Architectures and Algorithm for Multicasting in WDM Optical Mesh Networks using Opaque and Transparent Optical Cross-Connects

Narendra K. Singhal and Biswanath Mukherjee
Department of Computer Science, University of California, Davis, CA 95616
Tel: (530) 752-5129, Fax: (530) 752-4767, Email: {singhaln,mukherje}@cs.ucdavis.edu

Abstract

As the WDM technology grows, multicast applications will become widely popular. In this study, we present two kinds of switch architectures to support multicasting. We present preliminary results obtained for efficient routing and wavelength assignment (RWA) of multicast sessions.

I. INTRODUCTION

Multicast applications such as television broadcasts, movie broadcasts from studios, video-conferencing, live auctions, interactive distance learning, distributed games, etc. are becoming increasingly popular. These applications requires point-to-multipoint connections among the nodes in a network. In order to support multicasting in WDM optical networks, which are expected to form tomorrow’s Internet backbone, we need multicast-capable wavelength-routing switches (MWRSs) [3] at network nodes, which can replicate bit stream from one input port to multiple output ports.

There are two approaches to design switches capable of supporting multicast. Fig. 1 shows a hybrid approach, where the optical bit streams are converted to electronic data, switched using electronic cross-connect, and then electronic bit streams are converted back to the optical domain. This “opaque” approach is currently very popular due to existance of mature technology to design high-bandwidth multi-channel (N x N) non-blocking electronic cross-connect fabrics [2]. Some companies are already shipping optical cross-connects (OXC) based on O-E-O conversion. As an example, Vitesse’ VSC836 is a 64 x 65 non-blocking crosspoint switch capable of supporting multicast, which can be used for building MWRS with O-E-O conversion.

Fig. 2 shows a multicast-capable all-optical switch which cross-connects optical channels directly in the optical domain. Here, the switch operation in “transparent” to the bit rate or bit-encoding schemes as opposed to a switch with O-E-O conversion which is opaque. Again, several companies are working toward building all-optical switches using tiny mirrors based on microelectromechanical (MEMS) technology. For multicasting in all-optical switches, “optical splitters” are needed to replicate an incoming bit stream to two or more outputs as shown in Fig. 2. Amplifiers are required because the output signal power weakens when the input signal is split.

Consider a simple network topology shown in Fig. 3, where we wish to establish a multicast session from the source node F to a set of destination nodes B, C, and D. The point-to-multipoint connections for the session are shown in thick lines. These thick lines are based on a light-tree [3] approach, where each multicast session forms a tree with the source node as the root and the destination nodes as leaves. In a network equipped with all-optical switches, an optical splitter is needed at node B for setting the above multicast session. In absence of wavelength converters, this light-tree based multicast session exhibits the wavelength-continuity constraint [3]. Extra wavelength converters are not needed in a network where nodes are equipped with optical switches based on the hybrid approach of Fig. 1, because once the bit stream is converted to electronic domain, it can be switched and converted back to optical domain on any wavelength. In other words, full-range wavelength conversion is an inherent property of such switches and the wavelength-continuity constraint need not be obeyed.

When we are given several multicast sessions to be established in a network, proper routing and wavelength assignment is essential for setting up all of the sessions at minimum cost. The cost of a multicast session
is calculated by summing the weights associated with the links occupied by the session. For example, the cost of the session shown in Fig. 3 is 19. In case of multiple multicast sessions, there will be a need for an array of optical splitters at nodes. This requires splitter bank at nodes equipped with all-optical switches as shown in Fig. 2. When an optical splitter splits an incoming signal \( n \) ways, the output power becomes \( 1/n \) of the incoming power. This puts a limitation on the splitting degree of a splitter. Observe that in Fig. 3, optical splitter at node B has a splitting degree 3.

The problem of setting up a minimum cost multicast session forms a Steiner-tree and the problem of finding a Steiner-tree is NP-complete. The problem of establishing several multicast trees at minimum aggregate cost is also an NP-complete problem. We formulate the problem of setting up several light-tree based multicast sessions on a given network topology mathematically. The formulation turns out to be a mixed integer linear program (MILP) which is solved using a MILP solver, CPLEX.

