-Based Protection Algorithm for Multicast Sessions in Optical Networks with Mesh Topologies

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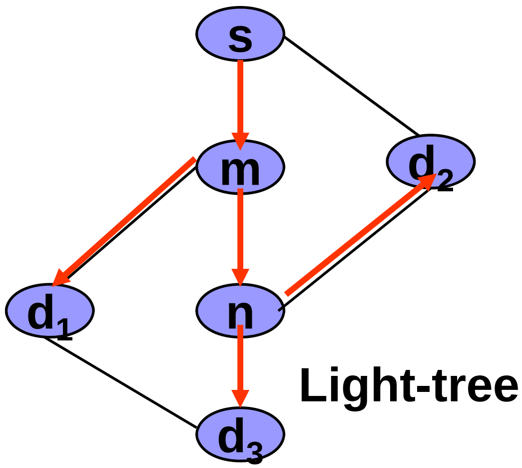
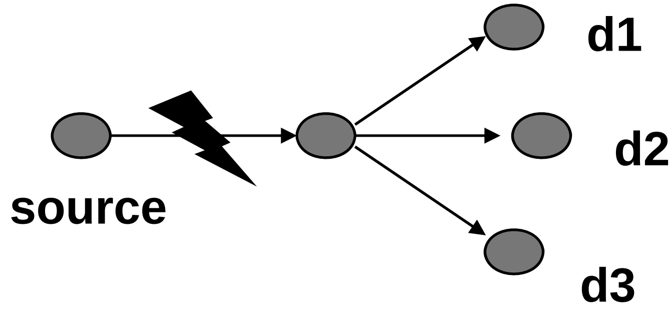
Multicast Connections

- **Multicast connection:**
  - One-to-many connectivity
  - Light from one source reaches many destinations.
  - In transparent optical networks optical splitters must be used inside the nodes to split the incoming signal to multiple output ports.

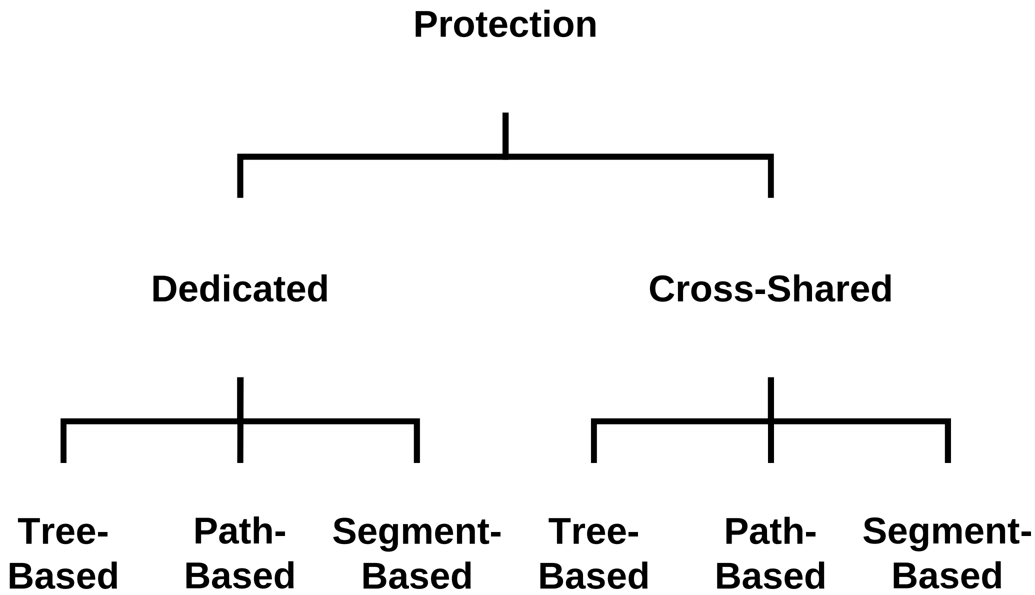


- It is important that the multicast traffic is not only routed efficiently through the optical network but it is protected against any possible failures in the network.

