# Performance Analysis of Hybrid Optical Networks (OCS/OBS) considering the Time Period to Successfully Deliver a Data Flow

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***Abstract*— This paper presents a performance evaluation study that compares Optical Circuit Switching (OCS), Optical Burst Switching (OBS) and OCS/OBS networks. This study considers two types of traffic flow, long (5GB) and short (50MB). The main contribution of this paper is comparing such switching paradigms in terms of the time to successfully deliver a flow. Besides, we identify the problem of blocking due to outdated information when OCS network works under short data flow.**

***Keywords-All-Optical Networks; WDM; Simulation Tool.***

## I. INTRODUCTION

The popularity of the Internet and the emergence of sophisticated applications are demanding more bandwidth in transport network links [1]. Figure 1 shows the average annual growth rate of international Internet traffic between 2007 and 2011. In 2010-2011, for example, the average Internet traffic growth was 47%. Applications involving voice, video-on-demand, teleconferencing, high-resolution medical imaging and e-science applications have increased the bandwidth demands in transport networks. In general, these sophisticated applications need to transfer large volumes of data under high Quality of Service (QoS) requirements.

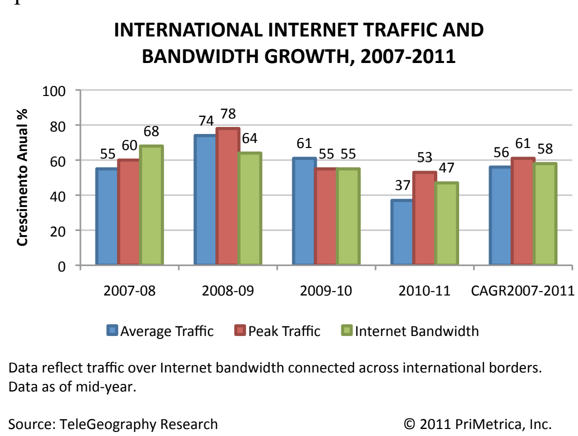


Figure 1. Average annual growth of international Internet traffic between 2007 and 2011. Adapted from [2]

A new generation of networks is based on an optical infrastructure that has been developed to support the growth of Internet traffic. This infrastructure uses optical fibres, which are mainly characterised by their ability to provide high bandwidth and their immunity to noise and electromagnetic interference. The use of this new material is justified by the existing infrastructures incapacity to efficiently serve a growing number of users and sophisticated applications. The use of Wavelength Division Multiplexing (WDM) can increase the efficient use of bandwidth in optical fibres [3]. With WDM technology, it is possible to establish multiple optical channels working at different wavelengths simultaneously in a single optical fibre.

WDM optical networks can be classified as opaque or transparent. In a transparent optical network, intermediate nodes transmit signals without converting them to electronic impulses. Opaque optical networks perform wavelength routing in the electronic domain. Therefore, each network node must convert the optical signal into an electrical signal and vice versa. Opto-Electro-Optical (OEO) converters are needed to convert the signal. The disadvantage of OEO converters is that they introduce processing delays. In transparent optical networks, wavelength routing is performed in the optical domain and does not require OEO converters, eliminating this limitation [3].

In general, the available methods for data switching in transparent optical networks are: Optical Circuit Switching (OCS), Optical Packet Switching (OPS) and Optical Burst Switching (OBS). In addition, there are hybrid architectures that combine these existing paradigms.

To transfer information in transparent optical networks, it is necessary to define a route and to assign a wavelength to each route's link. This is known as the Routing and Wavelength Assignment (RWA) problem. RWA algorithms aim to simultaneously minimise the blocking probabilities of circuits, bursts and packets [4], [5].

This paper presents a performance evaluation study of OBS, OCS and hybrid OBS/OCS network. The main contribution of this paper is comparing such switching paradigms in terms of the time to successfully deliver a flow. Besides, we identify the problem of blocking due to outdated information when OCS network works under short data flow. The remainder of this paper is organised as follows. A description of switching paradigms is presented in Section II. The TONetS simulator is

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presented in Section III. How the switching paradigms function is discussed in detail in Section IV. Section V reviews relevant literature. Sections VI and VII present our results and conclusions, respectively.

