On the Performance of Dynamic Source Aggregation of Sub-Wavelength Connections in EONs

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ABSTRACT
In elastic optical networks, heterogeneous traffic demands are typically supported by a single type of bandwidth-variable transmitters, which is not always spectrum and cost efficient. In light of this, we recently proposed a novel algorithm for dynamic aggregation of same source but different destination sub-wavelength connections in elastic optical networks, aiming to obtain both transmitter and spectrum usage savings. In this paper, the performance and feasibility analysis of the proposal is presented. The obtained results demonstrate considerable improvement in the network spectrum utilization, as well as a significant reduction in the relative network cost.
Keywords: elastic optical networks, source aggregation, network optimization.

1. INTRODUCTION

In Elastic Optical Networks (EON), several key optical technologies are used. Among them, Bandwidth-Variable (BV) transmitters play a crucial role. Such transmitters should support flexible central frequency tuning and elastic spectrum allocation, which can be achieved thanks to recent technology advances [1]. To realize traffic accommodation, the bandwidth of transmitters is discretized in spectrum units (*i.e.* 12.5 GHz), referred as Frequency Slot (FS). For example, a 50, 100 and 400 GHz transmitter's bandwidth correspond to 4, 8 and 32 slots, respectively. The spectrum variability of lightpaths is achievable by tuning the number of allocated FSs. The incoming traffic is mapped onto individual BV transmitters generating the appropriate-sized optical lightpaths between end-nodes. However, the capacity of a transmitter may remain underutilized when the traffic demands are lower than the transmitter's full capacity (sub-wavelength connections). In simple words, despite the crucial role of BV transmitters in increasing the spectrum efficiency of network, their full capacity cannot be utilized efficiently. It is therefore essential to introduce a solution for maximizing their capacity utilization.

To address the problem, we proposed a novel dynamic source aggregation algorithm, aiming to improve the utilization of available spectrum resources and transmitters capacity in the network [2]. In general, this proposal tries to aggregate multiple sub-wavelength connections into one transmitter and serve them as a whole over the network. To realize the proposal, additional capabilities should be added to network nodes. Therefore, we also introduced a cost-effective enabling node architecture. In this paper, the feasibility of the proposal in [2] is validated through extensive simulation studies. The rest of paper is organized as follows. In Section 2 we explain the principles and benefits of source aggregation. The proposed enabling node architecture as well as proposed dynamic source aggregation algorithm are also reviewed in this section. We describe the model of the EON network under study in Section 3. Simulation results are presented in Section 4. Finally, Section 5 concludes the paper.

2. SOURCE AGGREGATION IN EON

2.1 Principles and Benefits

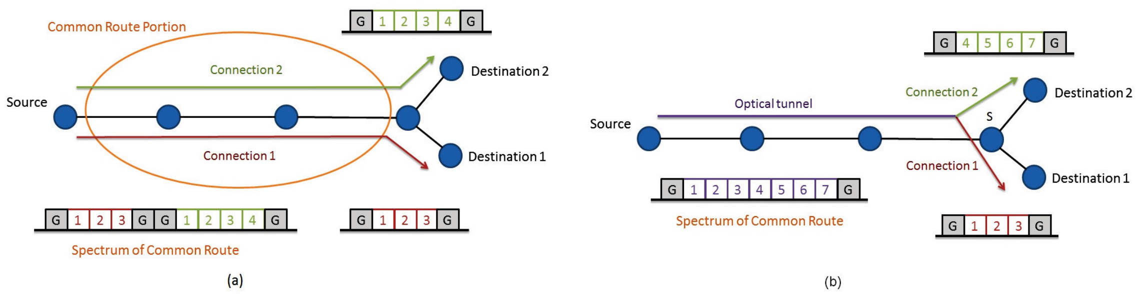

Figure 1. Two exemplary elastic optical networks, (a) without source aggregation (b) with source aggregation.

