Lossless photonic switched networks for metro-access

Yara Martins, F. Rudge Barbosa, Indaya Bertoldi and E. Moschim
Faculdade de Engenharia Elétrica e Computação –FEEC, Unicamp
University of Campinas, SP, Brasil
rudge@dsif.fee.unicamp.br

ABSTRACT

We evaluate through computer simulation the performance of Photonic switching OPS/OBS networks of various sizes and configurations, based on a lossless (amplified) photonic switching node experimentally demonstrated previously. The great advantage of photonic switching is transparency to signal rate and format. Thus we propose a basic flexible network, with low-energy consumption and high-efficiency. In simulations traffic load is varied and network parameters such as, average number of hops (ANH), network latency (delay) and packet loss fraction are evaluated. Consistent results for the various configurations are presented, analyzed and discussed; and Interesting conclusions emerge.

1. INTRODUCTION

Based on the fact that Metro-Access presently tends to be the bottleneck of high-capacity networks, we propose photonic switching as a means of speeding up client traffic with transparency to rate and format. Several technologies apply [1,2], and we adopt a SOA-based photonic node, which has been experimentally demonstrated previously [3], and allows for lossless switching and routing over tens of kilometers in the metro-access range. In order to quantify this (being limited to construction of a few nodes, we have evaluated via computer simulation the performance of OPS/OBS (optical packet/burst switching) photonic networks with different sizes and configurations. We believe that these networks are very adequate solutions for convergent fiber-wireless networks [4], with optical nodes at individual or aggregate base stations (depending on capacities).

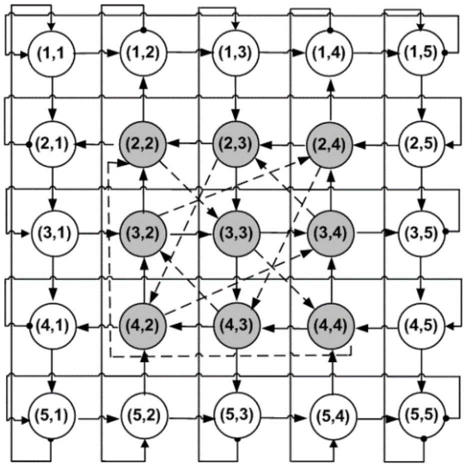
We adopt a modified Manhattan St. mesh topology, with direct and cross-links, to fit the dynamics of our optical switching networks [5,6]. Two different routing protocols store-&-forward (SF) and deflection routing (DR) are used to evaluate network parameters, under varying link load. Average number of hops (ANH), network latency (delay) and packet loss fraction (PLF) are considered. Physical constraints, such as switching and propagation losses are also taken into account. The network performance results that have been obtained are rather informative, not only on ANH and delay behaviour, but on sources of PLF. Such extensive investigation (networks with 16, 25 and 36 nodes; with two routing protocols) could not be performed without the aid of our recently developed simulation platform [7]. A small size prototype network is planned to be assembled to validate this model.

2. PHOTONIC SWITCHING (PS) NETWORKS

The choice of technical detail and traffic conditions of PS networks (OPS/OBS) is decided on application [5,8]; generally our proposed model can operate in both. It is understood that OBS networks are better for live applications, such as video-conferences and live sports or events, whenever continuity of traffic is required; whereas, OPS is more flexible and efficient when connections are *not* time-sensitive and packets may flow asynchronously and be rearranged after detection on destination. In both cases, what really matters is that the number of hops (ANH) along the network should be minimum and latency (delay) should not be perceived by the end-users. The OPS/OBS networks studied here aim at medium range distances (wide-metropolitan area) with moderate-high link capacities (2.5 to10Gb/s); they are essentially lossless [3] because switching is performed by SOAs, which overcome link and routing losses, without impairing signal quality – it is why we restrict our model to metro-access, and 36 nodes. Larger networks would require further considerations on signal quality, ASE noise, and eventually non-linear effects. We shun this situation. If larger covering is needed, then break-up into 16- and 25-node networks is recommended. The mesh networks considered in this work are actually modified Manhattan

