Network Traffic Reduction using a Hybrid Opto-Electronic Switch with Different Packet Classes

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Abstract- Network traffic is the large amount of data that is moving across a network in the form of discrete packets. As Optical networks or light paths are capable of delivering bandwidth in a flexible and reliable manner, they are deployed in all kinds of telecommunication networks.But to translate the control information from one protocol to another (routing),optical signals areconverted into electronic domain.They are then converted back into optical signals for transmission. This O-E-O conversion in the networks has caused too much energy consumption which increases the traffic due to packet contention. The following hybrid switch uses an electronic buffer and provides efficient optical switching. By having only a few electronic ports to the buffer,the hybrid switch has shown a significant decrease in the number of O-E-O conversions and packet loss rates (PLR) compared to an all optical(buffer less) switch and thereby reduces network traffic.

Keywords:- *Packet Contention, Packet loss rates, Optical communication equipment, Optical packet switching, Optoelectronic devices.*

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I. INTRODUCTION

The significant increase [14]in network traffic has paved way to encourage new services,in designing new optical networks and curbing their energy consumption. Network traffic is carried as optical signals at low energy per bit.But still optical signals fail to support routing[9]. Routing is very essential for supporting services such as connection on demand,which has to be offered by the service providers. The network will dynamically determine a path via routing and setup the connection upon request.Routing is also needed to improve bandwidth efficiency [1]or resource utilization of the network which requires advanced routing algorithms.

So for routing and switching purposes, and for re-amplification[12] or reshaping purposes the optical signals have to be converted into electrical domain and for further transmission, they have to beconverted again into optical signals. Hence it is obvious that numerous O-E-O conversions are required which adds to the energyconsumption. The network electricity consumption is growing rapidly (at rate of 10% per year).In order to overcome this problem, we have to provide economic as well as efficient switching technologies.

All-optical packet switching [2],[12] may replace O-E-O conversions and minimize consumption of energy. But in contention handling where two or more packets are to be sent to the same output port, these solutions are not practical. Even at low loads this leads to Packet loss rates(PLRs).So only for quasi-static switching, all optical switching solutions have been successful.

The hybrid Opto-electronic switch has the combined advantages of both optics and electronics[4]: it routes packets rapidly at a low energy cost, or stores them in an electronic buffer to avoid their loss due to contention[11].With few buffer ports, the hybrid switch has shown good performance in terms of packet loss rates, sustainable load compared to an all optical type switching. This was confirmed by simulations. These results were also proved by another analysis where various other service classes were considered.

The access to different buffer input ports was investigated based on defining the priorities of the packets only in terms of PLRs.The study takes into account different switching strategies of the hybrid switch in an intra data network without priority classification. It also uses deflection routing[1](to reduce contention among packets)and Fiber delay lines(FDLs) besides the electrical buffers;while considering the PLR as a performance criterion, the use of FDLs [4]on various system loads is discussed.To avoid packet contention,the optical switching is provided by a shared electrical buffer.Here,through simulations the operation of the hybrid switch that supports various different priority packets is studied. Hence, the packet classification is quite realistic: reliable, fast, anddefault packets.

First, the hybrid switch design and the switching mode are explained in Section II. The switching mode has been established so as to find a trade-off between the PLRs and the latencies and to satisfy the constraints of each class of packet:mainly null PLR for reliable packets and low latency for fast packets. Next, in Section III, the performance improvements in terms of the PLR and the sustainable load obtained by the hybrid switch compared to an all optical switch are discussed.It is showed that,the total number of optical ports can be effectively replaced by a few numbers of electronic ports to the buffer.The switching delay is also negligible[5],[6], even for fast packets.Also, the significant reduction of O-E-O conversions is quantified and this indicates that the hybrid switch may be a potential solution to the problem of energy consumption. Section V concludes the paper.

II. DESIGN AND SWITCHING MODE

Hybrid switch design consists of an optical switching matrix provided with an electronic shared buffer to store packets during contention. The hybrid switch design is shown in Fig.1. The key parameters to dimension the switch are the number of connected azimuths (n_a) which are bidirectional[5], the number of supported channels per azimuth in each direction (n_c), and the number of electronic input andoutput ports (n_e).Label processing and pay load switching allows the packets to be routed independent of payload bit rate, coding format and packet length. This label processing and unit of control for the matrix is supposed to be generic[11]. By sending labels out-of-band, or as a reduced-bit-rate header,it is assumed that label processing will not require O-E conversion of the entire packet.So as the channels are independent, an azimuth has the capacity to receive up to n_c packets simultaneously.

