Cost-effective Burst-Over-Circuit-Switching in a hybrid optical network

Jens Buysse, Marc De Leenheer, Chris Develder, Bart Dhoedt, Piet Demeester
Research Group Broadband Communication Networks (IBCN)
Department of Information Technology (INTEC)
Ghent University/ IBBT
Gaston Crommenlaan 8 bus 201, B-9050 Gent, Belgium
jens.buysse@intec.ugent.be

Abstract

All optical switching has been proposed as a candidate to allow high capacity networking in the future. Currently, Optical Circuit Switching has been widely deployed, although this approach is potentially bandwidth-inefficient for small granularity flows and needs relatively long set-up times. Research is being done into Optical Packet Switching (OPS) and Optical Burst Switching (OBS), but these kinds of architectures are not yet able to be deployed due to the large network cost they impose. This paper tries to combine the benefits from OCS and OBS, by investigating a hybrid switching technique called burst-over-circuit-switching (BoCS) where both OBS and OCS are used at a specific part in the network. First, as short summary will be provided, categorising existing hybrid ideas. Then, a simulation study will evaluate how well BoCS performs compared to pure OBS or OCS and finally the feasibility of the proposed method will be investigated by a network cost analysis.

1 Introduction

The rapid development and deployment of fiber transmission technology and wavelength division multiplexing have made it probable that future networks will consist of some form of all-optical switching. Because of that development, transmission capacity got available in huge volumes, and it became clear that electronic processing at such line rates is very challenging. As a consequence, Optical Circuit Switching (OCS) was introduced. In OCS networks, bandwidth granularity is at the wavelength level since one or more wavelengths are allocated to a connection, while connectivity between source and destination is established using a two-way reservation. However, this form of transportation in optical networks can be very inefficient, especially in networks where applications generate bursty traffic. This is because OCS is neither sufficiently flexible nor bandwidth-efficient to support applications that require sub-wavelength bandwidth granularity in an on-demand fashion or for a short duration of time.

To tackle the problems associated with OCS, Optical Burst switching (OBS) [5] has been introduced. OBS networks can be bufferless (unlike Optical Packets Switching (OPS) [4]) and can support users with different traffic profiles by electronically reserving the necessary bandwidth on a link only for the duration of a burst.

Although OBS is a very promising technique, it is not yet ready for deployment in large networks because of the high cost of OBS-supporting switches. Research is being conducted to hybrid techniques, which combine the merits and strengths of the basic switching technologies they are composed of. This work presents an attractive motivation to deploy a form of hybrid optical switching, namely Burst-over-Circuit-Switching (BoCS), as we demonstrate that it allows important cost-savings in comparison to the single technology switching solutions.

The remainder of this paper is as follows. First we give a overview of some hybrid switching ideas. We show how BoCS performs compared to OCS and OBS by a simulation study and we finally conclude with an cost analysis that for a specified type of network, the cost of an OBS wavelength to a OCS wavelength is bound by a parameter α_{max} which in most cases is large enough to deploy BoCS in future networks.

2 Hybrid Switching

Hybrid optical network architectures try to combine two or more basic network technologies at the same time. By exploiting the merits and avoiding the disadvantages of the basic network technologies, the overall network design can be improved. In recent years, a lot of these technologies have been proposed and have led to a classification based on the degree of interaction and integration of the network technologies (see [2] and references therein for an overview):

1. client-server hybrid optical networks
2. parallel hybrid optical networks
3. integrated hybrid optical networks

2.1 Client-Server Hybrid Optical Networks

In the client-server optical network model, the circuit-switched network technology works as a server layer providing a virtual topology with light paths to a burst-switching client layer. This is depicted in figure 1. Optical burst are only switched in the client layer nodes and transparently flow in light paths through the server layer nodes. In section 3 we will investigate a form of this switching technique.