The basic idea of source aggregation proposals is to group multiple connections with same source into one transmitter and switch them as a whole over the network. This group of connections is called an optical tunnel. In this way, such proposals can provide better utilization of the transmitter capacity. Moreover, since guard bands are only necessary between different optical tunnels for switching purposes, better bandwidth utilization is also achievable. As highlighted in Fig. 1(a), both connections 1 and 2 share a portion of their routes from source to destination. By aggregating traffic demands over this common route portion, spectrum savings as well as better transmitter capacity utilization can be achieved. As shown in Fig. 1(b), both connections can be grouped in a single optical tunnel over the common route portion. Since the traffic demand over the resulting optical tunnel is assumed to be less than the whole available spectrum of a transmitter, it can be established using only one transmitter instead of two transmitters as in Fig. 1(a). In addition, a portion of the spectrum equal to a couple of guard bands (2 FSs) has been saved in this example. At the end of common route portion, each connection can be extracted from the optical tunnel and continue its way to the destination. As mentioned before, guard bands are necessary at both sides of the individual connections, once extracted from the optical tunnel. In Fig. 1(b), frequency slot 4 in the optical tunnel is treated as a signal slot in connection 2, and as a guard band slot in connection 1. In order to provide such functionality special node architecture has to be employed. The proposed node architecture is detailed in the following section.

2.2 Enabling Node Architecture

To realize the proposal, an intermediate node should be able to drop a specific portion of an optical tunnel (corresponding to one or multiple connections) to an outgoing port, while continuing the remaining part of it to another outgoing port. Authors in [1] employed the B&S architecture. In this architecture, the spectrum of the incoming optical tunnel is broadcasted to all outgoing ports, and filtered by different BV-WSS to send the desired spectrum bands to each outgoing port. Although this is an easy architecture for an optical node, it has some drawbacks. First, this node architecture is neither scalable nor cost-effective. Second, spectrum of optical tunnels will suffer from the internal optical signal splitting. In fact, internal optical signal splitting decreases the energy level of optical signal, which may lead to difficulties in signal detection at the receiver side and worse signal to noise ratio. To address the mentioned problems, it is desirable to reduce the number of BV-WSS in the node architecture. In [2] a new architecture, named shared splitting architecture, has been proposed. As illustrated in Fig. 2, the architecture consists of two main sections, namely switching section and splitting section. The Bandwidth Variable Optical Cross-Connect (BV-OXC) module switches portions of spectrum without any signal splitting. To do so, the BV-OXC should be able to configure its spectral switching window in a continuous manner according to the spectral width of incoming optical signal. Thanks to the advances in liquid crystals on silicon (LCoS) wavelength-selective switch (WSS) technology, BV-OXCs with these features are available nowadays [3]. In addition, the proposed node should also be able to drop a specific spectrum portion of the optical tunnel to an outgoing port, while continue the remaining part of it to another outgoing port. As shown in Fig. 2, the splitting section of the node performs this functionality. In this section, a shared BV-WSS is employed to filter the broadcasted signals and to send the appropriated spectral bands to their desired outgoing ports. As a matter of fact, in contrast to B&S architecture, no BV-WSS (which are relatively expensive devices) are placed per outgoing port in our proposal; instead they are moved from the output ports to the splitting section. Therefore, the number of necessary BV-WSS per node is reduced significantly which leads to considerable cost and energy savings. In this paper, we will see how many splitting sections per node is sufficient to keep the performance and cost of the node in a reasonable level.

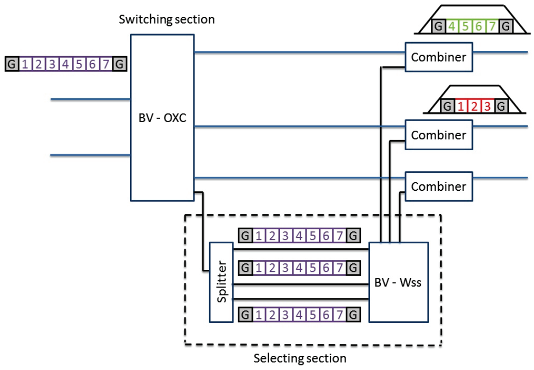

Figure 2. Shared splitting node architecture.

