Placement of Light Splitters in Optical Networks

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Abstract*: For a multicast routing algorithm to be applicable in optical networks, it must route data only to group members, optimize and maintain loop-free routes, and concentrate them on a subset of links. In order to do this, light trees must be generated to route data in the optical layer to all the group members. To apply this, optical nodes have to branch one incoming light wave to more than one output port. Optical nodes must be equipped with light splitters that split one light wave to more than one output. The output light waves may conserve the same wavelength, or use another. Due to its complex design, a light splitter is very expensive equipment, thus, equipping all optical nodes with splitters will increase the cost of the optical network setup. This leads to a consensus that not all optical nodes on the network will possess this splitting capability. In this paper, we study the required density of nodes in the optical networks that must possess light splitting capability. This study is done in order to assure good performance of multicast trees. Also, we discuss the optimal placements of optical splitters, and how this can increase the efficiency of the multicast signaling and routing techniques

I. INTRODUCTION

Because of its design, an optical cross connect OXC can switch an incoming optical signal to one output interface. The output light wave can have the same wavelength as the input, or can be mapped to another wavelength. In order for the OXC to generate multiple copies of the incoming input, and forward each on different interface, it must be equipped with light splitters. Because of the high cost of an optical splitter, a limited number of optical nodes will have this splitting capability.

Advanced studies [1] [2] show that less than half of the network nodes must be equipped with splitters in order to have a compromise between the multicast routing efficiency and the cost of the nodes with optical splitters. Other studies [3] [4] propose enhanced splitting architectures in order to reduce the cost of an individual multicast capable cross connect MC-OXC. Some of these proposals modify the architecture of the Split and Delivery SaD component. Integrating configurable power splitters [5] inside the SaD component leads to a better performance in terms of the power loss, and in terms of the total cost of the switch itself.

This paper studies the best placement of light splitters to resolve the principle issue that not all nodes in the network are multicast capable. The next sections provide propositions to resolve some faces of this principle issue. Each of these propositions is simulated to evaluate its performance and criticize its efficiency.

In Section 2, relevant propositions for enhancing the internal structure of the Multicast capable optical cross connect MC-OXC are presented The enhanced structure is designed to reduce the cost of the SaD switches on the one hand, and reduce the power loss resulted of multiple splitting on the other hand.

Section 3 discusses the optimal placements of optical splitters, and how this can increase the efficiency of the multicast signaling and routing techniques. It can also reduce the number of splitters required, thus the cost of the optical network setup. A new placement mechanism is proposed; it explains how to place those splitters taking into consideration new parameters that are based on provisioned multicast traffic and link characteristics of the network. In this section, simulation is done, and results of the performance evaluation shows that efficient placement of those splitters based on links characteristics may enhance the multicast routing from one side, and reduce the numbers of splitters needed from the other side.

Section 4 studies the required density of nodes in the optical networks that must possess light splitting capability. This study is done in order to assure good performance of multicast trees. This density is measured as a percentage of the total number of nodes in the network. Multiple real networks are studied, simulation is done, and results show that this density depend on different characteristics of the network topology in terms of nodes and links distribution. The performance evaluation shows that a limited number of splitters may be sufficient in terms of their affect on the cost of the multicast trees, and their performance. It also shows that this number depends on the structure of the network topology.

At the end, a conclusion for all both propositions given in sections 3 and 4 are summarized. This provides valuable recommendation on both the network design phase, and the multicast routing phase. Regarding network design phase, propositions of how many light splitters must be placed to assure efficient multicasting and the optimal placement of these splitters are defined. The effect of the splitting factor is studies in order to know what splitting capabilities are best to implement.

II. MULTICAST CAPABLE OPTICAL CROSS CONNECT

An all-optical network is composed of Optical Cross Connects OXCs. An OXC is designed to switch an optical signal from an input port to an output port. This switching can conserve the wavelength or map one wavelength to another. For the OXC to be able to do the multicasting in the optical layer, it must be equipped with an optical light splitter.

The SaD switch structure is shown in Figure 1 with all the required components.

