SLIP-IN Architecture: A new Hybrid Optical Switching Scheme

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***Abstract*— In this paper, we present a new hybrid switching architecture, termed as SLIP-IN, that combines electronic packet/burst with optical circuit switching. SLIP-IN architecture takes advantages of the pre-transmission idle periods of optical lightpaths and slips into them packets or bursts of packets. In optical circuit switching (wavelength-routing) networks, capacity is immediately hard-reserved upon the arrival of a setup message, but is only used after a round-trip time delay. This idle period is significant for optical multi-gigabit networks and can be used to transmit traffic of a lower class of service. In this paper, we present the main features and dependencies of the proposed hybrid switching architecture, and further we perform a detailed evaluation by conducting network wide simulation experiments on the NSFnet backbone topology. For this purpose, we have developed an extensive network simulator, where the basic features of the architecture were modeled. The extensive network study revealed that SLIP-IN architecture can achieve and sustain an adequate data rate with a finite worst case delay.**

***Index Terms*— Hybrid optical switching, optical wavelength routing, packet switching, class of service**

I. INTRODUCTION

The advent of WDM technology has resulted in transmission capacities that have increased manifold in recent years. It is the router/switch throughput, however, that really transforms the raw bit rates into effective bandwidth, and current switching technologies are typically capable of handling line rates of up to 10 Gb/s. Current optical networks are wavelength (circuit) switched, where OXC are used to switch traffic [1]. Optical circuit switching (OCS) is perfectly fitted for relatively static traffic profiles. However, it is well known that Internet traffic exhibits multifaceted burstiness and correlation structures over a wide span of time scales (short or long time variations).To this end, the use of optical circuits to transport IP traffic results in a low capacity utilization, primarily due to the low statistical multiplexing efficiency. Optical packet and burst switching (OPS, OBS) [2],[3] has been proposed for "*on demand*" use of capacity. Although very promising, these technologies lag behind due to the lack of a true optical random access memory. This stresses the need for "*on-the-fly*" packet processing, which is impossible with the current state of the art of all-optical logic [4].

A very promising solution is hybrid optical switching that is a mutual compromise of both (electronic) packet and (optical) circuit switching. Hybrid switching combines the merits of both paradigms to increase the link utilization efficiency, decrease the required number of wavelengths and maintain to the bare minimum the traffic load processed by electronic IP routers.

Various hybrid switching architectures have been proposed so far, including the *hybrid optical switching* -HOS- [5]-[7], and the *hybrid optical transport network* (HOTNET) [8], where optical circuit and packet switching are integrated in a cooperative manner to transport a variety of traffic types efficiently by complementing each other. In the HOS approach best effort data are transported using OBS technology, while high priority traffic uses optical circuits. At the ingress node, OBS and OCS fairly compete for all wavelengths during the resource reservation process. In HOTNET, a time-slot switching approach enables slotted OBS to be co-implemented with OCS in TDM frames.

Other pure hybrid switching approaches include the *light-trail* [9],[10], the *light bus* concept [11], the *polarization-based* scheme [12] and the *ORION* concept [13],[14]. In the first two schemes, the nodes have access over the passing through lightpaths and/or wavelengths to add or drop packets. In the polarization-based concept, the polarization state (SOP) is used to differentiate OCS traffic from best effort IP traffic. Finally, in ORION, packets are transmitted in the idle periods of the wavelength channels. In order to do so, ORION architecture requires specific hardware enhancements in the core nodes [15].

In this paper, we present a new hybrid optical switch architecture, termed as SLIP-IN architecture, that takes advantage of the idle round trip time during lightpath establishment phase. It is based on a wavelength switched network that uses immediate reservation protocols for

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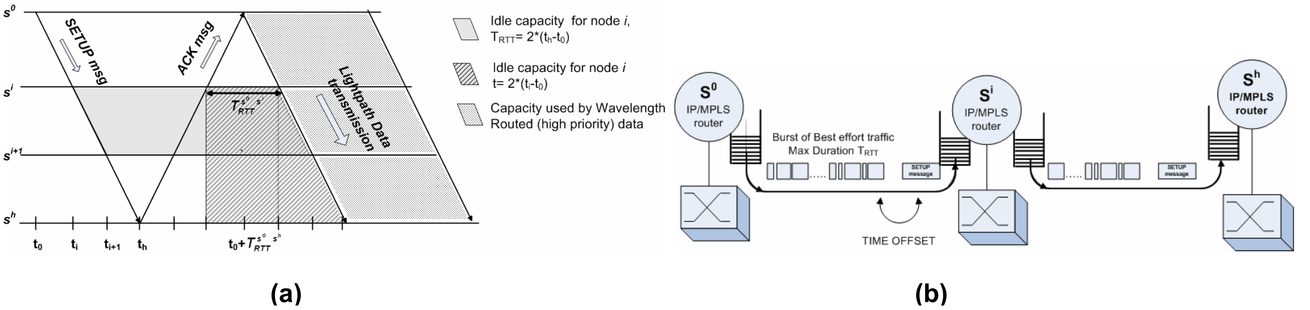

Figure 1: (a)Timing considerations in the proposed hybrid switching scheme and idle capacity of node s^i..(b) Best effort data insertion in the established lightpath between s^0-s^i node. Data will be extracted in the next node, s^i.

lightpath setup. In high-speed, optical core networks, this idle period is significant and thus capacity is inefficiently used. SLIP-IN architecture exploits this idle capacity to transmit packets or bursts of packets of a lower class of service. In particular, best effort data packets are slipped into optical circuits, during the idle pre-transmission time, heading either to their next hop across their path or directly to their end-destination if it matches the lightpath destination.