2.2 Parallel Hybrid Optical Networks

In this class of hybrid optical networks two or more optical network technologies are provided to the entity requesting the network service. When an edge node has to transport data to a certain destination, an intelligent component of that edge will employ the different network technologies individually or in combination to optimally serve the customer service requirements. This type of parallel hybrid network architectures only expects the edge nodes to be aware of the different network technologies. The intermediate core nodes only switch according to their respective switching technique without inspecting the packets inside the light path, in contrast with the next class. Note that the two layers can physically overlap or even coincide, e.g. with collocated OBS and OCS switches sharing the same fiber infrastructure. On a logical level however, OBS and OCS switches are unaware of each other, and the choice between them is made solely at entry point of data units at the network edge.

2.3 Integrated Hybrid Optical Networks

In the last category the different basic technologies are integrated into one. As a result, all the network technologies share the same bandwidth resources in the same network at the same time and traffic is either transported in wavelength-switched or in burst-switched mode. In contrast to parallel hybrid optical networks where the switching decision is made at the edge, each node can choose to do two things:

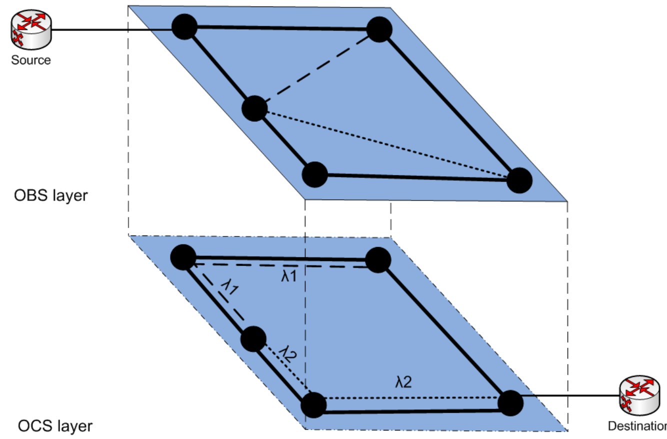


Figure 1. A client-server hybrid optical switching architecture. The OCS layer presents a virtual topology to the OBS layer where the circuits in the OCS topology are observed as physical links.

1. Opt to use a given wavelength segment as part of a predetermined wavelength path and send the traffic wavelength switched.
2. Ignore the established circuits and pass the traffic to a neighboring node using OBS.

Choosing between the two views is done on the fly and possibly on a packet to packet basis. Both modes can even share the same physical wavelengths, but this calls for appropriate markers and adapted hardware [6]. Choosing not to use the created circuit can for example be appropriate in case of congestion. The node can then dynamically choose to transfer the data packets using another route using OBS. Alternatively, the choice between the two modes, can also be motivated by QoS differentiation, e.g., wavelength-switched for high priority traffic.

3 Analysis

3.1 Case study

The lack of attention to the dynamics of OBS can lead to severe service degradation in terms of packet loss and congestion in some parts of the network. But on the other hand, by continuously keeping optical circuits alive for every connection between a source and a destination node, the network resources cannot reach their full potential. The goal of this paper is to investigate how the introduction of circuits (and therefore change over to a hybrid optical switching technique) into the core of the network influences the network resources. We have implemented a form of the client-server hybrid optical technology: burst-over-circuit switching. This technique has OCS as the server- and OBS as the client technology. When computing a path from a source node to a destination node, the shortest path is calculated in the virtual topology presented to the client layer, where circuits are observed as one edge while they physically consist out of a consecution of links.

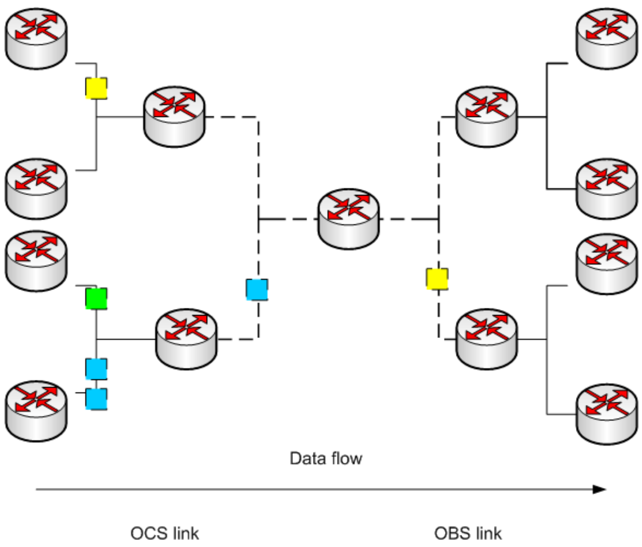


Figure 2. A H_1^4 topology. Each sub tree has 4 leaf nodes and circuits are put in the core of the network on the first pair of links starting from the core switch.

