Grooming of Multicast Sessions in Sparse Splitting WDM Mesh Networks using Virtual Source Based Trees

N.Sreenath, Balaji Palanisamy, S.R. Nadarajan
Department of Computer Science and Engineering,
Pondicherry Engineering College, Pondicherry-605104, India.
{nsreen@yahoo.com, balajipec@gmail.com, nattu_pearl@yahoo.com}

Abstract

Cost effective grooming of several sessions with fractional wavelength bandwidth onto a single wavelength has become prominent in WDM networks. We, in this paper, address the problem of routing and wavelength assignment of multicast sessions with sub-wavelength traffic demands in sparse splitting WDM networks. We assume a sparse splitting node architecture in which only a few nodes in the network are split-capable. A node with splitting capability can forward an incoming message to more than one outgoing link in the optical form. The multicast capability at the non-split nodes can be achieved by converting the optical signal into electronic form and transmitting in optical form onto all the required outgoing links. However, the traffic duplication at the electronic level is more expensive than the optical level in terms of the delay incurred due to the optical-electronic-optical (O/E/O) conversion. We study the problem of assigning routes and wavelengths to the multicast sessions with the objective of minimizing the resources required for electronic copying. Since the multicast traffic grooming problem is computationally intractable, we adopt a heuristic approach called VSGroom. The performance of the proposed heuristic is studied and compared through extensive simulation experiments.

Keywords: Optical WDM mesh networks, Multicast routing and wavelength assignment, optical splitter, Traffic grooming.

1.Introduction

Wavelength division multiplexing (WDM) is currently believed to be the most promising technology for terabits per second (Tb/s) fiber optic communications. The data rate per wavelength is in the Gbps range for allowing the end user equipment to operate at peak electronic speed. A lightpath can be used for only one-to-one communication. One-to-one communication is referred to as unicasting and one-to-many communication is referred to as multicasting. Multicasting is the ability to transmit information from a source to a group of destinations. This is bandwidth-efficient because it eliminates the necessity for the source to send an individual copy of the information to each destination. As WDM provides efficacy to support high bandwidth services, there is an increasing need to implement multicasting efficiently at the optical layer [1]. To support multicasting in a WDM network, nodes in the network need to have light (optical) splitting capability. A split capable node is very expensive due to its complex architecture. Hence, we assume only a few split-capable nodes in the network. A network with a few split-capable nodes is called a *sparse splitting network*. The multicast RWA (routing and wavelength assignment) problem has been addressed in the case of sparse splitting networks [2]. In [3], virtual source based trees for multicast routing in sparse splitting networks has been proposed.

In an optical link, each wavelength supports traffic in the Gbps range. However, traffic requested by individual connection is still in terms of Mbps. Hence, to utilize the available bandwidth efficiently, several connections have to be grouped onto the same wavelength. This requires strategic routing and wavelength assignment (RWA) of each connection because the traffic on a wavelength requires an opto-electronic conversion whenever a part of that traffic needs to be switched to another wavelength or has to be added/dropped at some node. The cost incurred due to the delay in opto-electronic conversion is the dominant cost in setting up the network. The problem of RWA of sub-wavelength demands with the objective of minimizing the network cost, called "traffic grooming" problem, has been studied widely in the literature. Most of the work in this direction has been focused on ring networks [4], with emphasis on minimizing either the number of wavelengths or the number of Add/Drop Multiplexers (ADMs) required. In the recent past, there have also been efforts towards solving the problem for the case of mesh networks. This issue has been addressed in both the static [5] as well as the dynamic [6] scenarios.

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A survey and review of traffic grooming with several switching architectures is presented in [7]. Multicast traffic grooming in the case of ring networks is proposed by the authors in [8], wherein node architectures were proposed with heuristic algorithms to groom the multicast traffic demands with a major goal to reduce the number of electronic ports required for a given set of multicast traffic demands. In [9], heuristics namely GCOT, GRS and k-SPT are proposed for multicast grooming in full splitting networks. These algorithms try to minimise the electronic ports usage. The above heuristics use shortest path trees for routing the multicast sessions. GCOT heuristic computes overlapped trees for all wavelengths and chooses the wavelength for which there is maximum overlap. GRS tries to reroute a few old sessions if there are bottleneck links for a new session. k-SPT heuristic computes k shortest path trees and chooses the one for which a wavelength with minimum opto-electronic conversion is available. In [10], the grooming issue in sparse splitting networks is solved with an ILP and heuristic solution for minimizing the number of wavelengths required for a given set of multicast traffic demands. Here, the network is assumed in such a way that for every node there is atleast one adjacent node with optical splitters. However, it may be difficult to maintain such a constraint in a dynamically changing topology as in the case of IP-over-WDM networks. Moreover, it may not be possible to protect the sessions using link disjoint and arc disjoint trees [11] in such a constrained network. This is because, the constraint that every node has an adjacent node with optical splitters may not remain satisfied after removing a set of links from the topology while computing link (arc) disjoint trees.

