MULTICAST ROUTING WITH POWER CONSIDERATION IN WDM NETWORKS

Kun-Da Wu

Dept. of CSE,
National Sun Yat-Sen University
kdwu@cse.nsysu.edu.tw

Chu-Sing Yang

Dept. of CSE,
National Sun Yat-Sen University
csyang@mail.nsysu.edu.tw

Jieh-Chian Wu

Dept. of CCE,
National Kaohsiung First University of Science and Technology
jcwu@ccms.nkfust.edu.tw

Abstract

To support multicast communications in WDM networks has become an important and attractive topic recently. In this paper, we study constrained multicast routing with power consideration in WDM networks, where power is attenuated due to (i) the number of concatenated fan-outs (splitting), and (ii) the propagation distance from source node to any multicast member. It can be shown that the problem can be modeled as a Steiner tree problem, and we propose a heuristic algorithm called centralized-splitting algorithm to construct the multicast routing paths with small power loss. To evaluate the performance, we compare this algorithm with the Member-Only algorithm [15], which can provide the best bandwidth and wavelength usage in the multicast routing construction with sparse splitting constrain. Our simulation results show that the centralized-splitting algorithm can reduce the power loss by 7%, while it still maintains proper bandwidth, wavelength usage and delay requirement.

1. Introduction

The fast explosion of Internet traffic is demanding more and more network capacity every day. It is becoming evident that all-optical wavelength-division multiplexing (WDM) technology, offering terabit rates, is the strong candidate for the future backbone and will soon become the core technology for the next-generation Internet [1][4][6]. One of the most important applications on the Internet is the multicasting service [8][9], which provides simultaneous transmissions to several destinations. The focus of this paper is to study the multicast routing in the all-optical WDM networks.

All-optical networks are networks where fibers are connected with optical (photonic) switches, and data remains in the optical domain from its source to the destination. Wavelength-division multiplexing provides an economical way of utilizing the tremendous bandwidth of a fiber by dividing the overall bandwidth into many non-overlapping wavelengths (WDM channels). Recently, several researches have been devoted to the issues of supporting multicasting at the WDM layer [10][11][12][15], where the optical switches have light splitting capability to multicast data optically from one source node to multiple destinations. In [11], the concept of a *light-tree* in a wavelength-routed optical network is introduced. In general, the virtual topology based on light-tree is a superset of the topologies based on light-path [3]. In the light-tree scheme, data can be transmitted to multiple destinations all-optically and simultaneously so that the resources can be shared on the common links of the light-tree. It has been shown that the light-trees can also provide improved performance over unicast traffic and support broadcast traffic more efficiently because of their inherent point-to-multipoint nature. The corresponding performance measurement is based on the average number of hops and total number of optic-electronic components. The works in [10] and [12] focus on constructing a wavelength-routed WDM multicast tree with small blocking probability, and efficient utilization of wavelength and bandwidth, where the information of the network topology and multicast membership are given. The work in [15] considers that only some of the nodes provide light splitting when constructing multicast routing paths. Given this constraint, only a subset of switches in the WDM network can multicast as many copies as needed, but the rest of the nodes have no splitting capability. In this case, a single light-tree may not be sufficient for multicasting data to all destinations in a multicast session. Thus, another multicast medium called *light-forest* is proposed, which consists of several light-trees rooted at the same source node.

Multicasting by light splitting will result in power loss. In addition to the power attenuation in propagation, transmitting power must be carefully designed to guarantee a satisfactory signal to noise ratio at every receiving destinations. Although optical amplifier, for instance, the erbium-doped fiber amplifier, can be used to compensate the power attenuation and splitting loss, the cost of the device is still expensive and the gain bandwidth may not be sufficiently wide [5]. Therefore, constructing a multicast routing tree with small power consideration is very important in all-optical networks.

The objective of this paper is to find a multicast routing path with power budget consideration. When the information of the network topology and multicast membership are given, we consider how to construct a wavelength-routed multicast routing tree with small power loss among multicast members, while (*i*) utilizing the wavelengths and the bandwidth efficiently, and (*ii*) satisfying delay requirement

The rest of this paper is organized as follows. First, the problem description of the multicast routing with power consideration will be presented. It will be shown that the problem can be formulated as Steiner tree problem. Then, a heuristic algorithm will be proposed to solve this problem efficiently based on several observations. Finally, the numerical results are discussed and the conclusions are given.