Channels are also supposed to be inter-changeable: an ingress packet can use any available channel of its egress azimuth. This assumption works with space division multiplexing (SDM) non-wavelength-specific channels, such as parallel optical fibers in the same cable or differentcores in a multi-core fiber. Wavelength division multiplexing (WDM)[15],although commonly used to combine a number of information carrying wavelengths onto the same fiber,affects the switch performance; the present study is not directly applicable to them, at least not without use of wavelength converters, which consume power and may negate the energy savings of the hybrid switch compared to an electronic one.

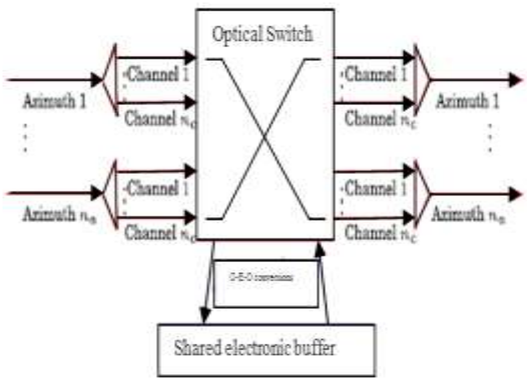

Fig.1.Hybrid Switch Design

Three different service classes are taken into consideration: reliable (R), fast (F), and default (D) packets, that account for 10%, 40%, and 50% of the global traffic[10]. These percentages are obtained from original data of circulating packets on metro and core networks. Reliable packets (R)which refer to digital data and file transfer packets must reach their destinations without loss, but they are the lowest priority packets in terms of delay. Fast packets (F)which could refer to voice and interactive video packets[16] have the highest priority regarding latency, but they are more tolerant than R packets with regard to the PLR. Default packets (D)which represent other type of packets are the least restrictive with respect to both PLR and latency.

A constant packet duration of σ =10 µs, represents about 100 Kbits for standard 10 Gbit/s systems. It may correspond to a jumbo Ethernet frame or an aggregation of several IP packets[13].So the system load ρ will depend only on the mean idle time per source τ, which is the average time interval separating two consecutive packets arriving from the same channel of a given azimuth:

$$\Sigma$$

$$\rho = \tau \quad \sigma \qquad (1)$$

τ is generated randomly.When packets are sent one after another unceasingly (τ 0),the system is called "fully loaded" (ρ 1).

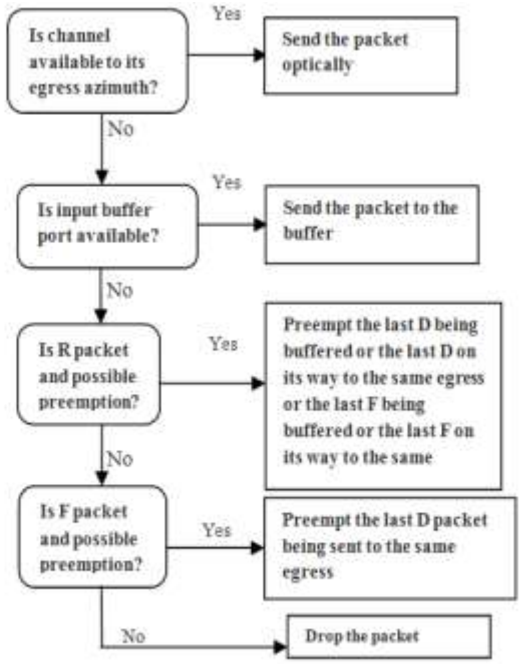

Fig.2. Switching strategy

The hybrid switch operates in asynchronous mode: packets can come at any instant of time[5]. Given this assumption, the study is similar to the case of having variable σ. Fig. 2 describes the switching strategy.When a packet is received, the switch checks if there is a channel available to its egress azimuth. If yes, the packet is sent directly sent over this channel. Or else if an input electronic port is available, the packet is buffered and reemitted whenever a channel is released and an output electronic port is available. The first in first out (FIFO) [7]principle is applied at the buffer output ports: the first buffered packet is the first one to be reemitted; also, for a given destination, the reemission of buffered packets has priority over incoming packets. Otherwise, there is a preemption policy depending on the class of the packet: if the newly received packet is of type R, the switch may interrupt the transmission through the optical switching matrix of the last (preferably D, or F) packet being sent to the buffer or the last (preferably D, or F) packet being sent to the samedegrees azimuth and send the R packet. Otherwise, if the newly received packet is of type F, the switch checks if there is a D packet being sent to the same egress azimuth to preempt it and send the F one instead.

