Protecting dynamic multicast session in optical networks

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Abstract

Recent advances in wavelength division Multiplexing (WDM) technology are expected to facilitate bandwidth –intensive multicast applications. However, a single fiber (bundle) cut on such a networks can disrupt the transmission of information to several destination nodes on a light tree based multicast session. Thus, it is imperative to protect multicast session. A shared path protection algorithm for dynamic multicast sessions (SPP-DM) is proposed in this paper. It enables a present protection path to share wavelengths with already built protection paths as well as the sharing between working paths.

We first study the problem of protecting a single tree, find a link-based approach to protect it, and then extend the approach to the Dynamic case, where multicast connection requests come in sequence. The simulation with the topology of the ARPA Network shows that SPP-DM performs better in blocking probability than the algorithm proposed in [1], called an Optimal path-pair-based shared disjoint paths (OPP-SDP) algorithm, which has been showed in [1] to be more efficient than other existing algorithms.

Keywords: WDM, Protection, Multicast, Shared protection, ARPA network

1. Introduction:

THE GROWTH of wavelength-division-multiplexing (WDM) technology [1] and the promise of aggregate Fiber bandwidth in terabits per second (Tb/s) have opened the gates for bandwidth-intensive applications. In addition, as the Internet expands and multicast applications such as HDTV,video conferencing, interactive distance learning, live auctions, and distributed games, gain popularity [3]–[4], there is an Emerging need to efficiently protect critical sessions against failures such as fiber cuts. In the event of a fiber cut (or, more precisely, a fiber-bundle cut since fibers are laid in bundles), all connections going in either direction of the fiber (bundle) are disrupted, and the affected destinations may have to be reached on alternate routes. Because single fiber failures the predominant form of failures in an optical mesh network, we concentrate on this form of failure. A single cut on a "light tree"-based multicast session may have a larger impact because several destination nodes become victims as opposed to a cut on a *light path* [5], where only one destination becomes unreachable.

A link failure or a node failure can make a great impact on the multicast service if the node or the link is on the tree carrying traffic to multiple destinations. Since the frequencies of cable cut events are hundreds to thousands times higher than those of transport layer node failures according to [6], we focus on the protection against single fiber cut for multicast sessions. Although not too much work has been done in protecting multicast sessions, [2] proposes several algorithms for this problem and compares them with two existing algorithms, which use link-disjoint tree method and arc-disjoint tree method respectively. Pointing out the poor efficiency of building disjoint trees for protection, [2] bases one of their approaches on segments, which are defined as the sequence of edges from the source or any splitting point to a leaf node or to a downstream splitting point. Segments in the primary

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tree are protected and the protection paths can share wavelengths with each other. A more efficient algorithm, called an optimal path-pair-based shared disjoint paths (OPP-SDP) algorithm, is also presented, where optimal arc-disjoint path pairs are found to connect the source node to one of the estimation nodes in a multicast connection request. Sharing between different path pairs is also pursued in OPP-SDP.

2. General Problem formulation and Algorithm

In this section, we first focus on the problem of creating the protection of a single multicast connection request and then extend it to the dynamic situation.

A. Problem Description

1. The problem to be solved can be described as follows:
The given network can be abstracted into a directional graph G (V, E), where V denotes the set of network vertices and E denotes the set of directional edges. We assume there are always two fibers between each pair of vertex whenever they are connected. The directions of the two fibers are opposite and fixed. The graph is supposed to be disconnected to assure protection [9], i.e. it has at least two vertex-disjoint Paths between each pair of vertices.
2) Every node in the network is assumed to have both full splitting and full wavelength conversion capabilities. Suppose the amount of wavelengths that can be used in each fiber is uniform and the cost between a pair of connected vertices is 1 in both directions.
3) For a given multicast connection request, a working Path should be established unidirectional for connection Between the source node and each destination node. For every link failure on that working path, a protection path should be found to protect such a path. The routing is said to be successful only if both the route for the working path and the routes for the protection paths are found for the whole multicast connection request.
4) The objective of optimization is to fulfill the multicast connection request with minimum aggregate cost. Since we define the cost between each pair of nodes is 1, the purpose can also be described to minimize the amount of wavelength links.

B. ILP Formulation

1) .Sets.

V denotes the set of all of the N vertices in graph G.
E denotes the set of all edges in graph G.
C denotes the two-dimensional cost matrix.
W denotes the two-dimensional wavelength matrix Indicating remaining available wavelength sources in the network.
S = {s, d1, d2... d_K } represents the multicast connection request, where s denotes the source node and d_k denotes the kth destination node. k is in the range of 1 to K, where K =1 V -1.

2) .Variables:

$P^d{}_{mn}$ indicates whether the link from node m to node n is occupied by the established working path from s to d.
$B^d{}_{mnpq}$ indicates whether the link from node m to node n is occupied by the established protection path from s to d when a failure occurs on the link from node p to node q. P^d_{mn} and B^d_{mnpq} are equal to 1 when the link from node m to node n is occupied, otherwise they are equal to 0. l_y=1 if there exists a link (fiber) from node i to node j, otherwise l_y = 0 .
w_y denotes the number of remaining available wavelengths on the link from node i to nodej.
C_y denotes the cost on the link from node i to node j. We use the value 1 here.
F^d_{pq} = 0 if the link from node p to node q is occupied by the working paths from s to node d, otherwise it could be 1 or 0.
T_{mn} =1 if the link from node m to node n is occupied by the working paths or protection paths, otherwise T_{mn} =0.