2. Multicast Routing with Power Consideration

2.1 Problem Description

In this paper, we assume that *(i)* the traffic pattern is static; *(ii)* the number of wavelengths supported in a fiber link is not limited; *(iii)* only a fraction of the nodes provide light splitting and wavelength conversion capabilities; and *(iv)* the optical switches in the WDM network have no amplifiers.

After a multicast tree in the all-optical WDM network is constructed, the power is attenuated due to *(i)* the number of concatenated fan-outs along the paths from source node to each destination node, and *(ii)* the distance from source node to any multicast member. That is, splitting loss on each node is dependent on the outgoing links at that node in the established multicast tree. Our objective is to find a Steiner tree such that the maximum power is minimum. Since finding a solution to the Steiner tree problem (STP) is proved to be NP-complete [1][13], a heuristic algorithm is proposed to find the feasible solutions.

2.2 Observations

When only power budget is considered in finding the multicast routing path for a multicast session, the construction of multicast tree (forest) is straightforward. For example, given a multicast session, the source node can establish each separate light-path for each multicast member by the shortest path mechanism. Another possible scheme is to construct the multicast routing without any splitting and all multicast destinations are concatenated on a light-path. Based on both schemes, the power loss of each multicast member is caused by propagation attenuation only and the power loss can be guaranteed to be small. However, the utilization of the wavelength and bandwidth may not be efficient and delay may not be sufficiently small in comparison with existing multicasting algorithms. Therefore, exploring the characteristics of light splitting is the key issue in designing multicast construction algorithm with power budget consideration.

We observe that the splitting occurred near the root (source node) results in balancing power budget on each sub-tree, however, the effect of the power loss will be propagated to all children nodes located within its sub-trees. Thus, assigning the splitting capability to the node far from the source node, if possible, to get small power loss is important. Another observation is that, when the number of splitting at a node increases, the increment of the power loss caused by splitting is getting small. Therefore, if a node is chosen to be a splitting node, the more number of splitting assigned at this node is preferable. In addition, the impact on the power loss of a multicast routing, when a node is chosen to join the multicast session, is not deterministic. This is because the power (propagation) attenuation on the transmission line is determined after the distance between two nodes are defined, but the splitting loss at node is dependent on the construction of the multicast tree. Accordingly, we propose a new multicast routing scheme called *centralized-splitting heuristic*, in which the concatenated splitting in a particular sub-tree will be replaced by a centralized splitting node, which is defined as a node with the smallest average distance to the destination nodes in this sub-tree.

3. Proposed Algorithm

Centralized-Splitting Heuristic Algorithm

Input: Network topology *G*, multicast membership *M*, and
splitting capability distribution *S*.

Output: Multicast routing with power budget consideration F.

Step 1. Applying Member-Only algorithm referred in [15] to construct a light-forest F. Let $T_i=(N_i, E_i)$ denotes one of the light-trees in the light-forest F, say $F=\{T_i, \forall i\}$, where N_i is the set of nodes in T_i, and E_i is the set of edges in T_i.

Step 2. For each light-tree T_i in F with more than 2 splitting nodes,

2a. Find the splitting node, denoted as node k, with the shortest distance from the source node of T_i. The path from source node to the node k is defined as the *main path* $P = (V_p, E_p)$, where V_p is the set of the nodes on the main path including the source node and the node k, and E_p is the set of edges in the main path.

2b. For each node j in G, calculate the average distance d_j from j to all other nodes in $(N_i - V_p) \cup M$. Then, sort d_j in a list R based on ascending order.

2c. Find the centralized splitting node h which has the smallest average distance from node h to all other nodes in $(N_i - V_p) \cup M$.

2d. If node h does not possess splitting capability (multicast-incapable), then choose the next candidate in the sorted list R.

Step 3. New multicast tree is constructed as follows.

3a. Extend the main path from the node k to the centralized splitting node by adding the shortest path between node k and centralized splitting node.