- A fiber cut (link failure) may jeopardize the entire multicast session



Multicast Protection



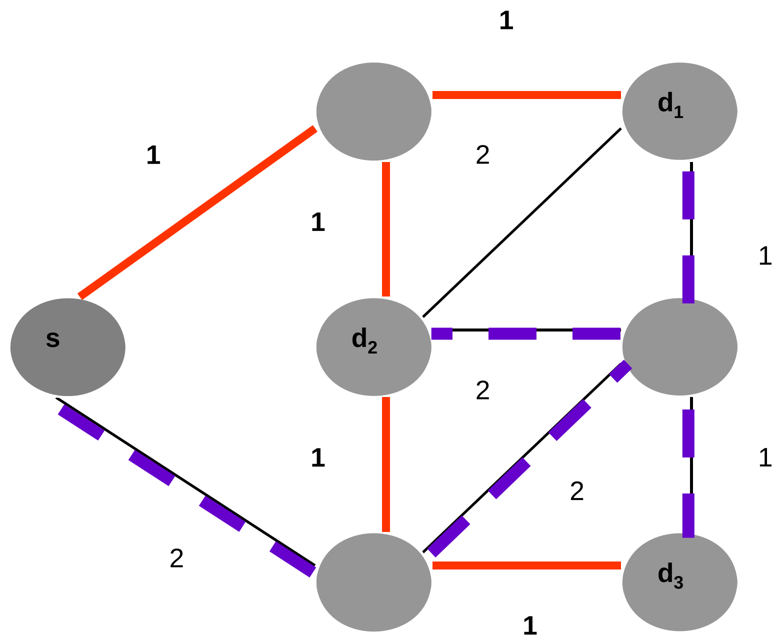
Dedicated: Resources along the backup path(s) are dedicated for only one connection and are not shared with the backup paths for other connections.

Cross-Shared: Resources along a backup path may be shared with other backup paths for other connections.

Multicast Protection-
Tree-based

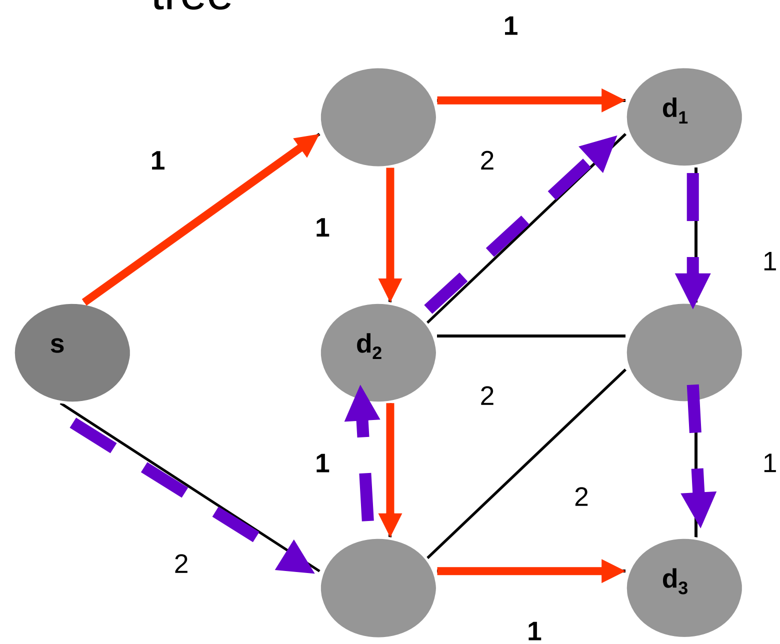
Link-Disjoint (LDT):

1. A primary tree.
2. A link-disjoint backup tree.



Arc-Disjoint (ADT):

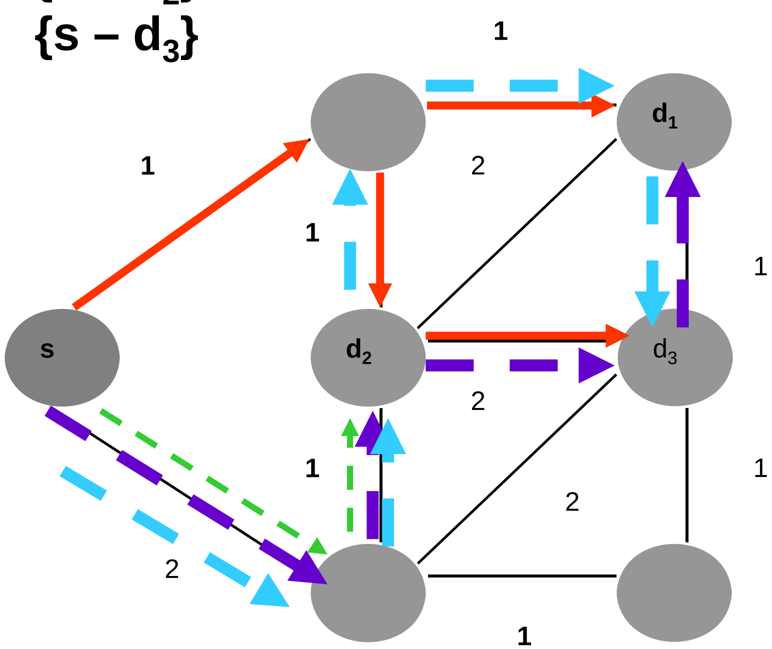
1. A directed primary tree.
2. A directed arc-disjoint backup tree



Multicast Protection-
Path-based

1. Find primary Light-tree.
2. Divides primary tree into several paths according to the destination nodes.
3. For each path a minimum cost path from the source to the destination node is computed, that is arc-disjoint from its primary path.