3) Objective:

Minimize the total number of wavelength links.

$$\text{Minimize } \sum c_{mn} T_{mn} \qquad (1)$$

4) Constraints:

$$\forall d: \sum P_{sn}{}^{d} = 1 \qquad (2)$$
$$\forall d: \sum P_{ns}{}^{d}, = 0 \qquad (3)$$
$$\forall d: \sum P_{dn}{}^{d} = 0 \qquad (4)$$
$$\forall d: \sum P_{nd}{}^{d} = 1 \qquad (5)$$
$$\forall d, \forall m \in S: \sum P_{mn}{}^{d} = \sum P_{nm}{}^{d} \qquad (6)$$
$$\forall d,m,n: P_{mn}{}^{d} \leq l_{mn} . W_{mn} \qquad (7)$$
$$\forall d, p, q: F_{pq}{}^{d} \leq 1 - P_{pq}{}^{d} \qquad (8)$$
$$\forall d, p,q: \sum B_{snpq}{}^{d} + F_{pq}{}^{d} = 1 \qquad (9)$$
$$\forall d, p,q : \sum B_{nspq}{}^{d} = 0 \qquad (10)$$
$$\forall d,p,q: \sum B_{dnpq}{}^{d} = 0 \qquad (11)$$
$$\forall d,p,q : \sum B_{ndpq}{}^{d} + F_{pq}{}^{d} = 1 \qquad (12)$$
$$\forall d,p,q, \forall m \in S: \sum B_{mnpq}{}^{d} = \sum B_{nmpq}{}^{d} \qquad (13)$$
$$\forall d,p,q: B_{pqpq}{}^{d} = 0 \qquad (14)$$

$\forall d,m,n,p,q: B_{mnpq}^{d} + F_{pq}^{d} \le 1$ (15)

$\forall d,m,n,p,: B_{mnpq}^{d} \le l_{mn} . W_{mn}$ (16)

$\forall m,n: \sum P_{mn}^{d} + \sum\sum B_{mnpq}^{d} \ge T_{pq}$ (17)

$\forall m,n: \sum P_{mn}^{d} + \sum\sum B_{mnpq}^{d} \le k(1 + (N.(N-1)/2).T_{mn}$ (18)

Equation (1) calculates the total cost of the working pathsand the protection paths. Equation (2)-(6) and (9)- (13) restrict the incoming flow and outgoing flow at each node for working paths and protection paths, respectively.

C.Heuristic Algorithms

Our given problem requires looking for backup paths based on the solution of the minimum-cast Steiner tree problem, which has been proved in [10] to be NP-complete. Thus, a heuristic algorithm is needed to solve such a problem in practice.

Reference [2] proposes two algorithms, Optimal Path Pair-Shared Dis-joint Segments (OPP-SDS) and OPP-SDP, for protecting a multicast session and compares them with existing algorithms. It has been shown that the OPP-SDP algorithm is the most efficient algorithm among them, and performs closely to the optimal solution of the ILP formulation given in [2].The OPP-SDP algorithm builds an optimal path pair from s to the destination nodes one by one. For already-found optimal path pairs, the cost is set to '0' to enable sharing wavelengths between different pairs.

OPP-SDP uses only one protection path for each working path for any link failure. Because of this the protection path is not able to share wavelength with the working path but, however to protect a working path we need to ensure always a path from Source to Destination should exists in the case of link failure.

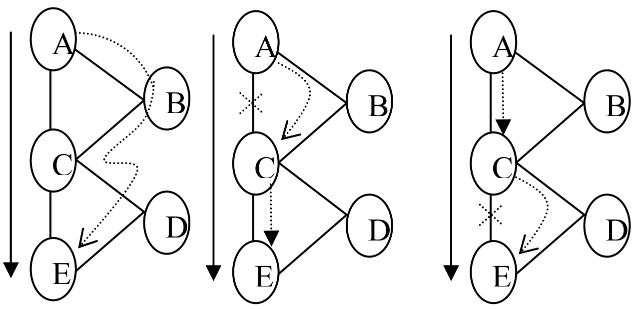

Fig.1 (a), Fig.1 (b), Fig.1 (c),

Fig. 1. Comparison between the failure-independent method and the failure-dependent method. The solid arrow lines show the working path. The dashed arrow lines show the protection paths.

Fig.1 (a), OPP-SDP will find A->B->E as the working path and A->B->C->D->E as the protection path for a single connection request from A to E. Yet, if we let A->B->C and C->D->E protect the link from A to C and the link from C to E respectively, see Fig. 1 (b) and (c), only 2 links will be occupied at the same time. Those conserved links can be used for the working or protection paths for the other multicast sessions if we use an efficient sharing.