## II. SWITCHING PARADIGMS

The most important feature of the OCS paradigm is the reservation of resources (wavelengths) in the establishment phase of the optical circuit (lightpath) [5]. The source node sends a control message before sending the data. This message aims to reserve the necessary bandwidth and configure the optical cross-connect (OXC) along the data's route. The data are sent only after the source node receives a confirmation message that bandwidth has been reserved. OCS systems allow resource reservation with high QoS, but they are not very efficient for short communications.

The OPS paradigm is the least developed of the three switching strategies [6]. OPS is a more efficient alternative when traffic is characterised by a high rate of change in the presence of data packets of variable lengths. OPS switching does not use resource reservation, making it difficult to guarantee QoS in this paradigm. Due to limited progress in processing and optical storage, we consider this technology insufficiently mature.

The OBS paradigm uses optical bursts. A burst is a set of data packets sent to the same destination [7]. In an OBS system, a control message is sent before the burst to try to reserve the necessary bandwidth and configure the OXCs along the route. However, OBS does not wait for a message to confirm the reservation of resources. The optical burst is sent without a guarantee of successful resource allocation.

The literature addresses OBS as a flexible alternative suitable for transporting small volumes of traffic through a transparent optical network [7], [8]. This alternative is more appropriate for scenarios that require less rigorous QoS. By using bursts, it is possible that a given data flow will exceed the maximum size of the burst. When this occurs, the flow is fragmented and sent in several separate bursts. This requires a control message for each burst, and may cause signalling overhead.

Hybrid optical switching (OCS/OBS) is an alternative switching paradigm that allows OCS or OBS in the same network infrastructure. Previous research has addressed the mechanism required to decide which switching strategy should be used to serve a given request in this type of switching architecture [9], [10]. In a scenario with several different classes of users, a service provider should be able to offer differentiated services. That is, a WAN service provider must have the ability to provide services with higher or lower levels of QoS that approximate actual demand.

Under heterogeneous scenarios, OBS is thought to be a good alternative for short-term network services, while OCS should be used for long-term network services. In this scenario, given the different characteristics of circuit switching and burst switching, a hybrid OCS/OBS network should be the optimal solution for a diverse set of users. Users with high QoS requirements can use the dynamic provisioning of circuits, while users who demand small volumes of data can use the OBS switching service.

This work focuses on a hybrid network that allows circuit switching or burst switching within the same network. Our study simulates the performance of a hybrid OCS/OBS switching architecture.

## III. TONETS

The TONetS (Transparent Optical Network Simulator) simulation tool is a discrete event simulator developed in the Java programming language. TONetS was integrated with OB2S [8]. Both simulators were developed for specific switching technologies. The former simulates OCS networks, and the latter simulates OBS networks. We used the following metrics present in TONetS to assess performance:

- Blocking probability: the probability that a given request arriving in the optical network is blocked.
- Blocking probability due to outdated information: also called backward blocking [11]; the blocking of a request due to outdated network state information. This occurs when a request notes that a wavelength is free, but in the time required to perform the allocation, the resource is assigned to another request.
- Queue time: the time that a request spends in the queue of blocked requests waiting to be sent.
- Signalling time: the time spent on signalling messages in the control plan before actual data transmission.
- Successful delivery time: the time between the arrival of a data flow in the optical network and the instant that flow is transferred successfully. This time is the sum of the Queue Time, Signalling Time and Transmission Time.

## IV. SWITCHING PARADIGMS PRESENT IN THE SIMULATOR

### A. OCS

To establish a connection between two nodes in an OCS network, the required resources (wavelengths) must be reserved for the selected route. Signalling messages are sent through the control plane to reserve these wavelengths. Each node in the route processes these messages. Figure 2 shows the OCS control plane procedures.

