Fault Tolerant Multicast Couple Hop Routing

(Invited Paper)

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I. INTRODUCTION

Light trails, a fairly recent optical networking architecture for LAN and MAN, and possibly WAN applications, can support both optical unicast and multicast. In this paper we consider routing both types of traffic in a survivable light trail network with multiple wavelengths. The algorithm supports multi-hop routing where traffic may use up to two light trails to reach its destination. An ILP is developed to help plan traffic placement in such a network. Our results show that considering the multicast nature of traffic may be necessary when planning optical routing and protection.

Keywords: Light trails, point to multi-point traffic, traffic grooming, survivable networking

II. GRAPH MODEL

To model such a network we use a directed acyclic graph to select light trails that can accommodate the routing and fault tolerance requirements. Our graph model can be visualized as a set of three layers. Each layer consists of all the nodes in the physical topology. The first layer represents physical nodes acting as sources. The second layer represent physical nodes as intermediate sinks/sources, where optical-electronic-optical (OEO) conversion allows signals to hop between two light trails. Finally, the third layer represents destinations. Since we assume a given physical node can play any or all of these roles each physical node in a network is represented by three nodes for routing in our graph model. We compute a set of candidate light trails. Edges exist between nodes only if a light trail connects them and the direction fits with their roles. For instance a source node may have an edge leading to a destination node, but a destination node cannot have an edge to an intermediate node even if a light trail exists.

Routing in this model is straightforward since it can be modelled as a flow problem, in that traffic flowing into an intermediate node must also flow out. However, our model is different from common flow problems since capacity constraints apply to the sum of the flows across a group of links. This is because groups of links correspond to the same light trail.

Routing flows between each source/destination pair is its own flow problem. However some flows should not add cumulatively towards total capacity used. Flows representing the same information from a source to different destinations for instance need not add since they represent the same physical transmission. Flows used to plan backup routes for failures that are not simultaneous need not add. To reflect this in our model variables representing flows do not obey link capacity constraints directly, instead they lower bound variables representing the maximum capacity require by the non-interfering flows. It’s these variables that add cumulatively towards total capacity used.

To route the traffic, the network is assumed to have uni-directional physical edges. An un-directed edge therefore is represented by two directed edges in opposite directions. A physical edge failure thus affects both directions, in case both edges exist. The network traffic routing plans in advance on how to reroute traffic on light trails that uses the failed links. All nodes are capable of sinking, sourcing, or rebroadcasting connections. We assume that the traffic is routed with no more than two light-trail hopes on the path. On such a path, a node on a light trail sinks the traffic and rebroadcasts to the next light trail as an intermediate source.

The multi-hop case is more complex. For instance a source node may have an edge leading to an intermediate node even if a light trail exists. However, our model assumes that the traffic is routed with no more than two light-trail hops on the path. On such a path, a node on a light trail sinks the traffic and rebroadcasts to the next light trail as an intermediate source.

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Our model is illustrated in Figure 1. Figure 1(a) is a very simple network that can support fault tolerant connections. In Figure 1(b) is depicted the three layers when the set of candidate light trails is limited to being one link in length. This is an unrealistic candidate set, but its selection is necessary.

Abstract— Light trails, a fairly recent optical networking architecture for LAN and MAN, and possibly WAN applications, can support both optical unicast and multicast. In this paper we consider routing both types of traffic in a survivable light trail network with multiple wavelengths. The algorithm supports multi-hop routing where traffic may use up to two light trails to reach its destination. An ILP is developed to help plan traffic placement in such a network. Our results show that considering the multicast nature of traffic may be necessary when planning optical routing and protection.

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to keep the figure readable. Nodes 1a, 2a, 3a represent the first layer depicting source flows that are originated by nodes in the physical networks in Figure 1(a). Nodes 1c, 2c, 3c represent the physical nodes acting as sinks in the third layer, and nodes 1b, 2b, 3b represent the physical nodes performing OEO conversion (intermediate nodes as part of the second layer) to allow traffic. Figure 1(c) shows only links that have non-zero flow in our model when it is solved for supporting a connection starting at node 1 and ending at node 3. A light trail carries traffic from 1 to 3, while the backup path follows a trail from 1 to 2, and then uses a trail from 2 to 3. While this is the result obtained when solving our ILP given below, having 1 to 3 act as the backup path and the primary take the trails 1 to 2, and 2 to 3 is allowed.

III. ILP MODEL

We state our model more formally below. Note that it has indexes for both physical links as well as links in the our graph model that represent connectivity from light trails. Thus, it needs to be read carefully to avoid confusion. The index \( l \) refers to edges in our transformed graph, and \( p \) refer to edges in the graph of the physical network. The index \( n \) refers to nodes in our graph model. A connection in the network can have multiple recipients, with the destinations being referred to by the index \( d \). Wavelengths are indexed by \( w \). The constant \( M_{l,p} \) is 1 when link \( p \) is part of light trail \( t \), 0 otherwise. \( C_{l,n} \) is plus or minus 1 when link \( l \) connects to node \( n \) with the sign selected by the direction. \( J_{l,p} \) is 1 when the light trail it corresponds to uses physical link \( p \). The constant \( J_{l,p} \) is the same except it is also 1 if a light trail travels between the nodes \( p \) is connected to but in the opposite direction. This is to account for the fact such an edge is likely routed with \( p \) physically and will fail at the same time. Information about connection requests are contained in the constants \( S_{n,r,d} \) and \( N_r \). The constant \( S_{n,r,d} \) takes on the values one, zero, or negative one depending on if node \( n \) is sourcing request \( r \), is the \( d \)th receiver of request \( r \) or if it is not involved. The constant \( N_r \) takes on the values one, two, four, or eight depending on how many of the sixteen units of light trail bandwidth a requests needs. The constant \( K_{l,t} \) is 1 if edge \( l \) carries traffic that light trail \( t \) carries.