Once the new higher priority packet is received,the preempted packet is dropped while it was still being transmitted through the optical switching matrix to its destination or the buffer input port and is taken into account to calculate the PLRs. In the worst case, when there is none of the possibilities listed above, the incoming packet is dropped.

This switching strategy, and mainly the preemption policy, is chosen to meet the constraint of each service class of both the PLR and latency.The policy described above leads to the best trade-off between the PLR and the latency for all the packet classes.

III. PERFORMANCE IN TERMS OF PLR

When two or more packets moving across a network fail to reach their destination,packet loss occurs[10].It is mainly due to network congestion.Fig. 3 and 4shows, the PLR_D and PLR_F as functions of the system load for eight channels per azimuth, and for different values of n_e. A system load of 60% was considered as a minimum operating point.

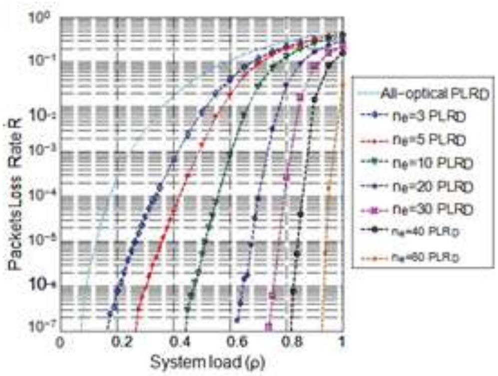

Fig. 3. PLR_D versus system load

With the inclusion of just a few electronic ports ($n_{e=}$ 5, for example), PLRs decrease significantly compared to an all optical switch. At ρ= 0.6, PLR_D is reduced by a factor of 5 from 10^{-1} to 2×10^{-2}, and PLR_F is reduced from 2×10^{-3} to 1.4×10^{-4}, which shows that reduction better than an order of magnitude. The more the number of buffered ports, greater is the decrease of PLR_D and PLR_F.

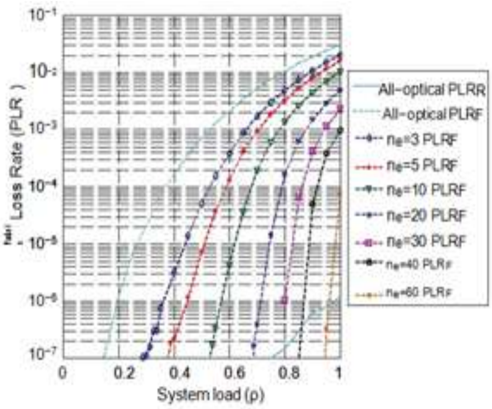

Fig. 4. PLR_F versus system load

For a 60% loaded system (ρ= 0.6) which has only about 20 electronic ports, PLR_D is around 10^{-7}, while PLR_F is around 10^{-8}. While using the hybrid switch, no R packets were lost. R packets indeed have the favor of preemption at the level of the buffer access and also at the level of the optical ports. Thus the PLR constraint of the reliable class service is satisfied.PLR_R is under the sensitivity of simulations, or at least is always less than ⁻ln 5% ⁄n_p R ≈ 10^{-7}, where n_p (R) represents the number of all switched R packets.

Thus, the hybrid switch satisfies the entire service classesrequest in terms of PLR, especially the R packets[11]. Also as it has good performance compared to an all optical switch, it is definitely a good solution for the contention problem.

IV. PERFORMANCE IN TERMS OF SUSTAINABLE SYSTEM LOAD

At a given value of PLR, the sustainable system load is the maximum system load for which the PLR is less than or equal to the given value. For an 8- degree switch, in Fig. 5 and 6 the evolution of the sustainable system load (at $PLR_D=10^{-4}$ and at $PLR_F=10^{-4)}$is plotted as a function of the ratio between the number of electronic ports and the optical links (n_e ⁄$n_a \times n_c$).This ratio denotes the reduction of the number of electronic ports[3] by the hybrid switch (n_e ports) compared to an electrical switch ($n_a \times n_c$ ports).

