Traffic performance study of all-optical label swapping isolated and full network topologies

J. M. D. Mendinueta[1,2], I. Tafur Monroy[1], J. J. Vegas Olmos[1], N. Yan[1], Y. Dimitriadis[2], I. de Miguel Jiménez[2] and A. M. J. Koonen[1]

[1] COBRA Research Institute, Faculty of Electrical Engineering, Eindhoven University of Technologie, Den Dolech 2, PO BOX 513, 5600 MB, Eindhoven, The Netherlands.
E-mail: mendi@ulises.tel.uva.es

[2] Higher Technical School of Telecommunications Engineering, University of Valladolid, Camino del Cementerio s/n, 47011, Valladolid, Spain.

In this paper, we present simulation results of traffic performance of the All-Optical Label Swapping (AOLS) nodes. Firstly, we consider the case of a single isolated node. Secondly, we study the performance of full network topologies comprising several AOLS nodes. To cope with the features of AOLS nodes and networks a new cell optical network simulation platform has been developed. Our developed simulation environment accommodates easily arbitrary scenarios of either a single node or full connected network topologies, due to its independent treatment of the physical layer and the logical node architecture of AOLS nodes.

1. Introduction

In recent years, label switching techniques such multi-protocol label swapping (MPLS) and Asynchronous Transfer Mode (ATM) have significantly boosted the packet handling speed of routing nodes. This is because of the introduction of Internet Protocol (IP) packet forwarding and switching based on swapping of short labels instead of locating the unique IP addresses. However, these techniques and protocols have been only employed in routers that use electronic or electro-optic technologies to perform routing and switching of data [1]. As traffic continues to grow, there is a foreseen bottleneck of electronic processing speed. Moreover, with the introduction of high capacity WDM transmission systems the gap between the high line bit rates and the limited processing speed at the routing nodes is further increased. All-optical label swapping (AOLS) has been proposed as a viable approach towards resolving the mismatch between fiber transmission capacity and router forwarding capacity [2].

The European Commission funded project IST-LASAGNE aims at designing and implementing the first, modular, scalable, and truly all-optical photonic router capable of operating at 40 Gb/s. The proposed AOLS architecture uses all-optical logic gates using the same fundamental building block, namely a semiconductor optical amplifier-based Mach-Zehnder interferometer (SOA-MZI) [3]. Both the payload and the label are conveyed using intensity modulation (IM), in a time-serial fashion.

In this paper, we study the traffic performance of AOLS nodes, from the cell forwarding point of view, using ideal non-blocking switches as baseline for comparisons. Firstly, we describe the node architecture employed in the simulator model set-up, comprising of ingress-egress and pure core nodes. Secondly, we present the simulator developed for our study, and introduce the node and fully connected topologies under study followed by discussions about the obtained simulation results. Finally, conclusions are drawn.

2. Node architecture

For purposes of simulation, we make a distinction between nodes that can *get-back* an incoming cell to the sender node at optical level (`type_1`), and nodes without this feature (`type_2`). Figures 1.a and 1.b correspond to the ingress-egress `type_1` (**A** node) and `type_2` (**B** node) nodes of 3 ports (three input - three output fibers). The only difference between **A** and **B** nodes is the wiring matrix at the end of the optical switch. Input ports 0 and 1 correspond to node-to-node connections, while input port 2 is the ingress port. In the same manner, output ports 0 and 1 are node-to-node connections and 2 and 3 are egress ports. For a full explanation of the elements of the nodes, see references [1, 3]. Figure 1.c is a 4 ports (four input - four output fibers), `type_1` AOLS node (**C** node). We applied the same rules as the previous cases.