The proposed algorithm is as follows:
Given network G (V, E), wavelength matrix W and Multicast connection request $S = \{s, d_l, d_2,., d_K\}$

Step1: Create a working tree using minimum-cost path heuristic (MPH) [8], then for each link from node i to node j on the working path, repeat step2 and step3.

Step2: Make cost=infinite for the link in failure and the links that have no available wavelength. Make cost=0 for the links along the working paths and the links already occupied by established protection paths for the present request. Make cost=1 for the other links which still have available wavelengths.

Step3: Use Shortest path algorithm for wavelength graph(SPAWG) algorithm to find minimum-cost path from s to j. Step2 ensures the sharing of wavelengths between protection paths and working paths as well as among the protection paths themselves. The time complexity is O[(n+k)nk)],the complexity of the running time of this algorithm is better for efficient practical implementation.

3. SIMULATION RESULTS

To test the LB-SPDM algorithm and compare it with OPP-SDP for dynamic multicast connection requests, every multicast connection request is generated andomly, i.e. the source node s and the destination nodes are generated following uniform distribution. The arriving time of a request follows a Poisson distribution with the arriving rate of the holding time follows a negative exponential distribution with the mean of 1/ u. Since the load of the network is mainly related not to any single one of λ and, u but to their ratio, we pay much more attention to the performance for different arrival rate (R_a) ($R_a = \lambda$ (1/u)) 20000 connection requests are stimulated for each group of variables. A 24 node ARPA (Advanced Research Project Agency) network is used for simulation of blocking probability.

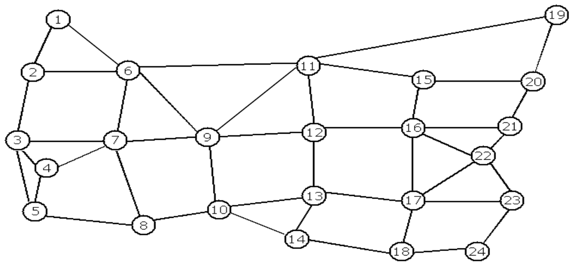

Fig.2. Topology of 24 node ARPA Network.

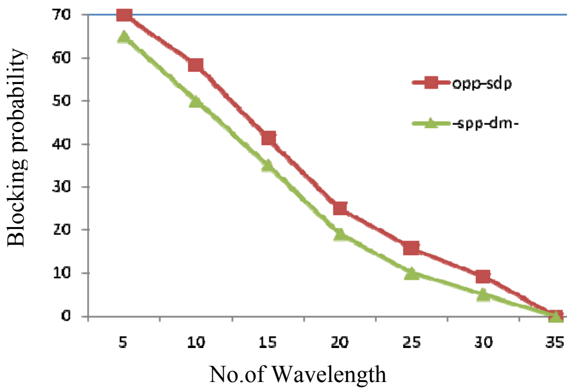

Fig.3. Blocking Probability vs. Number of Wavelength

Fig.3 shows the comparison of OPP-SDP and SPP-DM and we observe that the blocking probability decreases when wavelength number increases. For a given wavelength number, SPP-DM has a lower blocking probability than OPP-SDP, but the superiority weakens when more wavelengths are provided. This is because when given enough wavelength resources, the sharing between different multicast requests becomes less important than it is with limited wavelength resources.

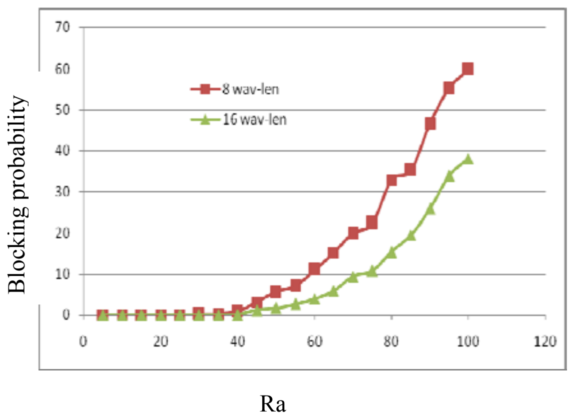

Fig.4. Blocking Probability vs. Ra

From Fig.4, where the number of wavelengths on each fiber is 16, we learn that when the network load becomes heavier, the blocking probabilities for both OPP-SDP and SPP-DM increase. However, SPP-DM SPDM performs better again than OPP-SDP and the superiority enhances when the increasing of R_a makes sharing between different multicast requests more and more important. Although the performance improvement becomes negligible when the number of wavelength is greater than 30 in Fig.3, Fig.4 proves that SPP-DM is more robust to the vibration of the network load than OPP-SDP.

IV. CONCLUSIONS

We give the mathematical formulation for the problem of finding a group of working paths and protection paths WDM mesh network for a multicast connection request. Shared-path-protection constrains are given to enable sharing wavelengths among those paths. An efficient algorithm, SPP-DM, is proposed for the dynamic case through sharing wavelengths among different multicast requests. Because SPP-DM enables a present protection path to share wavelengths with already built protection paths, it performs better in blocking probability than OPP-SDP in our simulation with APRA network. Our future work will focus on sharing wavelengths between a present working path and existing protection paths, as well as using a cycle-like structure to speed up the protection.

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