Optical Burst Switching With Burst Drop(OBS/BD): An Easy OBS Improvement

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***Abstract-* In this paper, the Optical Burst Switching with Burst Dropping (OBS/BD) technique is proposed to be implemented in an all-optical backbone network to support IP traffic. The OBS/BD is based on two main features: i) several IP packets are assembled in a single macro-packet, called burst; ii) the burst contention in an optical switch is handled by the means of two techniques: the wavelength dimension and the "burst dropping". In the Optical Burst Switching (OBS), the entire burst is discarded when all of the output wavelengths are engaged at its arrival instant. Whereas, the OBS/BD technique discards only the initial part of the burst and forwards the final part of the burst beginning at the instant in which one wavelength becomes free. Obviously, the OBS/BD, respect to the OBS, allows to increase the switch throughput, i.e. the number of forwarded IP packets. We develop the analytical models that quantify this increase tacking into account of several system parameters.**

I. INTRODUCTION

The increase in the demand of transport capacity due to the explosive growth of the Internet IP-based traffic has fueled the development of high-speed transmission systems and the emergence of Wavelength Division Multiplexing (WDM) technology [1] that, in the near future, it will be possible to support hundreds of wavelengths of several Gigabit/s each. However, the bottleneck due to the processes required for switching IP packets within the routers could not allow IP networks to take the full advantage of the huge capacity of the underlying transmission systems.

Some research efforts are directed towards the study and the definition of network architectures in which the transmission and the low level switching functions are realized in the optical domain while the forwarding and routing functions are implemented in the electronic domain. Such architectures aim at reducing the processing requirements in the IP routers and, furthermore, at implementing switching and transmission infrastructures transparent to the bit-rates and to the coding formats [2].

The first optical switching paradigm that has been proposed in the literature is the Optical Packet Switching (OPS) [3,4] based on fixed length packets and synchronous node operation. The drawbacks of this approach mainly consist in the difficulty to implement the optical synchronizer and to process the packet header in the electronic domain [5].

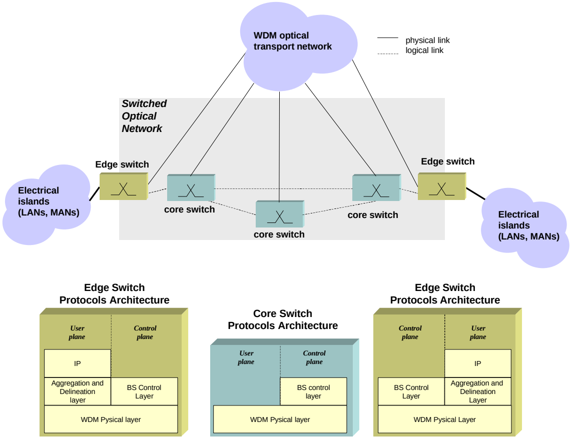

Fig. 1: Optical switched network architecture

A more recent and more promising proposal in this direction, at least in short-medium term, is a new switching paradigm called Optical Burst Switching (OBS) [6,7,8,9] based on variable length data units, named *bursts*, on asynchronous node operation and on the decoupling of the burst from its header (BHP), i.e. the header packets are transferred on the *control wavelengths*, whereas the bursts are transferred on the *data wavelengths*.

The question to be solved is how to carry IP traffic by the means of a new network architecture adopting the OBS switching paradigm. In order to reduce the "packet forwarding rate" in the core switches, OBS requires that the bursts should be at least several kilobytes long. Moreover, so long bursts overcome the link efficiency problems due to the guard times [10] among the bursts needed to cope with the switching times of the optical devices. Unfortunately, a single IP packet is not so long to satisfy the previous requirement, so it is needed to aggregate several IP packets in a single optical burst.

In this view, the Internet transport architecture is structured in two functional areas (Fig. 1): the external one, compatible with the today's Internet transport architecture, is the electronic area performing traffic aggregation, whereas the internal area, here called Switched Optical Network (SON), is based on the optical technology and performs transmission and low layer switching functions. Some Edge Switches (ES) are located at the boundary between the two layers. IP traffic is injected in the ingress ESs by standard electronics networks, i.e. LANs, MANs, etc. The ingress ES assemblies and delineates [14,15] in a single burst a set of incoming IP packets directed towards the same remote ES. Once a burst is composed, it is forwarded through the SON according to the OBS paradigm. On the other side, the egress ESs recover the IP packets contained in the bursts and deliver them to the addressed electronic network.