3b. Find the shortest paths in $G - P$ from the centralized splitting node to all of the nodes in $(N_i - V_p) \cup M$.

3c. If any shortest path to the multicast member y contains the node in V_p, put node y to the *DROP_LIST*.

Step 4. If all multicast trees in the forest are scanned, go to Step 5. Otherwise, go to Step 2.

Step 5. If *DROP_LIST* is not empty, sort the *DROP_LIST* in ascending order according to the shortest path to the source. Then, for each node in *DROP_LIST*, find the shortest path to all nodes in the network and sort them in the *Candidate_LIST*, and

Case 5a. If the candidate is a source node in the multicast group, then construct a new tree.

Case 5b. If the candidate is a leaf node or a splitting node in one of the constructed trees, then add this node to this tree .

Case 5c. Otherwise, choose the next candidate in the *Candidate_LIST*.

An example is shown in Figure 1, where node 10 is the source of the multicasting session, and node 1,2,3,4,5,7 are the destination nodes. Figure 1(a) is the multicasting tree constructed by the Member-Only algorithm [15] in the NSFNET-like network with sparse splitting, where the node 1 and the node 6 perform light splitting in the constructed tree.

Applying the centralized-splitting algorithm to the same NSFNET-like network, the average distances to all other members are first derived and the smallest one is chosen as centralized splitting node. In this example, node 1 is the centralized splitting node. Then we apply shortest path heuristic to construct a sub-tree rooted at centralized splitting node to all other destinations, namely node 2,3,5,7.

By the observation to this example in Figure 1(a), we find that the splitting nodes 1 and 6 are concatenated in the same multicasting tree and the power budget will be propagated to all destinations. If all of the links in NSFNET-like network topology were assumed to be unit cost, then the maximum power loss is 8.6 (dB) at both node 2 and node 3. However, after the multicasting tree is re-constructed by centralized-splitting algorithm, node 1 is the only node with light splitting and is defined as the centralized splitting node. Accordingly, the maximum power loss in the new constructed tree is 6.8 (dB). Thereby, around 20% improvement on power loss is achieved.

4. Simulation and Results

In this section, we compare the performance of the proposed centralized-splitting algorithm with the Member-Only forest construction algorithm referred in [15]. It has been shown that Member-Only algorithm provides the best bandwidth and wavelength usage in the construction of the multicast routing paths, it makes sense to compare our proposed algorithm with it.

A fixed 11-node network topology (NSFNET) is considered in this study and the simulation is performed according to four parameters, namely splitting capability, wavelength conversion capability, multicast generation probability and destination generation probability. Let S and C represent the average fraction of nodes in the network that possesses the splitting capability and wavelength conversion capability, respectively. We assume that the nodes with the splitting and/or wavelength conversion capability are independently distributed, and each is uniformly distributed throughout the network. In addition, the average number of multicast sessions to be generated at any instance has a Poisson distribution with a mean of $0 \leq P \leq 1$, where P is the multicast generation probability. For each multicast session, destination generation probability G denotes the probability of a given node to be a destination node (i.e., the fraction of nodes that are destinations).

We assume that $S = 0.5$, and $C = 0.2$, while P and G are varied in our simulation to show the effect of group size and the number of multicast sessions. For a given set of four parameters, 100 simulation runs are executed and the final result is obtained by averaging all individual results. The performance will be evaluated by (*i*) the power loss reduction ratio, (*ii*) the average bandwidth per forest, (*iii*) the average delay from source to a multicast member, and (*iv*) the highest wavelength index being used in the network, where the power loss reduction ratio, denoted as R, is defined as follow. Let A and B denote the overall power loss (walt) of the light forests constructed by the member-only and the centralized-splitting algorithms respectively, then $R = 100 * (A - B) / A$ (%). Figure 2(a) shows the reduction ratio of the power loss using the centralized-splitting algorithm to that using the Member-Only algorithm, under different P (the multicast generation probability) and G (the destinations generation probability). We find that (*i*) the probability of power budget reduction increases when P and G increase; (*ii*) the power loss can be reduced by 7% in average; and (*iii*) the maximum of the power loss reduction is 17% occurred when the multicast generation probability P is 0.9 and the destination generation probability G is 0.7.

