Protecting Multicast Session in Survivable WDM Mesh Networks

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ABSTRACT
Protecting light-tree based multicast connections are more demanding than unicast connections in wavelength division multiplexing (WDM) based mesh networks. In this work, we proposed two mathematical models and a heuristic based approach to protect multicast connections in WDM mesh networks. The mathematical models presented in this paper are based on multiple unicast connections. Link-protection and path-path protection schemes are considered to protect the multicast connections. Our heuristic based approach based on sub-path protection technique namely shared-segment protection (SSP) scheme. We simulate the above techniques on conventional networks and the results are compared to evaluate their performances. Simulation results show that SSP scheme offers a reduction in average cost for protecting multicast connections. Static and dynamic multicast connections have been used to calculate the average cost and the blocking probability respectively.

Keywords: light-tree, multicasting, protection, survivability, WDM networks.

1. INTRODUCTION
WDM optical networks are high speed networks and provide many potential applications [1-5]. In order to support multicast based applications the WDM network be required to employ multicast-capable wavelength-routing switches at the network node [6]. Theses switches are capable to replicate data stream from one input port to multiple output ports. There are two types of switch architectures are used [7]. Opaque switch which support electronic cross-connects with optical-electrical-optical (O-E-O) conversion and transparent switch architecture which support all optical cross-connects (OXCs). Significant work has been carried out to protect unicast connections in WDM networks, however, little effort has been made for protecting multicast connections in WDM mesh Networks.

Several schemes have been proposed in the literature to protect the multicast connections. The simplest idea to protect the multicast tree from single fiber failure is to compute a link disjoint backup tree is reported in [7]. Two trees are said to be link-disjoint if they do not have any common links. The drawback of this scheme is that it uses excessive network resources and also it is not always possible to find a link-disjoint backup tree. Ring based approach is proposed to protect multicast session in [8]. In this approach a ring has to be formed taking the source node and all the destination nodes participating in the multicast session. The limitation of this scheme is that, it is not always feasible to form such ring in all cases, particularly, when the session sizes are large. Hence the scheme leads to higher blocking probability. Segment protection scheme is reported in [9]. The author derived arc-disjoint backup segment for every segment on the primary light-tree. A segment in a multicast tree is defined as the sequence of edges from the source or any splitting node (on a tree) to a leaf node, or, to a downstream splitting node. A destination node is always considered as a segment end node because it is either a leaf node in a tree or a splitting node. The author also proposed optimal path pair based shared disjoint-path (OPP-SDP) scheme. OPP_SDP scheme finds optimal path pair between every source-destination pairs to protect the multicast connection. The author concluded that OPP-SDP is the best scheme w.r.t. average cost and blocking probability among other proposed schemes. Wavelength sharing can significantly reduces the unnecessary capacity reserved for protecting light-trees and they are classified mainly into three categories (self-sharing, intra-request sharing and inter-request sharing) [10-11]. Multicast protection scheme through spanning path is proposed to protect multicast session is reported in [12-14]. A spanning path in a multicast tree is defined as a path from a leaf node to any other leaf node in the light-tree. The scheme derives backup paths for every spanning path in the multicast-tree. The author used the above three kind of sharing and reported as the efficient technique in terms of average cost and blocking probability. Two heuristics based solution is reported for protecting light-trees such as optimal path pair based removing residual links (OPP-RRL) and source leaf path based avoiding residual links (SLP-ARL) in [15]. The author concluded that the scheme is better than OPP-SDP scheme.

In this paper we have extended the ILP based formulation used to protect the unicast (P2P) connections, i.e. a multicast connection is considered as multiple unicast connections from the source node to all the destinations
nodes participating in the multicast session. The rest of this paper is organized as follows. In Section 2, we discuss the proposed methods. In section 3 we present the numerical results and conclusions of this work is presented in section 4.

2. PROPOSED METHODS

A. Problem Description

A multicast connection can be realized as multiple unicast connections. Since in a multicast based application, several replicas of information are routed to the desired destinations, hence a single wavelength channel needs to be assigned for each light-tree.

In mathematical models (link-protection and path-protection), we consider single wavelength channel per fiber where as in heuristic approach (SSP), multiple wavelength channels per fiber are considered.