1. {s – d_1}
2. {s – d_2}
3. {s – d_3}



•**Self-Sharing:** Backup paths can share the primary arcs on the primary tree, as long as there are path arc-disjoint.

•**Drawback:** Only those paths that originated at the source node of the multicast tree and ended at the destination nodes are considered. Cannot derive the most efficient backup paths. (compared to segment that looks at segments and not the entire path)

Multicast Protection-
Segment-based

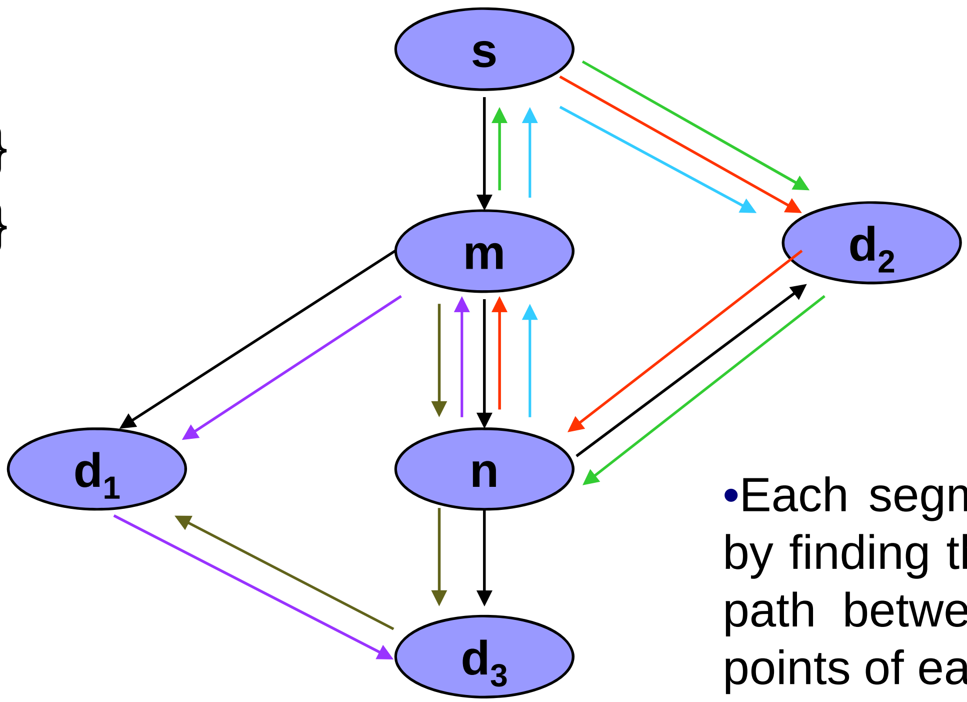
1. Find primary light-tree.
2. Divide primary light-tree to un-overlapped segments according to the segment points of the tree.
3. Find the backup paths for each segment

- **Definitions:**
  - **Segment :** A path between two segment points.
  - **Segment points :** Splitting nodes, source and destination nodes.

❑ **Self/Cross-Sharing techniques are used to further improve the resource utilization of the network**

Multicast routing and protection algorithms – Conventional Segment

- {s ->m}
- {m ->n}
- {n ->d3}
- {n -> d2}
- {m ->d1}



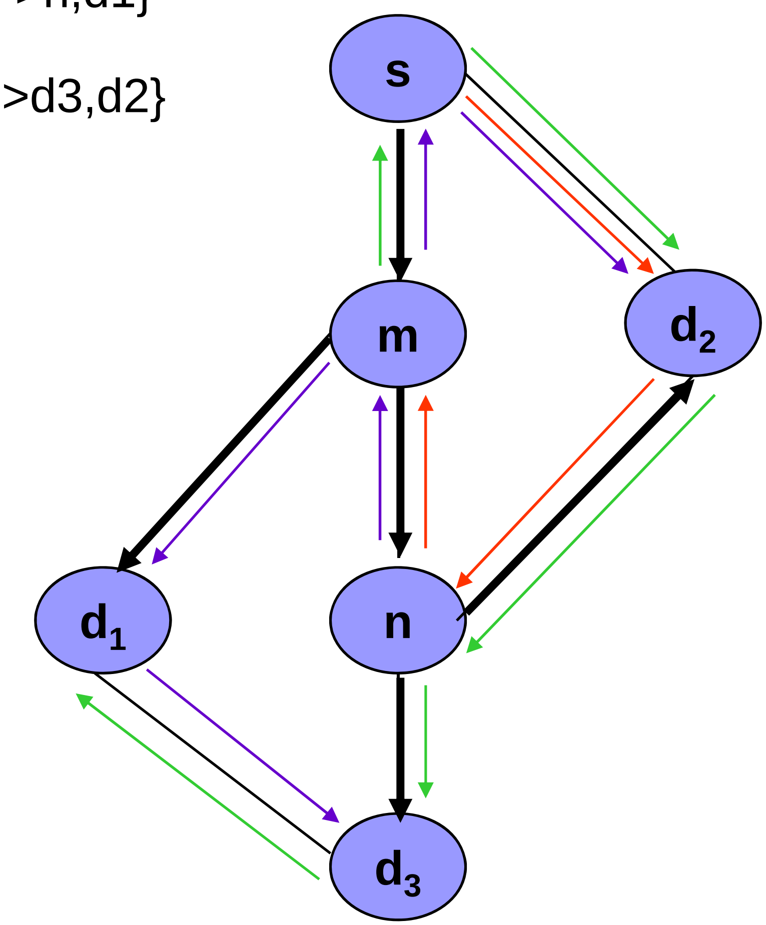
- Each segment is protected by finding the minimum cost path between the segment points of each segment.
- The backup paths must be arc-disjoint from their primary segments.