Optical Metro Networks and Short-Haul Systems VIII, edited by Atul K. Srivastava, Werner Weiershausen,
Benjamin B. Dingel, Achyut K. Dutta, Proc. of SPIE Vol. 9773, 97730C · © 2016 SPIE
CCC code: 0277-786X/16/$18 · doi: 10.1117/12.2211175

St. type, with toroidal closure (which allows for lower ANH) and direct and crossed unidirectional interconnections, having grade-2 (i.e., 2x2; in-ports x out-ports; grd-2) and/or grade-3 (3x3; grd-3) nodes, comprising total N=16, 25 and 36 optical nodes. A hybrid configuration with network [8], as in **Fig.1**, combines both grd-2 and grd-3.

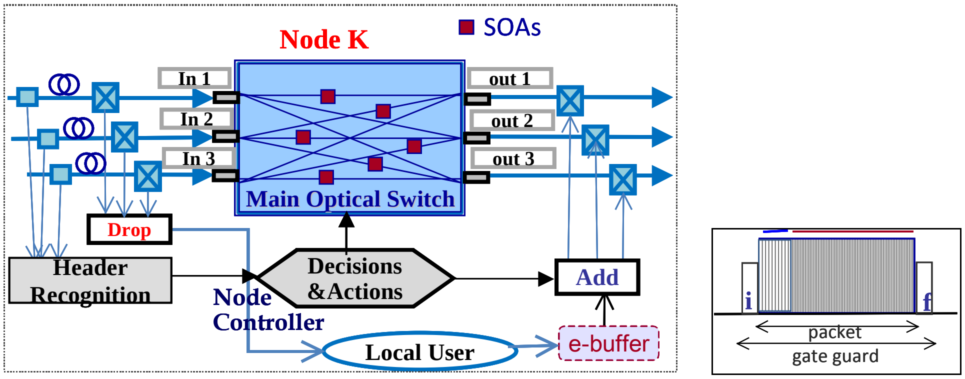


== **Fig.1** – Lossless PS network; hybrid model with 25 nodes.

To compare performances in different conditions, the transport protocols Store-&-Forward (SF) and Deflection Routing are adopted. SF protocol is based on the minimum path matrix (MPM), generated by the Dijkstra algorithm, in which case packets always follow de shortest path, but delay may increase; on the other hand, DR routes incoming packets to whatever port is avilable, and although MP matrix is not always followed, delay tends to be minimized. Our approach is totally original in analyzing ANH, delay and PLF, including a direct comparison of SF and DR in mesh topologies having various connectivity grades.

2.1 Photonic Node Architecture

A detailed description of the optical nodes dynamics is presented in [3]. For completeness, we present here the basic operation. The optical packets/bursts are defined by small header (20B) and large payload (500B, or more) fields, with guard bytes at beginning and end. Photonic switching and routing process for OPS and OBS are the same, based on header information only, which informs node *controller* to where packets/ bursts should be directed. **Fig.2** depicts the node architecture.



== **Fig.2** – Photonic node architecture.; and optical packet.

2.2 ANH, Delay and PLF

The average number of hops (ANH) in a limited area – such as metro-access must be also limited to a small figure, in order to avoid excessive delay in connections. Although delay is calculated based on ANH they are not the same parameter and they can behave quite differently, as will be seen in our results. Due to the combination of the three parameters, three node combinations, presence/absence of e-buffers, and two routing protocols, yielding a large amount of graphic data, we will detail results for the 25-node networks; whereas 16-node results for DR can be found in [7]. Presently the hybrid 36 nodes topology is being revised and will be soon available). Links are in the 5-10km range; bit-rates are in the 2.5-10 Gb/s range, adequate for metro-access environment. Node-to-node losses (connectors, link fiber, splitt/combine) add to less than 10dB, so we set SOAs for 10dB gain (with AGC, at the Controller). Optical links and connections with high quality *must* provide low PLF (range of 10^{-3}). Losses may occur at ingress of client traffic in the optical layer (Add-port; Fig.2; minimized by electronic buffering on client side); at input ports along the network nodes (resolved by the transport protocols); or at destination (input loss, or detection loss). In short, our results indicate that the most critical are input losses at client ingress.
In the next section we present the basic concepts and equations for quantitative evaluation of parameters.