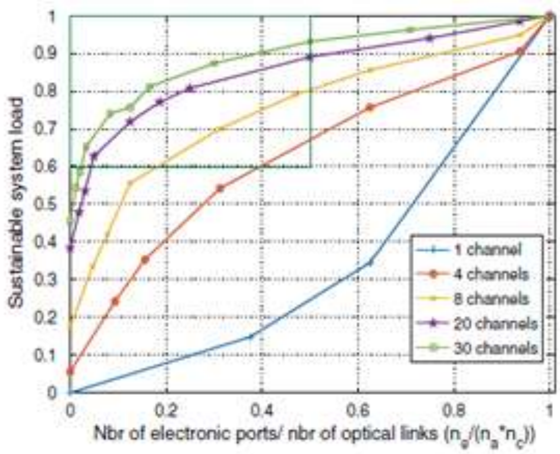

Fig. 5. Sustainable load versus $n_e /(n_a \times n_{c)}$at$PLR_D=10^{-4}$

The reduction of the electronic ports leads to reduction of the energy consumption[3]. For interactive video packets (F packets), it is recommended that the PLR must be lower than 10^{-2} across the network. Assuming paths can cross up to 100 nodes, when a single node PLR_F $10^{-4}$is taken as the reference node. The same constraint is imposed to PLR_D even though D packets are more tolerant to the PLR.

The hybrid switch can be of a good choice when it satisfies two conditions: first, since a system load of 60% was considered as a minimum acceptable operating point, the sustainable system load must be ≥0.6S.Next, the buffer must incur fewer O-E-O conversions than an all-electronic switch of the same size, which is expressed as the condition $n \leq n \times n/2$.

The area where these two conditions are fulfilled is presented by the rectangles in Fig. 6 and 7 and permits to find a trade-off between the performance improvement[6] and the energy savings.The sustainable load increases with n_e and reaches 1 for $n_{e=}n_a \times n_c$, where an ingress packet can always be collected by the buffer if it cannot be switched directly.Fig. 6 and 7 show that whenever the 8-degree hybrid switch is chosen, n_c and n_e have to be chosen among the values located inside the rectangles.For a 60% loaded system, with four or more channels per azimuth, just $(0.4 \times n_a \times n_c)$ electronic ports are sufficient to have $PLR_D \leq 10^{-4}$, while PLR_F is less than or equal to 10^{-4} for $(0.3 \times n_a \times n_c)$ electronic ports.

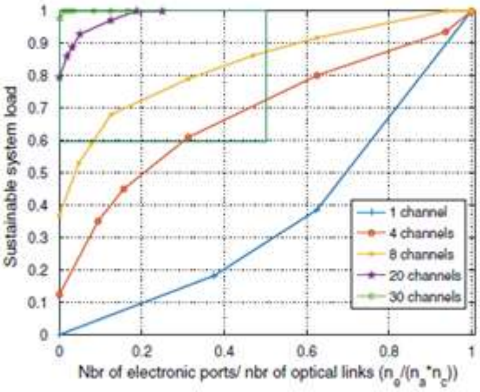

Fig. 6. Sustainable load versus $n_e/(n_a \times n_c)$ at $PLR_F=10^{-4}$

Thus, the hybrid switch leads to an acceptable sustainable system load with the number of electrical ports less than half that of optical links or even fewer.So it significantly reduces the number of ports.

V. CONCLUSION

The hybrid switch is a good solution between the alloptical buffer less switch and commercial electrical switches. It has much better performance in terms of PLR and sustainable system load compared to all optical switches[16].It also satisfies the requirements of the various packet classes even for a low number of electronic ports to/from the shared buffer.Also compared to an all-electronic switch, the hybrid switch reduces the number of electronic ports from $(n_a \times n_c)$ to only (n_e) ports. Moreover,it significantly decreases the O-E-O conversions, which mayreduce the energyconsumption[10].So it is a good solution for the problems in energy consumption. This is a great advantage as network data traffic is widely increasing each day. Replacement of the all optical buffer less switch and the electronic switch withthe hybrid switch significantly reduces network traffic.

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