Multicast Protection-
Segment-based (Sister Node First Technique)

- Sister Node First Algorithm (SSNF)
  - Differs from the conventional SP in the way the segments are identified
  - **Definitions:**
    - **Sister Nodes:** Nodes with a common parent in the tree.
    - **segment points** are as previously defined.

- 3 segments instead of 5
- The first segment is protected as in the conventional case.
- The next segments are protected by computing the minimum cost trees that start from the splitting nodes of each segment and span the sister nodes in the sets.

- {s ->m}
- {m ->n,d1}
- {n ->d3,d2}



Segment-Based Multicast Protection
Level Protection Algorithm (LPA)

- Level Protection Algorithm (LPA)

- **Main idea:** Protect a primary light-tree by dividing it to several un-overlapped segments based on the “levels” of the tree.

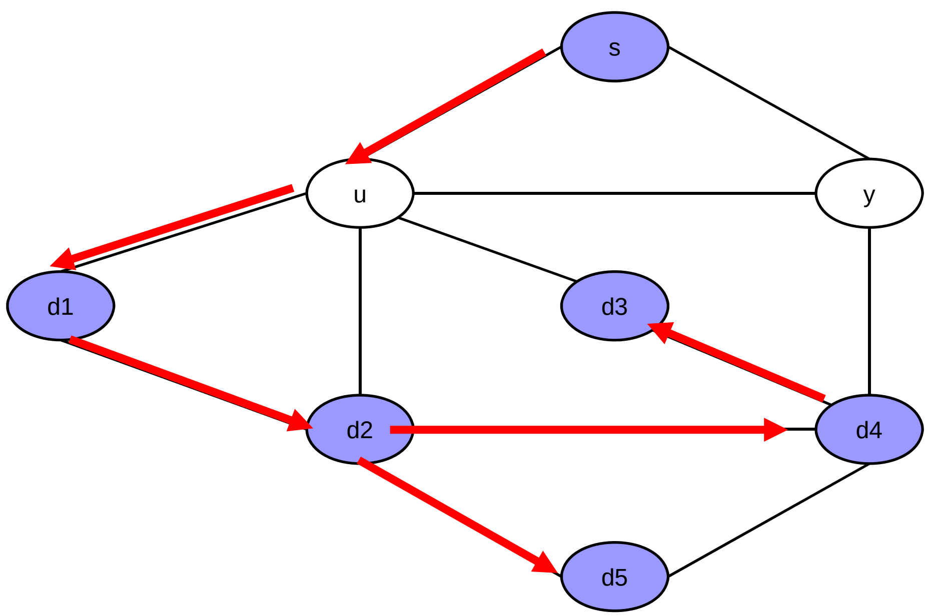
- **Definitions:**

  - **Segment:** a path between two segmentation nodes in the tree.
    - **Segmentation node**: source node and destination nodes.
    - **Level(i) of a segmentation node:** the number of the segments between that segmentation node and the source.
    - **Level (i-1, i) segment:** is the set of all the segments of the tree that are between level (i-1) and level (i) segmentation nodes.

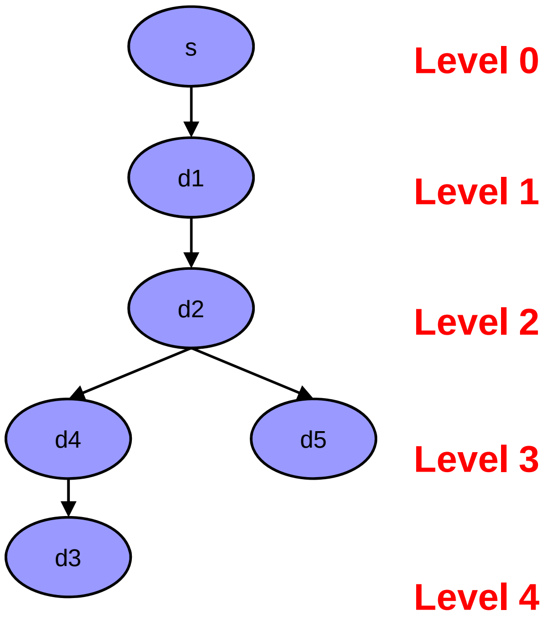
Segment-Based Multicast Protection
Level Protection Algorithm (LPA)