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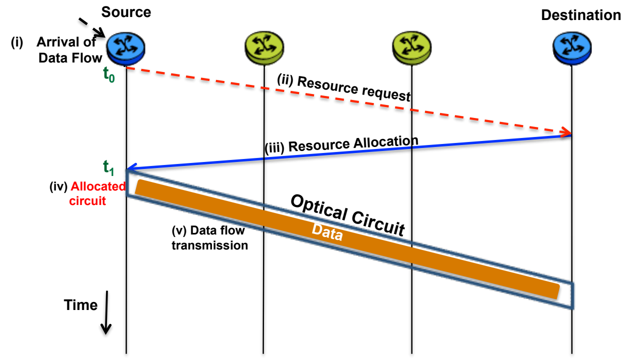


Figure 2. OCS Control Plane

With the arrival of a circuit request, the source node sends a control message requesting the reservation of resources. Each node in the route receives this message, processes it, and forwards the control message requesting resources to the next node in the route. When the message reaches the destination node, this node runs the wavelength algorithm, sets up its OXC, allocates the wavelength in its link, and then sends back a reserve message to the other nodes in the route, in reverse order. In the backward direction, each node receives the message, processes the message, sets up its OXC, allocates one wavelength and sends the message to the preceding node. This process is repeated until the source node receives the reserve message and configures its OXC. After this establishment process, the circuit is ready to transfer the data flow.

### *B. OBS*

In an OBS, the source node first assembles the burst. The burst contains packets that arrive at a given source node of the OBS network. These packets come from access networks (i.e., the client networks of an OBS network). One burst can only contain packets with the same destination node. In addition to building bursts, the edge node must be able to disassemble bursts. The data from the disassembled bursts are forwarded to access networks across the optical network.

The OBS that we implemented in TONetS takes into account two signaling protocols, JIT (Just in Time) and JET (Just Enough Time) [12]. A signalling protocol defines how message exchanges are made and when the allocation and release of resources occurs. In this simulation, the JIT signaling protocol is used for OBS switching. It uses explicit allocation and implicit resource releasing (i.e., a node does not have to wait for a control message to know when to release a resource). The node itself can predict when to release the resources because the control message contains the size of the burst to be sent.

In OBS, a peculiarity occurs when the data flow that will be sent exceeds the maximum size of the burst. In this case, the data flow must be fragmented into several bursts, which are sent individually. However, in OCS the data flow is not fragmented. In our OBS model, the data flow is fragmented, and its packets are mounted in several bursts. Therefore, a signaling message is required in the OBS, as shown in Figure 3.

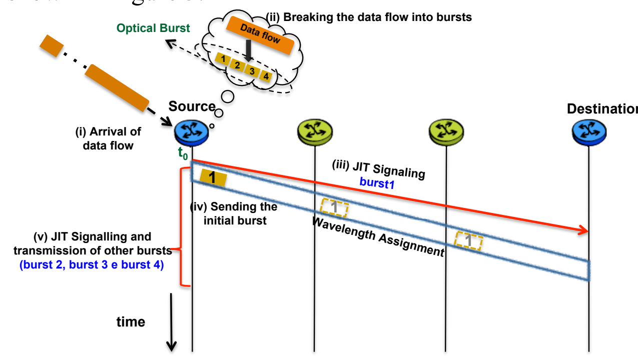


Figure 3. The fragmentation of a data flow into burst

### *C. Hybrid OCS/OBS Network*

The hybrid network implemented in our simulation is similar to the parallel architecture presented in [13]. The edge node of the network classifies the data flow as long or short. Long flows are sent using the OCS paradigm, and short flows are handled by the OBS paradigm. However, in our parallel architecture model, the OBS and OCS paradigms share resources, aiming for better network utilisation.

## V. RELATED WORKS

Several studies have been carried out comparing the performance of OCS and OBS paradigms without a hybrid model [14], [15], [16], [17], [18].

J.P. Jue and V.M. Vokkarane [14] evaluated these two switching paradigms taking into account three metrics: the blocking probability, the throughput and the recurrent blocking probability of a given request (circuit or burst), i.e., the probability that a request is blocked more than once.

A. Zalesky [15] proposed an analytical model to study a queuing scenario. After analysing OCS and OBS paradigms with regard to blocking probability, queue delay and network utilization, the authors concluded that future transparent optical networks must use hybrid approaches to achieve a better utilisation of network resources.

