Transparent Optical Packet Switching Node based on Bottom-up Organization Network

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***Abstract*— We present here the results of an analytical model describing the behavior of communication traffic in an optical packet metro-access network that is able to work without a control plane. The transparent optical node model exemplifies an application for a simple node behavior that has been experimentally demonstrated. The efficient optical nodes in 2x2 mesh architecture adequately connected to create a smart network that shows excellent performance, low latency and high throughput, with a minimum management cost. Without using control planes or complex network control protocols, the optical network functionalities emerge from simple physical properties associated with the operation of the optical packet switching node.**

***Index Terms*— Optical packet switching, photonic networks, optical communication systems.**

I. INTRODUCTION

The cost effectiveness demanded by future optical metro-access (OMA) networks is one of the main motivations for the present efforts on development of low complexity network nodes with optical packet switching functionalities. With this in mind we propose a node prototype that includes the new concepts of complexity used to describe bottom-up organized (BUPO) systems. A typical example of a BUPO system is the ant community, in which each ant acts as a singular node doing simple jobs whereas the ensemble, comprising many individuals all communicating only with their neighbors, allows for the emergence of superior organization functions, as can be observed in the behavior of the entire anthill. In the same sense the optical packet routing function emerges from the network of optical switches. The bottom-up concept is described by Morin and Le Moigne [1], and others, such as the interesting concept review presented by Steven Johnson [2].

We propose here a self-routing asynchronous optical packet transport model for network nodes, based on BUPO principles that dispense with special routing protocols, and/or fast control plane functions. This transport model can be used to switch and to route random size optical packets arriving also randomly in the time. This can be implemented by using the deflection routing technique and the hot-potato algorithm [3, 4]. We present a statistical analysis based on deflection probability and describe an application for a node architecture and experiments previously presented [5, 6]. Our node architecture is based on a BUPO system, in which a simple frequency header for each optical packet acts as the optical address and is responsible for the photonic switching process, thus directing the packet throughout the OMA network, delivering its digital payload transparently from end-to-end, without any opto-electric conversion of the packet itself.

II. NETWORK DESCRIPTION

A. *Node Architecture*

Each node in 2x2 architecture has two inputs and two outputs ports to deal with traveling packets. Those traveling packets are not generated at node location nor addressed to the node location because the packet drop is made before the switch and the packet insertion is made after the switch. Each node is able to insert simultaneously packets in both output ports and simultaneously receipt packets from each of the two input ports. In the ingression, packets are buffered electronically until the node find an interval of time were it could fit without collision. A sensing scheme based on samples obtained before a delay line is improved to deal with this functionality. Optical buffers are not used and there is not priority difference between packets. Node standby state is defined as the state with no packet passing trough it. That means that in the standby state no packet can be found in the node. Both inputs, both outputs and both delay line are all empty. The optical switch has only two possible positions: parallel and crossed. Only in the standby state the optical switch is permitted to move from parallel to cross or vice-versa. And that is the way we ensure that the optical switch never cuts a packet in two parts. Once in the network the packet will never be lost. From the standby state the first packet arriving will be attended. Any packet arriving after that, even if it arrives only few tens of nanosecond after the first packet, it will be sent to the available output port. Case two packets arrives simultaneously, packet in the input port number one will be attended. Once switched to attend a packet the node is maintained in the same position until new standby situation occurs. End of packet is detect with no doubt throw the presence of a specific RF ton added as the packet tail. There is no restriction on packet size.

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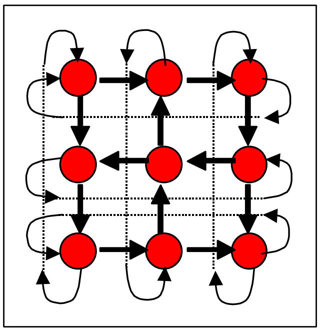

A nine-node MS network.

B. *Network Topologies*

The network topology used to connect the nodes is the Manhattan street topology well-known in the literature [6]. The main reason for that option is the best fit between logical and physical topology using a minimum length of fiber to connect the nodes in a mesh topology. Any other topology can also be used and we tried, as comparison, the ring topology. The ring has no advantage with respect to robustness of the mesh topology, but it is more often found in today real implementations due to the SONET/SDH protection mechanisms. The use of mesh topology in access network is new, and doughtily is not more expensive due to the robustness associated with it. Other topologies usually implemented in access network only achieve the same robustness by duplication of resources. In addiction, it is necessary to compute the save up in the routing software implementation that is not used in our approach.