Figure 2(b) shows the ratio of power reduction when splitting capability S and wavelength conversion capability C vary. We assume that both the multicast generation probability P and the destination generation probability G are 0.8. As it shows, the power reduction ratio goes up when the fraction of nodes possessing splitting capability S increases. On the other hands, the power reduction ratio is independent of the wavelength conversion capability C.

As shown in figure 3, the bandwidth usage of centralized-splitting is almost the same as the Member-Only algorithm. In other words, the centralized-splitting algorithm will not increase the utilization of the bandwidth, while achieving power saving. Similarly, figure 4 and figure 5 show that the performance of the average delay and the wavelength utilization will not be significantly degraded, when using the centralized-splitting algorithm.

5. Conclusions

In this paper, we have studied the problem of the multicast routing with power consideration in all-optical WDM networks. The problem can be modeled as a Steiner tree problem which is NP-complete, and we proposed a heuristic algorithm to construct the multicast routing with small power loss, while still maintaining proper resources utilization. To evaluate the performance, we compared the centralized-splitting algorithm with the existing Member-Only algorithm, which can provide the best bandwidth and wavelength usage in the multicast routing with sparse splitting constraint. Our numerical results showed that the power loss could be reduced by 7% in average, when wavelength conversion capability C is equal to 0.2, and splitting capability S is equal to 0.5. The maximum of the power reduction ratio is 17%, when the multicast generation probability P is 0.9 and the destination generation probability G is 0.7. To our knowledge, this is the first work devotes to power consideration on multicast routing in all-optical network. With the contributions of this work, it will be helpful for the source node to use small emission power to guarantee a satisfied optical signal strength for the receivers at all destinations in a multicast session.

6. References

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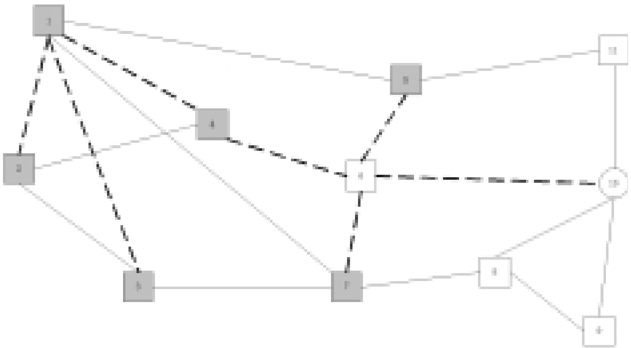
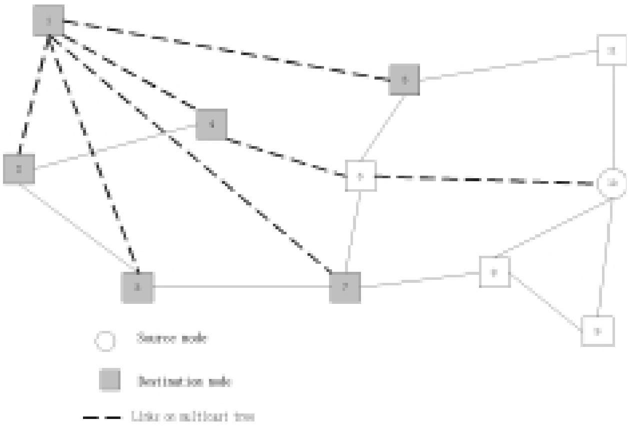
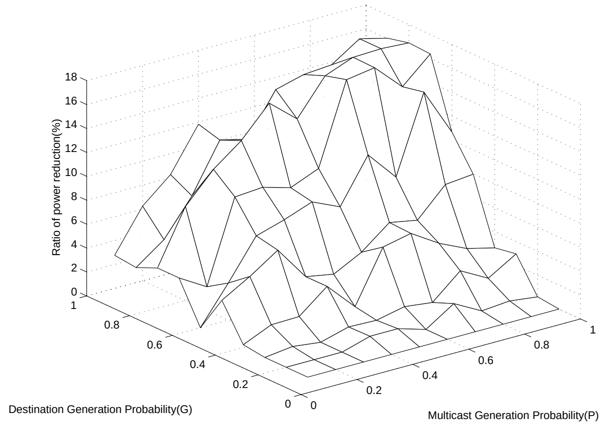


