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

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Abstract: This paper investigates the problem of protecting multicast sessions in optical networks utilizing a novel segment-based protection algorithm called Level Protection. Our proposed scheme exhibits improved performance compared to other traditional segment-based multicast protection schemes.

1. Introduction

High-bandwidth multicast applications are becoming widely popular, further driving the requirement for next generation optical networks to support all types of traffic (unicast, multicast, and groupcast) and all kinds of applications. Multicasting has been investigated in the research community since the early days of optical networking, but has only recently received considerable attention from the service providers, mainly because now many emerging applications can potentially utilize the optical multicasting feature. For such applications to be viable, it is important that the multicast traffic is not only routed efficiently through the optical network but it is also protected against any possible failures in the network.

In transparent optical networks, a light-tree is created to serve a multicast request [1]. In these networks, optical splitters can be used in network nodes to split the incoming signal to multiple outputs, thus enabling the establishment of connections with multiple destinations [2]. An effective solution to the multicast routing problem would be to calculate the Steiner Minimum Tree (SMT) between the source and destination nodes. However, as the SMT problem was proven to be NP-complete, numerous heuristics were developed to compute a multicast tree [3,4]. Protecting a multicast session against a link failure requires finding alternate paths for all failure scenarios prior to the occurrence of the fault. Various approaches exist for multicast protection including path-, segment-, and cycle-based techniques. This work investigates the problem of segment-based protection of multicast connections in mesh optical networks, as segment-based protection schemes are reported to have better performance than other known schemes in terms of resource efficiency and blocking probability. The proposed algorithm is compared to different segment-based protection algorithms described in the literature [5,6,7] and is shown to improve performance compared to previously published work. In order to improve the resource utilization ratio and reduce blocking probability, sharing techniques are also included in our algorithm (both self- and cross-sharing) as these are described in [8].

2. Multicast Protection

Several segment-based protection schemes proposed in the literature [5, 6] are based on the Conventional Segment Protection (CSP) algorithm. Given a primary light-tree, CSP first identifies the segments on the primary light-tree and then attempts to derive a link-disjoint backup segment for each segment on the primary light-tree. Here, a segment in a primary light-tree is defined as the path between two segment points of the tree and segment points are defined as all the splitting nodes, the destination nodes, and the source node. In [7], a segment protection scheme called segment-based protection with sister node first (SSNF) is proposed and its basic idea is to protect a primary light-tree using a set of backup segments, with higher priority to protect the segments from a splitting node to its children. In this work, we propose a novel and efficient algorithm called *Level Protection Algorithm (LPA)* that differs from the other segment-based protection algorithms proposed in the literature in how the segments are identified.

2.A Level Protection Algorithm Definitions

Segmentation nodes of a tree: Given a tree T, a vertex $n \in T$ is said to be a *segmentation node* if it is the source s or it is a destination node of the multicast request. In Figure 1(a), the segmentation nodes are the nodes s, d_1, d_2, d_3, d_4, and d_5.
Segments of a tree: Given a tree T, a path between two segmentation nodes is said to be a *segment of the tree* if the path does not pass through any other segmentation nodes of the tree except the two end-nodes of the path. The primary light-tree given in Figure 1(a) is divided to five primary segments, that are $\{s, u, d_1\}$, $\{d_1, d_2\}$, $\{d_2, d_4\}$, $\{d_2, d_5\}$, $\{d_4, d_3\}$.
***Level** i* **of a segmentation node:** Given a tree T, the *level of a segmentation node* is the number of the segments between that segmentation node and the source node s. In Figure 1(b), as an example, the auxiliary graph of the primary light-tree is given and the level of each segmentation node is shown.
***L(i, i+1)* segment group of a tree:** Given a tree T, a *L(i, i+1) segment group* is the set of all segments that lie between the segmentation nodes of Level i and the segmentation nodes of Level *(i+1)*. For example, *L(2,3)* segment group is the group of segments $\{(d_2, d_4), (d_2, d_5)\}$. Note that a link in the auxiliary graph (Figure 1(b)) represents an $L(i, i+1)$ segment group.