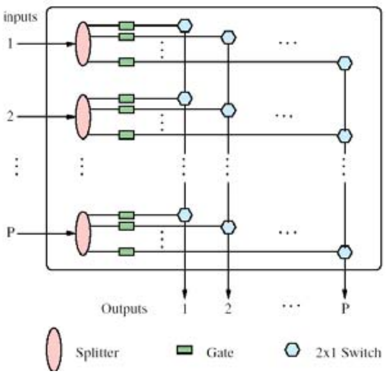

Figure 1 – Splitter-and-Delivery SaD switch

As shown in Figure 1, a P×P Splitter-and-Delivery SaD switch, which consists of P power splitters, P×P optical gates, and P×P photonic switching elements can be used. This reduces the cost and crosstalk on the one hand, and improves power efficiency on the other hand.

We assume that the splitters are configured to split an input signal into m outputs, $1<m<P$ (If $m = 1$, then there is no splitting. If $m=P$, then it is a broadcast splitting). By configuring the corresponding photonic switches, each of the m resulting signals can be switched to the desired outputs.

In order to realize all-optical multicast switching, the light trees concept was proposed in [6]. A light path consists of an all-optical channel, which may be used to carry circuit-switched traffic, and it may span multiple fiber links. In order to generate a light tree, splitting must happen in the optical layer. The main role of an all-optical MC OXC is to split the input signal into multiple outputs without the need of understanding the optical features of the input signal. Therefore, it is composed of multiple passive light splitters. A split operation reduces the power of each of the split signals. Ideally, the power of each of m output is the (1/m)-th part of the input signal.

The SaD switch was proposed to be the main component of the MC-OXC [3]. In order to reduce its cost and to improve power efficiency this architecture was modified in [4].

A configurable SaD switch using configurable splitters was proposed in [5]. Configurable splitters can be controlled in order to split the incoming signal into m outputs ($m \in \{1,..,P\}$), where $m = 1$ corresponds to no splitting and $m = P$ to a broadcast operation. After that, outgoing signals are switched to the corresponding output by using a P2 photonic switch matrix.

Relevant propositions for enhancing the internal structure of the MC-OXC multicast have been presented in [3] and [4]. The enhanced structure is designed to reduce the cost of the SaD switches on the one hand, and reduce the power loss resulted of multiple splitting on the other hand. Some of these proposals are based on configuring multiple wavelengths to be exclusive for multicast transmission. Other wavelengths are used only for unicast transmission.

Multiple enhanced architectures for the MC-OXC are proposed employing the SaD switch [3]. The Wavelength Path WP-OXC consists of de-multiplexers (Demux), SaD switches (SaD SW) and multiplexers (Mux). This arrangement is necessitated to ensure that the WP-OXC be strictly non-blocking. The SaD switch renders any input channel switchable to one or more outputs.

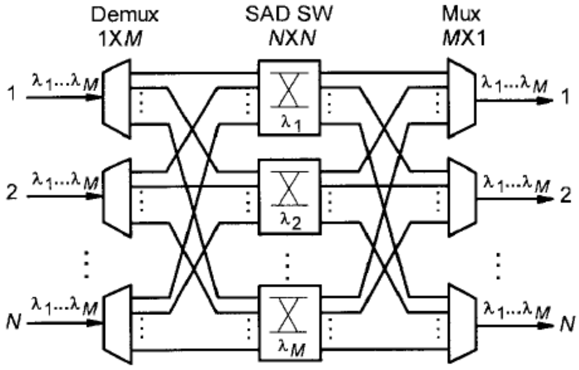

Figure 2 Wavelength Path WP-OXC

WP-OXC will turn blocking only if wavelength conversion is involved. Therefore, Virtual WP-OXCs are constructed in a different way. Other Virtual wavelength path VWP-OXCs consist of splitters, SaD switches, tunable filters (TF), wavelength converters (WC) and multiplexers.