III. STATISTICAL METHODOLOGY

The network performance was evaluated using a simple analytical model based on number of hops mean value E[hops]. A packet with no deflection, going always throw the preferred output port experiments the smallest possible number of hops. The occurrence of a deflection can increase the number of hops. We evaluated the probability of deflection in a non-saturated network. This means that the links are not full. For N nodes network we used a regular traffic were every one sends a CBR flow of packets to every one resulting N.(N-1) traffic flows. The bit rate for all individual flow is b and it is smaller than the link capacity bit rate B. The independent variable is the link charge presented by Lc that is zero for the empty link case and one for the full link case. Each node waits an available time to insert a packet in the network and maintains an electrical buffer to enable that operation. The traveling packets can arrive alone to a node with probability $(1-Lc)$ and in this case it is sent to the preferred output port. Other wise it can arrive together or just after a packet that is arriving in the other input port. Even if that happens the packet can go to the preferred output port case: a) the other packet is addressed to the local node; b) the other packet prefers to go to a different output port. We considered probability $1/(N-1)$ for the case (a) and probability 1/2 for the case (b) resulting a deflection probability $Pd=(1-Pnd)$, where P_{nd} is the non deflection probability given by:

$$Pnd=(1-Lc)+Lc\cdot\left(\frac{1}{N-1}\right)+Lc\cdot\left(1-\left(\frac{1}{N-1}\right)\right)\cdot\frac{1}{2}$$

We continue with the calculation a test packet addressed to node number one. It can be addressed to any node due to the symmetry of the network and the traffic. To calculate the probability of finding the test packet in any node along the time we mount a transition probability matrix T as shown in the following example for the Manhattan-street network with 9 nodes. Each column represents the node where the packet is at a particular moment and each line represents the probability of the packet to reach each one of the N nodes in the next moment. *Don't care* nodes; defined as the nodes that offers two equal paths for a packet in bough output ports, are not considered.

$$T=\begin{pmatrix}0 & Pnd & 0 & Pnd & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & Pnd & 0 & 0 & 0 & 0 & Pnd & 0\\ 0 & 0 & 0 & 0 & 0 & Pnd & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & Pd & Pnd & 0 & 0\\ 0 & Pd & 0 & Pd & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & Pnd & 0 & 0 & 0 & Pnd\\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & Pd & 0\\ 0 & 0 & 0 & 0 & Pd & 0 & 0 & 0 & Pd\\ 0 & 0 & Pd & 0 & 0 & 0 & Pd & 0 & 0\end{pmatrix}$$

Following a test packet in a starting moment k=1 we have probability 1/N of finding it in any one of the N-1 nodes and zero probability of finding it at the node number 1 itself. This defines a column matrix P_1 ,

$$P_1=\begin{pmatrix}0\\ 1/9\\ 1/9\\ 1/9\\ 1/9\\ 1/9\\ 1/9\\ 1/9\\ 1/9\end{pmatrix}$$

where each line "i" represents the probability of finding the test packet in node number "i". In a instant moment k=2 we can calculate the probability column matrix $P_2=T.P_1$, and find all $P_k=T.P_{k-1}$ for any moment k. The first element of P_k represents the probability of the tested packet to be at the node number 1 at the moment k. That means that the test packet arrived to the final address after *k*-1 hops. The mean value of the number of hops $E[hops]$ is calculated by

$$E[hops]=\sum_{k=2}^{\infty}kP_k(1)$$

IV. RESULTS

Figure 1 shows P_k as a function of k for a Manhattan Street network with N=9. It can be noted that for nine hops the probability falls to 10^{-2}, and the value of P_H goes down to 10^{-6} when mean value of hops reaches 26. This clearly indicates first that the effective mean number of hops is quite low, and second that a packet extinction mechanism is taking place rapidly after 10 hops or so. This is compatible with the previous observations of high throughput and low latency [4, 5].