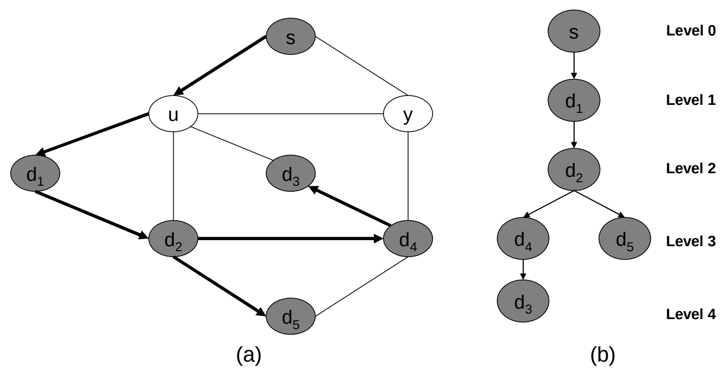

Figure 1: (a) Primary light-tree *T* for *R(s, d_1, d_2, d_3, d_4, d_5)* and (b) Auxiliary graph based on the segmentation nodes of the primary light-tree *T* with the Levels shown.

2.B Level Protection Algorithm Description

The basic idea behind the Level Protection algorithm is to protect a primary light-tree by dividing it to several un-overlapped segments based on the "levels" of the tree. The proposed algorithm aims at minimizing 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 link-disjoint backup path that starts from any lower-level segmentation node and spans every segmentation node in the same group. The protection process of the Level Protection Algorithm starts from the lower levels and continues to the higher levels in a hierarchical manner. Therefore, backup paths have to be link-disjoint from their segment group and link-disjoint from the segment groups that lie between higher levels. Self- and cross-sharing are also considered with this approach, with the different backup paths sharing the primary links on the primary tree (self-sharing) or sharing the common backup links on the same wavelength if their corresponding primary trees are link-disjoint (cross-sharing).

Specifically, the proposed LPA algorithm works as follows: Once a multicast request arrives into the system, the algorithm first calculates the primary light-tree *T* on graph *G* using the Steiner tree heuristic [2], and the link weights of graph *G* are updated to zero value if $l \in T$. Next, the algorithm identifies the segmentation nodes, the segments, the *level i* values on the auxiliary graph, and the *L(i, i+1)* segment groups as defined above. Once the *L(i, i+1)* segment groups are identified, *i* is initialized to zero value and *k* is assigned the level value of the leaf nodes on the auxiliary graph. The algorithm starts the protection procedure for the *L(i, i+1)* segment group by calculating all backup paths that start from every segmentation node that belongs to level *j*, where $0 \le j \le i$, and span the segmentation nodes that belong to level *(i+1)*. The minimum cost backup path amongst them is then chosen. The algorithm keeps incrementing *i* by 1 and the protection procedure terminates when *i=k-1*.

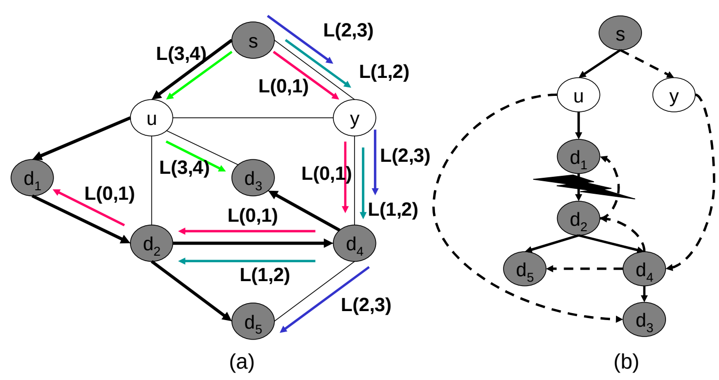

Figure 2: (a) Protection paths for each level segment group and (b) Combined primary light-tree and backup paths.

Note that the backup paths of the *L(i, i+1)* segment group are calculated using Dijkstra's shortest path algorithm if the number of segmentation nodes in *level (i+1)* is less than two; otherwise it is calculated using the Steiner tree heuristic. To improve the resource utilization in the network, each time a backup path is chosen, the link weights on graph *G* are updated to zero if the links are used for the construction of the backup path.

Figures 1 and 2 are used to illustrate the operation of the LPA algorithm. Once the primary tree, segmentation nodes, segments, levels on the auxiliary graph, and *L(i, i+1)* segment groups are identified, backup paths are determined starting from the lower levels. For example, in Figure 2(a), for the calculation of the *L(0,1)* backup path, the algorithm uses the shortest path heuristic starting from node *s* at *Level 0* and moving to the d_1 node of *Level 1*. Figure 2(a) shows the backup paths found for each *L(i, i+1)* segment group (wavelength sharing is clearly illustrated). In Figure 2(b), primary light-tree *T* and backup-paths are combined together and it is shown that in case of any single link failure, data from the source can reach every destination node on the multicast tree.