2.3 Dynamic Optical Path Aggregation Algorithm

Beside the node architecture, a dynamic Routing and Spectrum Assignment (RSA) algorithm is necessary in order to add the proposed source aggregation capability in to a network. We developed the First-Possible Aggregating (FPA) algorithm in [2]. The FPA algorithm maximizes the transmitter capacity utilization of the network by aggregating same-source sub-wavelength connections over their common route. It improves the spectrum utilization of the network by reducing the number of required guard bands between connections. These features can be easily translated to more established connections over the network and a lower number of required transmitters per node. Note that the maximum number of aggregated connections in a single transmitter is limited by its bandwidth capacity.

The FPA algorithm starts with calculating the shortest route (ShR) between the end nodes of incoming connection. Then, it selects already existing connections in the network with the same source and following a route that shares some links with the ShR. Next, the residual capacities of transmitters which are supporting the selected existing connections are calculated, and the first transmitter with enough idle capacity is selected. The spectrum continuity and contiguity constraints for establishing the incoming connection using the selected transmitter over the ShR are examined. If the constraints are satisfied, source aggregation is performed, otherwise the next possible transmitter with enough capacity is selected and again spectrum continuity and contiguity constraints are checked. This search goes on until the source aggregation is done. In case of failure, the next disjoint shortest path is calculated and same already existing connections selection routine plus all other mentioned searches are carried out for this new route. If there is no way to preform source aggregation, the incoming connection request is established without source aggregation by using a separate transmitter and employing k-shortest path routing and first-fit spectrum assignment.

3. NETWORK MODEL

We consider EON with the family of mesh topologies: chordal ring with nodal degrees between 3 and 5. Each member of a family may consist of different number of nodes but all of them have the same nodal degree. A general degree three topology family is represented by D3T(w_1, w_2, w_3) and it is basically a bi-directional ring network, in which each node has a link to the previous node, a link to the next node and an additional bi-directional link. w_1, w_2, and w_3 are called chord lengths. The number of nodes (N) in a chordal topology is assumed to be even, and they are indexed as 0, 1, 2, ..., $N-1$. Each odd-numbered node i (i = 1, 3, ..., $N-1$), in addition to its next $((i+1) \bmod N)$ and previous $((i+(N-1)) \bmod N)$ nodes, is connected to a node $(i+w) \bmod N$, where w is a positive odd number. Considering the general notation of the degree three topology, a chordal ring family is simply represented by D3T(1, $N-1$, w). Keeping the same notation in mind, for a given nodal degree n, each odd-numbered node i (i = 1, 3, ..., $N-1$) is connected to the nodes $(i+w_1) \bmod N$, $(i+w_2) \bmod N$, ..., $(i+w_n) \bmod N$, where the chord lengths, w_1, w_2, ..., w_n are assumed to be positive odd, with $w_1 \leq N-1$, $w_2 \leq N-1$, ..., $w_n \leq N-1$, and $w_i \neq w_j$, $\forall i \neq j$ and $1 \leq i, j \leq n$. In this sense, the general degree n topology family is represented by DnT(w_1, w_2,..., w_n).