- **Objective:** Minimize the resources used to protect the multicast light-tree by grouping together segments that lie between the same successive levels.
  - Segments in the same group are protected by computing a single arc-disjoint backup path that starts from any lower-level segmentation node and spans every segmentation node in the same group.
  - While in the previously proposed segment based heuristics, only a single backup path is searched for to protect a segment (CSP) or segments (SSNF), in LPA many alternate paths can be searched to protect a group of segments.

Segment-Based Multicast Protection
Level Protection Algorithm (LPA)



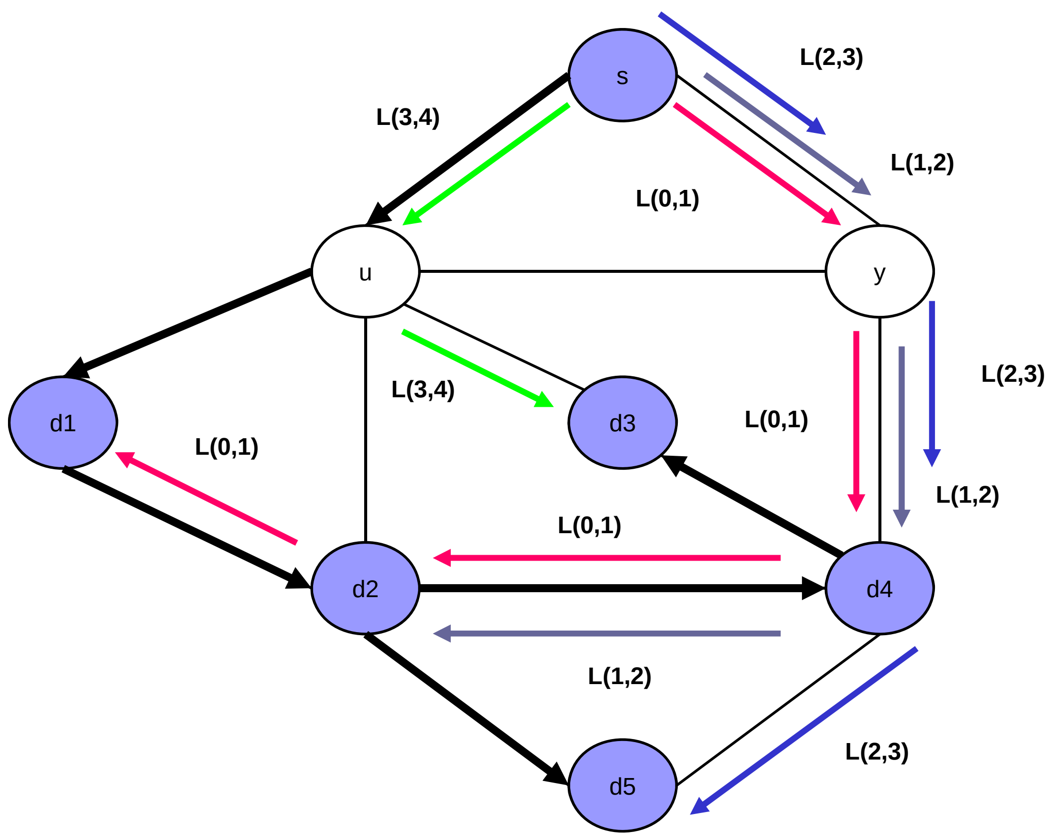
•Auxiliary graph (AG) consisting of segmentation nodes and level segments



•The level of each segmentation node is identified on AG.

Segment-Based Multicast Protection

Level Protection Algorithm (LPA)

