Multicast Protection in WDM Optical Networks with Scheduled Traffic

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Abstract *We formulate and investigate the multicast tree protection in WDM optical networks with scheduled traffic. By optimizing the network resources jointly in space and time, survivable multicast sessions can be provisioned at much lower costs.*

Introduction

Nowadays, multicasting over a WDM optical network is an efficient means to deliver many popular applications such as video-on-demand, interactive distance learning, etc., which require point-to-multipoint connections. To assure the service availability, it is imperative to protect the optical multicast sessions, since a single failure may disrupt several downstream destinations and cause huge data loss. Singhal[1] studied protecting a single link failure using directed-link-disjoint backup trees. Link, segment and path protection can be utilized to provide survivability to multicast sessions.

Most of the previous works on multicast protection considered either a static or dynamic traffic model, which may not well-characterize the applications that require bandwidth at a specific time interval[2]. Network resources may be reserved by users in advance. For instance, a soccer game is usually broadcasted to audiences according to a predetermined timetable. Therefore, scheduled traffic model[2], in which the setup and tear-down times of the traffic demands are known in advance, is a more proper traffic model for these kinds of applications. With the scheduled time information, network resources can be further optimized both in space and time. The routing and wavelength assignment problem for survivable unicast scheduled traffic demands has been studied[2-3].

In this paper, we provide integer linear programming (ILP) formulation to solve the multicast tree protection problem in a WDM optical network with scheduled traffic. Both wavelength-convertible and wavelength-continuity constrained cases are investigated. With the guaranteed 100% restorability against any single link failure, the formulation can achieve a global minimum cost for establishing all multicast sessions. Numerical experiments indicate that the proposed Multicast Tree Protection with Scheduled Traffic (MTP-ST) can achieve significant reduction in the cost for establishing all multicast sessions compared to the previous schemes which are unaware of the traffic time information, hence, better network resource optimization is realized.

Scheduled Traffic Model for Multicast Protection

In this work, we consider a set of multicast sessions with scheduled traffic. Multicast session $\boldsymbol{S_i}$ is represented by $\{s_i, (d_{i1}, d_{i2}, \ldots, d_{ij}, \ldots), (t_{is}, t_{ie})\}$, where s_i is the source node and d_{ij} is the j^{th} destination of the session $\boldsymbol{S_i}$. t_{is} and t_{ie} are the setup and teardown times of $\boldsymbol{S_i}$, respectively.

Problem Formulation

The inputs of the problem are listed as follows:

- The network topology $\boldsymbol{G} = (\boldsymbol{V}, \boldsymbol{E})$ is given as a weighted undirected graph. $\boldsymbol{V}$ is the set of N multicast capable network nodes. $\boldsymbol{E}$ is the set of weighted links. $\omega_{m,n} = \omega_{n,m}$ is the cost of using one wavelength on the link between nodes m and n. $\boldsymbol{D}_p(m)$ is the degree of node m and equals the number of fiber links connecting to node m.
- $\boldsymbol{W}$ is the maximum number of wavelengths in each direction of a fiber link.
- A set of k primary multicast sessions (trees). $\boldsymbol{P_i}$ =1 or 0 indicating whether session $\boldsymbol{S_i}$ requires protection or not, respectively. If the primary tree $\boldsymbol{S_i}$ requires protection, the backup tree for $\boldsymbol{S_i}$ is denoted as $\boldsymbol{S_{i+k}}$. So there are totally $2k$ trees at most. $\boldsymbol{L_i}$ is the number of destinations in the tree $\boldsymbol{S_i}$. $\boldsymbol{T_{p,q}} = \boldsymbol{T_{q,p}}$ is a Boolean, indicating whether tree p and tree q overlap in time (=1) or not (=0). Each multicast session requires a full wavelength bandwidth.

