

A resilience-based comparative study between Optical Burst Switching and Optical Circuit Switching technologies

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ABSTRACT

Internet operators and ISP providers have traditionally designed network resources following an over-planning policy, on attempts to maintain a desired grade of service and network availability, regardless of network failures.

This work presents a comparative study of two resilience mechanisms in the design of optical networks either based on Optical Burst Switching (OBS) or Optical Circuit Switching (OCS): the M:N protection scheme with dedicated backup channels. It is further analysed and discussed the benefits and disadvantages of such mechanism based on an analytical model.

Keywords: resilience mechanisms, M:N protection, OCS, OBS, Erlang-B, Erlang-C.

1. INTRODUCTION

The fall of prices in optical devices, together with the high capacity and low bit-error rates offered by fibre optics, has made network operators and ISP providers consider optical DWDM networks as a promising future backbone technology, and triggered accordingly a new research field in the design and engineer of optical-switched based networks. Essentially, three different approaches for carrying IP traffic over DWDM networks have been proposed: the optical packet switching, optical burst switching and optical circuit switching. While the former's feasibility is still questioned, researchers have focused their attention on the other two technologies: OBS and OCS.

Optical Circuit Switching is based on establishing lightpaths between the end systems prior to any transfer of data, similarly to conventional telephony technology, while OBS proceeds rather differently. In OBS networks, ingress nodes generate optical bursts made of tens or hundreds of incoming packets, which are transmitted all-optically as a single piece of data.

Nevertheless, the use of one or another technology requires network operators and ISPs to define a set of quality of service parameters, which must be guaranteed at all times, regardless of network failure. Often, some of these parameters are a minimum offered grade of service (also referred to as GoS) and system availability. In the light of this, resilience techniques arise as fundamental mechanisms to guarantee such system availability, especially when a number of failure events occur. In the so-called deflection routing technique [5], the optical data is transmitted through an alternative path when it finds a malfunctioning node. In the technique known as 1+1 protection [6], the optical data is transmitted through two different paths, such that, it is very unlikely that both paths fail at the same time. This work considers the M:N protection scheme with dedicated backup channels, and analyses its suitability in protecting OBS and OCS networks, and compares the two optical switching approaches based on the grade of service provided and the end-to-end delay obtained when a number of failure events occur, as pointed out in [1] and [2]. These metrics are analyzed through section 2. Section 3 provides a discussion of the results obtained, followed by the conclusions in section 4.

2. ANALYSIS

This section analyses one of the main resilience techniques found in the literature, namely: the M:N protection mechanism with dedicated backup channels, and provides a framework for designing OBS and OCS protected networks. In this strategy, each optical fibre contains up to M+N wavelengths or channels, but only a subset of M wavelengths are used for conventional data transmission under normal operation. The other N wavelengths are reserved as backup channels, that is, they carry no traffic unless one or many of the primary data transmission channels are damaged or become unavailable for some reason.

The following analyses the effect produced of such failure situations in OCS and OBS networks, and presents a brief comparison study between the two technologies, based on the delay suffered by the optical data either upon burst drop (OBS) or packet waiting time in queue (OCS).

2.1 Considerations when comparing OBS and OCS

OBS and OCS networks are very different approaches for carrying data traffic though the same optical media. In OBS networks, data bursts are swiftly transmitted in the optical domain, with no queuing at intermediate nodes. As a result, the end-to-end delay is similar to the propagation delay, hence close to the theoretically minimum possible value. However, it may well occur that an optical burst finds all the switch's output channels occupied, and has to be dropped consequently. In this case, all the packets in the burst have to be retransmitted, thus suffering extra delay.

However, OCS networks behave very differently. After a lightpath is established, the optical data is transmitted through it. Incoming packets must wait in a queue before entering the E/O converter when the incoming traffic rate is higher than the outgoing traffic rate. It is worth remarking that, although no data loss occurs in OCS networks, it may well happen that packets must wait a very large amount of time at the outgoing queue.

The following analyses such blocking probability of OBS.

2.2 OBS blocking probability

In OBS networks, under the assumption of constant offset times and intermediate nodes without Fiber Delay Lines, the probability to find that all output channels are busy upon burst arrival is given by the Erlang-B formula, namely:

$$E_b(I, M) = \frac{\frac{I^M}{M!}}{\sum_{k=0}^M \frac{I^k}{k!}} \quad (1)$$

where I refers to the traffic intensity arriving at the switch in Erlangs, and M refers to the number of output data channels.

2.3 Delay upon burst loss

This section compares the delay suffered by the optical data in the two cases: OBS and OCS, especially when a number of failure events occur. Let us assume an optical fibre with $M+N$ output ports, fed with I Erlangs of traffic intensity.

In OBS networks, burst losses occur with a probability given by the Erlang-B formula above. The lost packets are recovered at the end-systems which, for simplicity, detect a packet is lost if no acknowledgement is received within a round-trip time (RTT). Then, the average end-to-end delay is given by the sum:

$$\sum_{n=0}^{\infty} \left(\frac{RTT}{2} + nRTT \right) p^n (1-p) = \left(\frac{RTT}{2} (1-p) + RTT \frac{p}{1-p} \right) \quad (2)$$

where $p = E_b(I, M)$ obtained above.

