Designing and Engineering Metropolitan Area Transparent Optical Networks for the Provisioning of Multicast Sessions

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Abstract: We investigate the problem of designing and engineering metropolitan area optical networks for the provisioning of multicast sessions. The Q-factor for each session is taken into account, aiming at maximizing the admitted number of connections.

1. Introduction

Advances in optical WDM networking have made bandwidth-intensive multicast applications such as interactive distance learning, video-conferencing, distributed games, movie broadcasts from studios, etc., widely popular. Multicasting has been investigated in the research community since the early days of optical networking, but has only recently received considerable attention from the service providers, mainly because now many emerging applications can potentially utilize the optical multicasting feature. In WDM networks optical splitters can be used to split the incoming signal to multiple output ports thus enabling a source node to establish connections with multiple destinations. In this case, a light-tree is created to serve a multicast request. To investigate whether a multicast connection should be admitted to the network, apart from finding the minimum cost tree, this paper considers a Q-budgeting approach as a metric on the physical performance of the system. There exist several heuristics on finding these light-trees and this work presents "tree-balancing techniques" aiming at maximizing the multicast connections that can be admitted to the network. It is shown that different node design and engineering approaches as well as different system physical parameters produce different multicast group blocking results, a strong indicator that a better interaction between the physical and logical layers is needed for multicast connection provisioning in optical networks to be more effective. We focus on the metropolitan area network environment where such applications are currently gaining traction.

2. Physical Layer System Modeling

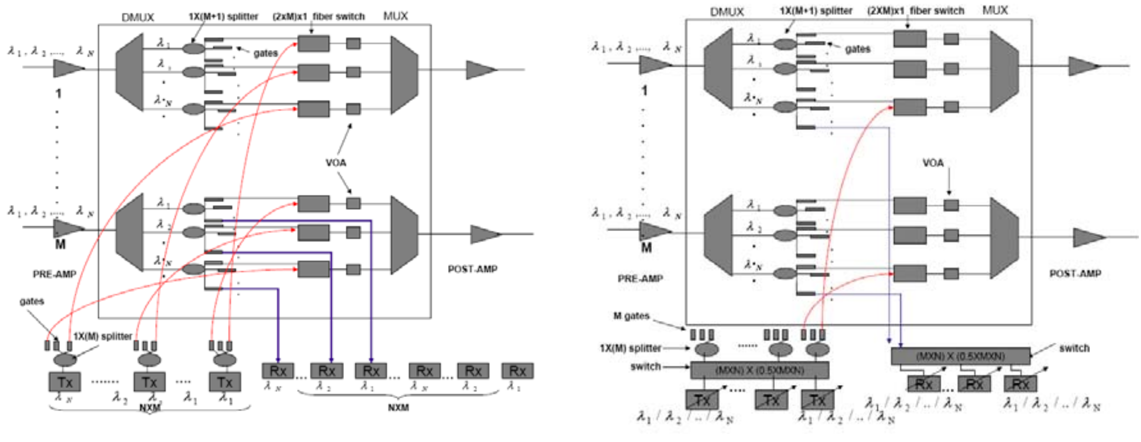
We utilize a typical approach in physical layer system modeling where the required system Q-factor for a target BER is derived using the equation below [1-2]:

$$Q = \frac{I_1 - I_0}{\sigma_1 + \sigma_0} \quad \text{where} \quad \sigma_i^2 = \sigma_{th}^2 + \sigma_{shot-i}^2 + \sigma_{ASE-ASE}^2 + \sigma_{s-ASE-i}^2 + \sigma_{RIN-i}^2 + \sigma_{ASE-shot}^2$$

The above equation assumes a baseline system that includes amplified spontaneous emission (ASE) noise from the optical amplifiers and incorporates the sum of the variances of the thermal noise, shot noise, various beat noise components, and RIN noise at the receiver in the form of σ_i. A Q-budgeting approach that calculates the Q penalty due to each introduced impairment is then used as described in detail in [2] and references therein that results in a lower system Q than the initial baseline. This approach provides a good trade-off between accuracy and computational complexity especially given the fact that thousands of connections are being routed in each iteration and interaction with the physical layer is needed in each one. In a real system this interaction happens during the provisioning phase to decide whether a multicast connection will be admitted to the network or rejected. The modeling based on the Q-performance of the connection is used during the provisioning phase where the multicast trees are being set up to decide whether a multicast connection will be admitted in the network. If the derived Q for any path on the calculated tree is below a pre-determined threshold, then the new call will be blocked. In our case, a Q-threshold of 8.5 dB is assumed which corresponds to BER of 10^{-12}. Budgeting for crosstalk, nonlinearites, PMD, filter concatenation and component aging is as described in [2].