One of the key problems in application of burst switching in optical domain is the handling of burst contentions that take place when two or more incoming bursts are directed to the same output line. Various techniques have been examined in the literature, the most important ones are buffering and wavelength dimension. Unfortunately, at least with current technology, optical buffer can be only implemented through a bundle of Fiber Delay Lines (FDLs). This significantly reduces the buffer capacity of a optical packet switch and the number of FDLs becomes a critical system design parameter because it has a heavy impact on the optical hardware volume, on the switch size and on the noise level due to the transit of optical signal in FDLs. The wavelength dimension technique [11] uses the wavelength dimension as a logical buffer in the WDM optical network layer. In [11] a network solution is proposed that eliminates the need for optical buffers by splitting the traffic load on the wavelength channels by means of Tuneable Optical Wavelength Converters.

In this paper, we propose and analyze a new switching paradigm, called *Optical Burst Switching with Burst Dropping* (OBS/BD*),* to be implemented in the SON for the support of IP traffic. The OBS/BD is derived from the OBS and its basic features is the burst contention, handled by the means of two techniques: the wavelength dimension (WD), already proposed for the OBS, and the *"burst dropping"* (BD), here proposed. In an optical switch where the WD technique is used to solve output contentions, an entire burst is discarded when all of the output wavelengths are engaged at the arrival instant of the burst. On the contrary a switch adopting also the BD technique discards only the initial part of a burst as long as a wavelength becomes free on the output fiber; from this instant the switch will transmit the rest of the burst.

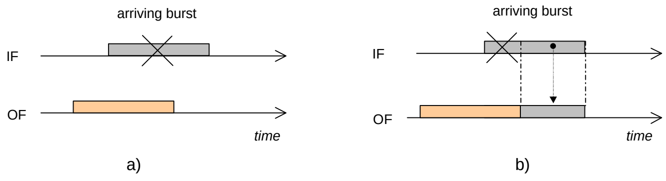

Fig. 2: “Burst Dropping ” technique with one OF data wavelength

The BD technique mode of operation is illustrated in Fig. 2 when just one wavelength is used. Fig. 2.a shows as the output burst contention problem is handled when the WD technique is adopted; a burst finding the output data wavelength busy is completely discarded. On the contrary, the BD technique, illustrated in Fig. 2.b, consists in discarding only the initial part of the burst, as long as the output data wavelength returns to be free, and in forwarding the final part of the burst. Since a burst contains several IP packets [12,13] the BD allows the switch traffic capacity to be increased in terms of the number of forwarded IP packets. As a matter of fact, the forwarded remaining part of the burst may contains a conspicuous number of IP packets that can be delivered to the destination ES.

As far as the implementation issues is concerned, the dropping of the burst requires to modify its BHP (at least the field related to the burst length). This involves an increase in the demand placed on the BHP-processor that it is worth to quantify. Moreover, it is also to investigate on the delineation protocol [14,15] that allows to recover IP packets inside a partial dropped burst. However, in this paper we focus on the performance evaluation of the OBS/BD and do not deep into the feasibility issues.

The present paper is organized as follows: the analytical models to evaluate the OBS/BD node performance are described in sec. II. In the sec. III numerical examples and performance results are given out. Finally, in sec. IV, we discuss the achieved results.

II. PERFORMANCE EVALUATION

In our analysis we introduce the analytical models that will allows us to evaluate the effectiveness of the technique and in particular the savings obtained in terms of IP packets loss probability P_{loss}^{p} when both the wavelength dimension (WD) and the burst dropping techniques (BD) are adopted.

The effectiveness of the BD technique is evaluated for a single *N*x*N* switch with *W* data wavelengths for each input/output fiber. We model the traffic offered to an output fiber (OF) as the superimposition of $N{\times}W$ *on-off* independent processes, where the *on* period is in correspondence with the duration of an optical burst. The single process represents the ‘stream’ of bursts coming from a specific couple input-fiber/data-wavelength and going to the considered OF. The model is reasonable if the *offset time* [8] of each incoming burst is the same or if a horizon scheduling with reordering strategy is employed [6]. Moreover, we consider a symmetric traffic scenario, i.e. all the streams have the same statistical behavior.

We denote L^b and S as the random variables characterizing the *on* and the *off* periods respectively; while their density functions and expected values will be indicated by $f_{L^b}(x)$, $f_S(x)$, $\overline{L^b}$, $\overline{S}$. With these assumptions, notice that : i) the traffic offered by each *stream* is $A=\overline{L^b}/\left(\overline{L^b}+\overline{S}\right)$; ii) the total traffic offered to one *OF*, normalized to the number of data wavelengths (*W*), is $A_T = N{\times}A$.