The study presented in [16] performed a network utilisation analysis comparing an OCS network with three different approaches to OBS networks: a pure OBS strategy, OBS considering wavelength conversion and a last variation that considers both load balancing and wavelength conversion. The authors concluded that more research was needed to determine the appropriate paradigm for a variety of traffic conditions and available network resources.

Liu Xin, Qiao Chunming, Yu Xiang and Weibo Gong [17] investigated the rates of packet delivery and packet loss of OCS and OBS paradigms. In [18], the authors compared the financial costs of the OBS and OCS

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networks equipment needs. The comparisons took into account the cost-effectiveness of these networks.

With regard to hybrid optical networks, C.M. Gauger, P.J. Kuhn, E.V. Breusegem, M. Pickavet and P. Demeester [13] proposed a classification, dividing hybrid networks into three types: client-server, parallel and integrated. The authors presented a client-server architecture and an integrated architecture. In [9] and [19], the authors presented parallel hybrid architectures.

Yeshuang Wang and Sheng Wang and Shizhong Xu and Xiufeng Wu [20] created a model for hybrid architecture and conducted a simulation of this architecture type. Compared with the OCS paradigm, the proposed hybrid model had the worst performance in regard to the time for a successful delivery. P.S. Khodashenas, J. Perelló, S. Spadaro, J. Comellas and G. Junyent [21] presented a different hybrid architecture, and a study of its financial cost and burst loss rate. We observed that the literature shows a deficiency of papers in which it is advantageous to use hybrid architecture.

Additionally, no studies were found that compared a hybrid paradigm to both the OCS and OBS paradigms regarding the successful delivery time of a data flow. It is noteworthy that this metric is relevant to the network user. Therefore, this paper presents a simulation comparing a hybrid architecture with the OCS and OBS paradigms regarding the time to successfully deliver the data flows.

## VI. PERFORMANCE ANALYSIS

The experiments were carried out using the NSFnet topology, illustrated in Figure 4. Traffic is uniformly distributed between all source-destination node pairs. The request generation algorithm is a Poisson process with average rate $\lambda$, and the circuits' average hold time is exponentially distributed with the mean $1/\mu$. The network´s traffic intensity in Erlangs is given by $\rho = \lambda / \mu$. All links in the network are bi-directional and have 40 wavelengths in each direction. A randomisation algorithm is used for wavelength assignment. The maximum burst size is 250 MB.

For each simulation study in this article, 10 replications are performed with different, randomly generated, variable seeds, and 100,000 requests are generated for each replication. The graphical results present the confidence intervals evaluated at the 95% confidence level. Although confidence intervals have been plotted on all graphs in this article, they may be so small that they are hardly visible.

We assume a scenario with full wavelength conversion [4]. Therefore, it is not necessary for the assigned wavelength to be the same along the whole light path. We also considered the use of request queues. When a request is blocked (because no resources are available), the request is queued to be sent later when resources are available.

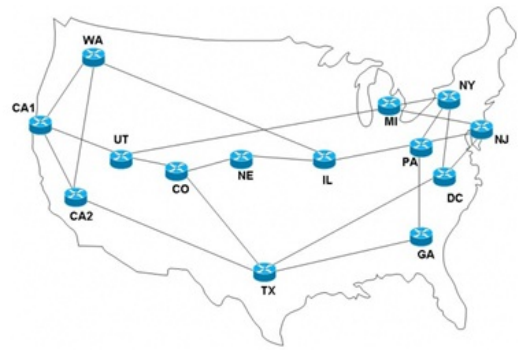


Figure 4. NSFnet Topology.

Figure 5.a shows the performance of OBS and OCS networks in terms of successful delivery time in a scenario with small data flows (50 MB). Figure 5.b shows the components of blocking probability (absence of resource and outdated information) when the network uses OCS technology.