3. Network Design/Engineering

This article expands on the work in [2], where the optical node was treated as a "black box", by examining different node architectures, including cases with fixed or tunable transmitters (Tx)/receivers (Rx) (the number of transmitters/receivers varies from being equal to the number of wavelengths to being equal to the number of wavelengths times the degree of the node). In this work passive splitters are used at each node (see Fig. 1) and power is split as many times as the fan-out of the node plus one to account for the add/drop ports. Controllable SOAs are used as gates to "cut-off" power at outputs where the signal is not destined for. All gates are controlled together in an intelligent manner in order to avoid clashing at the same output/same wavelength of the switch. The effects of the described node design and proper system engineering on the performance of multicast algorithms have not been studied before and provide a good insight into the interaction of physical and network layers in an optical network. Figure 1(a) shows the node design for the case of fixed Txs/Rxs, while Figure 1(b) shows the node design when tunable Txs/Rxs are assumed. For the latter, a switch is added at the add/drop ports respectively in order to allow for maximum flexibility for the multicast connections; its size depends on the number of working wavelengths and the fan-out of the source node. As the size of switches increases their loss increases too. Table 3 shows typical losses in dB for different sizes of MEMS switches assumed in this work.



(a) (b)

Fig. 1: (a) Node design for fixed Txs/Rxs. The number of Txs/Rxs allowed equals the number of wavelengths times the degree of node (ie. NxM), (b) Node engineering for the tunable Txs/Rxs case. Access to 50% of traffic is assumed.

To engineer the network 32 wavelengths spaced at 100GHz with 10 Gbps bit rate are assumed. The gain of each post-amp Erbium Doped Amplifier (EDFA) (see Fig. 1) compensates for the node loss and is engineered based on the worst case insertion loss through the node. Worst case insertion loss is limited either by the maximum splitting loss in the case of fixed Txs, or by the maximum loss of the transmitter's switch in the case of tunable Txs. Maximum node degree in this network is six thus the maximum times the power is split is seven to account for the add/drop ports (8.5dB loss), while the maximum size of the transmitter's switch (NxM >100 in Table 3) for the tunable Txs case corresponds to a maximum loss of 5 dB. The optical power launched into the system is set to +5dBm, and the losses for the various node components are shown in Table 1. Each node's EDFA is assigned a typical noise figure which depends on its gain (Table 2). The gain of each pre-amplifier in Fig. 1 compensates the loss of each preceding fiber span with a fiber loss of 0.3 dB/Km. Variable optical attenuators (VOAs) are responsible for attenuating the total power to a prescribed value when needed, since our node design includes passive optical splitters. Note that VOAs are needed for PDG compensation (topic of future work). At the destination nodes PIN photodiodes are used and Rx pre-amps have noise figure of 4.5 dB.

COMPONENT LOSSES IN THE NODE

Component	*Losses in dB*
MUX/DMUX	3
Splitter	$10 * log(Fanout)$
Gate	0.6
VOA	0.5
Switch	1

Table 1

NOISE FIGURE OF EDFAS

Gain in dB	*NF*
$G < 13$	7
$13 < G < 15$	6.7
$15 < G < 17$	6.5
$17 < G < 20$	6
$G > 20$	5.5

Table 2

MEMS LOSSES

Size	*Losses in dB*
$X \leq 25$	1
$25 < X \geq 36$	1.5
$36 < X \geq 56$	2.2
$56 < X \geq 68$	3
$68 < X \geq 80$	3.7
$80 < X \geq 100$	4.5
$X > 100$	5

Table 3

4. Multicast Algorithms with Physical Layer Constraints

Several heuristics have been developed and compared in this work for multicast routing when physical layer impairments are taken into consideration:

(a) Steiner Tree (ST) heuristic: Determines the tree of minimum cost for a multicast tree rooted at the source and spanning all the destinations in a given multicast group. This heuristic is used in this work as the baseline for comparison purposes [3].

(b) Shortest Paths Tree (SPT): Finds unicast shortest path connections from source to all destinations separately and then merges these paths to create the multicast tree. It keeps destinations as closer (in distance) to the source as possible, thus it can improve the Q-factor for the destinations. However, it also increases the total number of links used in the tree.