We denote L^p as the random variable characterizing the length of the IP packet while $f_{L^p}(x)$ and $\overline{L^p}$ indicate its

density function and expected value. Further, we denote by N_p the average number of IP packets contained into each burst.
The OBS and OBS/BD switching paradigm will be evaluate in terms of IP packets loss probability P_{loss}^{p}; the evaluation of this performance index is done in sections II.A and II.B.

A. *Performance evaluation: OBS*

Since in the OBS according to the data wavelengths availability a burst is either entirely accepted or rejected, we can affirm that P_{loss}^{p} equals the burst loss probability P_{loss}^{b}. P_{loss}^{b} can be evaluated according to the well know Engset formula [17]:

$$P_{loss}^{p} = \binom{H-1}{W}\left(\frac{l}{m}\right)^{W} \Bigg/ \sum_{j=0}^{W}\binom{H-1}{j}\left(\frac{l}{m}\right)^{j} \qquad (1)$$

where $l = 1/\overline{S}$, $m = 1/\overline{L^{b}}$ and $H=W\cdot N$.
Moreover, according to [16,17], it can be demonstrated that the expression (1) depends on the distribution of the *on* and *off* periods only through the parameter *A*, that is the traffic offered by each stream and not of the distribution type of the *on* and *off* periods. Hence, this property, famous in the literature as the insensitivity property, allows us to evaluate the performance of the optical switch by the means of (1) for any distribution of the *on* and off periods.

B. *Performance evaluation: OBS/BD*

In order to evaluate the performance of the switch when OBS/BD technique is adopted, we first determine the fraction of the offered traffic that is rejected by the output fiber (OF), called r_l. Afterwards, we evaluate P_{loss}^{p} from r_l.
In our analysis we will denote $L_n^{b,a}$ as the length of the accepted part of the *#n* burst according to the burst drop (BD) technique; obviously if no drop is performed and the burst is entirely accepted we have $L_n^{b,a} = L_n^{b}$, whereas if the burst is completely discarded we have $L_n^{b,a} = 0$. Let us notice that $L_n^{b,a}$ is composed by a useful part $L_n^{b,a,u}$ of entire IP packets and a not useful part $L_n^{b,a,nu}$ relative to the broken IP packet (see IP packet #2 in Fig. 3) due to the drop of the burst.
The not useful part will be discarded by the destination ES when the delineation operation of the IP packets contained within burst is performed. In fact, only entire IP packets can be accepted. Since the random variables { L_n^{b} n=0,1,…} are identically distributed, the random variables { $L_n^{b,a}$ n=0,1,…}, { $L_n^{b,a,nu}$ n=0,1,…},{ $L_n^{b,a,u}$ n=0,1,…} are identically distributed, as well.

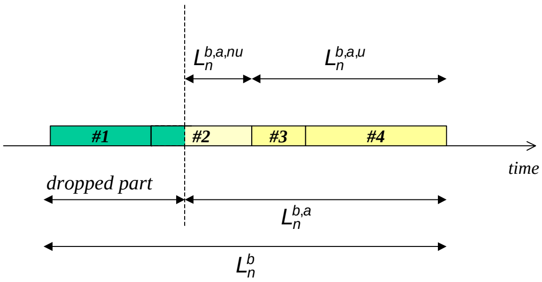

Fig. 3: Aggregation of IP packets in an optical burst

We denotes these random variables by $L^{b,a}$, $L^{b,a,nu}$, $L^{b,a,u}$ respectively, while by $\overline{L^{b,a}}$, $\overline{L^{b,a,nu}}$, $\overline{L^{b,a,u}}$ we indicate their expected values.
The fraction of the offered traffic rejected by the OF (r_l) , is:

$$r_l = 1 - r_a \qquad (2)$$

where r_a indicates the fraction of the offered traffic carried by the OF. At an equilibrium instant the OF is able to forward at most *W* bursts. At this instant, a stream is active with probability $p=A$ then we can express the carried traffic A_S by the OF as:

$$A_s = \sum_{k=0}^{W}\binom{H}{k} k p^{k}(1-p)^{H-k} + \sum_{k=W+1}^{H}\binom{H}{k} W p^{k}(1-p)^{H-k} \qquad (3)$$

and hence r_a can be written as follows:

$$r_a = \frac{A_s}{W\cdot A_T} = \frac{\sum_{k=0}^{W}\binom{H}{k} k p^{k}(1-p)^{H-k} + \sum_{k=W+1}^{H}\binom{H}{k} W p^{k}(1-p)^{H-k}}{N\cdot W\cdot A} \qquad (4)$$