3. BASIC CONCEPTS AND ANALYTIC MODELLING

Link capacity (*Lc*) and node connectivity *g* are considered the basic parameters for network effective capacity, C_{PU} given by,

$$C_{PU}(Lc) = \frac{\sum_{g=2}^{n} g.N_g.S}{\overline{H}}.Lc \tag{1}$$

where, N_g is the number of nodes with grade-g; *S* is the link transmission bit-rate; *n* is the largest grade in the network (here *n*=3, but can be made up to 6); and ~~*H*~~ is average number of hops (~~*H*~~ =ANH), evaluated from,

$$\overline{H} = \frac{\sum_{i=1,\, j=1} Cm_{ij}}{(\sum_{g>1}^{3} N_g) * ((\sum_{g>1}^{3} N_g) - 1)} \tag{2}$$

where Cm_{ij} are the Dijkstra matrix elements for total number of minimum paths of a given configuration.
The effective Network Throughput ***T***p ; including link load ***L***c is given by,

$$T_p = \frac{\sum_{i=1}^{N} \frac{g.N.S}{\overline{H}} \times L_c}{N} \tag{3}$$

which in turn can be used to evaluate delay,

$$D = \frac{p}{T_p} \tag{4}$$

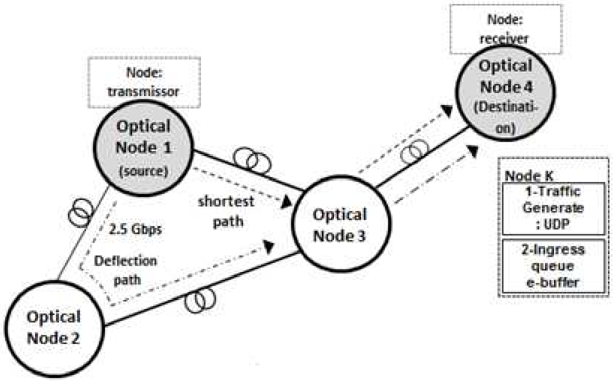
where *p* is the total number of optical packets generated in a given run of the network traffic. The PLF is evaluated simply as,

$$PLF = \frac{p - r}{p} \qquad (5)$$

where r is the number of optical packets actually received (detected) at destination nodes, in a given run of network traffic.

4. SIMULATION DYNAMICS AND CONDITIONS

Simulations were carried out on a platform developed in our labs using the open network simulator NS-2; compilation of results and graph displays were done with MatLab©. The basic equations in the previous sections are implemented in the scripts of simulation. In the present model, it is assumed that difference between OPS and OBS is just the size of payload (PL); PL may vary from 500 B (or less) up to 1500 B in OPS mode; and up to 50 kB in OBS mode; these figures are typical for metro-access, not for trunk/backbone [9,10] . The SF and DR protocols are alternatively used to direct packets/or/bursts through network nodes from origin to destination. Our data was obtained setting 500 and 1500B packets (negligible differences), with variable intervals in 0.1-1 packet range. Each simulation graph-point had 200 thousand packet runs, with ~20ms computation time per point. Results are displayed in the next section.