SLIP-IN is a pure hybrid switching scheme in the sense that best effort data do not compete with wavelength-routed traffic. It has been designed to support two classes of services; high-priority traffic (wavelength-routed, WR- traffic) that explicitly requests and setups an end-to-end lightpath before transmission, and best effort traffic that is transmitted without service guarantee (loss ratio and delay). WR-traffic is transported transparently until its destination while best effort traffic (depending on the routing policy enforced) is treated by intermediate electronic IP/MPLS routers. SLIP-IN architecture is relative simple and requires few hardware enhancements for its implementation.

In this paper, we present the main features of the SLIP-IN architecture and a detailed, network wide performance evaluation. We have developed an extensive network simulator, where the basic features of the architecture were modeled. It is shown that SLIP-IN architecture can achieve and sustain an adequate data rate with a finite worst case delay and thus can be used as hybrid architecture for the transmission of best effort data traffic over a wavelength (circuit) switched network.

The rest of the paper is organized as follows. Section II presents the concept of the proposed hybrid switching scheme, while, Section III presents a suitable SLIP-IN node architecture. Section IV presents a thorough performance assessment of the proposed architecture at the network level, where the effects of various dependencies are investigated.

II. SLIP-IN HYBRID ARCHITECTURE

A basic cause of the inefficiency of optical circuit switching networks is that the capacity that is reserved for a session is actually used at least one round-trip time after the arrival of the setup packet at a node. This applies to the source as well as to all intermediate nodes, since data is transmitted from the source after the reception of an ACK message. Over long transmission distances, the round-trip propagation delay may be comparable to, or even larger than, the sessions' holding times. In such cases, connection oriented architectures results in a poor utilization of fiber capacity. SLIP-IN architecture takes advantage of the pre-transmission idle time to transmit best effort data, either to the next node across their path or directly to their end-destination.

Figure 1(a) depicts graphically the reservation process and the un-used pre-transmission idle period. In particular, when a lightpath request arrives at the edge router, s^0, the latter generates a SETUP packet and sends it downstream to reserve the appropriate resources. The path is specified in the SETUP message with a sequence of link identifiers ($L_1, L_2,\ldots,L_h$) corresponding to the links that this packet must traverse and thus the SETUP packet is forwarded from node s^0 to node s^h. When node s^i receives the SETUP packet at t_i time it hard-reserves outgoing resources of link (L_i) immediately. However, s^i node is aware that WR-data will arrive at least a round-trip time ($T_{RTT}^{s^o-s^h}$) later and thus, it uses the capacity of this specific link for best effort data transmission. Similarly, node s^{i+1}, upon receiving the SETUP message, can use the capacity of the link L_{i+1} for $T_{RTT}^{s^o-s^h}$ time. During this period of time, data packets are extracted from a local FIFO buffer, and inserted (*slipped-in*) in the established lightpath. Depending on the routing/forwarding policy, *slip-in* data may either be extracted in the next node and stored in the local FIFO buffer, or transparently forwarded along with the preceding setup packet towards their end-destination. For example, as Figure 1(b) illustrates, IP/MPLS router of node s^0 sends out a SETUP message and then inserts best effort data in the lightpath. *Slip-in* data are either extracted by IP/MPLS router of s^i node or forwarded transparently to s^h.

If call establishment is successful and the SETUP packet reaches the destination node, an acknowledge message (ACK packet) is generated and sent back to the source. The ACK packet informs the intermediate nodes for the successful establishment of the optical lightpath. Upon reception of the ACK packet, node s^i becomes aware that the whole optical path, up to s^h node, has been established. To this end, it may transmit best effort data transparently to any of the subsequent nodes of the path. In this case, the subsequent nodes will treat these data packets as packets belonging to the established lightpath and will forward them to the correct outgoing port.

