A HYBRID ARCHITECTURE USING BOTH OPTICAL BURST SWITCHING AND ROUTED WAVELENGTH

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ABSTRACT

The development of wavelength division multiplexing opens a new horizon in optical networks and promises to be one of the best solutions for the high demand of the bandwidth. However, with this technology, many problems arise, especially those related to the architecture to be used in optical networks to take advantage of the huge potential of this technique. Many approaches and architectures have been proposed in literatures to carry information in optical domain. Among them, optical burst switching and wavelength routed network seems to be the most successful. In this work we present a brief description of these two techniques, we discuss the advantages and disadvantages of each scheme, and we furthermore propose a new architecture that uses both methods in order to overcome the limitations imposed by each approach.

KEY WORDS
Burst switching, virtual topology, reconfiguration.

1. INTRODUCTION

With the progress and the development being made in wavelength division multiplexing (WDM), optical networks seem to be one of the best solutions to increase the bandwidth and face the increasing demand for high traffic. WDM is a fiber-optic transmission technique [1,2] that consists on multiplexing many different wavelength signals onto a single fiber to obtain a set of parallel optical channels. Each channel uses a specific wavelength or color. This allows efficient use of the fiber bandwidth and hence, limits the use of additional Fibers. Optical technology has been used for a long time to carry information in fibers; however, the rapid growth of the Internet and the progress being made in DWDM creates an opportunity for more extensive use of optical resources in switching and routing [3,4] in the second generation of optical network systems [5,6]. Regardless of the architecture deployed, an optical network should be seen as a cloud where intelligent edges, with capacity of buffering and processing, are connected. Inside the cloud, intermediate nodes, with limited resources but with high forwarding capacity, are connected together using DWDM technology. With this new approach, the optical network will not be only a bandwidth provider, but also a wavelength provider where the edges could be virtually connected via a light pipe. This will help shift from a static network to an agile architecture where a direct light path could be set-up, easily and fast, between the different edges on request.

Optical networks rely on technology to provide more equipments and devices that process and handle optical information or at least ease the information conversion from optical to electrical. But the big challenge is how to use the whole capacity and build an optical carrier that shares the resources efficiently between all the users while providing a good quality of service. Basically the trend in optical network is to carry IP traffic directly over DWDM [7]. The effort towards this goal has resulted in two kinds of strategies:

- The development of optical burst switching [8,9,10] as a forwarding technique to build a transparent optical backbone; this technique aims to keep a big part of the information in optical domain and hence, reduce the burden of opto-electrical conversion. However this technique suffers from the lack of intelligence inside the network resulting in a big loss amongst bursts as a result of contention. Indeed whenever two or more bursts compete for the same output at the same time, only the first will be sent and the others are dropped.
- The other technique is a wavelength routing [11] that consists of a direct channel between nodes. This path, also called light–path, carries traffic from source to destination without electronic switching. The whole path is seen as a single link leading to a virtual topology that substrate the physical one and provides a new topology to the higher layers.

Optical burst switching is suitable for networks where the traffic is uniformly distributed over the nodes with no regular load. This kind of architecture is good for providing a bandwidth service without any guaranty of delivery, whereas the wavelength routing is more suitable for a network with wavelength service. This new service that arises with WDM technology aims to replace the fiber provider by setting up a wavelength path between two edges either upon request or automatically when the traffic pattern changes in order to balance the load and adapt the network to the new traffic. In this work we will focus on each method and present the advantages and the drawbacks of each architecture, we will also present a hybrid architecture where both techniques are mixed together in order to provide simultaneously a bandwidth and a wavelength service. We will prove, through simulation, that with this hybrid architecture the loss observed with optical burst switching can be reduced and the network can aggregate different class of traffic. The rest of this paper is organized as follows, section 2 presents a wavelength routed network and its limitations. Section 3 presents a description of some variant of optical burst switching techniques. In section 4, we present the hybrid architecture that enhances the optical burst switching. Section 5 presents some numerical results that prove the effectiveness of the hybrid architecture and section 6 concludes this work.