4. SIMULATION RESULTS

We evaluated the performance of the proposed source aggregation proposal through extensive discrete event simulation studies and compared it with the non-aggregating scenario (*i.e.*, a conventional elastic optical network using a k-Shortest Path computation algorithm with a First-Fit slot assignment, starting with the shortest computed path). Chordal ring family of D3T(1,15,5), D4T(1,15,5,13) and D5T(1,15,7,3,9) have been selected for this purpose. As mentioned previously, despite the number of nodes in the network topology, the nodal degree in these families are 3, 4 and 5, respectively. We assumed total optical spectrum of 1.5 THz per link and the spectrum slot size of 12.5 GHz [2]. By assuming an appropriate modulation format (*e.g.*, BPSK), each spectrum slot has a capacity of 12.5 Gb/s. The full capacity of a transmitter is 100 Gb/s which supports 8 frequency slots. The guard band size is assumed to be 1 frequency slot at each side of a connection [1]. In addition, according to the asymmetric nature of today's Internet traffic uni-directional connections between end nodes were considered. The traffic generation follows a Poisson distribution process, so that different offered loads are obtained by keeping the mean Holding Time (HT) of the connections constant to 200 s, while modifying their mean Inter-Arrival Time (IAT) accordingly (*i.e.*, offered load = HT/IAT). Traffic demands for each source-destination pair are randomly generated with normal distribution over the range of 12.5 Gb/s (1 frequency slot) to 100 Gb/s (8 frequency slots). Regarding the traffic load, we have offered from 4.5 up to 6 Erlangs per node (total offered traffic to the network ranging from 72 to 96 Erlangs). The average demand of each connection request is assumed to be 55 Gb/s. Hence, the total traffic generated per node ranges from 247.5 Gb/s to 330 Gb/s in this study. In addition, we assumed 10 transmitters per node.

As stated previously, having enough number of parallel splitting sections in the proposed structure to avoid any collision is crucial. As a matter of fact, it is a function of network nodal degree. Keeping this in mind, in the first study, we fixed the number of nodes in the abovementioned Chordal ring families on 16 and examined the influence of number of parallel splitting sections in the performance of the proposal. In order to quantify the benefits due to the increase of parallel splitting sections, we introduce the splitting section gain as $G(i,j) = [(BP(i) - BP(j)) / BP(i)] \times 100$ where $BP(i)$ is the network blocking probability in the network with i parallel splitting sections per node and $BP(j)$ is the network blocking probability of the same network but with j parallel splitting sections per node (same total spectrum per link, same number of nodes, *etc*.). In simple words, $G(i, j)$ shows the changes in the performance of network in terms of blocking probability by increasing the number of parallel splitting sections per node from i to j.

Figure 3 shows the splitting section gain achieved in three mentioned topologies. From the results, we observe that by changing the number of parallel splitting sections in the proposed shared splitting node architecture from 0 to 1 significant improvement in the blocking probability of networks under study is achieved. This is quite reasonable conclusion, since with 0 splitting section per node (standard EON), it is not possible to realize source aggregation in the network (as mentioned previously, the First-Fit slot assignment is applied in the standard EON case). By introduction of at least one splitting section in the network nodes, realization of source aggregation becomes possible which increases the transmitter capacity usage and providing more flexibility for establishing connections over the network. As illustrated, introduction of more parallel splitting sections per node can slightly change the performance of network. Therefore, it can be inferred that one splitting section per node is sufficient to keep the performance and cost of the node in a reasonable level. To compare the cost of already available B&S node architecture with the proposed shared architecture, by taking the nodal degree of

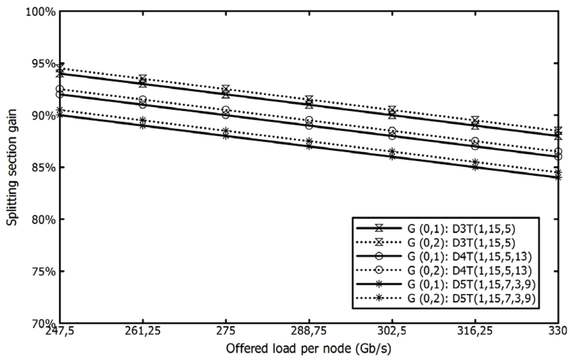

Figure 3. Splitting section gain due to the increase of the number of parallel splitting sections per.

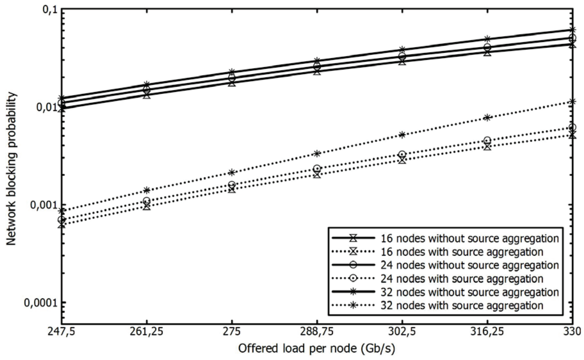

Figure 4. Network blocking probability vs. offered load.