The variables for the ILP are defined as follows:

- Boolean variable $X^{c}_{m,n}$ indicates whether wavelength c on the link from node m to n is occupied by one or more multicast trees.
- Boolean variable $M^{i,c}_{m,n}$ indicates whether wavelength c on the link from node m to n is occupied by tree i (=1) or not (=0).
- Boolean variable V^{i}_{p} indicates whether node p belongs to tree i (=1) or not (=0).
- Integer commodity-flow variable $F^{i}_{m,n}$ is the number of commodity flow units of tree i going through the link from node m to n. Each destination requires 1 unit of commodity.
- If there is no wavelength converter, Boolean variable C^{i}_{c} is needed which indicates whether tree i uses wavelength c (=1) or not (=0).

The objective of the ILP is:

$$\text{Minimize } \sum_{c=1}^{c=W} \sum_{m,n} \omega_{m,n} \cdot X^{c}_{m,n} \quad (1)$$

Subject to:

Tree creation constraints:

$$\forall i, \forall n \neq s_i : \sum_{m,c} M^{i,c}_{m,n} = V^{i}_{n} \quad (2)$$

$$\forall i : \sum_{m,c} M^{i,c}_{m,s_i} = 0 \quad (3)$$

$$\forall i, \forall j \in S_i : V^{i}_{j} = 1 \quad (4)$$

$$\forall i, \forall m \neq d_{ij}, j \geq 1 : \sum_{n,c} M^{i,c}_{m,n} \geq V^{i}_{m} \quad (5)$$

$$\forall i, m : \sum_{n,c} M^{i,c}_{m,n} \leq D_p(m) \cdot V^{i}_{m} \quad (6)$$

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Commodity flow constraints:

$$\forall i, \forall m \notin S_i : \sum_n F^i_{m,n} = \sum_n F^i_{n,m} \quad (7)$$

$$\forall i, \forall m = s_i : \sum_n F^i_{s_i,n} = L_i \quad (8)$$

$$\forall i, \forall m = s_i : \sum_n F^i_{n,s_i} = 0 \quad (9)$$

$$\forall i, \forall m = d_{ij}, j \geq 1 : \sum_n F^i_{n,m} = \sum_n F^i_{m,n} + 1 \quad (10)$$

$$\forall i, m, n : \sum_c M^{i,c}_{m,n} \leq F^i_{m,n} \quad (11)$$

$$\forall i, m, n : F^i_{m,n} \leq N \cdot \sum_c M^{i,c}_{m,n} \quad (12)$$

Directed link disjointness constraint:

$$\forall i = 1 \cdots k, \forall m, n : \sum_c M^{i,c}_{m,n} + \sum_c M^{i+k,c}_{m,n} \leq 1 \quad (13)$$

Wavelength usage constraints:

$$\forall m, n, c : X^c_{m,n} \leq \sum_i M^{i,c}_{m,n} \quad (14)$$

$$\forall m, n, c : k \cdot X^c_{m,n} \geq \sum_i M^{i,c}_{m,n} \quad (15)$$

Time joint constraint:

$$\forall m, n, p, q(T_{p,q} = 1) : M^{p,c}_{m,n} + M^{q,c}_{m,n} \leq 1 \quad (16)$$

Wavelength-continuity constraints
(when there is no wavelength converter)

$$\forall i : \sum_c C^i_c = 1 \quad (17)$$

$$\forall i, c, m, n(n > m) : M^{i,c}_{m,n} + M^{i,c}_{n,m} \leq C^i_c \quad (18)$$

Our formulation allows wavelength sharing by different trees which do not overlap in time, which is a special feature of the scheduled traffic model. Equation (14) ensures that a wavelength on each direction of a link is occupied if one or more trees choose to use it. Equation (15) ensures that a wavelength on each direction of a link can be shared by k trees at most. This is because a primary tree and its backup cannot share a wavelength in the same direction of each link. Equation (16) ensures that two trees cannot share a wavelength in the same direction of a link if they overlap in time. Due to lack of space, please refer to the paper by Singhal[1] for detailed interpretation of other constraints.