3.1.1 Setup

The network topology which we have considered consists of two binary-tree topologies of switches which are linked together by sharing the same root node. This type of network is representative for access/aggregation-type networks (e.g. PONs), while the center nodes are an abstracted form of the edge and/or core networks. The leaf nodes of the former tree create data, which has to be conveyed to the leaf nodes of the latter tree. The edge nodes use OBS as switching technology until a certain depth into the tree has been reached, where the switch aggregates the bursts and starts to send using OCS. In the remainder of this paper we will address a topology with n leaf nodes and which has circuits starting from depth X in the tree as H_X^n. An example of a H_1^4 topology is presented in figure 2.

3.2 Burst Loss

In order to evaluate the hybrid switching technique, we have constructed a simulator as part of a work package of the Phosphorus project [1]. The simulation actually represents a Grid architecture supported by an optical network.

Table 1. Table showing the different symbols and parameters

Parameter	Info
λ	The interarrival rate of the process of creating data packets.
μ	The processing power of a wavelength on a link
H_X^n	A topology with n leaf nodes for each tree and circuits starting from depth X
ω	Number of wavelengths per fiber
K_n	Cost for the entire network
K_c	Cost per circuit wavelength
K_o	Cost per obs wavelength
No	Number of necessary OBS wavelengths in a H_0^n
Nc	Number of necessary circuit wavelengths in a $H_{\log_2 n}^n$
N_c^h	Number of necessary circuit wavelengths in hybrid case
N_c^h	Number of necessary OBS wavelengths in hybrid case
L	The length of the path a burst follows
η	The number of places on a path where blocking can occur
ρ	The load on a link. $\rho = \frac{\lambda}{\mu\omega}$

Client nodes, which are in this case the leaf nodes of one sub tree, generate jobs which follow a Poisson process with an inter arrival rate λ. The data sizes of the jobs are also distributed as a Poisson process. These jobs are stuffed into an OBS packet and are send to a resource node, which is situated at some leaf node of the opposite tree. These jobs are scheduled using a round-robin scheduler. Hence, we acquire a complete symmetrical case in every extent: every client has the same arrival rate, every link on a degree in the tree has the same amount of wavelengths and every destination (resource nodes) receives an equal part of the jobs.

The topology we have taken into consideration is a H_x^{16} network where x ranges from 0 (complete OBS network) to 4 (complete OCS network). What we expect is that the H_0^{16} topology will have the least amount of burst losses due to the statistical multiplexing property, in contrast to the H_4^{16} counterpart which should have a much larger burst loss that can be calculated using the well-known ErlangB formula. The H_x^{16}, with $x \in [1..3]$, burst loss rate should lie in between. This is exactly what our simulator demonstrates us and is portrayed in figure 3 where the burst loss percentage is shown in function of an increasing load $\rho = \frac{\lambda}{\mu\omega}$.

From figure 3 we can see that the difference between H_n^{16} burst loss and H_{n+1}^{16} burst loss, rises with increasing n. This makes us conclude that the impact of OCS introduction into the core is not that large on burst loss when keeping the introduction insertion level x of H_x^{16} low.

Moreover we can make a mention that with a rising load the burst loss for every switching technique converges to a same fixed point. This leads us to the conclusion that a network should employ enough bandwidth, because the otherwise most expensive H_x^{16} shall perform almost even abominable as a cheaper H_y^{16}.