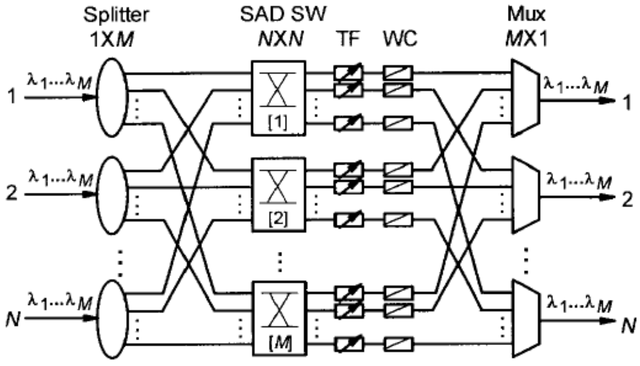

Figure 3 Virtual Wavelength Path VWP-OXC

III. OPTIMAL PLACEMENT OF LIGHT SPLITTERS

Given a network topology made up of optical nodes interconnected by optical links. In order to have a good distribution of splitters over the network, different parameters must be taken into account. Node degree (number of neighbors) is one of these parameters. The provisioned multicast traffic is a factor that allows placing splitters in locations that will be the most useful once multicast trees are being generated. It is very important to place splitters where multicasting will occur more frequently.

When a node must have several downstream nodes and does not possess light splitting capability, then several trees [7] have to be created. In this case, the link usage will increase (for instance the same link could have to support several copies of the same signal on different wavelengths) and the multicast structure generated (composed by several trees) will be less efficient. As a result, efficient placement of splitters will increase the efficiency of the generated trees.

Optical links capacity needs also to be taken into account. Each link in the network has its own capacity which determines the amount of flows it can carry simultaneously. The more traffic is being transmitted on a link, the less residual capacity is available for other transmissions. The capacity of links is mostly determined during network design, by the traffic requirements. In consequence, high capacity must be assigned to links where high traffic is expected.

Generally, each optical link in the network is given a specific weight or cost. We assume that the cost of an optical link is determined in terms of the link capacity. This is cost is inversely proportional to the capacity of the link. We assume that not all links in the network are identical and that each link has its own capacity, thus the splitter placement can no more be based on the number of links connected to each node (the node degree).

On contrast, the splitter placement must be based on the number of links on one side, and the cost of each link on other side. To combine these two objectives, we introduce the concept of weighted nodal degree. We consider the network topology shown in Figure 4. This is a well known and a well connected carrier's backbone topology. Assuming a network of 24 nodes, let us suppose that a total of 6 splitters have to be placed. Distributing these splitters on the nodes with the highest nodal degrees (as in Node Degree Splitter Placement NDSP) [10] means that they must be placed on nodes 6, 7, 9, 11, 16, and 17. Each of those nodes has direct links with 5 adjacent nodes.

The node-degree method of placing splitters in the network does not take into consideration any of the optical links characteristics. This method is simple: the data needed to perform the splitter placement with this method is easy to obtain.

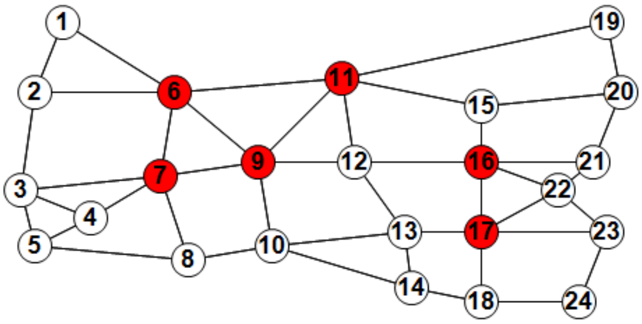

Figure 4 – Splitters distributed based on nodes degree

Table 1 : Node Degrees

Node	Node degree
6,7,9,11,16,17	**5**
3,10,12,13,22	4
2,4,5,8,14,15,18,20,21,23	3
1,19,24	2

However all links are considered the same without paying attention on link capacity or wavelength availability. In consequence the splitter placement may turn out to be inefficient, (in accordance with multicast traffic requirement). In order to place splitters efficiently, each optical link in the network is assigned a weight factor which defines the cost to use the link. Based on multicast traffic provisioning, optical links are designed each with a capacity corresponding to the flow expected to be transmitted over this link.

Figure 5 shows the same network topology as Figure 4 for which each optical link is assigned a specific weight. We assume that this weight is in fact based on the link capacity. Weighted node degrees are computed as the sum of costs of all links attached to the node.