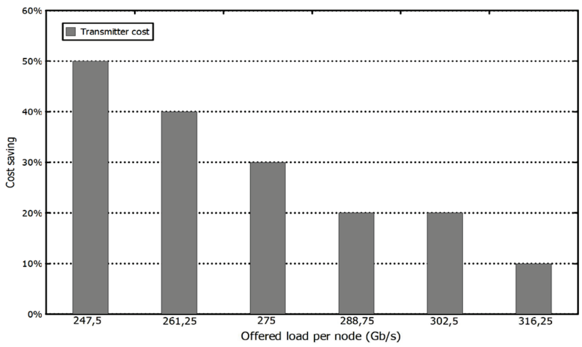

Figure 5. Relative cost savings for different offered loads.

networks under study into account and considering one BV-WSS per output port in a B&S node architecture, the relative cost reduction using the proposed node architecture is calculated as *Cost reduction* = $[(N_{\text{B\&S}} - N_{\text{Shared}}) / N_{\text{B\&S}}] \times 100$ where $N_{\text{B\&S}}$ is the number of BV-WSS in the B&S node architecture and N_{Shared} is the number of parallel splitting sections in the proposed node architecture (which is 1 according to the above discussion). Considering this, the relative cost is reduced by 66% in the case of D3T(1, 15, 5) ($[(3-1)/3]\times 100$), 75% in the case of D4T(1, 15, 5, 13) ($[(4-1)/4]\times 100$) and 80% in the case of D5T(1, 15, 7, 3, 9) ($[(5-1)/5]\times 100$) using the proposed node architecture. Based on this discussion, the number of splitting sections per node is fixed on one from now on.

Figure 4 shows the bandwidth blocking probability achieved in both source aggregating and non-aggregating scenarios for the topology family of D3T(1,15,5) with 3 different number of nodes 16, 24 and 32. From the results, we observe that source aggregation case outperforms the non-aggregating scenario in all three study cases and the entire offered load range. It is worth to mention that by increasing the number of nodes in the network, the relative improvement in the performance of the network decreases. The reason is that in such network the chance for having long distance connections (connections spanning more hops) is increased. Considering the existence of spectrum fragmentation in network links, the proposed algorithm cannot aggregate connections as it did in smaller network.

Figure 5 illustrates the relative cost savings of the source aggregating scenario versus the non-aggregating scenario in the same network as above. According to the results, source aggregation can reach the same blocking probability performance as non-aggregating scenario, while it achieves 50% transmitter savings under low traffic load. By increasing the load, since the transmitters are become more occupied the proposal cannot provide significant benefits.

5. CONCLUSION

In this paper, we verified the feasibility and performance of our previously proposed dynamic source aggregation algorithm which supports grouping of multiple sub-wavelength connections with the same source into a single transmitter. Performance evaluations were made to compare the spectrum usage and transmitter saving benefits of source aggregation and non-aggregating scenarios. Our results show that the proposal achieves significant cost savings, with better or equal spectrum utilization compared to non-aggregating case.

ACKNOWLEDGEMENTS

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REFERENCES

[1] G. Zhang *et al*.: "Optical traffic grooming in OFDM-based elastic optical networks", J. *Optical Communications and Networking*, vol. 4, no. 11, pp. B17-B25, 2012.

[2] P. S. Khodashenas *et al*.: "Dynamic source aggregation of subwavelength connections in elastic optical networks," *J. Photonic Network Communications*, vol. 26, no. 2-3, pp. 131-139, 2013.

[3] R. Ryf *et al*.: "Wavelength blocking filter with flexible data rates and channel spacing", *IEEE/OSA J. Lightw. Technol.*, vol. 23, no. 1, 2005.