When the load is rather low ($\rho \leq 0.6$), H_0^{16}, H_1^{16} and H_2^{16} are very close together which means they almost perform as well as a complete OBS network i.e. the H_0^{16}, which is the lower bound for every other switching approach.

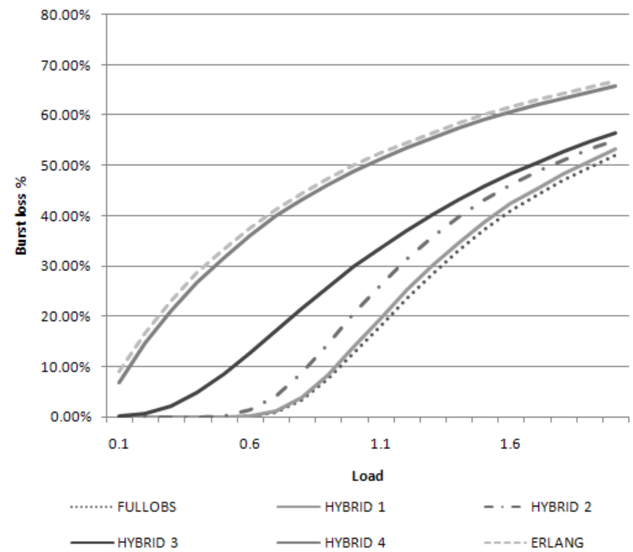


Figure 3. OBS blocking for the different switching techniques

3.3 Network Capacity

An important aspect of a switching technology is the allocation of network capacity to transfer data to and from end nodes, given a specified maximum loss rate. It is obvious to see that OBS will need fewer wavelengths than OCS due to the statistical multiplexing property. In what follows we will calculate how much wavelengths are needed per link for a certain H_X^n topology and show that we can optimize the network cost by using burst-over-circuit switching.

3.3.1 Bandwidth calculation for H_0^n

The probability that a burst is dropped in the network (P_d) is given by equations 1 and 2 where δ is the uniform burst drop probability per location where a burst drop event can take place and L is the length of the path from source to destination. The number of position on the path where a burst can be dropped is η.

$$\eta = L \tag{1}$$

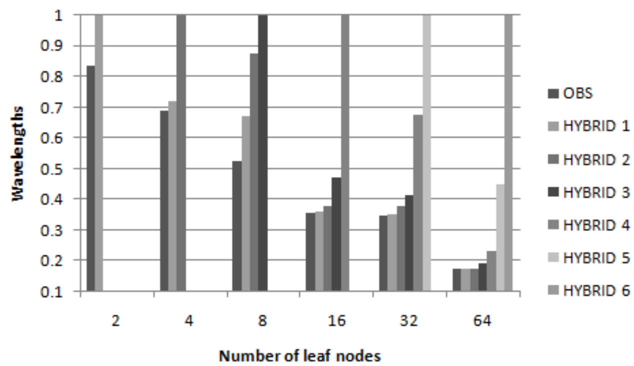
$$P_d = 1 - \prod_{1}^{\eta}(1-\delta) \tag{2}$$

This formula gives us a non-linear equation which we can solve for δ. Consequently, the individual link blocking probability δ can be modeled by the Erlang B formula (3). This is based on the assumption that jobs are generated following a Poisson process as is also the case for the data size of these jobs. Now we can use numerical methods to solve the ErlangB formula equal ing a target δ for its parameter λ, as expressed in Eq. 4. Also note that blocking of a switch is independent from all the other switches.

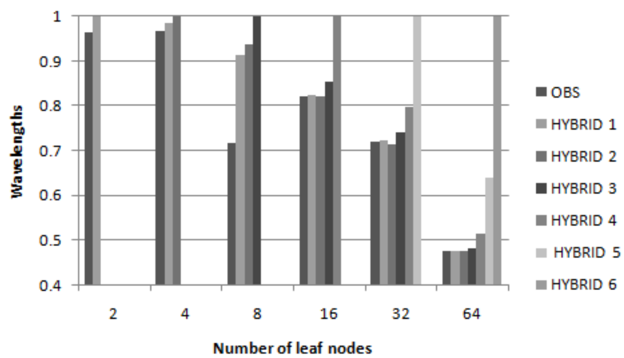
$$ErlangB(\lambda, \mu, \omega) = \frac{\frac{\lambda}{\mu}^{\omega}\omega!}{\sum_{i=0}^{\omega}(\lambda/\mu)^i/i!} \tag{3}$$

$$ErlangB(\lambda_i, \mu, \omega) = \delta \tag{4}$$

From equation 4 we find λ_i. This is the rate parameter for the expected number of burst arrivals for the ith switch on the path from a client- to a resource node. When the number of wavelengths of the previous link is estimated,