The rest of the paper is organised as follows. Section 2 describes the sparse splitting node architecture considered in our work. Section 3 explains our heuristic approach. Section 4 presents and discusses the simulation results and section 5 concludes the paper.

2. Node Architecture

We consider a sparse splitting node architecture where only a few nodes in the network are equiped with optical splitters and wavelength converters. The nodes that have the splitting and wavelength conversion capability are called VS nodes. The node architecture of the VS nodes basically consists of two main units o-SaD (optical split and delivery) and e-SaD (electronic split and delivery). The basic function of the o-SaD unit is to split the incoming signal on incoming wavelength and deliver on different output wavelength ports, all in the optical domain. The second one is the e-SaD unit, which carries out duplication in electronic domain with functionality such as traffic add/drop/copy with switching to different wavelength ports. The incoming wavelengths are demultiplexed and switched through the OXC to appropriate unit i.e., o-SaD or e-SaD unit, based on a predefined strategy. Here node architecture provides an optical bypass to the traffic on those wavelengths which are not having any local add or drop. When all the traffic on the incoming wavelength needs to be duplicated, the e-SaD unit is redundant because there is no necessity to examine the header of each individual packet (since every packet needs to be duplicated). Clearly, in such a scenario, splitting can be done at the optical layer rather than implementing it at the electronic level. The o-SaD unit is highly cost-effective in comparison with that of e-SaD unit as this obviates the need to examine the header of each packet being added/dropped at a node. In addition to the o-SaD and e-SaD units, VS nodes have a DaC switch to drop a small amount of optical power from a wavelength channel that is forwarded by that node. A non-VS node has only the e-SaD unit and a DaC switch. Here the splitting in done only in the electronic form. For the above architecture, the algorithms proposed in [8] may not be efficient. This can be explained with the following example.

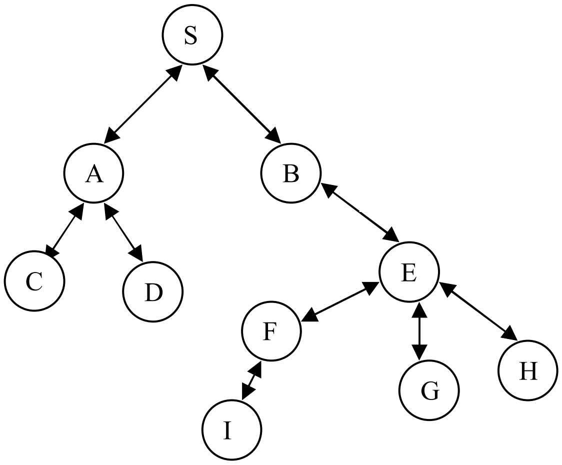

Figure 1 (a) Multicast tree constructed using SPT - No of e-SaD ports =9

Consider figure 1(a). S is the source of a multicast session and nodes A,B,C,D,E,F,G,H and I are the destinations. The heuristics proposed in [8] construct the shortest path tree for the session without considering the sparse splitting and DaC capability of the nodes. Hence, the number of e-SaD ports required is 9. Figure 1(b) shows the tree generation by considering the sparse splitting and DaC capability of the nodes. Here the number of e-SaD ports is reduced to 5. Since nodes C and D are VS nodes, no e-SaD port is required at nodes C and D as splitting can be done in the optical domain. Also, these heuristics (k-SPT, GRS, GCOT) [8] have an inherent assumption that a session is routed using the same wavelength on all the links of the multicast tree. But such a restriction is not required when VS nodes are present in the network. VS nodes have optical splitting capability with wavelength conversion. Hence, the wavelength conversion capability of the VS nodes needs to be taken into account while grooming the sessions.

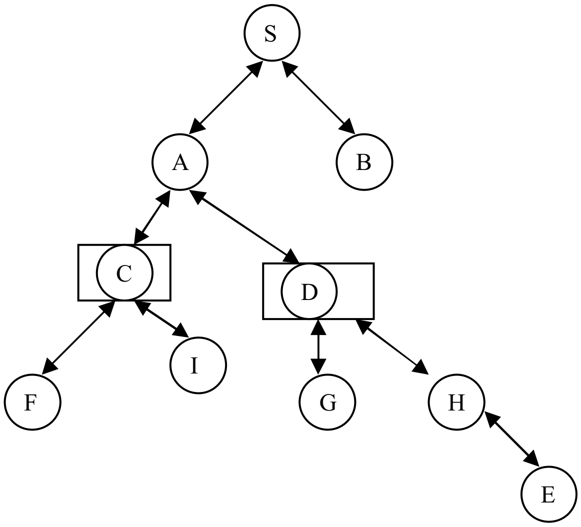

Figure 1 (b) Multicast tree constructed by considering the capability of the VS nodes - No of e-SaD ports =5