2. Wavelength Routed architecture

With the development being made now in WDM, that provides more wavelengths in the same fiber, and the capability of a cross-connects to switch a wavelength separately it is possible to get a direct light path between two edges. This pipe of light can be seen as a separate link operating autonomously without interaction with any other links or awareness of any router crossed by the pipe. This path, called also virtual link, can carry information transparently in one hop from a source to a destination without need for any conversion to electrical domain. And hence avoid the bottleneck observed in the intermediate nodes.

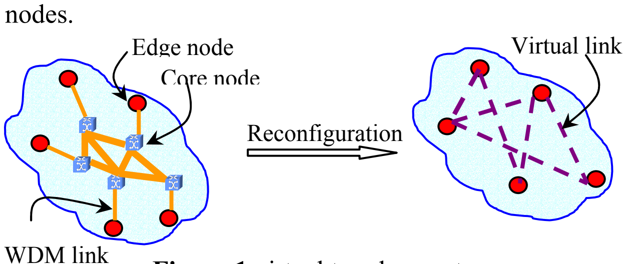


Figure 1 virtual topology set up

Even better, this technique can be used to build a new topology by setting up many paths inside the network as shown in figure 1. This new architecture aims to build a virtual topology [11,12] completely different from the physical one and subtracts the complexity related to optical technology. The presence of such a layer enhances the transport network and bridges the gab between the conventional and optical networks by providing a flexible high-capacity interconnection service to electrical transfer modes; indeed the reconfiguration provides a new topology that can be used with the well-known protocols and principles. The virtual topology that can be completely different from the underlying physical topology is re-configurable, which means adaptability to traffic load. This idea seems to be very attractive and maybe one of the best ways to take advantage of the big potential of WDM technology, but there are many challenges and difficulties to overcome especially those related to the assignment of the different wavelengths available also the optimization of the bandwidth and the propagation delay. The set-up of the new architecture could be done synchronously or asynchronously:

- Asynchronous reconfiguration: Whenever an edge requests a bandwidth to carry information to a given destination, the network manager will analyze the resource and set up a new path between the source and the destination. The path can cross several physical links and several cross-connect to provide a direct light path from source to destination. This virtual link can use the same wavelength or can switch from different wavelength if there are some wavelength converters. The main concern in this architecture is how to deliver light paths in cost-effective and timely manner. The functionalities needed in this architecture to achieve that goal are:
Network state information: to maintain the state of the available resources, the topology and the schedule of the used resources.
Light path computation: basically this is the algorithm and the strategy used to assign wavelengths to a virtual link.
Light path services: the global management of the virtual links especially the establishment of a new path, the release and the modification of a link.
When a request is received, a perfect manager, will analyze the available resources and establish a direct light path from the source to the destination. If there are many possibilities, the optimum will be taken. The optimization could be simply the propagation delay or could be more complicated and takes into account many other parameters such as the effective cost and the restoration constraints. If there is no possibility to establish a direct path, the manager will establish one or more light path in such a manner that the information can reach the destination with one or more hops, the new path can particularly use the already established paths if some bandwidth is left from the previous allocation. The main goal here is to minimize the number of hops and aggregate the traffic to avoid bandwidth waste. This path can be set for a limited time; this way the manager can schedule the set up of different links.

- Synchronous reconfiguration: In this approach all the edges requests are collected and the reconfiguration is performed at the same time. The network seems to shift from a configuration to another to meet the new load. The reconfiguration could be done periodically or only when the traffic pattern is too different from the previous one. The functionalities needed at this are:
Load management: the goal is to collect the requests of the edges, in term of the bandwidth and eventually the quality of services needed for each class of traffic
Coordination and synchronization: to keep track of the traffic being carried on the virtual network, and

coordination among all the edges to switch to the new topology at the same time

Light path computation: depending on the requests by the edges, this function should provide the set of light paths.