(a) $\lambda = 10$



(b) $\lambda = 100$

Figure 4. Number of wavelengths needed for every switching technique, relative to the total number of wavelengths needed when deploying only pure OCS.

we can compute a new inter arrival time λi by equation (5) and (6) as a result of the symmetry of the network.

$$ArrivalRate(\lambda, \mu, \omega) = 2(1 - ErlangB(\lambda, \mu, \omega))\lambda \quad (5)$$

$$\lambda_i = ArrivalRate(\lambda_{i-1}, \mu, \omega), \lambda_0 = \lambda_{clientnode} \quad (6)$$

This process is repeated, until we find all the wavelengths per link. This idea of estimating the net arrival rates based on loss rate estimates on previous links is known as a reduced load model [3].)

3.4 Bandwidth Calculation for H_X^n

This computation differs from 3.3.1 because we have to incorporate the blocking events which are deserved by the circuits. When the circuit is inserted at level X, the number of possible places where a burst can be dropped becomes:

$$\eta = L - X + 1 \quad (7)$$

With this η we can compute δ out of equation (2). The number of wavelengths per OBS link follow from equation (4). When the algorithm arrives at the beginning of the circuit, the number of wavelengths ω for that link follows out of equation (8) and (9). This is because we have to calculate the number of wavelengths per destination.

$$ErlangB(\frac{\lambda_i}{2^X}, \mu, \hat{\omega}) = \delta \quad (8)$$

$$\omega = 2^X * \hat{\omega} \quad (9)$$

3.5 Discussion

In figure 4 we see the number of wavelengths each switching technique requires relative to the total number of wavelengths which are needed in the $H^n_{\log_2 n}$ case. We can see that the difference between the switching techniques plunges when the network gets larger. This conclusion is of value to the minimization of the overall network cost. The overall network cost K_n is given by (10) where K_c is the cost per circuit wavelength, K_o is the cost per OBS wavelength, N_c is the number of circuit wavelengths and finally N_o is the number of OBS wavelengths.

$$K_n = K_c N_c + K_o No \quad (10)$$

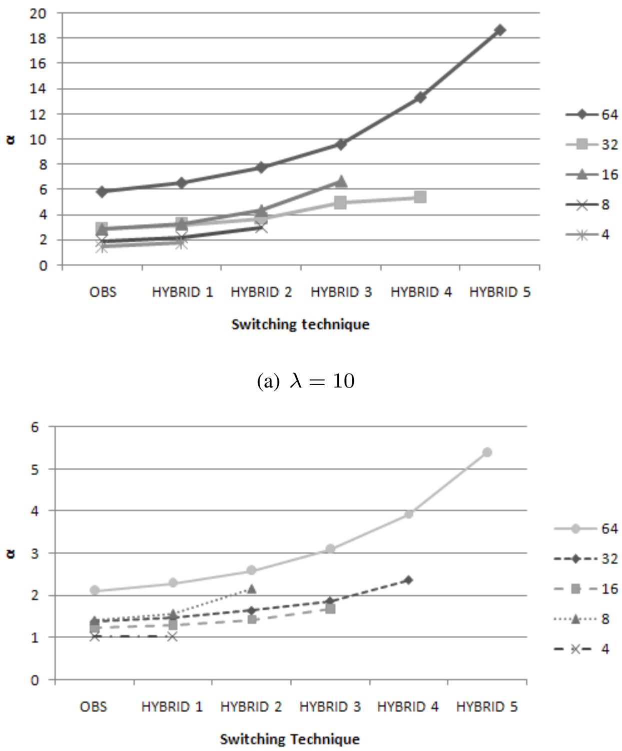
If we want that the hybrid switching is cost-effective than (11) should be satisfied.