Once we have evaluated r_l by the means of (2), (3), (4) we are able to determine P_{loss}^{p}, in fact r_l and P_{loss}^{p} are related by the following expression:

$$P_{loss}^{p} = r_l + P_{cut}\,\overline{L^{b,a,nu}}\Big/\overline{L^{b}} \qquad (5)$$

where P_{cut} is the probability that an arriving burst is dropped (refer to the authors for the proof). So, in order to evaluate P_{loss}^{p} from (5) we must determine P_{cut} and $\overline{L^{b,a,nu}}$; P_{cut} can be obtained from the equation:

$$P_{cut}=1-(P_a+P_r) \qquad (6)$$

wherein: P_a is the probability that a burst is entirely accepted and P_r is the probability that a burst is rejected. P_a is evaluated by taking into account that an arriving burst is entirely accepted if it finds less than W active streams and hence:

$$P_a = \sum_{i=0}^{W-1} \binom{H-1}{i} p^i \left(1-p\right)^{H-1-i} \qquad (7)$$

The probability P_r that a burst is rejected can be evaluated by applying the law of the total probability :

$$P_r = \sum_{i=W}^{H} \left[\sum_{j=W}^{i} \binom{i}{j} P_c^j \left(1-P_c\right)^{i-j} \right] \left[\binom{H-1}{i} p^i (1-p)^{H-1-i} \right] \qquad (8)$$

where P_c is the probability that the active residual time of a stream is greater than the length of an arriving burst; we can write:

$$P_c = \int_0^\infty \left[\frac{1}{\overline{L^b}} \left(1 - \int_0^x f_{L^b}\left(y\right) dy \right) \right] f_{L^b}\left(x\right) dx \qquad (9)$$

Relative to $\overline{L^{b,a,nu}}$ of (5) we can express it by taking into account that it is the residual length of an IP packet and hence:

$$\overline{L^{b,a,nu}} = \frac{\overline{L^p}}{2} + \frac{s^2_{L^p}}{2\overline{L^p}} \qquad (10)$$

where $s^2_{L^p}$ is the variance of the random variable L^p.

When $s^2_{L^p} \le \left(\overline{L^p}\right)^2$ an upper bound of P^p_{loss} can be obtained by taking into account that $\overline{L^{b,a,nu}} \le \overline{L^p}$

III. NUMERICAL RESULTS

In order to evaluate the effectiveness of the OBS/BD with respect to the OBS, in this section we first investigate on the increase in traffic capacity yields by the OBS/BD, fixed the packet loss probability. Afterwards we investigate on the packet loss probability decrease yields by the OBS/BD, fixed the amount of offered traffic.

Let us define the utilization percentage gain (g) as follows:

$$g\left(P^p_{loss}\right) = 100 \left[A_T^{OBS/BD}\left(P^p_{loss}\right) - A_T^{OBS}\left(P^p_{loss}\right) \right] \Big/ A_T^{OBS}\left(P^p_{loss}\right) \qquad (11)$$

i.e. $g\left(P^p_{loss}\right)$ is the percentage increment in traffic capacity fixed packet loss probability (P^p_{loss}). As a matter of fact, $A_T^{OBS/BD}(P^p_{loss})$ and $A_T^{OBS}(P^p_{loss})$ are the values of the switch offered traffic, normalized to W, in order to obtain the fixed P^p_{loss} when the OBS/BD and OBS switching paradigm are respectively adopted.

In Fig. 4, we evaluate g as a function of the average number of IP packets contained into each burst, i.e N_p, for $P^p_{loss}=10^{-6}$. We have assumed N=16 and W varying from 1 to 64. Moreover, in Fig. 5 we report g versus W for N=16, for N_p=100 and for several values of packet loss probabilities. In these plots the IP packet length is assumed exponentially distributed. However, by the means of the analytical model of section II.A, II.B, we are also able to obtain more general results with IP packet length distributed according to more general statistic.