▭ -- Split node ○ -- Non-Split node

3. VSGroom heuristic

Since unicast traffic grooming for mesh networks in NP-complete [2] and as unicast is a special case of multicast with one node in the destination set, the traffic grooming problem in the multicast scenario is also NP-complete. Hence, we resort to a heuristic solution. In this section, we describe our heuristic approach for grooming multicast sessions. The heuristic algorithm tries to minimize the total number of grooming ports required on the e-SaD unit present in the architecture at every node for a given set of traffic demands. We use the heuristic algorithm in [3] for generating the multicast trees. The virtual source based tree generation algorithm first finds the shortest path between the source and a destination. It then adds the VS nodes along this path to the set of sources (virtual sources) and then considers the other destinations. For the subsequent destinations, the shortest path is computed from all the virtual sources as well as from the leaf nodes of the tree generated so far. The shortest of all these paths is added to the generated multicast tree. VSGroom recursively assigns wavelength by exploiting the sparse splitting and wavelength conversion capability.

The heuristic finds a segment in the generated multicast tree. The segment starts from the source node to the nearest node that is either a branch node or a leaf node. If the end node of a segment is not a VS node, the heuristic assigns wavelength using the procedure Frontconnect(). This procedure assigns a wavelength for every link of the segment. Among all wavelengths that undergo electro-optical conversion at the segment source (starting node of the segment), the wavelength that traverses the maximum length along the segment is chosen.

Algorithm

Create the virtual source based multicast tree for all sessions.

```
For every multicast session
    VSGroom(Session.Tree, Session.source);

Procedure VSGroom( Tree, Source)
{

if(source is a leaf) return;

      for all outgoing edges E in Tree from Source
      {
      Segmentpath=findsegment(Tree, E);

      If(Segmentpath.Dest. VS==false)
      {
         x= Segmentpath.Source
         while(x==Segmentpath.Dest)
          {
            x= Frontconnect(Segmentpath);

Truncate the nodes from Segmentpath.Source to node x in Segmentpath.

       Segmentpath.Source=x;

          }
```

```
        VSGroom(Tree, Segmentpath.Dest);
      }

else // if Segmentpath.Dest is a VS node
{
  for all wavelengths W
    {
        Computeoverlap(Tree,W,Segmentath.Dest.Prev)
      }
  choose the wavelength $W_{max}$ such that
Computeoverlap(Tree,W,Segmentpath.Dest.Prev) is
maximum
    for all outgoing edges E in Tree from
Segmentpath.Dest
    {
  z = Assignsession(Tree, Segmentpath.Dest.prev,
$W_{max}$ , E)
       VSGroom(Tree, z);
    }
        BackConnect(Tree,Segmentpath.Source, $W_{max}$);
  }
 }
}

Procedure FrontConnect( Segmentpath)
{
  for all wavelengths W such that
(Segmentpath.Source.E/O=true)
        Compute the number of links traversable along
the Segmentpath without opto-electronic conversion.
    Choose the Wavelength W that traverses maximum
number of links till a node say x;
     Assign the wavelength W along the links traversable
by the wavelength W.

  return x;
}

Procedure BackConnect(Tree,Segmentpath.Dest,W);
{
 For the wavelength W find the node y along the
SegmentPath from the Segmentpath.Dest to
Segmentpath.source such that there is no opto-
electronic conversion required till node y along the
Segmentpath.

Assign the wavelength W till node y along the links of
the Segmentpath.
Segmentpath.Dest=y;
Frontconnect(Segmentpath);
}
```

While considering the availability of a wavelength, the free capacity of the wavelength is verified with the bandwidth required by the current session. If no wavelength undergoes electro-optical conversion at the segment source or if the free capacity of the wavelengths is less than the required bandwidth, then a new wavelength is chosen. The chosen wavelength is assigned along the segment path till another opto-electronic conversion takes place at an intermediate node say x along the segment path. Frontconnect() returns the intermediate node x where an opto-electronic conversion is needed. At the intermediate node, the same procedure is repeated till all the links along the segment path are assigned a wavelength.

If the destination node (ending node of the segment) in the segment path is a VS node, then the heuristic considers all wavelengths that are present in the link preceding the destination node. For each of these wavelengths, the set of branches where the wavelength is getting optically splitted is found. The heuristic computes the overlap between these branching paths and the branches in the new multicast tree using Computeoverlap(). The Wavelength W_{max} for which there is maximum overlap is chosen and the new session is added along the new and existing branches where the wavelength has to be splitted till an opto-electronic conversion is required at an intermediate node say z. At these intermediate nodes VSGroom() is recursively called to repeat the same process. VSGroom then calls Backconnect() which assigns a wavelength from the destination of the segment path back to the source of the segment. Backconnect() is similar to Frontconnect() except that it tries to assign a wavelength from the destination of the segment to the source of the segment in the reverse direction along the wavelength W_{max}. It stops at an intermediate node y where there is an opto-electronic conversion required. It then calls Frontconnect() to assign wavelengths along the segment path from the segment source to node y.