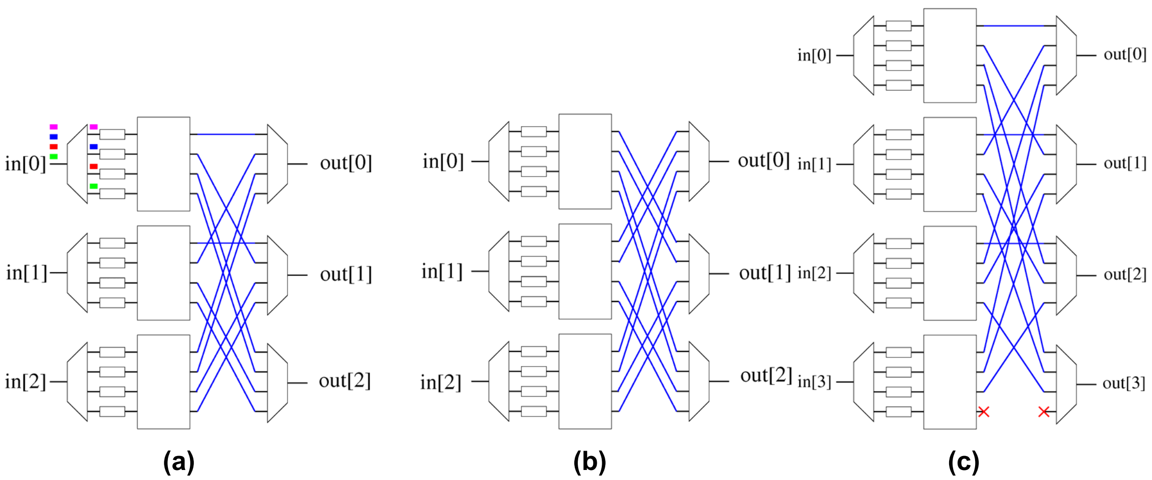

Figure 1: AOLS `type_1` with 3 ports (a), `type_2` with 2 (b) and `type_1` with 4 ports (c) node models.

The LASAGNE AOLS nodes use *four wavelengths* dense multiplexed *fixed length cells*. At the input, the incoming cells are demultiplexed and pass through the *all-optical label swapper* [1]. This block reads the incoming cell label, and eventually changes the wavelength channel of the payload according to the internal routing tables. A new label is then generated and merged with the payload. An arrayed waveguide grating (AWG) routes the cell to the correspondent output port.

The block at the end of the three nodes of Figure 1 is a contention resolution and a multiplexer. Contention occurs when two or more cells want to reach the same destination during the same time slot. In this case, it is clear that if more that four cells must go to the same output fibre, there will be no available wavelengths to allocate for it. Several mechanisms based on optical buffering have been proposed [4, 5]. For the purposes of simulation, the next *blocks* were coded: 1) `DropMux`: detects contending cells, and drops one of them, 2) `DropMuxWC`: changes the wavelength of a contending cell if there are available wavelengths, if not drops the cell, 3) `DropMuxWCFB`: stores contending cells in a fibre delay line (FDL) buffer for one slot. Buffered cells have priority over new cells in the next time slot. If there are not wavelength channels available, cells are dropped. In all three cases, we applied the policy that cells with lower wavelength channels have priority to be forwarded.

3. Simulator design and experiment setup

We developed our custom simulator in order to cope with the previous tasks. After a *state of the art* analysis, we did not find a simulator capable of doing the above tasks in an easy way. Discrete event time simulators spent a lot of CPU time scheduling new events for each cell, so a fixed slotted scheduling by means of passing matrix of cells between objects is employed. We think this is a good compromise for fixed length, synchronous cell optical network simulations.

As it stated in previous references [6], it is important to choose a good traffic model for network traffic simulations. We used Bernoulli, geometric and self-similar traffic models for synthetic traffic generation, for both isolated and topology simulations. Deflection and multicasting were not used in the simulations for this work. We omitted in the statistical analysis the first 10^6 cells of the simulation in order to prevent transient simulation effects [7]. In order to guarantee good statistical properties with small confidence intervals (minor that 95 % in all cases), a statistical method found in [8] was employed. We have chosen two metrics to evaluate the network performance: network throughput and cell loss rate. The network throughput is defined as the normalized fraction of cells that reach their destination and null slots. Both measurements indicate *network utilization* and *reliability* of the optical network [9]. The simulator was written in C++ language because its run-time speed. For complex task like data storage, parse of files and graph manipulation, the Boost Libraries [10] were employed.

For the purposes of comparison, several non-blocking switches were coded. These architectures perform in the same manner that an optical AWG based switch with wavelength converters both at the input and the output of the AWG [11].

3.1 Isolated node analysis

Firstly, we studied the three presented AOLS nodes in an isolated way. Figure 3 shows a representation of the simulation experiment, for the AOLS **A** node of 3 ports. On the left is shown a physical object model for this simulation. The labeled objects correspond to transport layer objects, such as traffic generators, switches and counters, and the dashed lines are the optical labeled switched paths (OLSPs), which generators send traffic to. On the right there is a logical plot of the simulation.