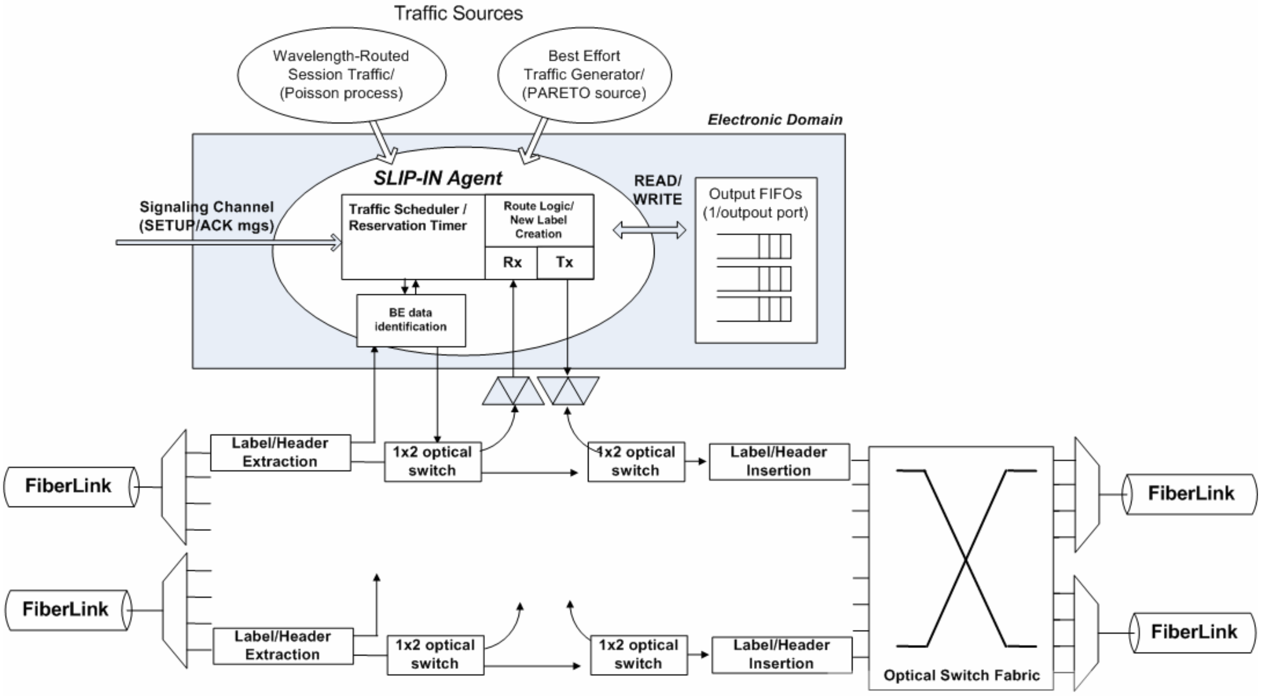

Figure 2: SLIP-IN node architecture employing a dedicated agent that acts as a timer, calculating the time that the first data will arrive. Fast switches are used for the insertion and extraction of best effort traffic.

To this end, each node may use this capacity in order to transparently forward best effort data directly to their end destination, for a time period equal to $T_{RTT}^{s^o-s^i}$, that is the round trip time between s^0 and s^i nodes. After this period, data belonging to the established lightpath will arrive.

Based on the above analysis, we define three prime routing/forwarding policies that can be applied in the proposed architecture. In particular:

- **Hop-by-Hop** routing, where best effort data are uploaded at every intermediate node. Figure 1(a) shows this case. Upon the reception of a SETUP packet and the immediate reservation of capacity, best effort data are inserted in the lightpath and extracted in the next node. This routing policy is the simplest one and resembles the case of a pure point-to-point, packet switching network. As it is shown in the performance evaluation section, *hop-by-hop* routing performs best, yielding an effective throughput of up to 400Mbps with a relative low delay, albeit the fact that data re-enter the FIFO queues in all the intermediate nodes.
- **Path-Entry** routing, where best effort data are transmitted only during the acknowledgement phase. Upon the reception of the ACK packet, capacity is reserved for the whole route from that node to the lightpath destination. To this end, best effort data with a matching destination are sent out as a single burst, heading directly to their end-destination node. As it is shown in the performance evaluation section, the *path-entry* policy is the worst performing, primarily due to the small period of time that it utilizes the idle, unused capacity. However, it alleviates IP router from the additional overhead of processing data in the electronic domain, since data are forwarded transparently.
- **Tell-and-Go** routing, where best effort data are sent as a single burst after the SETUP packet transmission. This policy resembles the optical burst switching paradigm, with the additional feature that if WR connection establishment is blocked at an intermediate node, the best effort burst that follows are instantly uploaded in that node. Otherwise, the burst remains in the lightpath and is routed in the network along with the SETUP packet. The time offset needed, so that data burst does not surpass the SETUP packet is $h\bullet\delta_i$, where δ_i is the processing time of the SETUP message and h is the number of hops. The principal idea of this routing policy is to combine the setup process of a wavelength-routed (WR) request with the setup process of optical burst switching, as in the JET protocol [16]. The *tell-and-go* policy can be considered as a compromise of *hop-by-hop* and *path-entry* policies.

The *path-entry* and *tell-and-go* policy can be both enhanced by transmitting not only the data (in the form of a burst) heading to the same end-destination, but all data in the form of individual bursts with an end-destination on the routing path. This requires a marking mechanism to show the exit point in the network that can be a simple optical label [17]. However, to keep the architecture as simple as possible, only a single burst, the one with a matching destination, is allowed to enter the lightpath.