Topology switcher: to switch to the new topology computed by the light path computation function, all the nodes must be engaged in this process, this is possible through a protocol that informs each node witch configuration to be set and the time to be performed.

When the manager decides to switch to another configuration, the edges requests are analyzed and the best topology is computed. The perfect situation would be to establish a virtual link between each source and destination, but this is impossible since the number of wavelengths is limited and the edges number may increase. Nonetheless an optimum is possible. The goal is to minimize the hop number, the delay and the throughput. In case of there are no direct path to some destinations, a tandem maybe used. Even if that incurs additional latency, it may be important to aggregate as much traffic as possible in the same wavelength and avoid the bandwidth waste. Virtual topology is one promising way towards an agile network that can be easily reconfigured to map any traffic pattern and hence, balance the load. However one of the challenges that face this technique is the traffic synchronization, especially during the reconfiguration process. Indeed, due to the propagation delay, the information will still remain inside the network when a virtual topology is being torn down to build another. The easiest way to deal with this problem is to stop sending information for a while, before each reconfiguration, until all the information reaches its destination. However, this technique can lead to a big waste of resources and bottleneck at the edges. The virtual topology can be very elegant when it is used with a specific architecture such as petaweb [13] where the regularity of physical topology makes it easy to synchronize and coordinate the entire nodes of the network. Virtual topology relies on a wavelength assignment algorithm [14], which can be formulated as an optimization problem with many constraints related to the physical resources and the edges requests. The optimization goal is to maximize the performance in term of throughput, propagation delay, restorability and many other parameters. To solve such a problem, one needs mathematical models [15] related to constraints satisfaction problems, however the problem complexity increases rapidly with the size of the network in the manner that an exact solution seems to be unfeasible. So heuristics and simplifications are needed in order to reduce the complexity of the problem [16,17].

3. Optical burst switching

To allow higher granularity in bandwidth assignment, an optical packet switching networks arises as an alternative to wavelength assignment. Optical burst switching (OBS) is a technique for transmitting information across the network by setting up the switch and reserving resources only during the time the burst is crossing. In OBS, the data enters the optical cloud via an edge router where it is converted to an optical burst to be sent to the core network. The principle is similar to the one used in conventional packet switching, however the information is separated into two parts; a header and a payload. The main goal of this separation is to minimize the opto-electrical conversion and avoid the limitation incurred by the electronic technologies such as the processing time and conversion. The header is converted to electrical domain, where it will be processed and converted back to the optical domain. The payload is simply forwarded in the optical domain according to the information transported by the header. In this technique, the concept of packet is replaced by a burst; this constitutes an interesting step towards an all-optical network where a big part of information remains in the optical domain.

In an optical network using optical burst switching technique, the edges nodes are able to store and process IP packets whereas the intermediate will perform forwarding according to the destination. In this architecture the incoming packets are buffered in the source edge routers to form bursts. Bursts are collected according to their destination and class of service. Then, a controller packet is sent over a specific optical wavelength channel to announce an upcoming burst. The controller packet, called also an optical burst header (OBH), is then followed by a burst of data without waiting for any confirmation. The OBH is converted to the electrical domain at every node in order to be interpreted and transformed according to the routing decision taken at each switching node. Also pertinent information is extracted; such as the wavelength used by the following data burst, the time it is expected to arrive, the length of the burst and the label, which determines the destination. This information will be used by the switch to schedule and setup the transition circuit for the coming data burst. There are several approaches to practically implement OBS, nonetheless the difference is related to the timing issues concerned with synchronization between the data bursts and their headers. Those techniques fall into two categories:

OBS with offset: in this category, the data burst is delayed at the source and sent after a short delay as shown in figure 2. This offset must be long enough to cover the processing time at all intermediate nodes. This assumes that the source knows the number of hops needed to reach the destination and the processing time at each node. The offset can be formulated as function of processing and switching time at each node and the number of node crossed by the burst as follows. Let Tp be the processing time of the optical header at each nodes and Ts is the switching time at each node; N is the number of nodes crossed by the burst, the offset for that burst must be greater than $N*Tp + N*Ts$ with the assumption that the processing time and the switching time is the same at all the nodes. The advantage of this method is that no buffers are needed at the intermediate nodes. Besides, this offset can be used to define several classes of services [18]; indeed an extra offset is added to the burst to give it higher priority, the longer the offset is, the higher is its priority.