(a) One of the multicast tree constructed by Member-Only algorithm

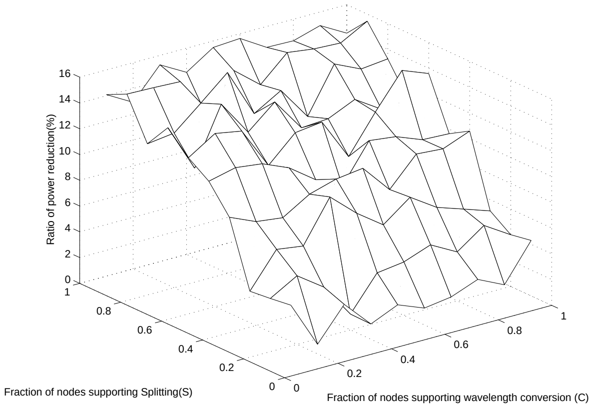


(b) One of multicast tree constructed by the centralized-splitting algorithm

Figure 1. An example of multicast routing by using the Member-Only algorithm and the Centralized-Splitting algorithm in NSFNET-like network.

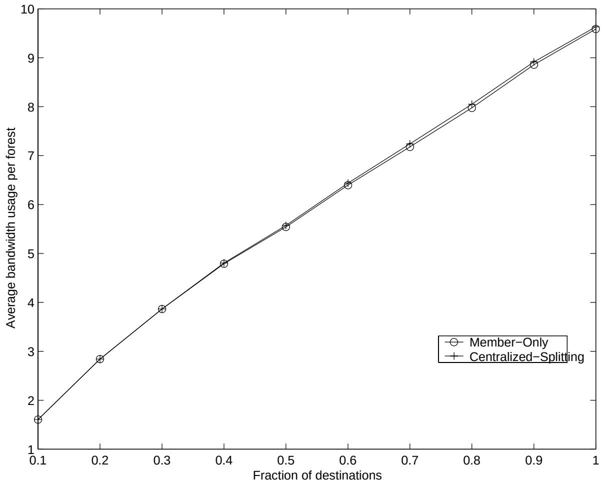


(a) The curves of the ratio of power reduction versus both the multicast generation probability (P) and the destination generation probability (G), when the fraction of nodes supporting splitting S = 0.5, and the fraction of nodes supporting wavelength conversion C = 0.2.

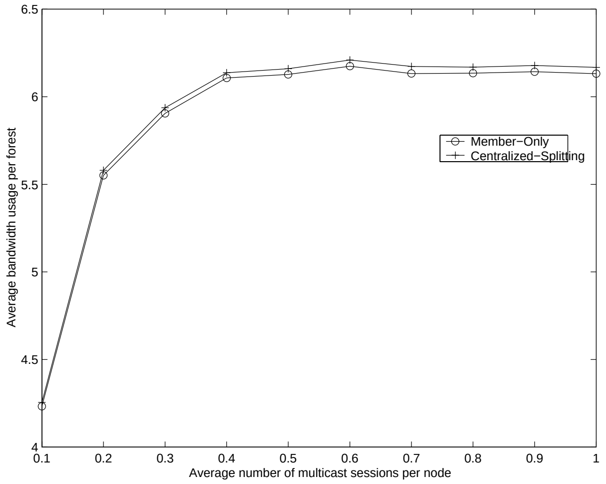


(b) The curves of the ratio of power reduction versus both the fraction of nodes supporting splitting (S) and wavelength conversion (C), when the multicast generation probability P = 0.8, and the destination generation probability G = 0.8.

Figure 2. Ratio of power reduction by using Centralized-Splitting algorithm.