(c) Balanced Light-Tree (BLT): The BLT approach considers only power budget constraints when constructing the light-tree. Initially, the algorithm finds a shortest path light-tree T that spans the source and the destination nodes for each multicast group [4]. Consider light-tree T and let u denote the node with the maximum degree, and v denote the node with the minimum degree. The idea behind BLT is to delete node u from T, and add it back to the tree by connecting it to some node y in the path from source s to node v. Doing so reduces the split ratio on node u, but it also increases the split ratio of all nodes below node y in the tree. Therefore, this pair of delete/add operations is performed only if it does not increase the split ratio of any node beyond that of node u. The algorithm terminates when two successive iterations fail to reduce the maximum split ratio.

(d) Balanced Light-Tree Qtolerance (BLT_Qtolerance): The BLT_Qtolerance algorithm is an extension of the BLT approach that takes into account the Q-factor by performing delete/add operations on the paths of an initial light-tree T based on the Q-factor of the destination nodes [2]. Considering that the minimum acceptable Q-factor for each path is q, this algorithm tries to maximize the Q-factor only at those destination nodes where its value is lower than q. Thus, if after a number of iterations the minimum Q-value for all destination nodes is higher than q, or if two successive iterations fail to increase the minimum Q-factor, then the balancing algorithm terminates.

5. Performance Evaluation

In order to evaluate the average performance of the algorithms for different network designs/system engineering parameters, we simulated multicast connections on a metro network consisting of 50 nodes and 196 links, with an average node degree of 3.92 and an average distance between the links of 60 Km. We used a dynamic traffic model where multicast sessions arrive at each node according to a Poisson process and the holding time is exponentially distributed with a unit mean. In each simulation 5,000 requests were generated for each multicast group size for a total of 40,000 multicast requests, and the results were averaged over five simulation runs. Thirty-two wavelengths per link were utilized to evaluate the blocking probability versus the multicast group size for a network load of 100 Erlangs.

For each multicast request, the algorithm first solves the routing problem by finding a tree that can accommodate the request and then tries to assign a wavelength for that tree based on the first-fit algorithm. If a wavelength assignment is possible, the Q-factor for each path on the tree is evaluated and the multicast request is blocked if there is at least one route on that tree with a Q value that falls below a predetermined threshold value and there is no alternate wavelength assignment possible. Otherwise, a new wavelength assignment is implemented and the heuristic is repeated. If a wavelength assignment with an acceptable Q value is possible, the availability of Txs and Rxs is examined, and the multicast request is blocked if there is no Tx or Rx available and no alternate wavelength assignment is possible. Otherwise, a new wavelength assignment is implemented and the heuristic is repeated. Figures 2(a) and 2(b) show the simulation results for the blocking

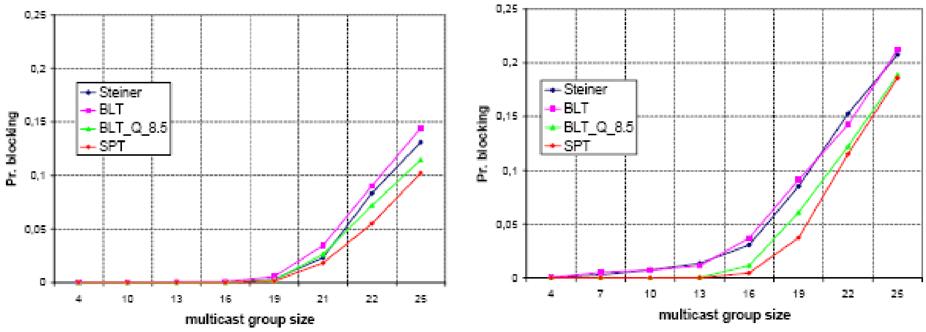


Fig. 2: (a) Blocking Probability versus multicast group size for node engineering with fixed transmitters/receivers (number of transmitters/receivers for each node equals to the number of wavelengths times the degree of node), (b) Blocking Probability versus multicast group size for node engineering with tunable transmitters/receivers (number of transmitters/receivers for each node equals to the number of wavelengths).

probability versus the multicast group size when a number of multicast algorithms are used assuming node engineering with passive splitters for the cases of fixed Txs/Rxs and tunable Txs/Rxs respectively. The SPT algorithm performs better than the other algorithms as blocking in this case is not limited by the Q-factor but by the network resources (wavelengths, Txs/Rxs) with the BLT_Qtolerance being the second best as it tends to create trees that have more breadth than depth, limiting the blocking due to Q. Also, the node design with the fixed Txs/Rxs performs slightly better in this case, only because the number of Txs/Rxs in that design is larger than the corresponding number in the tunable design. Our work has shown some of the impacts of node engineering/design on the algorithms for multicasting and the impact of physical layer constraints via Q factor.

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