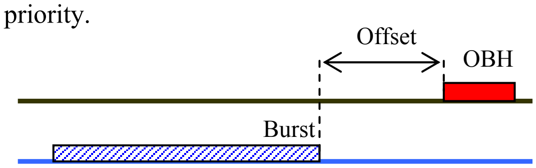


Figure2 Optical burst with offset between the header and the burst

OBS without offset: in this category, the data burst is sent at the same time as the OBH, as shown in figure 3, and delayed at the switch by the fiber delay line (FDL). The delayer in this case is different from the buffer since we don't need to store the burst. The burst needs to be delayed at the local node. This delay must be long enough to cover the header processing time and the switching time. The feasibility of this technique relies on how fast the switch is. Indeed the length of the FDL used to delay the burst, can range from a few hundreds meters for fast switchers to hundreds of kilometers for slow switchers. This method has the advantage to free the edge from the burden of calculating the offset. This method can also be used with routing methods when the path is determined hop by hop. The bandwidth is used optimally with OBS without offset.

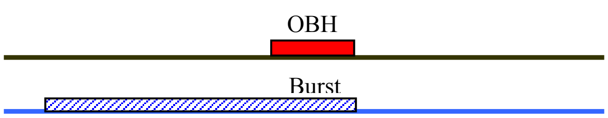


Figure3 Optical burst without offset between the header and the burst

So far the OBH is processed electronically and it may be processed optically in the future, but whether in optic or in electronic form, the most important feature is the switching speed since the switching time is considered as a waste of bandwidth. The Optical burst switching combines the intelligence and the capacity of processing and buffering of the electronic edges with the capacity of optical forwarding of the core. Thereby the network can face the increasing traffic and accommodate a different kind of information. Basically OBS is designed to avoid the long end-to-end setup times of conventional virtual circuit configuration with no need for memory at intermediate node. However, the main problem is contention, which may occur when one or more bursts arrive at the same time and try to leave from the same output, using the same wavelength of course. The way this contention is resolved can affect tremendously the performance of the network. Indeed when the packet-loss ratio increases, the efficiency as well as the delivery rate decreases and hence the throughput is improved. In other words the contention makes the delivery not guaranteed and not deterministic

4. Hybrid architecture

Used separately, neither OBS nor wavelength routed network is suitable for all class of traffic or to guaranty the quality of services needed for all the applications. Each method has its own limitations and suffers from many drawbacks. With OBS, the burst loss due to the contention, which is inherent to this technique, decreases the performance in term of throughput and delivery delay, especially with high load. Several methods have been proposed in literatures to decrease the loss ratio. Some of these techniques are purely software such as deflection routing and segmented burst [1] where the others require a specific hardware such as a burst buffering [8] and a wavelength converter [8]. These algorithms may reduce the contention, but they all remain sensitive to the traffic load. Indeed according to Jonathan's work, [8] it is clear that even in ideal network, where the switches use a number of buffers and can perform wavelength conversion, contention still occurs when the load gets heavier. This means that the delay and the delivery are not guarantied and hence, this type of networks may be useless for some kind of applications especially real time and delay sensitive applications. On the other hand wavelength routed network has known some improvement especially with wavelength assignment algorithms. Unfortunately this technique is still facing many problems; namely:

- The complexity of Wavelength assignment algorithm increases with the network size and the number of wavelengths, which can hinder the future expansion of the network.
- Due to resources limitations, it is sometimes impossible to establish a direct light path between all the edges. Therefore intermediate node must be used as a tandem, which can lead to additional delay and routing complexity
- Even when a light path is established between two edges, it is not necessarily the shortest one.
- Edges may not have enough loads to fill all the capacity of the established path, and hence a part of the bandwidth may be lost.
- To establish a new light path, the manager may need a long time to analyze the resources available.
- Some of wavelengths are left unused on some link.