The other nodes were simulated in the same fashion, but setting the OLSPs according to the node capabilities.

3.2 Full topology analysis

Secondly, it is interesting to study the performance in a more realistic network environment that the isolated case. Figure 4 shows the two topologies employed in the simulations. On the left we can see a ring topology of 7 nodes, comprised of AOLS ingress-egress nodes of 3 ports (**A** or **B**, Figure 1). The topology on the right contains two more AOLS nodes of 4 ports (**C** node, Figure 1). We used a full connected logical topology for the OLSPs using Dijkstra shortest path. Each node in the network sends cells to all the other nodes with the same probability.

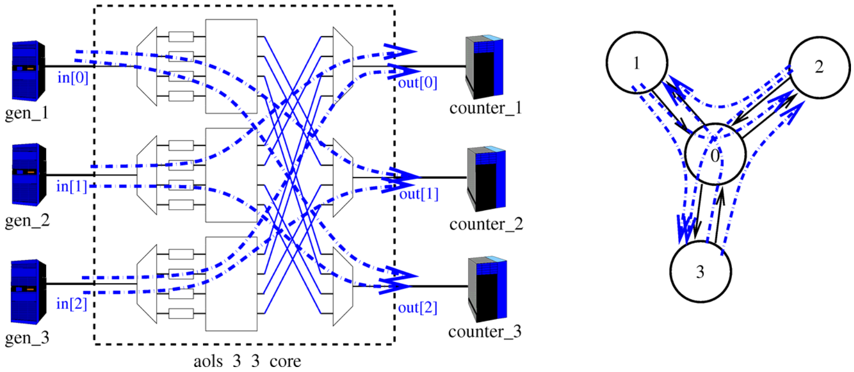

Figure 3: isolated experiment for AOLS core of three ports (left) and OLSP diagram of the simulation (right).

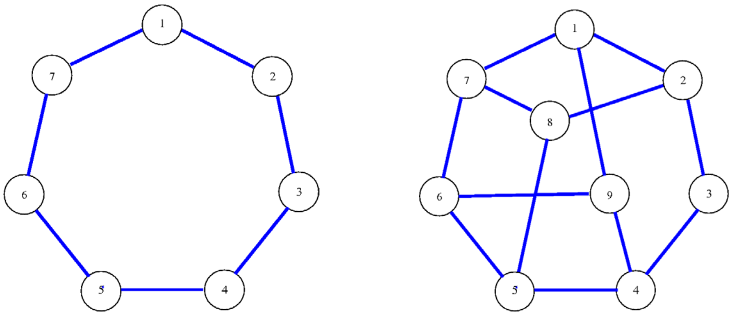

Figure 4: Ring topology of 7 nodes (left) and mesh topology of 9 nodes (right).

4. Isolated AOLS node analysis

Figure 5 compares the cell loss probability and network throughput of *isolated* AOLS **A** node of 3 ports for Bernoulli and selfsimilar traffic models. We used one slot of buffering for the `DropMuxWCFB` case in both traffic models.

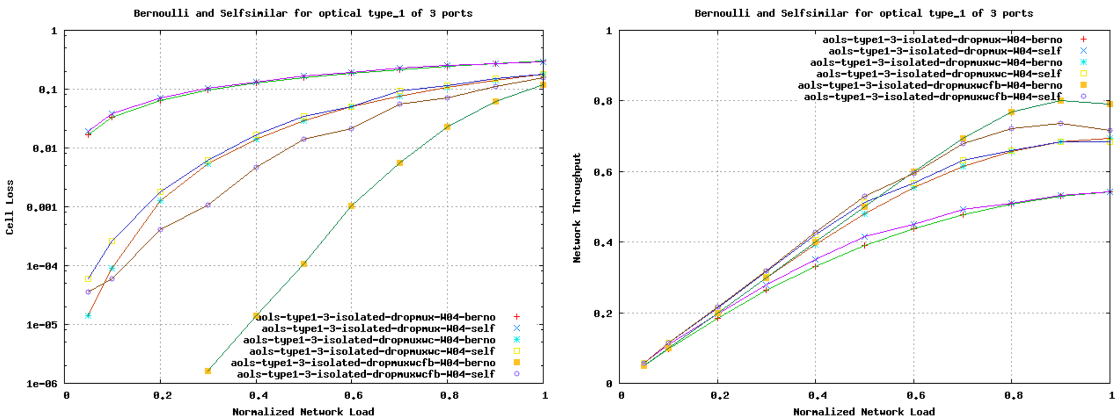

Figure 5: cell loss (left) and network performance (right) for an optical `type_1` node of 3 ports with Bernoulli and Selfsimilar traffic models.