$$K_c N_n \geq K_c N_c^h + K_o N_o^h \quad (11)$$

Hence, if we define α as $\frac{K_o}{K_c}$ then equation (12) should be satisfied for a hybrid approach to be cheaper than the pure OCS one. Note that OBS switching (at least with the current state-of-the art) is more expensive than OCS, so realistic values satisfy $\alpha > 1$.

$$\alpha \leq \alpha_{max} = \frac{N_n - N_c^h}{N_o^h} \quad (12)$$

Let us discuss figure 4(b) for example. We see that α increases with the level of circuit introduction. This lets us conclude that the relative cost of an OBS wavelength to an OCS wavelength can be larger with increasing circuit introduction. Or in other words the cost of an OBS wavelength can be maximum $\alpha \times K_o$ for a specified network and switching technique, to have the same burst loss rate. In graph 5(b) one can see that the development of a H^4_{64} topology the cost of an OBS wavelength is constrained by formula 13.



(a) $\lambda = 10$

(b) $\lambda = 100$

Figure 5. α_{max} computation for the different networks.

$$K_o \leq \alpha_{max} K_c, \alpha_{max} = 3.9 \tag{13}$$

For a known cost ratio α of OBS versus OCS switching, this study allows to find the BoCS variant which is cost-effective compared to pure OCS. The results show that hybrid approaches adopting an OBS/OCS combination have a larger margin to pure OBS: as long as the OBS technology does not mature and approaches OCS costs, a combination of OBS and OCS is advisable.

4 Conclusions

Hybrid optical network architectures, which combine two or more basic switching technologies, constitute a promising technique to optimize the overall network design. In this paper, a simulation analysis was used to evaluate one form of hybrid optical switching, namely burst-over-circuit switching. Results showed that depending on the expected load generated at the edge of a network, BoCS can be an attractive technology compared to the pure OBS and OCS alternative. Finally, we have conducted an analytical network dimensioning study which concluded that for a specified type of network, the cost of an OBS wavelength to a OCS wavelength is bound by a parameter α_{max} which in most cases is large enough to deploy BoCS in future networks. For the considered case study, we showed that as long as OBS switching costs are considerably more expensive than OCS, a hybrid BoCS approach is most cost effective.

The work described in this paper was carried out with the support of the BONE-project (Building the Future Optical Network in Europe), a Network of Excellence funded by the European Commission through the 7th ICT-Framework Programme, as well as the IST Phosphorus-project. The Flemish government partly funded this work through the Research Foundation (FWO). C. Develder is a post-doctoral fellow of the FWO.

References

[1] Phosphorus. http://www.ist-phosphorus.eu/.

[2] C. Gauger, P. Kuhn, E. V. Breusegem, M. Pickavet, and P. D. ". Hybrid optical network architectures: bringing packets and circuits together. *Journal of High Speed Networks*, 44:36– 42, august 2006.

[3] M. D. Leenheer, C. Develder, F. D. Turck, B. Dhoedt, and P. Demeester. Erlang reduced load model for optical burst switched grids. In *ICNS '07: Proceedings of the Third International Conference on Networking and Services*, page 117, Washington, DC, USA, 2007. IEEE Computer Society.

[4] M. O'Mahony, D. Simeonidou, D. Hunter, and A. Tzanakaki". The application of optical packet switching in future communication networks. *IEEE Communications Magazine*, 39:128–135, March 2001.

[5] C. Qiao and M. Yoo". Optical burst switching (obs) - a new paradigm for an optical internet. *Journal of High Speed Networks*, 8:69–84, 1999.

[6] E. Van Breusegem, J. Cheyns, D. De Winter, D. Colle, M. Pickavet, F. De Turck, and P. Demeester. Overspill routing in optical networks: A true hybrid optical network design. 2006.