To aggregate different classes of traffic and to overcome the limitations of these methods, used separately, we propose to combine the OBS and wavelength assignment in the same network. The basic idea of this architecture is to take advantage of the big number of wavelengths in the fiber by using only a part of the available wavelengths for wavelength routed network and the other part for OBS. Depending on the traffic pattern the wavelength routed sub network will be configured to balance the network load while the other part remains free to be used with the OBS technique.

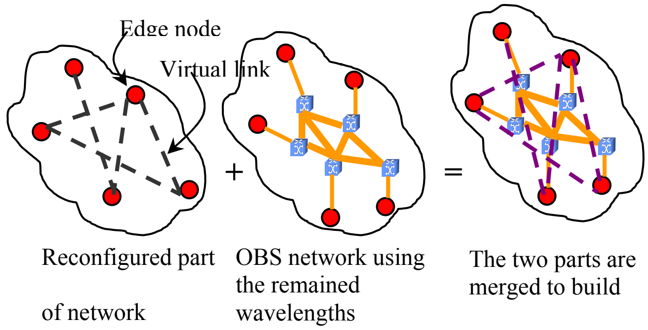


Figure 4 hybrid architecture

Figure 4 shows this hybrid architecture; the new network is the result of merging the two sub-networks. The new topology is better than the first one since we get more connectivity. And hence the OBS can use the new network, with many direct connections between the edges. Let CEi be the set of edges directly connected to the edge Ei via a light path after the reconfiguration of the wavelength routed part of the network.

The traffic can be carried on the new network whether using the deterministic way with the wavelength routed network, which can be suitable for many kind of applications or the spontaneous way with optical burst switching network, which is also very suitable for other kind of applications. Even better, the new architecture will improve the performance of the OBS technique; indeed whenever an edge decides to send a burst to a destination, it will first consider a direct light path. If there are many, the optimum is taken otherwise the burst will be carried over the OBS sub network. Another enhancement can be brought to the OBS technique using this hybrid architecture that can be seen when a contention occurs, instead of dropping the burst it can be rerouted to another destination; let Ej be the original destination. A destination Ek that belongs to CEj will be chosen. That way Ek can easily forward the burst to Ej. Also Ek can be the closest one to Ej among CEj. This can decrease considerably the dropping probability and hence decreases the delay and improves the throughput.

This architecture does not need any additional hardware and can be easily used with the infrastructure used in OBS. The whole network can be used to carry the traffic between the edges and provides, at the same time, wavelength service by establishing a direct and clear light path between edges. Besides, this architecture may simplify the assignment wavelength algorithm; indeed the complexity of this algorithm increases with the number of wavelength, thus using only a small number of wavelengths can reduce this complexity.

The combination of the two techniques may also increase the utilization rate of all network links; the links left idle in the wavelengths routed part can be used by OBS by adding some converters in the network. Furthermore, the network restorability may be improved by simply switching the traffic being carried on failed link to OBS sub network during the restoration period.

Different class of traffic can be carried on this network, depending on the destination and the quality of service needed, the source can use either the wavelength routed sub network or OBS or both of them in some case.