The main comments about the figures 4 and 5 are the followings:

i) fixed the packet loss probability, the OBS/BD technique allows to obtain an increment in the traffic that can be offered to the switch. As example, for N=16, for N_p=100 and for $W=8$ we have a 30% increment. Further, notice that when N_p is fixed we have an decrement of g for values of W increasing. As a matter of fact, the gain obtained with the burst dropping technique becomes marginal respect to the statistical multiplexing gain obtained with the wavelength dimension technique;

ii) according to Eq. (5), for a fixed number of data wavelengths (W), g increases when N_p increases. In particular for N_p=100, the packet loss probability already reaches its asymptotic value that, according to the Eq. (5), is equal to r_l. The above analysis can be helpful for establish some guidelines about the way to fix the design parameter N_p; in fact, as we can see from Fig. 4, for N_p ≥100, g practically reaches its asymptotic value that is “independent” of the packet loss probabilities (Fig. 5);

The Fig. 6 shows, versus W, the values of $A_T^{OBS/BD}(P^p_{loss})$ and of $A_T^{OBS}(P^p_{loss})$ in order to obtain values of P^p_{loss} from 10^{-4} to 10^{-7} for N=16 and for N_p=100. From Fig. 6 we can observe that, fixed the offered load, the OBS/BD technique allows to improve the packet loss performance of an order of magnitude. In fact, the OBS/BD curves for loss probability equal to 10^{-x} are placed on the OBS ones for loss probability equal to $10^{-(x-1)}$.

IV. CONCLUSIONS

In this paper we have illustrated and analyzed the OBS/BD technique which allows to increase the performance of an optical switch with respect to the case in which only the OBS technique is adopted. An analytical model, allowing to evaluate the IP packets loss probability, has been presented. The model has been applied to carry out a sensitivity analysis of the performance improvement with respect to the main system parameters (number of input and output lines, number of wavelengths, number of IP packets contained into each burst,…) and traffic values. The proposed technique allows, for a required loss performance, to increase the offered traffic of a percentage varying in the range [10%,50%] according to the number of employed wavelengths. Moreover, for a required traffic capacity performance, the OBS/BD decrease the packet loss probabilities of an order of magnitude.

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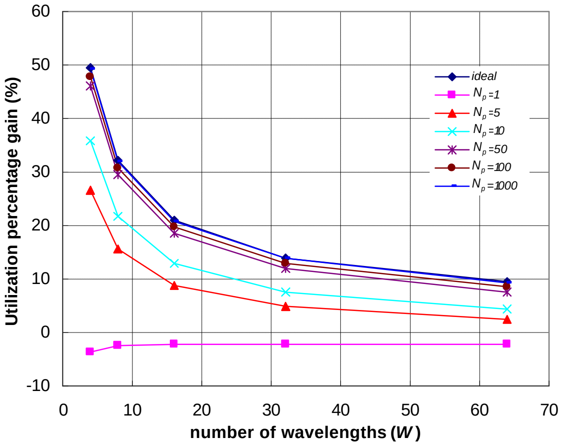

Fig. 4: Utilization percentage gain (*g*) versus the number of data wavelengths (*W*) for $P^p_{loss} = 10^{-6}$ and *N*=16

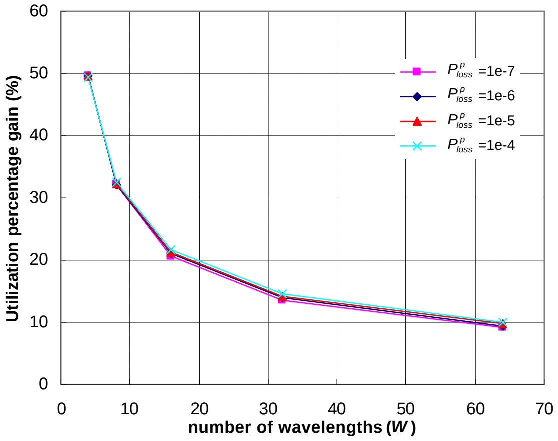

Fig. 5: Utilization percentage gain (*g*) versus the number of data wavelengths (*W*) for N_p =100 and *N*=16

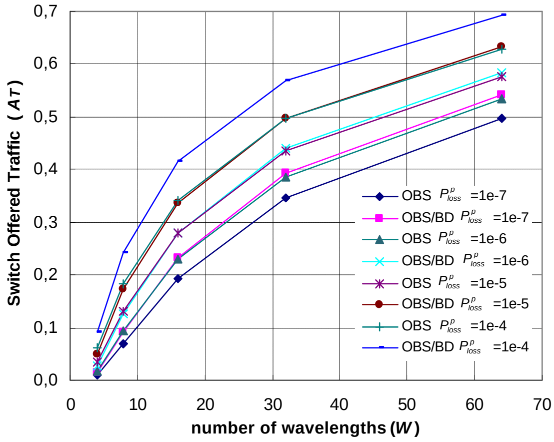

Fig. 6: Switch offered traffic (A_T), normalised *to W*, as function of the number of data wavelengths (*W*) in order to have P^p_{loss} varying from 10^{-7} to 10^{-4} for *N*=16