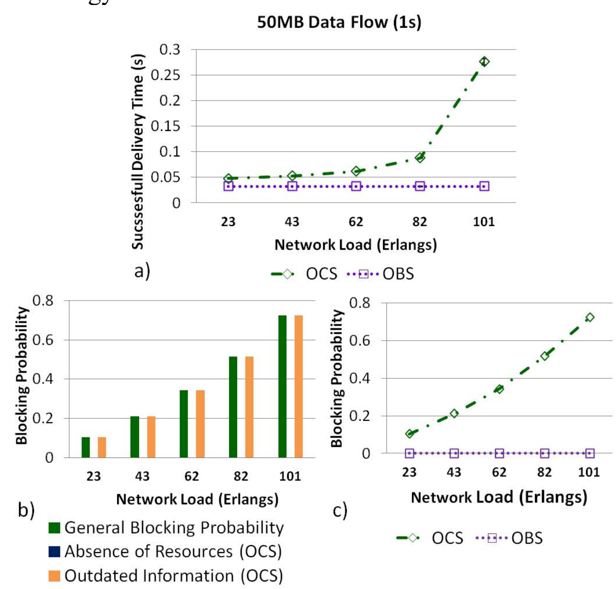


Figure 5. a) Time to successful deliver a flow of 50 MB. b) OCS Blocking Probability components of flows of 50 MB. c) OCS and OBS Blocking Probability under flows of 50 MB.

The OBS paradigm achieved better performance than the OCS paradigm when dealing with short data flows. The OBS paradigm delivery time also showed low growth as the network load increased compared to the OCS paradigm.

Of note in Figure 5.a is the worsening performance of OCS when the network load increases. In those cases, we incremented the request rate (λ) to increase network load ($\rho = \lambda / \mu$) because the average hold time must be proportional to 50 MB ($1/\mu = 0.01$ seconds). Therefore, when the request rate increases, the variability of the network resources also increases. This behaviour causes blocking due to outdated information in the network. The frequent changes in the state of the network promoted by short data flow ends up generating a high probability of blocking due to outdated information concerning the state of the network. In fact, in these instances the network has available resources, but outdated information in the control plan causes blocking as shown in Figure 5.c. Blocked requests increase the average queue time, and consequently increase the successful delivery time.

Figure 6.a presents, for the same metric, the performance of OBS and OCS working with a long data stream (5GB). Figure 6.b depicts the blocking probability for each kind of switching paradigm (OBS and OCS) for the same scenario of Figure 6.a.

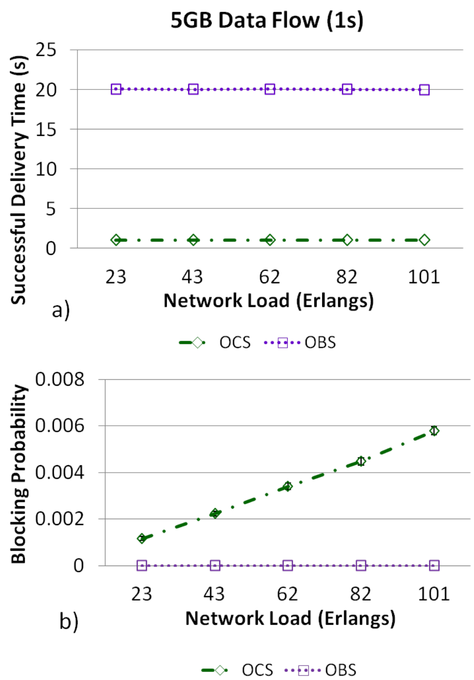


Figure 6. a) Time to successfully deliver a flow with an average duration of 1 second (5 GB). b) Blocking Probability in an OCS network.

For scenarios with an average flow under 5 GB, the OCS achieved better delivery time than the OBS paradigm. OBS must fragment the data when the flow is greater than the maximum burst size. For example, assuming the maximum size of the burst is equal to 250 MB, one flow of 5 GB must be fragmented into 20 bursts. As a result, one control message must be generated for each burst. Consequently, those control messages increase the overhead and the successful delivery time. For example, Figure 6.a shows that one flow of 1 second using OBS requires 20 seconds to be delivered successfully.

Although the OCS network presents a blocking probability worse than OBS (Fig. 6b), its performance in terms of time to successfully deliver a flow was better (Fig. 6a). In this situation, it is more relevant for the users the time to successfully deliver a flow. This behaviour showed that is important to study the time to successfully deliver a flow besides the blocking probability.