4. Performance analysis

In this section, the performance study of the proposed heuristic is presented. In order to study the proposed heuristic, we conducted simulations on the NSFNET topology. We studied the performance by varying the grooming factor **g** for various number of sessions. The performance of the heuristic was evaluated in terms of the overall cost, measured in terms of the total number of e-SaD grooming ports P and number of wavelengths W.

While generating a multicast session, each of the 14 nodes of the NSFNET, was given equal probability of being the source node for the session. The size of the destination set was generated as a uniformly distributed

Table 1. Performance of heuristics at g=48

Sessions	VSGroom		GCOT		GRS		k-SPT (k=10)	
	P	W	P	W	P	W	P	W
5	84	3	124	3	131	3	120	3
10	175	4	263	6	270	6	245	4
15	250	6	348	7	366	7	340	6
20	350	6	485	7	510	8	465	7
25	406	7	572	8	595	9	550	7
30	504	8	716	9	751	9	690	8
35	568	9	781	10	803	10	754	8
40	624	9	837	11	864	11	811	9

Table 2. Performance of heuristics at g=98

Sessions	VSGroom		GCOT		GRS		k-SPT (k=10)	
	P	W	P	W	P	W	P	W
5	72	3	113	3	122	3	104	2
10	150	3	245	4	251	4	212	3
15	216	4	312	4	346	5	292	3
20	302	5	421	5	474	5	408	4
25	348	6	504	5	537	6	476	4
30	432	7	640	6	683	7	607	5
35	473	7	686	7	722	8	634	5
40	502	8	712	8	741	9	671	6

random number in the range 2 to 13. After the size of the destination set was determined to be d, the nodes in the destination set were then chosen such that every subset of size d of remaining 13 nodes was equally probable of being the destination set. Four nodes out of the fourteen nodes in the NSFNET topology are assumed to be VS nodes. These nodes are randomly selected. Every node was given equal probability of being a VS node. The traffic generated for multicast sessions is integer multiples of OC-1 chosen randomly from the set {1, 3, 9, 12, 18, 24, 36, 48} when the wavelength capacity is OC-48. For OC-98 the set is generated from {1, 3, 9, 12, 18, 24, 36, 48, 98} and for OC-192 the set is generated from {1, 3, 9, 12, 18, 24, 36, 48, 92, 192}.

Table 1 indicates the results of VSGroom obtained from our simulation. It is compared with the other heuristics namely GCOT, GRS, k-SPT [8]. We have simulated these heuristics and observed their performance in a sparse splitting network. For the simulation of k-SPT, we have taken the value of k to be 10. It has been observed that VSGroom shows a very significant reduction in the e-SaD ports usage. This is due to the fact that VSGroom generates virtual source based multicast trees. Hence, many of the branch nodes in the multicast tree happens to be split nodes thereby the number of e-SaD ports for electronic splitting is reduced. Also, the wavelength assignment strategy of VSGroom tries to exploit the sparse wavelength conversion capability present in the VS nodes. Exploiting wavelength conversion in VS nodes not only reduces the wavelength usage but also the number of electronic grooming ports. Tables 2 and 3 indicate the performance of VSGroom and its comparison with the other heuristics when the wavelength capacity is OC-98 and OC-192.

5. Conclusions

In this paper, we studied the multicast grooming problem in sparse splitting WDM networks. As the

Table 3. Performance of heuristics at g=192

Sessions	VSGroom		GCOT		GRS		k-SPT (k=10)	
	P	W	P	W	P	W	P	W
5	63	2	97	2	114	2	78	2
10	124	3	193	2	208	3	174	2
15	181	3	248	3	276	4	219	3
20	253	4	332	3	348	4	306	3
25	297	4	396	4	417	5	357	3
30	362	5	473	4	492	6	433	4
35	402	6	528	5	554	6	492	4
40	447	6	571	6	596	7	538	5

multicast grooming problem is computationally intractable, we adopt a heuristic approach. We proposed and evaluated *VSGroom*, a grooming algorithm for grooming multicast sessions in a sparse splitting network. We studied and compared the performance of the proposed heuristic algorithm with the existing multicast grooming algorithms through extensive simulation experiments. The performance was studiedthrough simulation performed on NSFNET topology. The simulation experiments show a very significant reduction in the number of e-SaD ports used. In future, we intend to extend this work to a dynamic senario where the network resources are limited. Also, we are working on to devise distributed protocols to extend this work to IP-over-WDM networks.

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