We can see that the weighted node degrees (see Table 2) are different from strict node degrees (see Table 1). For example, node 10 is connected to four adjacent nodes, but the cost of those four links is high. As a result, this node has a high weighted nodal degree when calculated based on the cost of the four links. The weighted node degree is the sum of the links weights connected to it, which is equal to 10 for node 10.

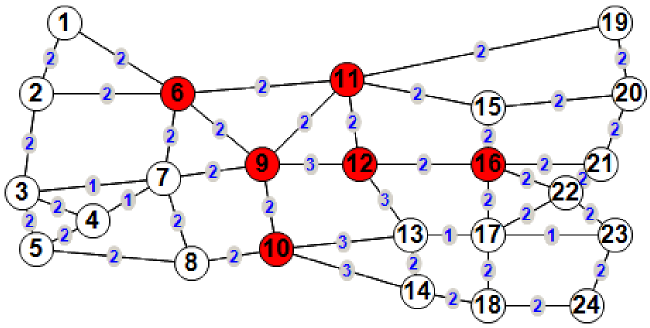

Figure 5 – Splitters distributed based on links cost

Table 2: Weighted node degrees	
Node	Weighted Node Degree
9	**11**
6,10,11,12, 16	**10**
13	9
7,17,22	8
3	7
2,8,14,15,18,20,21	6
4,23	5
1,5,19,24	4

Based on the Weighted Node Degree Splitter Placement WNDSP, the five splitters are now placed on nodes 6, 9, 10, 11, 12, and 16. The two splitters that were previously placed on nodes 7 and 17 are now relocated to nodes 10 and 12. Nodes 10 and 12 will benefit more from the splitters because of several reasons. This is because the use of links attached to those nodes will cost a higher loss because those links are higher in capacity (thus in weight). The cost of excessive use of those links will be higher when deploying any of the assumed propositions to solve the problem of incapability of multicasting in the optical layer. Whether signaling or data traffic in case multiple trees generated or rerouting to source happened, this cost shows high negative effect. An example of this is link 10-13 or link 12-13, because their weight is high and thus transmission on these is not recommended. Another reason is that more multicast traffic is expected on the links attached to this node and this is reflected by their assigned weights.

IV. REQUIRED DENSITY OF MULTICAST CAPABLE NODES IN THE OPTICAL NETWORKS

The required percentage of optical cross-connects that must be multicast capable varies with the diversity of the node degree distribution over the network nodes. This density does not depend on the network size or on the size of multicast groups. To demonstrate this, we consider several topologies with different sizes and structures.

We simulated different multicast group sizes and we measured the effect of the number of MCOXCs. This indicates that the required percentage of MCOXC does not depend on the size of the network, or on the size of the multicast group. It exclusively depends on the diversity of the node degree population.

This demonstrates that the required percentage of MCOXC depends on the standard deviation of the node degree. A low standard deviation indicates that the node degrees tend to be very close to the mean. In this case 40% or more of MCOXC may be required, whereas high standard deviation indicates that the data is spread out over a large range of values. In this case, 20% of multicast capable cross-connects may be enough to assure efficient multicasting.

a. Simulating different network topologies

We consider several optical networks with different sizes, node degree means and node degree standard deviations.

Table 3: Different Network Topologies			
Network	Number of nodes	Degree Mean	Degree Standard Deviation
New Jersey	11	4.18	2.08
NSF NET 14	14	2.71	0.73
EON	19	4.00	1.77
US backbone	24	3.58	1.02

As shown in Table 3, we consider 4 different network topologies, with different number of nodes, different node degree mean and different node degree standard deviation. The three parameters shows that those networks differ in the total number of network nodes, total number of network links and the way those links are distributed over the nodes. Figure 6 shows the first network which is New Jersey LATA network which is composed of 11 nodes interconnected by 23 links. The node degree mean is 4.18. The standard deviation of this network is 2.04, which means that the node degree values are spread apart. Nodes 0, 6 and 10 have degree equal to 2, Nodes 1 and 4 have degree equal to 3 which is less than the mean. On the other hand, Node 3 has degree equal to 8, Nodes 2 and 7 has degree equal 6 which is larger than the mean.