We assume that multicast connections or a light-tree is unidirectional in nature from source to each destination. The session size indicates the number of nodes takes part in a multicast session. In link-protection and path-protection techniques we consider one protected multicast session while as in SSP algorithm, multiple protected multicast connections are considered.

B. Mathematical Formulation

The ILP formulations in [16] are used for finding the minimum cost path to all the destinations. We then explain our approach with a suitable example.

Example: Suppose a multicast connection arrive as $S = \{1, 2, 3, 6\}$ i.e. node ‘1’ acts as the source and ‘2’, ‘3’ and ‘6’ are the destinations of the multicast session. If we can consider this as three unicast connections then, three different lightpaths of $P_1=(1,2)$, $P_2=(1,2)(2,3)$ and $P_3=(1,2)(2,6)$ needs to be assigned different wavelengths shown in fig. 1 (a). But, if we consider this is a multicast connection then, a single wavelength has to be used to send the information to all the destinations. Hence the light-tree $T = P_1 \cup P_2 \cup P_3 = (1,2)(2,3)(2,6)$ could be derived and is shown in fig. 1 (b).

![Diagrams](image)

Figure 1: (a) Three unicast connections. (b) One multicast connection taking union of three unicast connection shown in fig 1.(a)

Sets and Parameters:

- $N$: Set of nodes
- $L$: Set of links
- $E$: Set of edges contains arc $(i,j)$ and $(j,i)$
- $W$: Number of wavelength on each fiber link
- $d_{ij}$: Number of requested connections between node pair $i$ and $j$
- $D$: Set of demand pairs $(i,j) \in D$ implies that $d_{ij} > 0$
- $P_{ij}$: Set of paths between node pair $i$ and $j$, $\forall (i,j) \in D$
- $R$: Set of all paths
- $A_{ij}$: Set of paths contain arc $(i,j)$
- $Z_{st}$: Set of all paths from ‘s’ to ‘t’ except the direct link $(s,t)$
- $P_{ij}^{st}$: Set of directed paths accessible for restoration from ‘i’ to ‘j’ when $(s,t)$ fail.
- $P_{ij}^{st}$: Set of directed paths not accessible for restoration from ‘i’ to ‘j’ when $(s,t)$ fail.

Variables:

- $w_{ij}$: Primary capacity on link $(i,j)$
- $s_{ij}$: Spare capacity on link $(i,j)$
- $x_p$: 1 if lightpath $p$ exists, 0 otherwise.
- $y_p$: 1 if lightpath exists on path $p$ when link $(s,t)$ fail, 0 otherwise.

To establish a primary light-tree the ILP formulation can be written as

\[
\text{minimize} \sum_{(i,j) \in L} w_{ij}
\]

Demand between node pair: $\forall (i,j) \in D$

\[
\sum_{p \in P_{ij}} x_p = d_{ij} \quad (1)
\]

Working link capacity: $\forall (i,j) \in L$

\[
\sum_{p \in A_{ij}} x_p + \sum_{p \in A_{ji}} x_p \leq w_{ij} \quad (2)
\]

\[
\sum_{p \in A_{ij}} x_p \geq 0 \quad (3)
\]

Equation (1) ensure that the number of lightpath demand $d_{ij}$ between the node pair $(i, j)$ must be equal to the number of paths $x_p$ within the $P_{ij}$. In a multicast connection this is equal to 1. Equation (2) says about the...
number of connection passes in the direction ‘i’ to ‘j’ and ‘j’ to ‘i’ through the fiber link (i, j). Equations (3) and (4) ensures the non-negative and integer variables. This formulation provides the path from the source to all the destinations with minimum capacity. So taking union of all the selected paths we will get the set of links that a light-tree consists.

Spare Capacity Allocation Model

- **Shared Link Protection (SLP)**

In link based protection, we assume that each node is capable to detect a link failure and run a rerouting algorithm around the failed link. The traffic is rerouted only around the failed link. In this strategy, for calculating backup capacity we should have knowledge about the working capacity i.e. the number of primary lightpaths passes through the failed link. The technique followed to form a light-tree for a multicast connection, the backup paths for the failed link is calculated similarly.

| TABLE I |
|---|---|
| Working link | Backup route |
| (1,2) | (1,5) (5,2) |
| (2,6) | (2,5) (5,6) |
| (2,3) | (2,6) (6,3) |

TABLE I presents the links for the primary light-tree and the backup paths for the corresponding link. Taking the union of the entire backup route gives the cost of backup path which is 5 wavelength links. Since from the above backup capacity we can see that the link (2, 6) is being considered for both primary light-tree and the backup path shown in TABLE I.