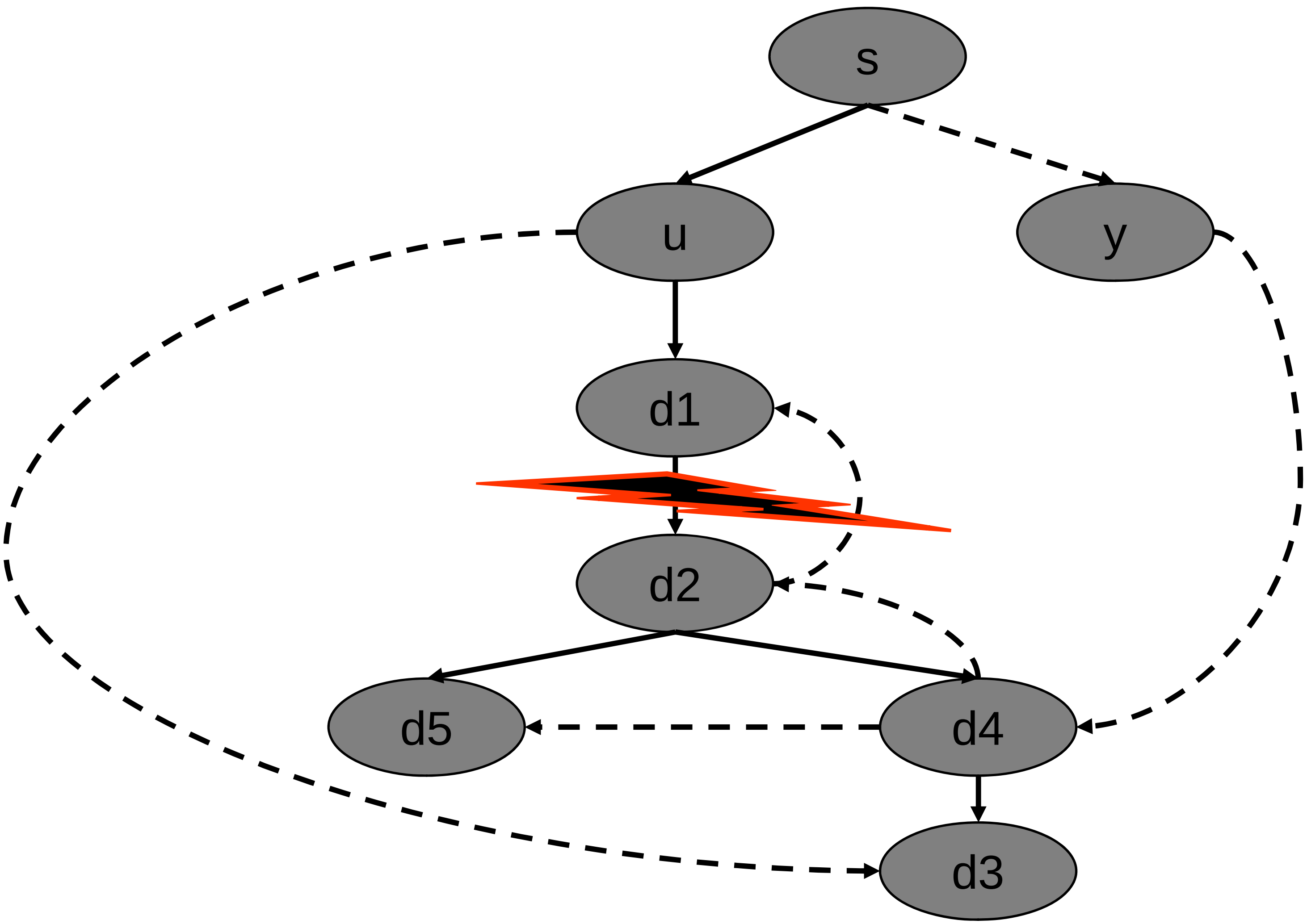


•**Backup path:** A minimum cost tree that starts from any segmentation node in lower levels, and spans every segmentation node in the current level.

•**Example:** if we want to protect the segments between levels 1 and 2, a minimum cost tree is computed that starts from any segmentation node in levels 0 or 1, and spans every segmentation node in level 2.

•**Constrain:** The backup tree, must be arc disjoint from its primary level segment and from every level segment that lies between higher levels.

Segment-Based Multicast Protection
Level Protection Algorithm (LPA)



MC-RWA Algorithm

- For each multicast connection request, the algorithm solves the multicast routing and wavelength assignment problem by finding a primary light-tree and its backup paths on the same wavelength using the first-fit wavelength assignment algorithm.
  - **Blocked:** There is no available wavelength for both the primary tree and the backup paths.

- **Assumptions:**
  - 64 wavelengths per fiber link
  - No wavelength conversion in the network
  - Optical splitters in each node
  - Directed connections