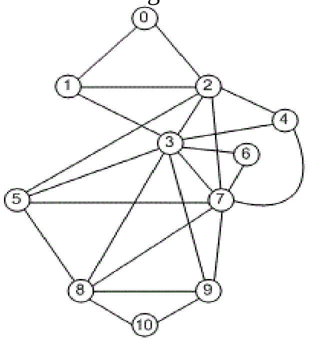

Figure 6 New Jersey LATA network

Figure 7 shows the NSFNET network. This network is composed of 14 nodes interconnected by 19 links. As a result, the node degree mean is 2.71. The standard deviation of this network is 0.73, which means that the node degree values are very close to each others. Nodes 0, 2, 6, 7, 10, 11 have degree 2, and nodes 3, 4, 8, 12, and 13 have degree 3.

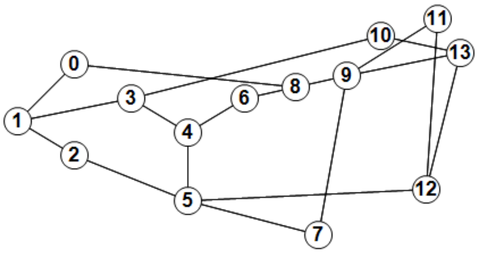

Figure 7 NSF NET

As shown in figures 8, the European optical network consists of 19 nodes with 38 links. The mean is 4 and the standard deviation is 1.77.

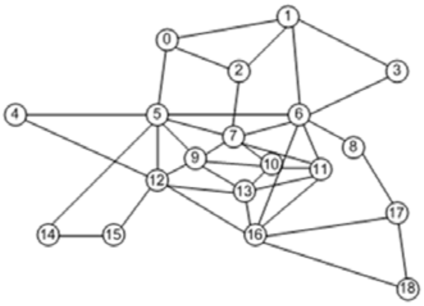

Figure 8 European Optical Network

Finally, the US IP backbone network shown in Figure 9 consists of 24 nodes with 43 links. The mean is 3.58 and the standard deviation is 1.02.

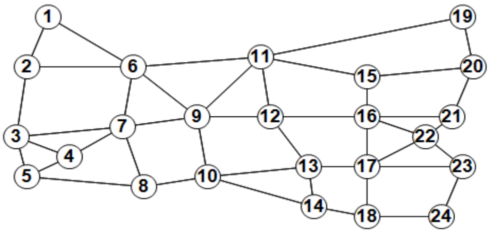

Figure 9 US IP backbone network

In order to know how many multicast capable nodes are enough to assure efficient multicasting, we simulated different multicast sessions. We generated a large number of multicast groups. We place the source each time on a different node, and generate the group members arbitrary. We assumed that the links in the network are all identical, and wavelengths are always available. We also assume that the splitters have full splitting capability.

In order to evaluate both the blocking rate and the resource usage for the generated trees, we assume the following functionality. When a node faces the blocking issue, it finds the closest upstream MCOXC and request from it to do the branching. In case no splitter is available, then a new tree is rooted the source (using a new wavelength).

Table 4: Average cost when no multicast capable nodes are available

Network	No MCOXC nodes	All nodes are MCOXC	Difference
New Jersey	7.77	6.02	23%
NSF NET	11.17	8.80	21%
EON	15.50	11.23	28%
USbackbone	21.02	15.57	26%

Table 4 shows the average cost in terms of number of links used in the multicast trees generated when all nodes in the network are MCOXC versus when all nodes in the network are not multicast capable.

We start to add splitters in the network and we measure the effect of their presence in the network on the cost of the generated trees. We measured this in terms of percentage of nodes being MCOXC.

Table 5: Effect of MCOXC density on the cost over all generated trees

MCOXC %	10%	20%	30%	40%	50%	100%
New Jersey	17	22	23	23	23	23
NSF NET	8	13	17	20	21	21
EON	21	24	26	28	28	28
USbackbone	10	19	23	25	26	26

Table 5 shows that if 10% of the network nodes are MCOXC in the New Jersey network, then an enhancement of 17% is achieved. If 20% of the network nodes are MCOXC then it perform as if all nodes are MCOXC. This is because this network variance is the highest, and there are few nodes of the network which have high degree compared to the rest.