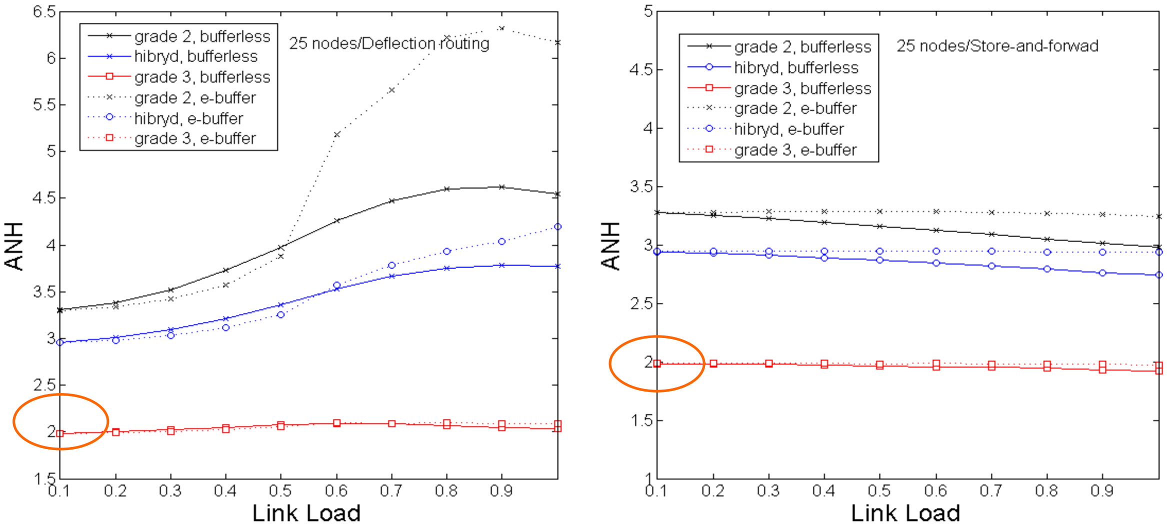


== **Fig.3** – Schematic of Simulation dynamics.

5. RESULTS AND DISCUSSION

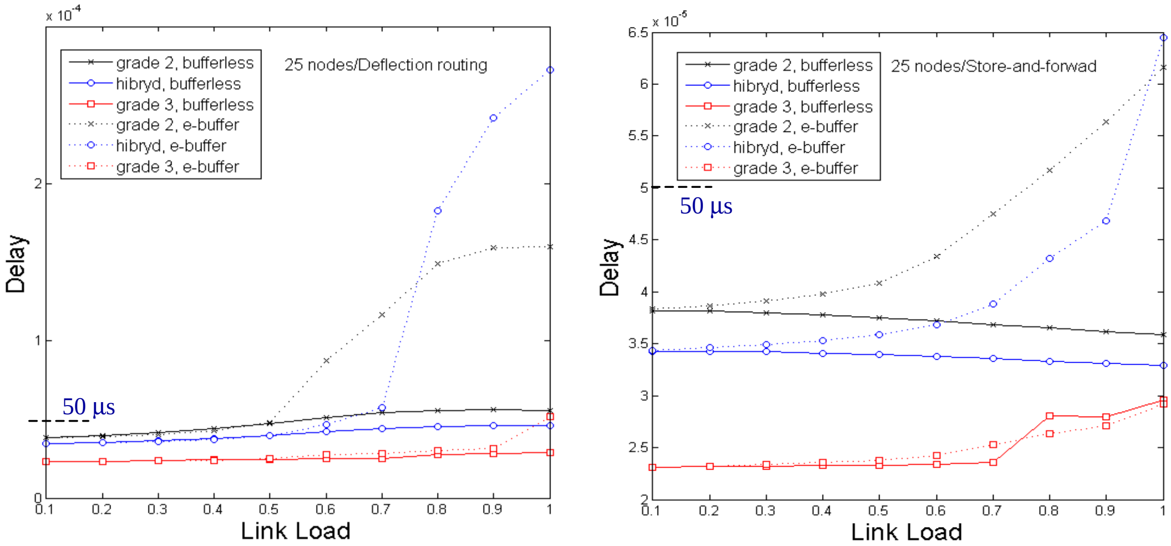
Several node configurations and network sizes in this PS model have been previously analysed and compared [5,7]. Here we will focus on the new 25-node configurations. It is interesting to see that although the “lossless” nodes themselves [6] are the same, the network behaviour differs and does not scale. The 25-node networks comprise nodes of grd-2, grd-3, and hybrid configurations. In those grd-2 and grd-3 networks, *all* nodes are grd-2 or grd-3, respectively; in hybrid networks a mix of grd-2 and grd-3 is adopted. The hybrid network depicted in **Fig.1** has been chosen for performance evaluations; nevertheless, the model accepts other configurations and closures to be designed and evaluated.