The frequency of state change in the network resources is very low under the traffic load considered, and with an average data flow of 5 GB. In this context, the blocking probability due to outdated control plan information is low, up to 100 times smaller than the blocking observed in Figure 5 scenario. Proportionally, the OCS paradigm performed better with data flows of 5 GB than with flows of 50 MB. In other words, the OCS paradigm performs better with long data flows. Previous studies indicate that the lower the duration of the circuit, the greater the likelihood of blocking due to outdated information [12].

Figure 7 illustrates the results for OCS, OBS and the hybrid (OCS/OBS) networks when subjected to two types of flow simultaneously. That is, when each node in the network generates 50% long flows and 50% short flows.

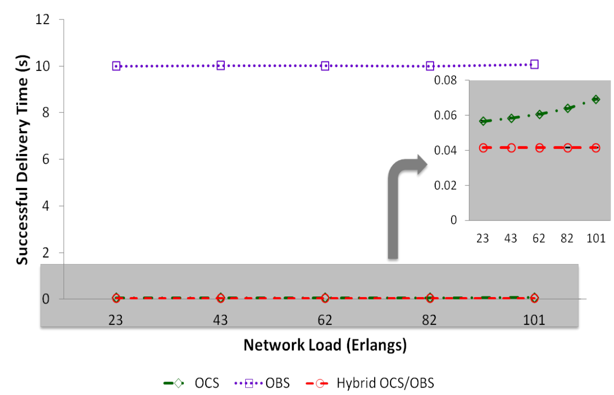


Figure 7. Successful delivery time in a OCS, OBS and Hybrid OCS/OBS network subjected to two types of flows.

The OCS network obtains a lower delivery time than OBS network. We believe that, in this scenario, the impact of signalling overhead in OBS was greater than the impact of blocking due to outdated information in OCS. For the hybrid network, we assume that the short flow is sent through OBS and the long flow is sent through OCS.

Figure 7 shows that the hybrid network delivery time is just above 0.04s. At first glance, this result might seem counter-intuitive given the fact that the OBS results in Figure 5.a are close to 0.04s while the OCS minimum time in Figure 6a is about 1 second. However, this occurs because the arrival rate of bursts is several times bigger than the arrival rate of circuits.

This simulation study increases the network load keeping the hold times ($1/\mu$) equal to 0.01s and 1s for short and long flows, respectively. Besides, both flows generate the same network load. Therefore, the arrival rate of the OBS flow is 100 times bigger than OCS flows. The simulation results regarding the hybrid network delivery time can be verified by the following equation:

$$T = \frac{N_{OCS} * T_{OCS} + N_{OBS} * T_{OBS}}{N_{OCS} + N_{OBS}}$$

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$T$ is the hybrid paradigm delivery time, $T_{OCS}$ is the OCS delivery time, $T_{OBS}$is the OBS delivery time and $N_{OCS}$ and $N_{OBS}$ are the OCS and OBS number of requests respectively. Replacing $T_{OCS}$ for the value from Figure 6.a (1s), $T_{OBS}$ for the value from Figure 5.a (aprox. 0.04s) and $N_{OCS}$ and $N_{OBS}$ for 1 and 100 respectively the resulting delivery time is similar to the results shown in Figure 7.

By weighting OCS and OBS delivery time in terms of their number of requests, the OBS delivery time had more impact the hybrid network delivery time which in turn presented a result just above 0.04 seconds.

The study showed that the hybrid (OCS/OBS) network obtained the best performance in terms of successful delivery time when compared with OCS and OBS networks.

## VII. CONCLUSION

This paper presented a performance evaluation study, carried out via simulation that investigates the efficiency of a hybrid OCS/OBS paradigm. As shown in Section VI, our hybrid network presented a shorter successful delivery time than the traditional OBS and OCS paradigms.

The distinct behaviour of the OBS and OCS paradigms allows the hybrid OCS/OBS network to use the strengths of the two switching paradigms and enables it to succeed with a diverse set of users.

## VIII. ACKNOWLEDGMENT

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