Potential light trails are represented by the variable \( T_{l,w} \). Flows to be routed are represented by \( F_{l,r,d} \). Variables representing how flows are rerouted for the failure of link \( p \) are represented by \( Z_{l,r,d,p} \). Sources and sinks of flows representing backup routes are modelled by \( V_{n,r,d,p} \). Variables in this paragraph are all binary variables, all other variables it does not matter if they are nonnegative integer or nonnegative continues.

\[
\text{Minimize } \sum_t \sum_w T_{l,w} \quad (1)
\]

Information between a source and each of its destinations individually act as a flow.

\[
\sum_t N_r \cdot C_{l,n} \cdot F_{l,r,d} = N_r \cdot S_{n,r,d} \quad (2)
\]

The total capacity needed by request \( r \) on light trail \( t \) is under bounded by \( F_{l,r} \).

\[
K_{l,t} \cdot N_r \cdot F_{l,r,d} \leq F_{l,t} \quad (3)
\]

The combined capacity of light trail \( t \) must be able to handle combined flow of all the links that correspond to it.

\[
\sum_w 16T_{l,w} \geq \sum_r F_{l,r} + Z_{l,t} \quad (4)
\]

At most one light trail may use wavelength \( w \) on physical link \( p \).

\[
\sum_t M_{l,p} \cdot T_{l,w} \leq 1 \quad (5)
\]

Flows disrupted by the failure of physical link \( p \) are identified.

\[
V_{n,r,d,p} \geq J_{l,p} \cdot F_{l,r,d} \quad (6)
\]

A backup flow must be routed for each flow disrupted by the failure of physical link \( p \).

\[
\sum_t C_{l,n} \cdot Z_{l,r,d,p} = S_{n,r,d} \cdot V_{n,r,d,p} \quad (7)
\]

A backup flow may not cross a light trail which uses a failed link.

\[
N_r \cdot Z_{l,r,d,p} \leq N_r \cdot (1 - J_{l,p}) \quad (8)
\]

A bound is found on capacity need on light trail \( t \) to protect request \( r \) in the worst case.

\[
K_{l,t} \cdot N_r \cdot Z_{l,r,d,p} \leq Z_{l,t,r} \quad (9)
\]

The previous estimate is reduced by capacity on the light trail already allocated to the connection. This could result in estimation errors in the amount of primary and backup capacity required, however their sum will be correct and this is the only quantity of importance in planning the connections.

\[
Z_{l,r,d,p} - F_{l,t} \leq B_{l,t,r} \quad (10)
\]

Per flow estimates of backup capacity are combined to form per light trail estimates.
The graph model allows a signal on a light path to undergo OEO from the path to itself. Equation 6 may allow the protection unfailed traffic. Both can be easily removed from the solution of the ILP should they occur.

### IV. Experimentation

An example solution to the ILP is given below in Figure 2 and Tables I, II, III. Table I shows traffic requests and capacity needs for the network in Figure 2.

The network is assumed to only have three wavelengths and some point to multipoint connections that need a lot of bandwidth. Note that at the first look the number of wavelength will look small. However, in a network where both full wavelength traffic and subwavelength traffic is combined, most wavelengths may be used to support full wavelength traffic requests and only some wavelengths may be reserved to support light trails to groom sub-wavelength traffics. These connections are large enough that if they were implemented as point to point connections, the network would not have the spare capacity to recover from some link failures. This can be seen by noting that if edge 3 to 5 were to fail, edge 2 to 4 would have to carry all traffic from nodes 1,2,3 to nodes 4,5,6. If point to point connections were used, the required bandwidth would be the equivalent of three and a half wavelengths, which exceeds what is available. However using the multicast nature of the traffic it can be protected. The results of our ILP doing so are shown below.

Table II lists light trails and wavelength selected to carry traffic, ID numbers given were assigned by our light trail enumeration program. The enumerated light trails are input to ILP. The pool of candidate light trails was taken to be the all light trails of length one to two links. Table III shows the ordered set of one to two light trails used by each request to reach each destination.

The cost in terms of the number of light trails to backup the network is more than doubling the number of light trails. This can be seen by removing equations 7 to 11 and the term $Z_t$ from equation 4 so the ILP routes without concern for protection. Doing so shows the traffic alone could have been routed with less than half the number of light trail with the same length restriction as before. This is shown in Figure 3.

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### V. Conclusion

This paper considered an optical network with unidirectional links, multiple wavelengths, and the survivability requirement that traffic must be rerouted to survive the single simultaneous failure of links going in both directions between any given node pair. The network supports both unicast and multicast traffic which is routed using light trails. Traffic may use up to two light trails to reach its destination. We provided an ILP to plan light trail placement in a survivable network. In the examples provided, point to multipoint traffic could be protected at the cost of more than doubling the number of light trails required.

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### References