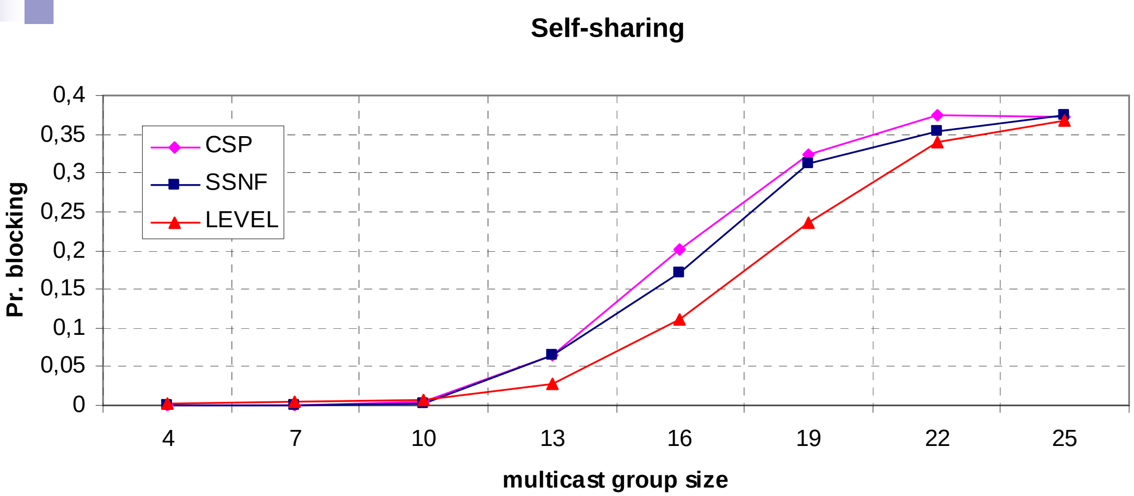
Simulation Parameters

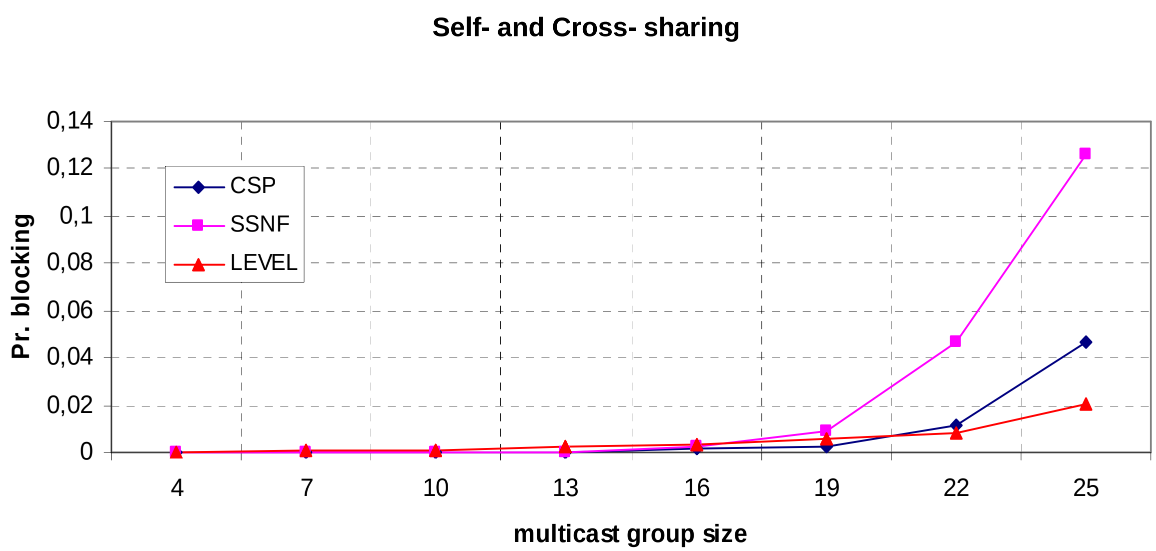
- **Network :**
  - 50 nodes
  - 196 bidirectional links
  - average node degree of 3.92
  - maximum node degree of 6
  - an average distance between the links of 60 Km

- **Dynamic System:**

- Poisson arrivals
- Exponentially distributed holding times with a unit mean.
- Load of 100 Erlangs
- For each run 5000 requests were generated for each multicast group size.
- The results for each simulation point were obtained as the average of 5 runs