We find that selfsimilar traffic always performs worse that the other traffic models employed in terms of the two simulated parameters, especially for optical buffering.

Another important fact observed is that traffic models can vary the expected results of the simulation experiments in a high degree. This variation is severely important when employing optical buffering as contention resolution mechanism. Moreover, analytical results exist for Bernoulli traffic models [12], so it is important to implement this and other non-realistic traffic models [6] with the *only purpose of testing* the simulation engine.

4.1 Comparison of isolated AOLS architectures

Figures 6, 7 and 8 show the comparison of AOLS nodes with similar characteristics non-blocking architectures (Figure 1). We employed only selfsimilar traffic model because is the more realistic one for network analysis [6].

We can see that wavelength conversion is the most effective technique of contention resolution, especially at low network loads. The AOLS switches performed only a little worse that ideal non-blocking switches with similar characteristics. It is also noted the improvement of optical buffering for 4 ports **C** node over **A** node for network throughput. This is a consequence of increasing the number of node ports without a corresponding growing of other contention resolution mechanisms, namely wavelength channels. It is important to effectively combine the number of different contention mechanisms [9, 11].

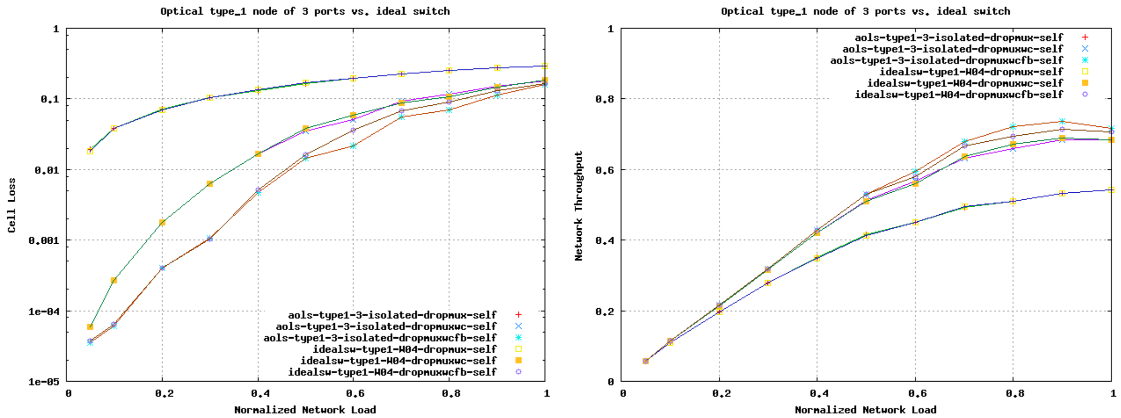

Figure 6: cell loss (left) and network performance (right) for A node and vs. non-blocking switch.

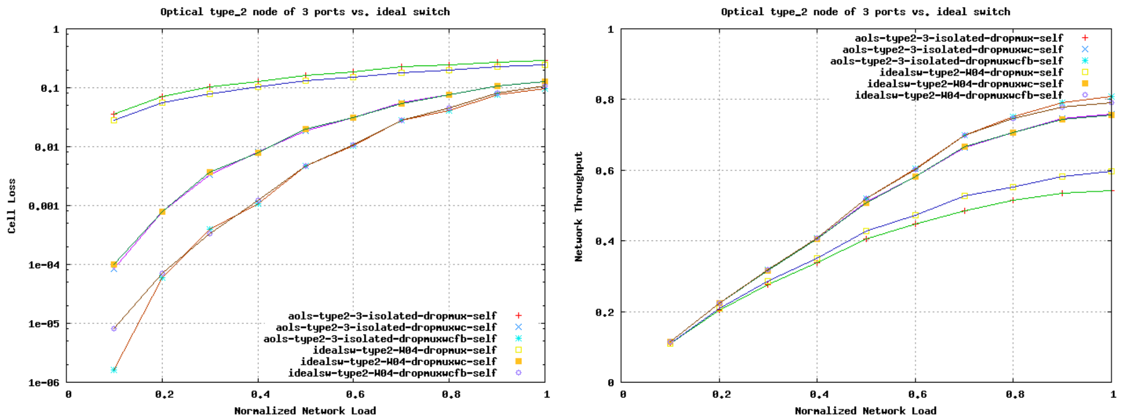

Figure 7: cell loss (left) and network performance (right) for B node vs. non-blocking switch.