SLIP-IN architecture is relative simple to implement and requires few hardware enhancements. SLIP-IN relies on the control plane that is responsible for traffic scheduling for both classes of services. Since, in typical circuit switching optical networks signalling messages are transported on a separate channel, the data channels can independently operate to transmit best effort data. Further, the control plane overhead is relative low, since SLIP-IN operation relies only on the tight, timely scheduling of traffic.

III. SLIP-IN NODE ARCHITECTURE

The implementation of the SLIP-IN architecture requires the design of a suitable core router, capable of handling both traffic classes. Figure 2 shows an appropriate core router diagram. In the physical layer, fast 1x2 and 2x1 optical switches are used at the switch fabric input to extract and insert best effort traffic, while a tunable laser (Tx) encodes data on the correct outgoing wavelength. Furthermore, two label extraction / insertion modules read or write the packets' labels. These modules are needed in the case of an All-Optical Label Switching (AOLS) network. Alternatively, in a pure wavelength-routed network, with or without wavelength converters, identification of best effort traffic can be accomplished with a simple optical marker as presented in [17]. In Figure 2, blocks related to typical lightpath establishment and wavelength-routing functions are omitted for simplicity.

In the network layer, a dedicated agent is commissioned to schedule traffic of both classes. Specific modules of the SLIP-IN agent are:

Traffic Scheduler: The traffic scheduler module maintains a table where the state information for all wavelengths of all outgoing links is stored. When the node receives a SETUP packet, the scheduler immediately hard-reserves an outgoing wavelength and forwards the message to the next node. The traffic scheduler reads from the SETUP message the source and destination addresses of the flow and in the sequence calculate the round trip time, $T_{RTT}^{s^o-s^h}$. This is the corresponding pre-transmission idle period for which the reserved outgoing capacity remains idle. In the sequence, the Scheduler module signals the buffer module.

Route Logic module: For every new WR request, this module calculates the routing path using an RWA algorithm (e.g. shortest path) and is also responsible for establishing the lightpath. It also maintains a table with the network's virtual topology.

Buffer Module: Each outgoing link has an associated FIFO queue, which stores best effort packets. A FIFO buffer can be in one of two possible states; *Blocked* or *Unblocked* (initially all buffers are in a blocked state). Each time a SETUP message is accepted, and an outgoing wavelength is reserved, the FIFO buffer that corresponds to the outgoing link switches to the *Unblocked* state. Within this state, transmission of best effort data is performed. The FIFO buffer is scheduled to switch back to the blocked state after $T_{RTT}^{s_o-s_h}$ time, or after a REJECT message is received, meaning that the lightpath establishment process was eventually blocked at a subsequent node. In the case of *tell-and-go* and *path-entry* policies the buffer module is organised differently, maintaining a virtual output queue per node destination.

Best effort data identification module. This module handles the input 1x2 switch and either forwards best effort data in the electronic IP/MPLS router or to the next node. In particular, upon the reception of a setup message from input i and the successful reservation of capacity on outgoing link j, this module signals the 1x2 switch to forward data:

- to the electronic domain in the case of *hop-by-hop* routing
- to the next node across the network path transparently in the case of *tell-and-go* and *path-entry* policies.

Note that, the necessary number of Rx and Tx interfaces is a design parameter of the architecture, but to keep the