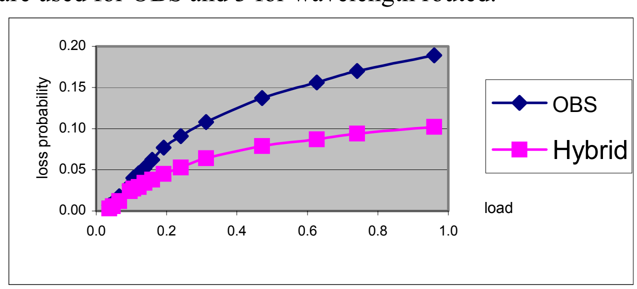
Another advantage of the new architecture is related to the blocking probability, indeed the wavelength routed part adds more links and hence the connectivity of the network is increased. The average number of hops to reach the destination is lowered consequently. The next section performs simulation to measure the blocking probability of this hybrid architecture

5. Simulation results

The blocking probability and delay of the hybrid architecture proposed in the previous section is evaluated on a random mesh network with 10 nodes and 6 wavelengths. The experimental setup for the simulation is based on the following assumptions (1) the burst arrivals to the network edges follow Poisson process with rate λ. (2) The burst length is exponentially distributed with rate μ. (3) The bursts are sent only by the edges and the destination is uniformly distributed over all the edges (4) the routing table is static, the burst takes the shortest path from source to destination (5) the transmission rate is 1 Gbps. (6) three wavelengths are used for wavelength routed sub network and the other three are used for OBS.

In this simulation we focus on two parameters; the lost ratio which is the number of dropped burst over the number of burst sent by the edge and the average delay which is the mean time of all the received burst from source to destination.

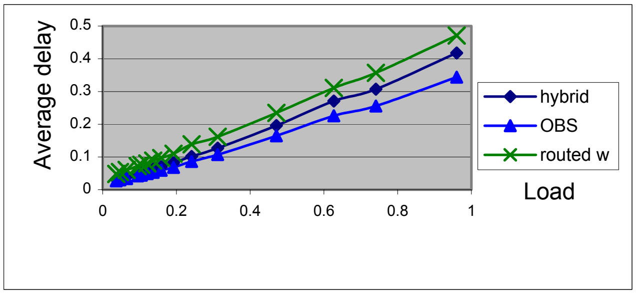
The simulation compares the performance of the network with two architectures: the first where all the wavelengths are used for OBS and the other one where 3 wavelengths are used for OBS and 3 for wavelength routed.



Graph 1 loss probability for OBS and hybrid architecture

The graph 1 shows that the blocking probability is always better with the hybrid architecture, and the delivery is improved by almost 50%. This enhancement is due to the fact that a part of the traffic is routed over a deterministic sub network where there is no contention. The loss depends also on the part of the traffic sent over the wavelength routed sub network in this case the burst is sent over network routed sub network only if there is a

virtual path between its source and its destination. Many policies could be applied; however the used policy may affect the delay due to the processing time at each intermediate node.
The new architecture also improves the average of a delivery delay as shown in graph 2. The delay is the average time from source to destination for all received bursts. This average includes the queuing time and the propagation delay. The offset time between the optical header and bursts is negligible (ignored) in this simulation.



Graph 2 the average delay (ms) of OBS, routed wavelength and hybrid architecture

The delay of the wavelength routed architecture is improved. Nonetheless, depending on the strategy used to dispatch traffic between the two sub networks the delay will range between the average delay of OBS and routed wavelength. This means that there is a tradeoff between the loss and the delay. Therefore one needs to take in consideration both the delay and the loss.

6. CONCLUSION

In this paper we proposed a hybrid architecture that uses both OBS technique and wavelength assignment to take advantage of the big capacity of optical networks. With this technique, the network can provide both wavelength services and bandwidth services and carry different classes of traffic, using either the deterministic way with routed wavelength or the spontaneous way with OBS.
An area for future work is the investigation of the optimum partition of the network in order to determine the percentage of the available wavelengths to be used with OBS and with routed wavelength as well. Another concern is the policy used by the edges to dispatch traffic over OBS and wavelength routed sub network. To reduce the burst loss and decrease the delay, one needs to classify and compare different dispatching policies.

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