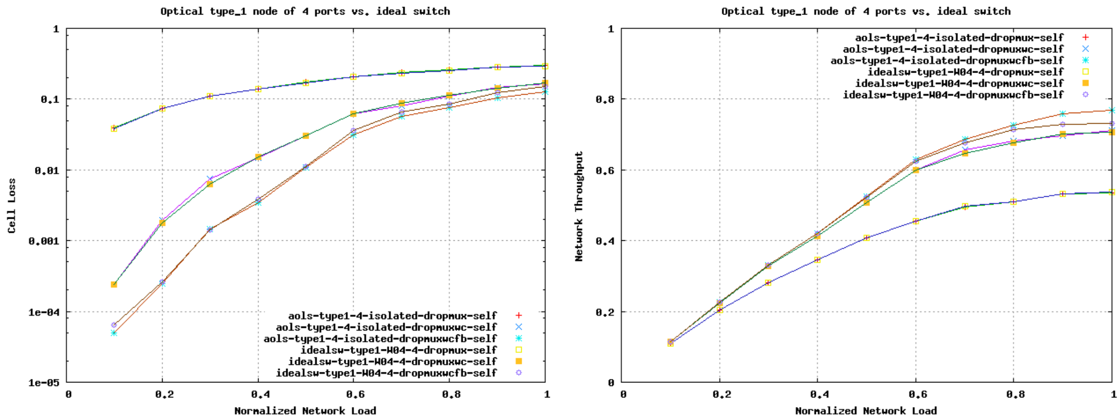

Figure 8: cell loss (left) and network performance (right) for C node and vs. non-blocking switch.

5. AOLS node analysis with complex topologies

5.1 <u>Ring topology of 7 nodes</u>

Figure 9 shows the results for a topology consisting of a ring of 7 nodes (Figure 4), for the three contention resolution mechanism proposed. Ring networks can be constructed employing `type_1` and/or `type_2` AOLS nodes. In this section, we built two different ring networks for `type_1` or `type_2` nodes.

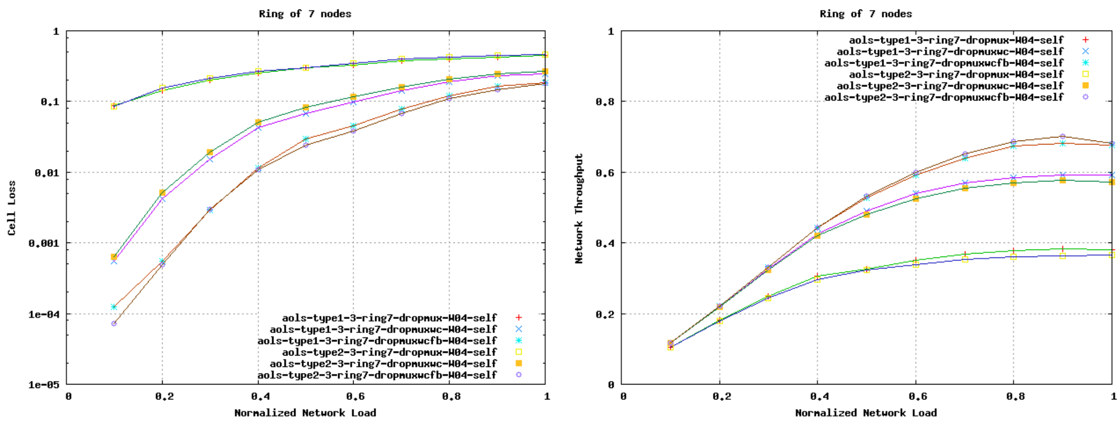

Figure 9: cell loss (left) and network performance (right) for a ring topology of 7 nodes.