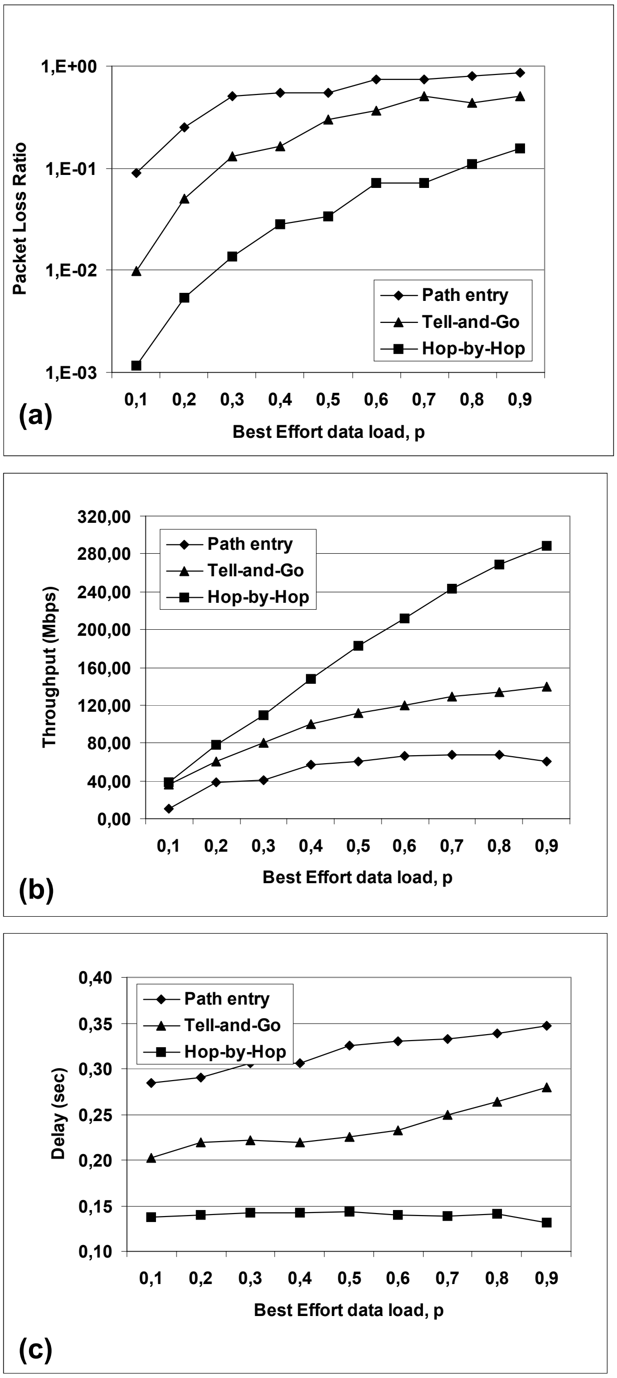

Figure 3: (a) Packet loss ratio, (b) throughput and (c) delay achieved for the three routing policies, namely: *hop-by-hop*, *tell-and-go* and *path re-entry*.

architecture simple and having in mind that all wavelengths of an outgoing link share the same buffer (one FIFO per outgoing port) only a single tunable Tx was employed per outgoing link. Thus, best effort data are allowed to enter only a single wavelength at a time, even if two or more lightpaths are being simultaneously established. Although this could limit performance, allowing simultaneous multi-lightpath entries would require additional hardware and would increase the management complexity. Nevertheless, as shown in the performance evaluation section, it is not essential to allow more than one wavelength of a link to transmit best effort traffic simultaneously, since the number of wavelengths per link has an indirect impact on performance.

IV. PERFORMANCE EVALUATION

In order to evaluate the SLIP-IN architecture, we have developed a discrete-event network simulator based on the ns-2 platform. Performance evaluation was performed on the NSFnet backbone topology. All links were assumed to be bidirectional, with 10Gbps capacity per wavelength. The traffic between each source-destination pair was modelled with two separate traffic sources: one that generates wavelength-routed requests for high-priority data, according to a Poisson process with mean value λ and exponential mean duration $1/\mu$ equal to 100msec, and one that generates best effort packets according to a Pareto process, with packet sizes drawn from a typical Internet mix size distribution [18]. The best effort packet generator parameters, (access rate, Pareto shape parameter and load) were maintained constant throughout a simulation cycle. In all the experiments the opto-electronic (O/E) conversion delay was set equal to 0.01*msec*, while it has been assumed that all link wavelengths can carry best effort packets and all have an individual terminating O/E interface, so that best-effort packet contention does not occur. Finally, the size of the best effort buffer was set equal to 512KB.

The prime target of the simulation experiments was to investigate what is the throughout and loss ratio that can be achieved for best effort traffic. To this end, we have measured these two metrics versus various dependencies as for example, the available number of wavelengths per link, (denoted as WL), the WR-traffic arrival rate λ, as well as the access rate of the best effort Pareto generator. It must be noted here that throughput is measured as the total bits transmitted versus the total transmission time. We have assumed that best effort data are not delay-sensitive and thus, packet loss occurs only due to buffer overflow (in the case that the transmission at idle periods is not sufficient and the stored best effort data exceed the available storage capacity).

Figure 3(a) to (c) displays the loss ratio, throughput and average end-to-end packet delay for the case of WL=4 and λ=16 (requests per sec) for the three different policies. From Figure 3, it can be seen that *path-entry* policy is the worst performing one. It exhibits a very high loss ratio and a very high delay. This is due to the fact that best effort data waits for a long period of time in the FIFO buffer in order to find a matching setup packet passing by. Thus, the yielding throughput is very poor and the idle capacity poorly utilized.