The mean value of the number of hops was calculated for various values of link charge L_C considered to be a fixed value in a steady state condition. From the link charge we calculate the CBR rate b that wood result in that link charge. The network capacity for all links full of packets, including deflected packets that enlarges the mean value of number of hops, would be:

$$C = \frac{2NB}{E[hops]}$$

For $Lc < 1$, the mean value of number of hops is less than in the maximum, increasing the throughput. We can evaluate the throughput for not-full link by:

$$Thr = \frac{2NB}{E[hops]} Lc$$

From that value we can evaluate the total charge emerging from each node by the relation:

$$N(N-1)b = \frac{2BLc}{E[hops]}$$

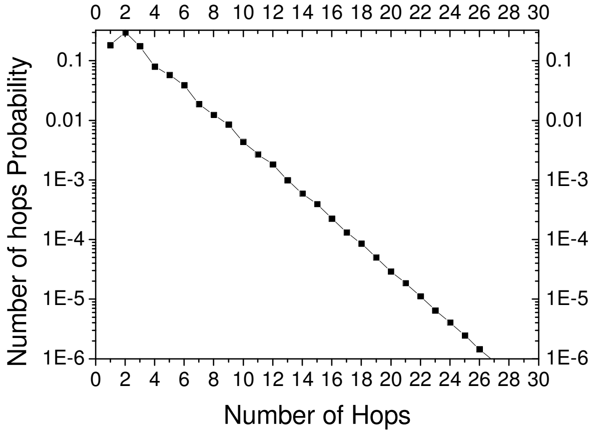

Fig. 1: Probability of occurrence of a given number of hops (P_H) versus number of hops.

Throughput was calculated from the number of hops mean value and the results are shown in figure 2. It is noticed that, first a mesh with four nodes is identical with a ring ; second, the throughput of MS-mesh networks is always superior. Further results on delays and packet loss are being obtained with the present method, and approximate well previous results [4].

V. CONCLUSION

To summarize, we have investigated the contribution of optical packet switching in OAM networks with spatial contention resolution and deflection routing, under a novel approach, which adopts the bottom-up organization (BUPO). This enhances the importance of the optical layer functionalities, and allows for true transparent transmission. Traffic analysis were performed in a mesh network topology with a 2×2 configuration employing the Network Simulator (NS). Our approach enabled the analysis of a deflection routing protocol in MS-16 network topology, with either temporal or spatial contention resolution methods. The results show that the deflection routing algorithm is very robust for photonic packet switching networks, and provides low packet losses when the optical network is under a low load of optical packets or demands of optical access by end users. Moreover, the average packet delay and packet lifetime have provided additional information for the evaluation of the network performance regarding QoS demands..

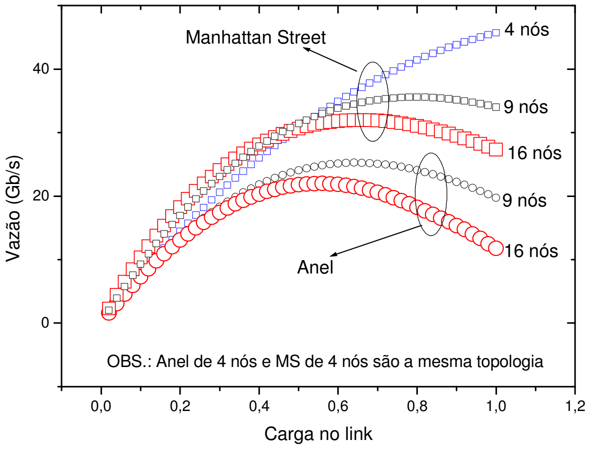

Fig. 2 – Network Throughput versus link load.

REFERENCES

[1] E. Morin, J. Le Moigne, *L'intelligence de la complexitè*, L'Harmattan, Paris, France 1999.

[2] Steve Johnson, *Emergence - The Connected Lives of Ants, Brains, Cities and Software*, Scribner, New York, 2001.

[3] A.S.Acampora and S.I.A.Shah, "Multihop Lightwave Networks: A Comparison of Store-and-Forward and Hot-Potato Routing", IEEE Trans. on Comm., Vol.40, pp1082-1090, June 1992.

[4] L. H. Bonani, M. T. Furtado, Edson Moschim, F. Rudge Barbosa, "Analysis Of Optical Packet Switching Performance With Spatial Contention Resolution For Optical Access Networks", *Intl. Conf. Communication Systems and Networks- IASTED/CSN'2003*, paper 393-073, Málaga, España, Sept. 2003

[5] F.R. Barbosa, Décio Maia, L. Pezzolo, A.C. Sachs, M.R. Salvador, "Optical Packet Switching Node for Metro-Access Networks", European Conference on Optical Communications, ECOC'2003, Sept. 2003, Rimini, Italy

[6] F. R. Barbosa, D. Maia Jr, L. Pezzolo, A. C. Sachs, "Optical Packet Switching and Routing Using RF Frequency Header Labeling for Application in Metropolitan Access Networks", *SPIE- Information Technologies & Communications- ITCom'2003,* paper 5247-20, Orlando Fla., USA, Sept. 2003