Simulation Results

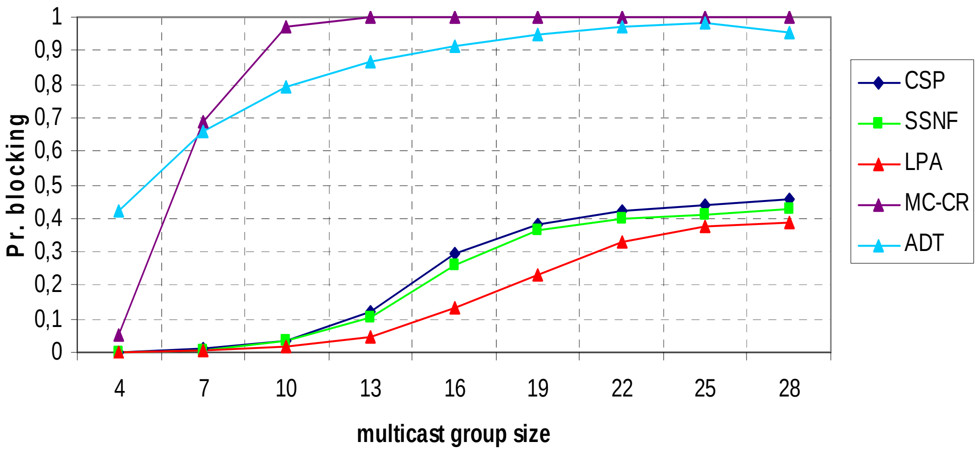




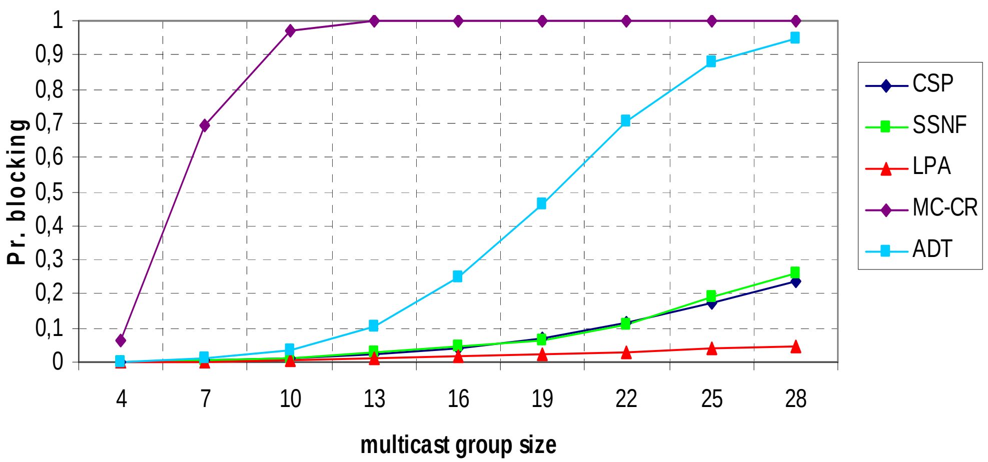
- **LPA** performs the best in both cases compared to the other segment based protection algorithms.
- **Cross-Sharing** significantly improves the network performance. (overall blocking probability)

Simulation Results with Physical Layer Impairments

Self-sharing



Self- and Cross- sharing



- **LPA** performs the best in both cases compared to:
  - Tree-based (ADT)
  - Ring-based (MC-CR)
  - Segment-based (CSP, SSNF)

  protection algorithms.
- **Cross-Sharing** significantly improves the network performance.
- When the PLIs are considered, the blocking probability is significantly increased.

Conclusions and Future Work

❑Conclusions:

- LPA algorithm achieves better performance compared to other segment based protection techniques when self sharing is utilized
- Cross sharing improves the overall network performance with the LPA technique showing its advantage for large multicast group sizes
- When PLIs is taken into consideration LPA performs the best compared to other segment, ring, tree, and path protection techniques

❑Future Work:

- Provisioning and protection of groupcast requests with/without physical layer constraints
- New algorithms for provisioning multicast requests that achieve a Steiner Ratio close to 1

Impairment-Aware Protection Physical Layer System Modeling

- Physical Layer Impairments must be taken into account during the provisioning phase of a request.
- Modeling of the physical layer is based on the physical path Q factor that is used to calculate the BER of the system.

$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0}, \textbf{\textit{where}}$$

$$\sigma_i^2 = \sigma_{th}^2 + \sigma_{shot-i}^2 + \sigma_{ASE-ASE}^2 + \sigma_{s-ASE-i}^2 + \sigma_{RIN-i}^2 + \sigma_{ASE-shot}^2$$

- This approach assumes a baseline system with various receiver noise terms as well as ASE noise.

- A Q-budgeting approach is used to include other effects such as:
  - Incoherent crosstalk channel penalty
  - Fiber nonlinearities
  - PMD
  - Optical filter narrowing penalty
  - Safety margin for component aging
  - ...

Impairment-Aware Protection Physical Layer System Modeling

- This approach enables a network designer to calculate the impact of physical layer effects, in the design of an optical network without the computationally complex time-domain approach.

- A Q threshold is set for a specified BER and the decision to provision a given multicast connection relies on whether we are above or below the threshold.

$$BER = \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}}\right) \approx \frac{e^{\frac{-Q}{2}}}{Q\sqrt{2\pi}}$$

- Q threshold set at 8.5 dBQ which corresponds to a BER of 10^{-12}

Simulation Parameters

- To determine the Q-value for each multicast call, a baseline system Q-value is first calculated based on the signal and noise terms, assuming:
  - 10 Gbps bit rate
  - a pre-amplified photodiode
  - 64 wavelengths in each fiber spaced at 100 GHz.
  - +5dBm power launched into the system .

- To include other common physical layer impairments a Q-budgeting approach is used that starts from the Q-value for the baseline system and budgets Q-penalties for the various physical layer impairments present.

- Each Q-penalty is calculated as the Q (in dB) without the impairment in place minus the Q (in dB) with the impairment present.