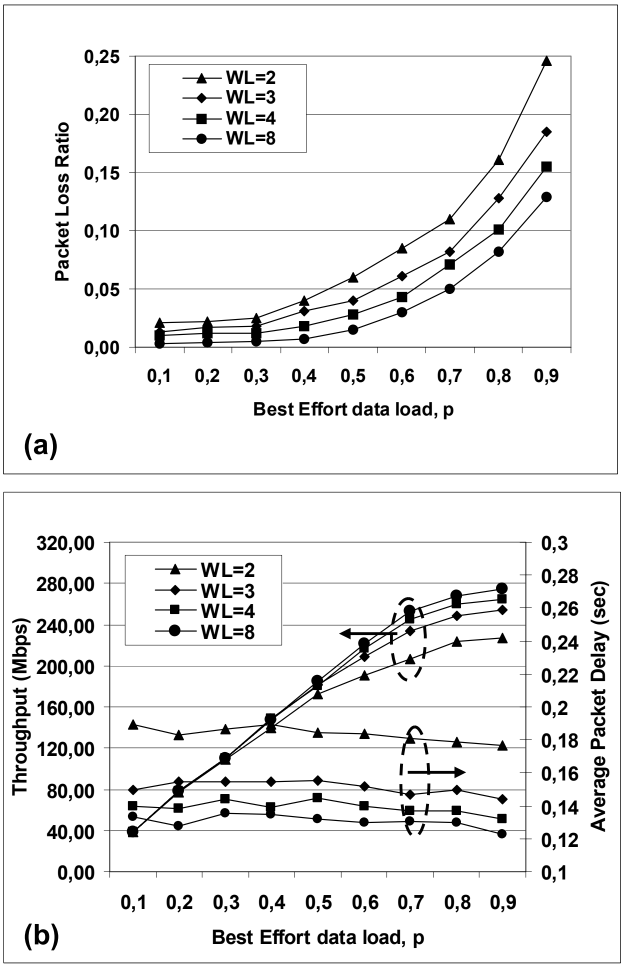

Figure 4: (a) Packet loss ratio and (b) throughput and delay achieved for WL=2, 3, 4 and 8 wavelengths per link. Arrival rate, λ, is set equal to 16. Results shown are for *hop-by-hop* routing policy

On the contrary *hop-by-hop* routing performs best, yielding a significant throughput of 280Mbps for a load of p=1, with almost a constant worst-case delay. This delay is primarily governed by the queuing delay in the FIFO buffers, which on average can be the same at all nodes.

Finally, *tell-and-go* policy exhibits a moderate throughout and loss ratio. Again, the transmission of a single burst with a matching destination with the setup message results in a poor utilization of the idle capacity of the lightpaths.

All the above results were obtained for an access rate and OFF period of the best effort Pareto sources of 25Mbps and 5msec respectively. It must be noted here that blocking probability of the high-priority data is independent of best effort traffic load and parameters, and was measured to be in the order of 10%.

In what follows the results are focused in the *hop-by-hop* routing policy, since it outperforms the others and further it purely reflects the concept of hybrid switching. More specifically, we have investigated the effect of the available number of wavelengths, the WR-traffic arrival rate λ, as well as the parameters of the best-effort traffic generating sources.

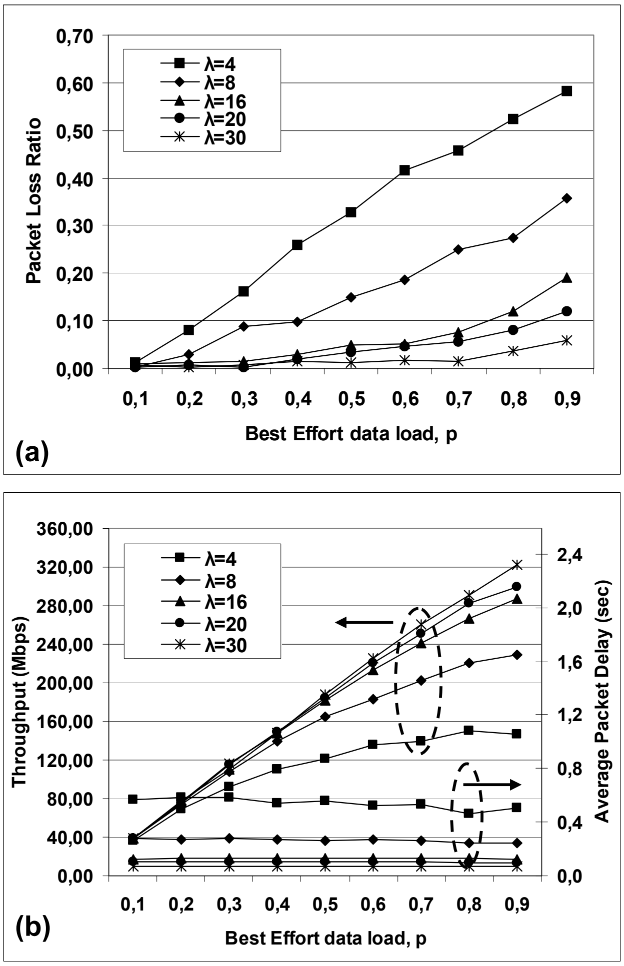

Figure 5: (a) Packet loss ratio and (b) throughput and delay achieved for an arrival rate of λ=4, 8, 16, 20, and 30 and WL= 4.