ANH results in Fig.4a (DR) show increase with load for grad-2 and for hybrid, with and without e-buffer; hybrid shows less increase because of the presence of the nine grd-3 nodes. By contrast, the pure grd-3 configuration remains virtually constant for all loads; this is attributed to the higher connectivity of grd-3, allowing more optical paths. In 4b, SF routing will always adopt shortest path, thus keeping ANH constant with load; the *apparent* decrease in ANH for grd-2 and hybrid *without* e-buffer is actually due to increase in packet loss (PLF) for higher loads, which decreases the number of packets in the effective traffic; which points for the necessary e-buffering at client ingress. The performance of grd-3 in all cases is superior and attributed to the higher connectivity; however, more connectivity means more equipment (and higher CapEx). In this sense, the proposed hybrid is intended for a balance between performance and cost [9,10].



== **Fig.4** – ANH for 25-node PS networks (a) DR; (b) SF.

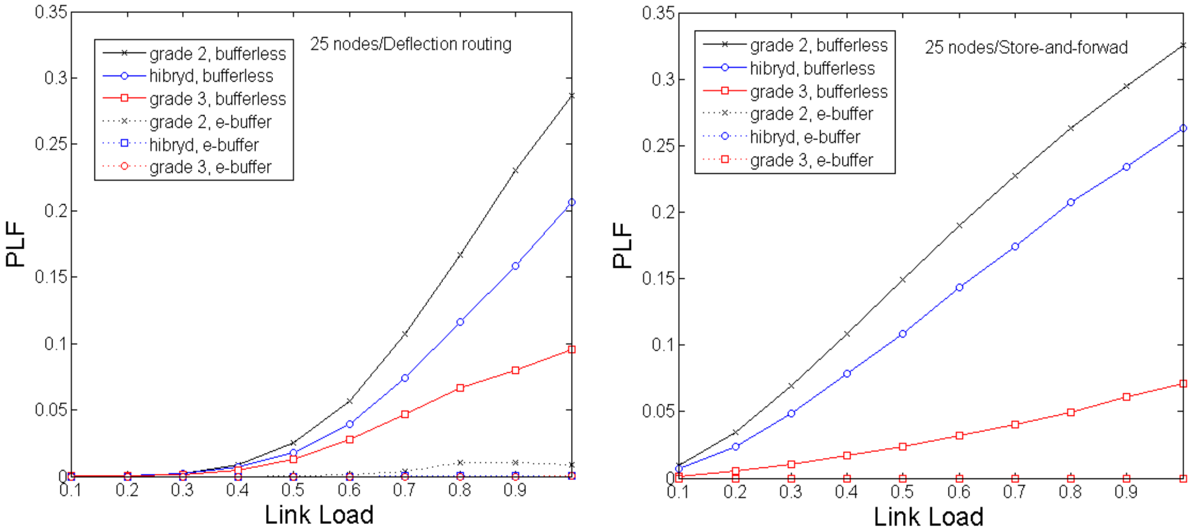
In **Fig.5a** (DR) results for Delay are depicted. Notice for grd-2 and hybrid traffic load above 50% of link capacity impacts a significant increase in delay times (two-to-four times increase). **Fig.5b** shows that in 25-node networks Delay results for DR and SF are similar, in contrast to 16-node networks [7], in which SF has higher delays than DR. It can be noticed however that the variation of results is smaller in SF because in this case the optical packets always follow the MP matrix rule. We also see that in this 25-node network the DR will take more alternate paths and ends up with larger delays in higher traffic.



== **Fig.5** – Delay for 25-node PS networks (a) DR; (b) SF.

It should be noted that in the case *with* e-buffers the actual number of packets circulating (and re-circulating) in the optical network is much larger than *without* e-buffers (as it should) -- and leads to further increase in delay. However, by way of comparison, the merit of the present PS networks proposal is that delays for optical packets in are *orders of magnitude* smaller than for IP packets in today's "conventional" optical metro-access networks, which require frequent OE conversions from origin to destination. Our results show maximum delays of hundreds of µs for PS networks, whereas typical IP-optical networks show hundreds of ms – this can be easily verified anywhere. Another aspect needs clarifying:: the case *without* buffering, although unrealistic, has been included because it helpis to better understand network dynamics; naturally, in real-world applications e-buffers are to be included to control PLF, which occurs mostly at node ingress (see below).