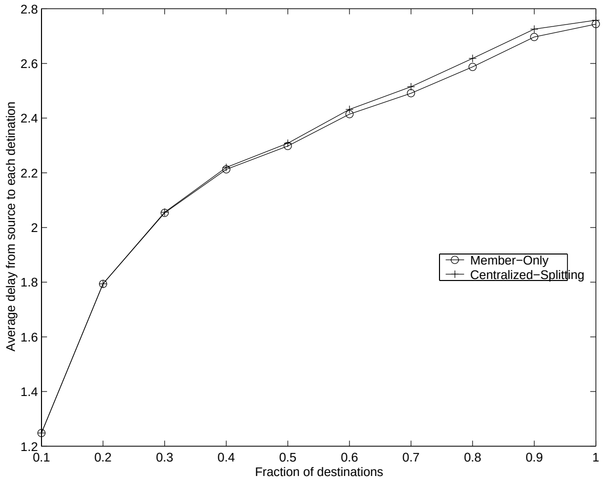


(a)Average bandwidth usage when G varies.

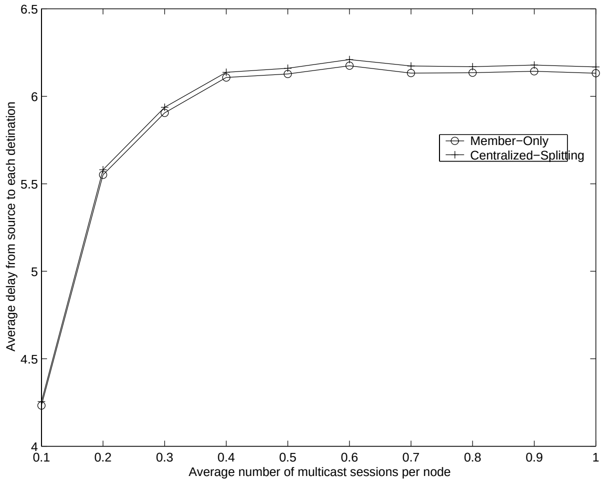


(b) Average bandwidth usage when P varies

Figure 3. The comparison on average bandwidth utilization per forest.

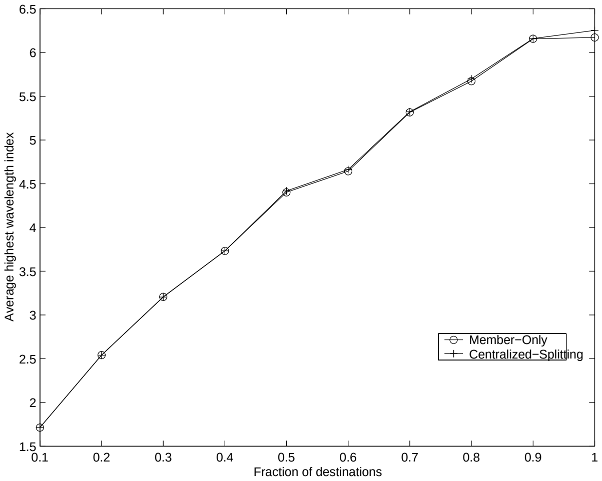


(a) Average delay when G varies.

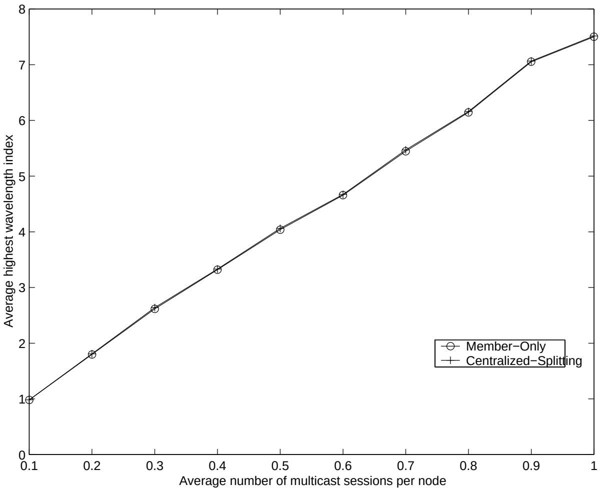


(b) Average delay when P varies.

Figure 4. The comparison on average delay from source to a multicast member.



(a) Average highest wavelength index used when G varies.



(b) Average highest wavelength index used when P varies.

Figure 5. The comparison on average highest wavelength index used in the network.