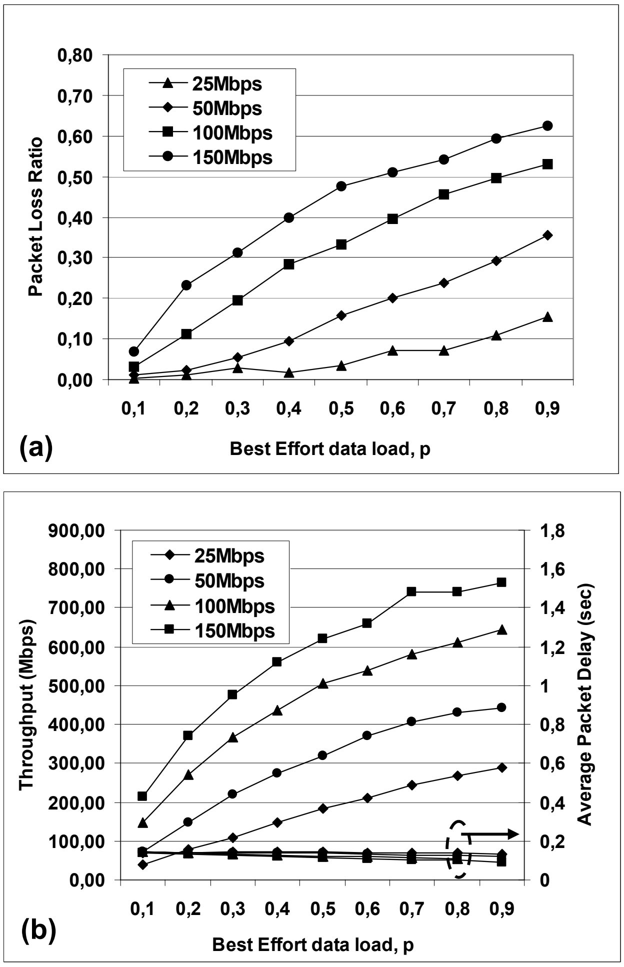

Figure 6: (a) Packet loss ratio and (b) throughput and delay achieved for a Pareto rate of 25, 50, 100 and 150Mbps. Arrival rate, λ, is set equal to 16 and number of wavelengths, WL, to 4.

Figure 4 shows the performance of the *hop-by-hop* policy when the available number of wavelengths per link (WL) is 2, 3, 4 and 8. It can be seen that the effect of WL is relative weak and this is due to the fact that it affects performance indirectly through the acceptance (or not) of more high-priority (WR) traffic requests. To this end, blocking probability of WR-traffic decreases slightly from WL=4 to 8, while from WL= 2 to 3, the gain is higher. To this end, loss ratio of best effort data exhibit a higher gain moving from WL=2 to 3, than from WL=4 to 8. This is clearer in Figure 4b, where we can observe that throughput curves diverge for an average load higher than 0.6. The same can be also observed in the delay performance graphs.

Figure 5 shows the effect of WR traffic arrival rate for WL=4. It can be seen that the increase of the WR arrival rate from λ=4 to 30 requests per sec results to a significant decrease in the best effort traffic loss ratio that reaches a maximum throughput of 320Mbps. This was expected, since the increase of the arrival rate actually increases the number of idle setup periods, and thus increase the throughput of best-effort packets. A higher gain was observed when λ increases from 4 to 8 for all examined metrics. In particular for load $p=1$, throughput increases by 55% (from 147 to 230Mbps) when λ increases from 4 to 8, and only by 5% (from 306 to 323Mbps) when λ increases from 20 to 30. It must be noted here that blocking of WR-traffic was not constant in this set of experiments but increased with the increase of the arrival rate. In particular blocking was measured to be *0.2%*, *2.0%*, *11%*, *16%* and *28%* respectively. However, the request rate, unlike the number of wavelengths, cannot be seen as a free parameter of the architecture but rather as an independent one.

Finally, we have also investigated the effect of the access rate of the best-effort Pareto source. Figure 6(a) and (b) shows the same set of experiments as previously (λ=16 and WL=4) but for an access rate of 25, 50, 100 and 150Mbps. It can be seen that throughput reaches an even higher value of 764 Mbps at a load of p=1 for a rate of 150Mbps. The increase of the access rate leads to an increase of the utilization of the edge router buffers and thus there is always data in the FIFO buffers to *slip-in*, when a lightpath request arrives. However, this comes at the cost of a very high loss ratio. In particular, loss ratio reaches a value of 62% for the extreme case of p=1 and Pareto access rate of 150Mbps.

Such a scenario, however, corresponds to an overloaded access network and is unlikely to occur. Clearly for this set of experiments, there is a trade off between loss and throughput, while the average packet delay is close to 0.1*sec* in all cases.

It must be noted here that in almost, all cases studied above, average packet delay was 0.1sec. This is ten times higher than the average propagation delay in the NSFnet topology (~13.2msec). Best effort end-to-end delay is mainly governed by the O/E conversion and the buffering delay. However, we may assume that this is not substantial for best effort traffic with no strict delay requirements.