![Fig. 1. Switch architecture for supporting multicast using all-electronic cross-connect and O-E-O conversion.](image)

![Fig. 2. Switch architecture for supporting multicast using all-optical cross-connects.](image)

![Fig. 3. A six-node network topology with the light-tree shown in thick lines carrying traffic from node F to nodes B, C, and D. (Link labels, chosen arbitrarily for this example, correspond to fiber length between node pairs.](image)

![Fig. 4. Aggregate cost of optimally setting up the group of five multicast sessions for different values of d (splitting degree) and B (splitter bank size) in a network with no wavelength converters. Infeasible means that all the multicast sessions cannot be carried and some sessions will be blocked.](image)

## II. Problem Statement

The problem of setting up a group of multicast sessions using a light-tree based approach on a given physical topology (fiber network) is formally stated below. We are given the following inputs to the problem:

1. A physical topology \( G_p = (V, E_p) \) consisting of a weighted undirected graph, where \( V \) is a set of network nodes, and \( E_p \) is the set of links connecting the nodes. Undirected means that each link in the physical topology is bidirectional. Nodes correspond to network nodes and the links correspond to the fibers between nodes. Each link is assigned a weight, which may correspond to the length of fiber between node pairs. A network node \( j \) is assumed to be equipped with a \( D_p(j) \times D_p(j) \) WRS, where \( D_p(j) \), called the physical degree of node \( j \), equals the number of physical fiber links emanating out of (as well as terminating at) node \( j \).
2. Number of wavelength channels carried by each fiber = \( W \).

3. A group of \( k \) multicast sessions.

Our goal is to set up (if possible) all the \( k \) multicast sessions on the given physical topology while minimizing the total cost. Details of the mathematical formulation are given in [4].

### III. ILLUSTRATIVE EXAMPLES

For illustration purpose, we consider a small example, namely the network topology in Fig. 3. Each link can carry \( W = 2 \) wavelengths. We are given a group of \( k = 5 \) multicast sessions: \( S_1 = \{ F, A, B, C, D \} \), \( S_2 = \{ C, A, E, F \} \), \( S_3 = \{ E, A, B, C, F \} \), \( S_4 = \{ B, D \} \), and \( S_5 = \{ A, C \} \) to be established in the network. The first node in a set is the source and the remaining nodes are destinations.

We formulate the problem mathematically for networks with two kinds of switch architectures discussed before. Fig. 5 shows that in a network with no wavelength converters, the total cost of optimally setting up the five multicast sessions is 60 which is slightly more than the cost of setting up the same group of multicast sessions in a network with full-range wavelength converters which is 59 as shown in Fig. 6.

In a network with optical splitters, there is a limitation on the size of the splitter bank (B) at a node and the splitting degree (d) of a splitter. Fig. 4 compares the aggregate cost of the optimally setting up the same group of five multicast sessions for varying values of d and B in absence of wavelength converters. It shows that the total cost of routing decreases with increase in either the splitting degree of a splitter (d) or the size of the splitter bank (B) at a node. The table also shows that multicasting is not possible with \( d = 1 \) and the total cost does not alter with increase in splitting degree beyond the maximum nodal degree of the physical topology.

**Fig. 5.** Optimal routing and wavelength assignment of the group of five multicast sessions with no wavelength conversion. The dark circles represent source nodes and the nodes where arrows terminate are destinations. Sessions on solid lines occupy wavelength \( \lambda_0 \) while the ones with dashed lines are on wavelength \( \lambda_1 \).

**Fig. 6.** Optimal routing of the group of five multicast sessions with full-range wavelength converters. The dark circle represents the source node of a session and the nodes where arrows terminate are destination nodes. Sessions on wavelength \( \lambda_0 \) or \( \lambda_1 \) are shown with solid lines and dashed lines respectively. Observe that we need a wavelength converter at node E for the session with source E.

### IV. FUTURE WORK

We discussed the results obtained by solving different flavors of the problem for a small network. We have attempted to solve larger problems using the MILP formulation and CPLEX, but we have been unsuccessful because the problem size of the MILP becomes too large. We are currently exploring adjustments to the MILP to make it tractable for larger examples. We are also exploring heuristics to solve larger problems as well as to solve dynamic versions of this problem.

### REFERENCES