3. Performance Evaluation

For each multicast request, the MC-RWA 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. We assume the presence of optical splitters in each node, directional connections, *W* wavelengths per fiber, and a network with no wavelength converters. The multicast group size of the session indicates the number of nodes participating in the multicast session ($|d|+1$). If a primary light-tree *T* can be provisioned and can also be protected, the multicast request is accepted in the network; otherwise it is blocked. To evaluate the performance of the different protection algorithms examined here, we used a metro network consisting of 50 nodes and 196 links, with an average node degree of 3.92 and an average distance between the links of 60 Km. Multicast requests arrive into the system dynamically according to a Poisson process and the holding time is exponentially distributed with a unit mean. In each simulation 5,000 requests were generated for each multicast group size for a total of 40,000 multicast requests, and the results were averaged over five simulation runs. Sixty-four wavelengths per link were utilized to evaluate the blocking probability versus the multicast group size for a network load of 100 Erlangs. Furthermore, as the LPA algorithm is designed to protect directed connections, for comparison purposes, the CSP and SSNF algorithms have been slightly modified to operate on directed light-trees.

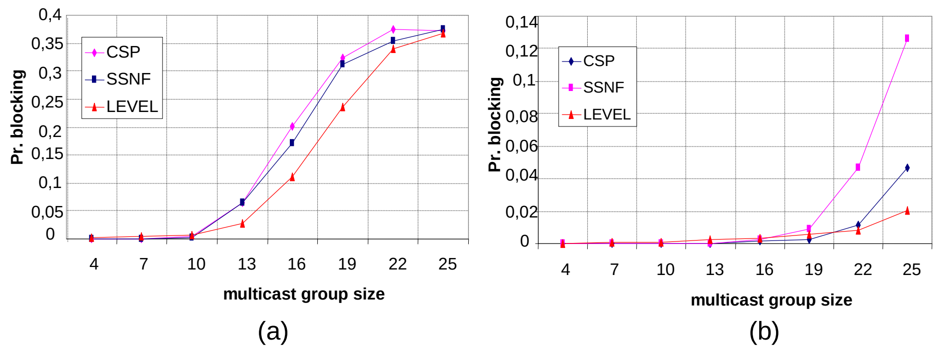

Figure 3: Blocking probability vs. multicast group size when (a) self-sharing is considered and (b) self-sharing and cross-sharing are jointly considered

Figure 3(a) shows the blocking probability versus the multicast group size when only self-sharing is considered while Figure 3(b) shows the blocking probability versus the multicast group size when self- and cross-sharing are jointly considered. In both cases, the Level Protection Algorithm performs better than existing segment-based protection approaches. The main reason is that the LPA algorithm has more flexibility in finding the backup paths and only a single backup path is required to protect a level segment group.

Acknowledgement: This work is supported by the Cyprus Research Promotion Foundation and the EU Structural Funds under Grant PENEK/ENISX/0308

References

[1]. T. Stern, G. Ellinas and K. Bala, *Multiwavelength Optical Networks: Architectures, Design and Control*, Cambridge University Press, 2008.

[2]. L. H. Sahasrabuddhe and B. Mukherjee, "Multicast Routing Algorithms and Protocols: A Tutorial", *IEEE Network*, pp. 90-102, January/February 2000.

[3]. N. K. Singhal, et al., "Provisioning of Survivable Multicast Sessions against Single Links Failures in Optical WDM Mesh Networks", *IEEE/OSA J. Lightwave Technology*, 21(11):2587-2594, 2003.

[4]. Y. Sun, et al., "Multicast Routing in All-optical Wavelength-routed Networks," *Optical Net. Mag.*, 2(4):101-109, 2001.

[5]. X. Wang, et al., "Segment Protection Algorithm with Load Balancing for Multicast WDM Mesh Networks", *Proc. 10th International Conference on Advanced Communication Technology*, Gangwon-Do, South Korea, February 2008.

[6]. A. Fei, et al., "A Dual-tree Scheme for Fault-tolerant Multicast", *Proc. IEEE ICC*, Helsinki, Finland, June 2001.

[7]. H. Luo, L. Li and H. Yu, "Algorithm for Protecting Light-trees in Survivable Mesh Wavelength-division-multiplexing Networks", *OSA Journal of Optical Networking*, 5(12):1071-1083, 2006.

[8.] N. Singhal, et al., "Cross-sharing vs. Self-sharing Trees for Protecting Multicast Sessions in Mesh Networks", *Computer Networks*, 50(2):200-206, 2006.