V. CONCLUSIONS

In this paper, we have presented a new hybrid switching architecture, called SLIP-IN architecture. The proposed scheme combines electronic packet with optical circuit switching, taking advantage of the idle time during lightpath establishment phase. In particular, in optical circuit switching networks, capacity is reserved immediately upon the arrival of the SETUP packet, but is only used after a round-trip time. SLIP-IN architecture exploits this idle capacity to *slip* packets into these lightpaths. The proposed scheme has been design to support two classes of services; namely a high-priority CoS that requests and establishes an end-to-end lightpath, and a best effort class (connection less traffic), whose data are only transmitted during the lightpath pre-establishment time. In this paper, we have presented the main features of the proposed hybrid architecture and further we performed a detailed evaluation at the network level in order to assess the yielding throughput and the delay. For this, we modeled a suitable node design, capable of handling data from both classes of service and we have defined three different routing/forwarding policies. The architecture performance has been studied against various dependencies and it has been shown that SLIP-IN architecture can achieve an adequate throughput, with a worst-case constant delay that is mainly constrained by the O/E/O conversions and electronic queuing delays.

VI. ACKNOWLEDGMENTS

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REFERENCES

[1] R. Ramaswami and K. Sivarajan, Optical Networks: a Practical Perspective, Morgan Kaufmann Publishers, 1998.

[2] M. Renaud, F. Masetti, C. Guillemot and B. Bostica, "Network and system concepts for optical packet switching", IEEE Comm. Mag., vol. 35, no. 4, pp. 96 – 102, April 1997.

[3] C. Qiao and M. Yoo, "Optical burst switching (OBS) - a new paradigm for an optical Internet", a special issue of Journal of High Speed Networks (JHSN) on WDM Networks, vol. 8, no. 1, pp. 69-84, 1999.

[4] K. Vlachos, N. Pleros, C. Bintjas, G. Theophilopoulos and H. Avramopoulos, "Ultrafast time-domain technology and its application in all-optical signal processing", IEEE/OSA J. Lightw. Techn., vol. 21, no. 9, pp. 1857 – 1868, Sept. 2003.

[5] Hai Le Vu, A. Zalesky, E.W.M., Wong, Z. Rosberg, S.M.H. Bilgrami, M. Zukerman and R.S. Tucker, "Scalable performance evaluation of a hybrid optical switch" IEEE/OSA J. Lightw. Techn., Volume 23, Issue 10, pp. 2961 – 2973, Oct. 2005.

[6] C. Xin, C. Qiao, Y. Ye, and S. Dixit, "A hybrid optical switching approach", in Proc. IEEE Global Telecommunications (GLOBECOM), vol. 7, pp. 3808 – 3812, Dec. 2003.

[7] G. M. Lee, B. Wydrowski, M. Zukerman, J. K. Choi, and C. H. Foh, "Performance evaluation of an optical hybrid switching system," in Proc. IEEE Global Telecommunications (GLOBECOM), vol. 5, pp. 2508–2512, Dec.2003,.

[8] Hyeong-II Lee, Seung-Woo Seo, "Hybrid optical transport Network (HOTNET): An optical network with hybrid switching technologies for integrated services", IEICE Transactions on Communications, Vol. E88-B, No. 10, pp. 3874-3885, Jan. 2005.

[9] A. Gumaste, I. Chlamtac, "Light-trails: an optical solution for IP transport", Journal of Opt. Netw. 3 (2004) 261–281.

[10] A. Gumaste and I. Chlamtac, "Light-trails: a novel solution for IP-centric communication," in Workshop on High Performance Switching and Routing (IEEE, New York, 2003).

[11] S. Balasubramanian, Ahmed Kamal, A.K. Somani, "Medium access control protocols for light trail and light bus networks", in Proc. of 8th IFIP Working Conference on Optical Network Design and Modeling, ONDM, 2–4 February 2004, Ghent, Belgium.

[12] S. Bjornstad, D.R. Hjelme, N. Stol, "A highly efficient optical packet switching node design supporting guaranteed service" in proceedings of ECOC 2003, paper Mo4.4.5, pp. 110–111, Sept. 2003.

[13] J. Cheyns, E. Van Breusegem, D. Colle, M. Pickavet, P. Demeester, "Controlling LSPs in an ORION network", Broadnets 2004, San Jose (California, USA)

[14] E. Van Breusegem, J. Cheyns,, D. de Winter, D. Colle, M Pickavet, P. Demeester and J. Moreau, "A broad view on overspill routing in optical networks: a real synthesis of packet and circuit switching ? ", Elsevier J. of Optical Switching and Networking, vol. 1, pp. 51–64, 2005.

[15] K. Christodoulopoulos et al. "Performance Evaluation of Overspill Routing in Optical Networks", accepted for presentation in IEEE International Conference on Communications, ICC 2006.

[16] M. Yoo and C. Qiao, "Just-enough-time (JET): A high speed protocol for bursty traffic in optical networks", IEEE/LEOS Technol. Global Information Infrastructure, pp. 26–27, Aug. 1997.

[17] K. Vlachos, et al. "An Optical FSK/IM coding technique for the implementation of a label controled, AWG-based Optical Packet Router", IEEE/OSA J. of Light. Techn., vol.21, no.11, pp. 2617-2628, Nov. 2003.

[18] Agilent Technologies. (2001, Aug.). "How can I generate traffic representative of 'Realistic' internet traffic?" Insight (1st ed.).: http://advanced.comms.agilent.com/insight/2001-08/Questions/traffic_gen.htm