In OCS networks, since no data loss occurs, the average end-to-end delay for a packet is given by:

$$\frac{RTT}{2} + \frac{2-\rho}{2\mu(1-\rho)} \quad (3)$$

where the second value refers to the average time a data packet experiences in a M/D/1 queue fed with $\rho = I/M$ traffic and average service time μ . We have further assumed constant packet size.

3. EXPERIMENTS AND RESULTS

For the experiments in this section, we have considered an optical fibre with $M+N=64$ output wavelengths. We have computed the minimum number M of optical fibres required to provide a grade of service to OBS, i.e. $GoS=0.001$, assuming several input traffic values: $I=10, 20, 30$ and 40 Erlangs. Obviously, the number N of backup channels are the remaining wavelengths until 64 (see table 1).

Table 1. Design of M:N for a 64-wavelength optical fibre.

	Traffic I (Erlangs)	Data channels (M)	Backup channels (N)
$\sigma_{OS}=0.001$	10	21	43
	20	35	29
	30	47	17
	40	60	4

Additionally, we have assumed that end-systems are separated 20000 kilometres, which gives a value of $RTT=67ms$. Finally, the value of $\mu=0.12ms$ has also been considered, which is the time taken to transmit 1500 bytes on a 1Gbps fibre.

Assuming such values for this numerical experiment, figure 1 presents the evolution of the average end-to-end delay as obtain from equations (2) and (3). As shown, under low traffic loads, the number of backup channels is large enough to permit several failures, up to 50 failing channels. However, as the traffic load increases, a smaller number of errors may cause serious performance degradation.

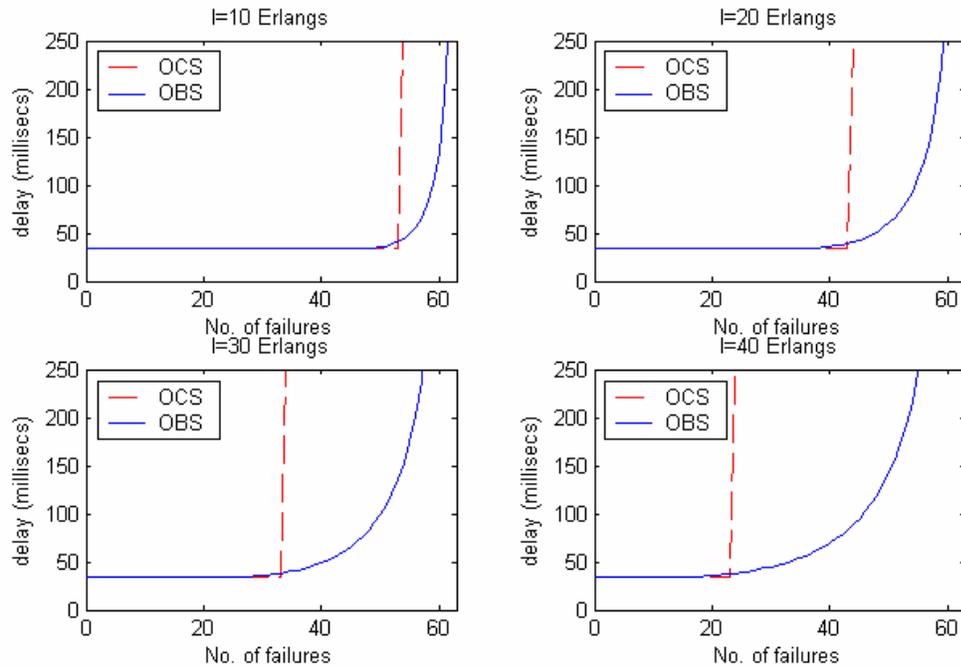


Figure 1. Delay analysis of an 64-wavelength optical fibre with M:N protection and input traffic: I=10 Erlangs (top-left), I=20 Erlangs (top-right), I=30 Erlangs (bottom-left) and I=40 Erlangs (bottom-right).

Comparing the two technologies, it is worth noticing the differences between OBS and OCS. As shown in figure 1, OCS performs similarly to OBS in a range of few failing events, i.e. less than 53 errors (top-left), less than 43 errors (top-right), less than 33 errors (bottom-left) and less than 23 errors (bottom-right). However, when the number of failures exceeds such threshold values, the performance of an OCS network degrades very significantly. Indeed, above such values, the average delay predicted by equation (3) approaches infinity.

Clearly, when a data burst arrives at a busy switch, OBS drops it whereas OCS just queues it until one channel is freed. Obviously, when the number of failing events is large, the average time spent in the queue grows very sharply in comparison to OBS. However, in OBS such growing tendency occurs only at a larger number of failures, and such tendency is not so abrupt as in OCS.

4. CONCLUSIONS

As shown in the previous experiments, the grade of service degradation in OBS has two main advantages:

- First, the knee of the average end-to-end delay curve occurs at a larger number of failures.
- Secondly, the degradation growth is much smoother than in OCS networks.

5. FUTURE WORK

There are many research avenues to pursue from this work:

1. The consideration of shared protection schemes, that is, scenarios at which the backup wavelengths are shared by several groups of primary data transmission wavelengths.
2. The analysis of shared buffer strategies in OCS, namely, several wavelength share the same input buffer. In this case, the average waiting at the queue requires a more elaborated analysis.

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