So the ILP formulation can be written as

\[
\text{minimize } \sum_{(i,j) \in L} w_{ij} + s_{ij}
\]

Lost link capacity: \( \forall (s, t) \in L \)

\[
\sum_{p \in E-ST} y_{p}^{ST} = w_{ST}
\]

Spare link capacity: \( \forall (s, t) \in L, (i, j) \in L \setminus (s, t) \)

\[
\sum_{p \in A_{ij}} y_{p}^{ST} + \sum_{p \in A_{ji}} y_{p}^{ST} \leq s_{ij}
\]

Fiber capacity limit: \( \forall (i, j) \in L \)

\[
w_{ij} + s_{ij} \leq W
\]

\[s_{ij} \geq 0 \ (i, j) \in L
\]

\[y_{p}^{ST} \geq 0 \ \forall (s, t) \in L, \forall p \in R
\]

where \( w_{ij} \) may be calculated from the working capacity model. Equation (5) ensures that the number of connections affected due to failure of link (s, t). The affected connections must be rerouted through all the paths from ‘s’ to ‘t’ except the failed link (s, t). Equation (6) ensures that the sum of backup paths passes through link (i, j) and (j, i) must be less than the total number of backup paths available. Equation (7) ensures that the sum of the primary lightpaths and the backup lightpaths on any link is limited to the number of wavelengths available on the fiber link. In our work we have considered homogeneous network i.e. all the fiber links have the same number of wavelengths. Equation (9) and (10) ensures non negative and integer variables.

- **Shared Path Protection (SPP)**

In our second formulation we apply shared path protection technique used for unicast connection.

| TABLE II |
|---|---|
| Working link | Backup route |
| (1,2) | (1,5) (5,2) |
| (2,6) | (1,5) (5,6) |
| (2,3) | (1,5) (5,6) (6,3) |

Taking union of the entire backup route gives the cost of backup path which is 4 wavelength links and shown in TABLE II.

Hence the ILP formulation can be written as

\[
\text{minimize } \sum_{(i,j) \in L} w_{ij} + s_{ij}
\]

Lost capacity in forward direction: \( \forall (s, t) \in L, (i, j) \in L \setminus (s, t) \)

\[
\sum_{p \in E-V_{ij}} y_{p}^{ST} + \sum_{p \in E-V_{ji}} y_{p}^{ST} \leq s_{ij}
\]

Lost capacity in reverse direction: \( \forall (s, t) \in L, (i, j) \in D \)

\[
\sum_{p \in E-V_{ji}} y_{p}^{ST} + \sum_{p \in E-V_{ij}} y_{p}^{ST} \leq s_{ij}
\]

Fiber capacity limit: \( \forall (i, j) \in L \)

\[
w_{ij} + s_{ij} \leq W
\]

\[s_{ij} \geq 0 \ (i, j) \in L
\]

\[y_{p}^{ST} \geq 0 \ \forall (s, t) \in L, \forall p \in R
\]
C. Heuristic Based Solution