On the other hand, if 10% of the NSFNET network nodes are multicast capable, then only a 8% enhancement is achieved. And a 20% density of MXOXC result in an enhancement in the performance equal to almost half the enhancement given when all network nodes are MCOXC.

This is because its network node degree variance is low, and most of the nodes have relatively close network degree.

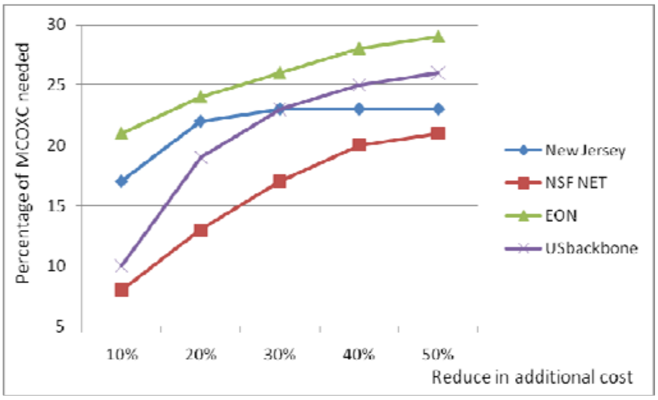

Figure 10 Effect of additional splitters

Table 6 shows the percentage of nodes that must be MCOXC to reduce the additional rerouting cost added because of the light splitters constraints by a 75%, 85% and 95%.

This indicates how many MCOXC are required to assure good performing of the generated multicast trees in each network.

Table 6: Percentage of MCOXC to assure good performing of the generated multicast trees.

	SD	75% Cost Reduce	85% Cost Reduce	95% Cost Reduce
NSF NET	0.73	28%	34%	42%
USbackbone	1.02	21%	26%	36%
EON	1.77	10%	21%	33%
New Jersey	2.08	9%	14%	19%

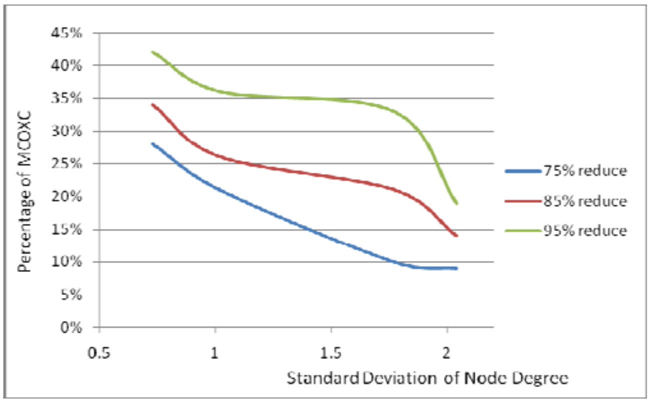

Figure 11 Required percentage of MCOXC versus the standard deviation of the node degree

Figure 11 shows that the percentage of MCOXC required to reduce the additional cost due to multicast incapability constraint depends on standard deviation of the node degree.

V. CONCLUSION

In order for an optical node to be able to perform all multicast tasks, it must be able to do branching in the optical layer. For it to do this, it must be equipped with a light splitter. Light splitters are expensive equipment and therefore a limited number of optical nodes will have this splitting capability. An important factor that affects the performance of the signaling to generate the multicast tree and the efficiency of the generated tree, is the number and location of light splitters placed in the network. In this research, we studied these two parameters.

First, we analyzed the required density of multicast capable optical cross connects and how this parameter depends on the nature of the optical network topology. We considered multiple real networks, and we simulated multiple groups of different sizes. Results show that the required number of splitters depends on the node degree population of the network topology. The more the node degree population is diverse the less the percentage of splitters needed.

Second, we studied the best location to place those splitters. We propose to define optical links weight based on their characteristics from one side, and on the multicast traffic provisioned and expected on the other side. After this, splitters are distributed based on those links costs, and multicast traffic is then simulated to show the advantages of this way of locating the splitters. Simulation is done and results show that efficient placement of those splitters based on links characteristics may enhance the multicast routing from one side, and reduce the numbers of splitters needed from the other side.

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