Finally, results for PLF show that DR and SF have different behaviour. With DR, for smaller loads and without e-buffer, the PLF may be acceptable; however even at moderate loads, it is not. With inclusion of e-buffer PLF gets down to less than 10^{-3} demonstrating that in this case the big loss is at ingress. In SF, without e-buffer even at low traffic PLF is high and not acceptable; by contrast with e-buffer the behavior becomes the desired PLF<10^{-3}. Penalty on latency (delay) grows significantly for grd-2 and hybrid; whereas for grad-3 it remains low, doubtlessly because of its higher connectivity and availability of alternate optical paths.



== **Fig.6** – PLF for 25-node PS networks (a) DR; (b) SF.

The present set of results indicate that not only network size, parameters and connectivity grade, but also the routing protocol will change traffic flow, and network efficiency. For DR and SF, it is seen that for 25-node network ANH and delays are within expected values; and PLF, although evaluated in cases with and without e-buffers, must be always implemented *with* e-buffers to avoid input losses.

6. CONCLUSION

In this work we have used computer simulations, which are a very useful tool for network planning, for performance evaluation of photonic switching (PS) metro-access networks. The metric parameters adopted were average number of hops (ANH), transmission delay, and packet loss fraction (PLF) in various mesh network configurations. Comparison of OPS/OBS networks with transport protocols DR and SF, and optical nodes of connectivity grade2, grade3 and hybrid architectures were analysed and have shown distinct performance. Grade2 is simpler, less costly and limited performance; grade3 has the best performance, but it is more complex and costly in equipment and installation. The intermediate hybrid network can have various degrees of "*hybridity*" meaning that the network designer can choose placement of grade-2 and grade-3 according to budget, network size and traffic requirements. The routing protocols (DR and SF) in these networks show different performances depending on network configuration and number of nodes. Simulations help decisions.

REFERENCES

[1] Lai, C.P., Naughton, A., et al., "Energy-Efficient Colourless Photonic Technologies for Next-Generation DWDM Metro-Access Networks", *IEEE Photon. Switching Conf.* – PS'2012, Barcelona Spain, **Sept.2012**.

[2] Maier, M, *Optical Switching Networks*, Cambridge Press, 2008.

[3] Rudge Barbosa, F., Decio, M., Moschim, E., "Analysis and characterization of Semiconductor Optical Amplifiers (SOA) for Photonic Switching Networks", ***SPIE Photonics West*** *2014*, paper Opto 9008-5, SanFrancisco CA, USA, Feb. 2014

[4] Ghazisaidi, N., Martin, M, Massi, C., **"**Fiber-Wireless access networks: a survey", *IEEE Communic. Mag*, Feb. 2009

[5] Martins, Y., Rudge Barbosa, F., Bertoldi, I.M,, Moschim, E., "Influence of Topological Connectivity for Transport in Optical Networks with Amplified Photonic Switches", *16th International Conference on Transparent Optical Networks* ***ICTON'2014***, Graz, Austria, July 2014;]

[6] Bertoldi, I.M,, Rudge Barbosa, F., Moschim, E., "Future-proof Photonic Switched Optical Networks for Metro-Access", *4th. Intl. Symp. on Photon.& Optoelectron. –* ***SOPO'2012***, Shangai, China, May 2012

[7]. Rudge Barbosa, F., Bertoldi, I.M, Martins, Y., Moschim, E., "Comparative Study of Latency and Throughput in OPS/OBS Metro Access Network", ***Networks' 2014*** –Madeira PT, Sept 2014.

[8] Huang S., Liu, J., Xiang., H., "Transmission Mechanism Based on Burst Filling in Hybrid Optical Burst/Circuit Switching Networks", *China Communic.* vol.13, p.72, Sept. 2013, Shangai, China.

[9] Zhang, P., Chowdhury, M., Tornatore, L., Mukherjee, B.,"Energy Efficiency in Telecom Optical Networks". In: *IEEE Communications Surveys and Tutorials* 12.4 (2010), pp. 441–458

[10] Develder, P.C., Fabio N., Solé-Pareta, J, Demeester, P., "Benchmarking and Viability Assessment of Optical Packet Switching for Metro-Access Networks," *J. Lightwave Tech.* **22** (11), Nov. 2004.