Illustrative Numerical Example

We employ the 15-node network[1] shown in Fig. 1. Each link carries four wavelengths in both directions. There are five primary multicast sessions (k=5). S_1 = {0, (1, 2, 4, 5, 10, 11, 12, 13, 14), (t_{1s}, t_{1e})}, S_2 = {9, (1, 2, 3, 4, 5, 6, 10, 11), (t_{2s}, t_{2e})}, S_3 = {12, (0, 5, 8, 9, 10, 14), (t_{3s}, t_{3e})}, S_4 = {14, (1, 2, 3, 4), (t_{4s}, t_{4e})}, S_5 = {7, (0, 6), (t_{5s}, t_{5e})}. t_{is} and t_{ie} are used as parameters to control the time overlap in our formulation. Sessions S_1, S_4 and S_5 require single-link protection. Each of them requires a backup tree S_6, S_9 and S_{10}, respectively. These backup trees have the same setup and tear-down time as their corresponding primary trees. The ILPs are solved by CPLEX.

Tab. 1 shows the costs of establishing all trees by different schemes. MTP and MTP-WC refer to the previously proposed Multicast Tree Protection[1] considering no time information without and with wavelength continuity constraints, respectively. MTP-ST and MTP-ST-WC refer to our proposed Multicast

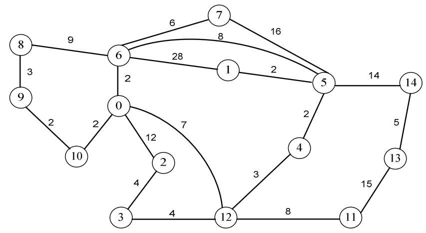

Fig. 1: A 15-node network with bidirectional links

Tab. 1: Total cost of establishing all multicast trees

Time correlation	MTP	MTP-ST	MTP-WC	MTP-ST-WC
High	377	**274**	377	**278**
Medium	377	**228**	377	**231**
Low	377	**216**	377	**219**

Tree Protection with Scheduled Traffic formulations without and with wavelength continuity constraints, respectively. Time correlation parameter refers to the relative degree of time-overlap among the trees. In our example, "High" means $T_{1(6),2}$= $T_{1(6),3}$= $T_{2,3}$= $T_{3,4(9)}$= $T_{3,5(10)}$= $T_{4(9),5(10)}$ = 1; "Medium" means $T_{2,3}$= $T_{3,4(9)}$= $T_{3,5(10)}$= $T_{4(9),5(10)}$ = 1; and "Low" means $T_{3,4(9)}$= $T_{3,5(10)}$= 1. The indices in the subscript brackets refer to the respective backup trees. From Tab. 1, it is observed that the lower the time correlation, the more improvement in our proposed MTP-ST and MTP-ST-WC formulations. Their performance improvements over their respective counterparts (MTP and MTP-WC) are about 27%, 39% and 42% under "High", "Medium" and "Low" time correlations, respectively. The costs of MTP and MTP-WC are independent of the time correlation parameters, since no time information is considered. With the additional wavelength continuity constraints, the costs of MTP-WC and MTP-ST-WC are no smaller than the costs of MTP and MTP-ST, respectively, if the same time correlation is applied. Fig. 2 depicts the routing and wavelength assignment of S_1 and its backup tree S_6 when MTP-ST-WC is used under "Low" time correlation, for instance.

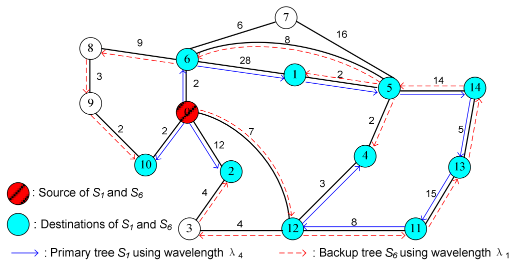

Fig. 2: An example of the established multicast primary tree S_1 (solid arrowed lines) and its respective backup tree S_6 (dashed arrowed lines).

Summary

We have formulated and numerically investigated the multicast tree protection with scheduled traffic. The results show that the network resources can be jointly optimized both in space and time to provision survivable multicast sessions at much lower costs.

References

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