As expected, `type_2` AOLS performs better that `type_1` for the measured parameters, but only with small difference. Indeed, the key element that enhances the performance of both switches is the contention resolution muxes at the output. Contrarily, well designed wiring matrix configurations between the AWG and the output multiplexers makes only slight difference [12]. Like the previous simulation cases, combined wavelength conversion and optical buffering is the best scheme in terms of network reliability and utilization. However, they require extra hardware in the contention resolution multiplexors, which increases the system cost. The improvement of implementing wavelength conversion is two orders of magnitude better that the `DropMux` case. If we add buffering to wavelength conversion policy, the improvement is one order of magnitude.

5.2 Mesh topology of 9 nodes

With current AOLS technology and architectural constrains, the number of different switches we can build is limited. For this topology was used AOLS **A** node of 3 ports for outer nodes and **C** node of 4 ports for inner nodes (Figure 1).

We can see in Figure 10 the results for the mesh topology of 9 nodes. Like in the previous simulations, AOLS nodes and ideal non-blocking architectures perform similarly. We see that for this network the total cell loss probability is slightly higher that in the previous simulation experiment, because nodes 8 and 9 (Figure 4) behave like network bottlenecks as they have more OLSPs crossing them. However, even at full network load operation the results are considered quite good [11], employing contention mechanisms in both wavelength and time dimensions.

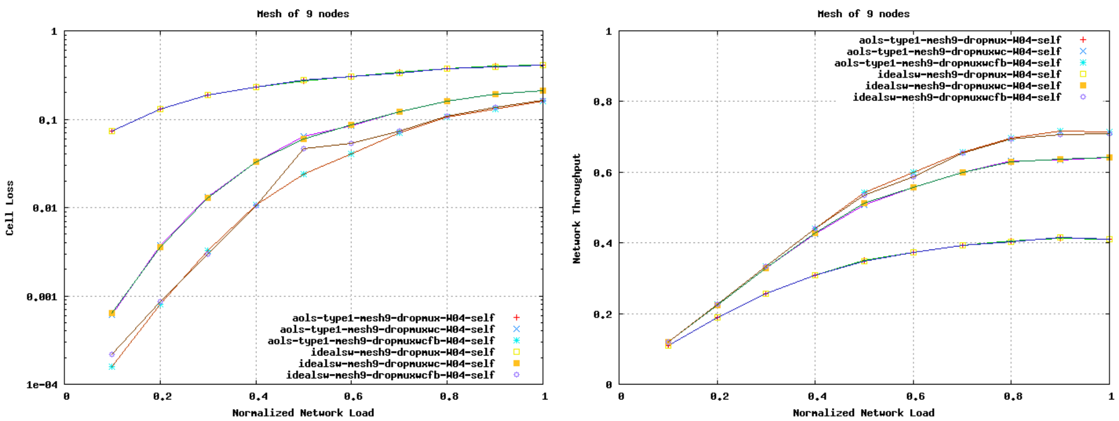

Figure 10: cell loss (left) and network performance (right) for a ring mesh topology of 7 nodes.

6. Conclusion

This paper presents a unified study on both isolated and full network topologies of AOLS nodes. Our simulation results are in accordance with previous published references on the subject. We found that combined wavelenght conversion with optical buffering in contention resolution multiplexors achive excellent network performance. Wavelenght conversion offers the best results over the other methods (namely, space and time contention resolution mechanisms) in all the simulation experiments carried out, althought its effectiveness depends on the number of wavelength channels in the optical network and the number of ports of the AOLS node.

Space-deflection routing dimension was not used in this study because the complexity of detect and forward contending cells in LASAGNE all-optical architecture. Indeed, according to [9] when wavelength conversion and optical buffering are both used, deflection routing does not have a prominent effect.

We found that LASAGNE AOLS architectures compared with ideal non-blocking switches of similar characteristics perform equally. These results can be explained by assuming that this architectures are well balanced comparing with ideal non-blocking switches, and that the key element of the AOLS switches in terms of network performance is the contention mechanism employed near the outputs. Further research should be done in designing all-optical cell contention resolution all-optical multiplexers. We stated the importance of combining the wavelenght conversion and buffering dimensions to achive an acceptable network performance in terms of the simulation measured parameters.

The simulation results for the ring and mesh topology suggest a small influence of network topology in network performance and reliability, for the two topologies taken into consideration. However, further research should be done in order to assess this for more general cases of real, implemented topologies.

Our ongoing research continues to explore AOLS switches with more wavelengths channels, along with other contention resolution mechanisms like deflection routing or traffic shaping at the ingress client interface.

Acknowledgements

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