- **Shared Segment Protection (SSP)**

Since the complexity of ILP formulation increases rapidly we study a heuristics approach based on segment protection [9] using minimum spanning tree algorithm such as Prim’s. First we generate a multicast session with a fixed group size. The minimum spanning tree (MST) is then pruned with respect to the nodes present in the multicast session. The pruned graph thus formed is the primary light-tree. Then we identify the segments in the primary light-tree. To find the backup paths for each segments in the light-tree remove a segment from the primary light-tree and find the backup (minimum cost path) path to the corresponding segment if exists. If a backup path is found then it is added to backup cost. Update the cost of the path to zero for already found path and repeat the same procedure until all the segments are removed from the primary tree. The backup to the segment is found by Dijkstra algorithm. Source is one end of the segment and destination is the other end of the segment.

```
Create the MST
Prune the MST as per the multicast session
Identify the segments on the primary tree
Remove a segment from the primary light-tree and find the optimal backup path
Add the cost of the backup path
Update cost=0 for already found backup paths
Is any segment left on the primary tree
If the backup path for every segments on the primary tree are found then select the multicast session else reject the multicast session
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**Flow model for SSP algorithm**

3. **NUMERICAL RESULTS**

We conduct extensive simulations to study the performance of the proposed protection scheme. We compare the proposed schemes with optimal path-pair based shared disjoint path algorithm (OPP_SDP) described in [9], which has been reported as the most efficient scheme by means of average cost and blocking probability.

- **Assumptions and Simulation Setup**

We simulate our schemes on two sample network shown in fig. (2) and fig. (3). For NSFNET the link cost represents the normalized length where as for INDIANET the link cost represents the fiber length between the node pairs in kilometers. We assume that fiber links are bidirectional in nature. The multicast connection is unidirectional in nature from source to destinations. For link-protection scheme and path-protection scheme, we applied precomputed sessions of fixed session size. In the case of SSP and OPP_SDP scheme multicast connections arrive with poisons distribution, and their holding time is set to one unit. The traffic load offered to the sample networks is the number of active multicast session per unit time. We assume that the wavelength converters are not available at the network node. Hence the multicast session or the light-tree occupies single wavelength links throughout their path. As the computational complexity increases with the increase in number of node, we present the average of 200 different multicast sessions for fixed session size for link-protection and for path-protection schemes. On the other hand for SSP and OPP_SDP scheme, we injected $10^5$ different multicast session of same session size. The ILP models are solved with CPLEX 10.2 solver. The SSP and the OPP_SDP algorithm and the k-Shortest path algorithm are implemented using ‘C’ language.

- **Results and Discussion**

Fig. 4 and fig. 5 shows the average cost for establishing multicast connections versus the session size for NSFNET and INDIANET respectively. Like path-protection and link-protection scheme for unicast connections, the average cost for protecting multicast connection using path-protection technique is much lower than link-protection technique. It is also observed from the above figures that the SSP scheme offers lower cost than the OPP_SDP scheme for protecting multicast session. The author in [9] pointed out that there are cases where backup segments may not be found always, we feel that such case arise rarely. Fig. 6 and fig. 7 shows the blocking probability (BP) offered by SSP and OPP_SDP scheme. It is observed that the BP offered by OPP_SDP is better than SSP scheme till we increase the session size up to approximately 8 and 9 for both NSFNET and INDIANET. But when we increase the session size, it is observed that the BP is almost equal offered by both the scheme as the number of segments increases with the increase in session size. Further we find the BP, keeping the session size in mind; we fix the session size and vary the load. From fig. 8 and fig. 9 it is observed that for NSFNET when we fix the session size equal to 7 the BP offered by OPP_SDP scheme is lower than SSP scheme.
where as when we increase the session size to 10 the BP is almost equal. Similarly from fig. 10 and fig. 11 it is observed that for INDIANET when we fix the session size equal to 10 and 15 the BP offered by both SSP and OPP_SDP schemes are almost equal.

Figure 2: NSF NET (14 nodes, 22 links)

Figure 3: INDIA NET (20 nodes, 33 links)

Figure 4: Average Cost Vs Session Size for NSFNET

Figure 5: Average Cost Vs Session Size for INDIANET

Figure 6: Blocking probability Vs Session Size for NSFNET

Figure 7: Blocking probability Vs Session Size for INDIANET

Figure 8: Blocking probability Vs Load with Session Size 7 and 32 wavelengths for NSFNET
Figure 9: Blocking probability Vs Load with Session Size 10 and 32 wavelengths for NSFNET

Figure 10: Blocking probability Vs Load with Session Size 10 and 32 wavelengths for INDIANET

Figure 11: Blocking probability Vs Load with Session Size 15 and 32 wavelengths for INDIANET

4. CONCLUSIONS

In this paper, we have investigated various protection schemes taking static as well as dynamic multicast sessions in WDM mesh networks. The proposed mathematical model for path-protection scheme offered lower cost over link-protection scheme to protect multicast connections. Also the heuristic based approach using shared segment protection scheme offers lower average cost for establishing protected multicast session in the WDM networks. The shared segment protection scheme offer equal blocking probability with the best reported scheme (OPP_SDP), particularly when the session size is larger. Moreover we are investigating further sharing techniques, to design efficient algorithm for protecting dynamic multicast sessions in WDM mesh networks.

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