

# STATISTICAL TRAFFIC MULTIPLEXING WITH SERVICE GUARANTEES OVER OPTICAL CORE NETWORKS

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**Abstract:** Statistical multiplexing at the optical layer has been considered a critical requirement in order to build the next generation of ultra-high capacity optical transport networks in a cost-efficient manner. However, even today, the state of the art of commercially available optical core networks is based on mature wavelength switching and routing technologies, which lack a transport and control plane architecture that can support statistical traffic multiplexing with guaranteed Quality of Service (QoS) across a wide range of QoS parameters even if they can support fast reconfiguration at msec time scales. For several years, most research efforts have focused on the concepts of Optical Burst Switching (OBS) and Optical Packet Switching (OPS), which are based on the hybrid use of electronic nodes and optical switches to exploit Time Division Multiplexing (TDM) in order to achieve statistical multiplexing and dynamic resource reservation over optical networks. While burst switching has been experimentally proven as a technically feasible technique, its performance suffers especially under strict requirements for QoS guarantees. In this paper we evaluate the performance gains that can be achieved exploiting statistical multiplexing over a large scale core optical network and we demonstrate the efficiency of the CANON architecture (Clustered Architecture for Nodes in an Optical Network) as a viable alternative to OBS, which can achieve both targets for statistical multiplexing gains and QoS guarantees at the same time.

## 1 INTRODUCTION

Latest trends in backbone network traffic demonstrate that apart from the tremendous increase in volume, modern telecommunication services result in traffic patterns with increased dynamics in the form of spatial and temporal asymmetry and stringent requirements for Quality of Service (QoS) guarantees. While the traffic growth can be accommodated by exploiting the capacity of WDM systems, the available fiber and wavelength resources will not be able to serve the constantly increasing demand unless the reservation of these resources is performed in an efficient manner.

To address these requirements one approach is to deploy a slowly reconfigurable WDM technology relying on commercially available ROADMs and MEMS-based OXCs. This will lead to a significant over-provisioning of links and large port-count switches to accommodate dynamic traffic patterns. In contrast, various dynamic resource allocation schemes like optical burst/packet switching, provide

an alternative to over-provisioning but they inherently lack QoS guarantees whilst they require the deployment of rather immature optical technology.

As proposed by A. Stavdas et al. (2008), an alternative optical multiplexing scheme based on TDM is CANON (Clustered Architecture for Nodes in an Optical Network), that reconciles dynamic resource allocation and statistical multiplexing gains with QoS guarantees. The CANON architecture refers to both a networking concept and the corresponding switching solution.

In this work, we benchmark optical statistical multiplexing schemes against static provisioning over the existing infrastructure of the Pan-European network topology as presented by S De Maesschalck et al (2003) and when CANON architecture is applied, to quantify performance results in terms of loss performance and cost.

## 2 ARCHITECTURAL CONSIDERATIONS

In order to quantify the gains and trade-offs comparing dynamic solutions vs. static provisioning we first examine the case of wavelength switching as a technology to implement the circuit switching concept (Optical Circuit Switching - OCS). OCS employs a pre-provisioned allocation of network resources in order to serve the capacity demand. OCS inherits both the advantages and disadvantages of circuit switching: it guarantees QoS with no losses or delay but at a high overall cost and poor resource utilisation.

In order to overcome the severe scalability limitations of OCS we consider sub-wavelength reservation and switching techniques and evaluate OBS as an indicative case. OBS, as proposed in the literature, is a dynamic resource allocation protocol and statistical multiplexing solution. An OBS node aggregates traffic destined to one destination and casts it into a burst after transmitting a reservation message informing the intermediate nodes for the upcoming burst transmission. It is well-known through numerous studies, that OBS cannot guarantee QoS due to this one-way reservation scheme that leads to high burst losses. Slotted OBS (S-OBS), presented by Z. Zhang, L. Liu and Yuanyuan Yang (2007) is an OBS solution where all bursts are constrained to a specific size. S-OBS is considered a superior solution not only due to the partial burst collision probability but also due to the reduced switching node control and scheduling complexity, when variable slot allocations need to be scheduled in real-time. Therefore in this work, the S-OBS is considered.

To limit the burst loss in large optical core networks where dynamic resource allocation is employed, CANON implements a hybrid reservation mode. Electronic buffering is still employed at network edge nodes, which are called Regular Nodes (RNs) but optical frame generation is not performed based on local RN queue status information as is done in OBS nodes but based on a MAC protocol executed between a Master Node (MN) and all RNs of a sub-net called "cluster". We will briefly describe this principle of operation in the remainder of this section and in the next section we will demonstrate how this distributed switching architecture leads to nearly optimal performance results.

### 2.1 CANON Architecture

The CANON solution has previously described by A. Stavdas et al. (2008) and by J. D. Angelopoulos et al. (2007) and the principle of operation is now summarized. CANON is organising the nodes of a core network in clusters, mainly based on vicinity, traffic, legacy infrastructure and administrative criteria. This process creates a new hierarchy since the core nodes are classified as Master Nodes (MN) and Regular Nodes (RN) based on functionality considerations and a differentiated traffic handling policy (i.e. traffic destined to nodes of the same cluster versus transit traffic destined to the nodes of a distant cluster). The role of the MN is to coordinate both inter and intra-cluster operations. In the latter process, the RNs contribute fixed size contiguous optical slots, which are marshalled into appropriately sized frames destined for other clusters, under the guidance of a reservation-based MAC protocol. In addition, under MN's supervision, RNs use the same frame and wavelength to transport traffic to the same destination cluster, so each ring is effectively operating as a "distributed switch". Details on traffic aggregation, flexible bandwidth allocation, robustness and resiliency are discussed by J. D. Angelopoulos et al. (2007). Regarding inter-cluster operation, a pre-provisioned scenario has been analysed by J. D. Angelopoulos et al. (2007) whilst a fully dynamic case based on one-way reservations over the pan-European network has been benchmarked by A. Stavdas, A. Orphanoudakis, C. (T) Politi, A. Drakos and A. Lord (2009).

Regarding CANON node architectures, the proposed MN has been presented by A. Stavdas, C. (T) Politi, T. Orphanoudakis and A. Drakos (2008). It is a wavelength and a link modular architecture allowing the node to gracefully scale to hundreds of Tb/s. On the other hand, the RNs are optical add/drop multiplexers (OADMs). This solution greatly supports the smooth migration from existing rings to the CANON solution. Conclusively, the combined operation of network and switch architecture allows to efficiently groom slots into frames in a collision free-way by means of a MAC.

## 3 BENCHMARKING CANON

### 3.1 Benchmarking Parameters

Since the performance of OBS is directly proportional to the available number of wavelengths

in a WDM system (since they provide the means for contention resolution) we need to establish a fair basis for comparison. The basic parameters for a benchmarking between the different schemes include the network topology, the available resources and node functionality. Thus, we first select a reference network topology and a traffic load profile to evaluate network performance, when serving this input traffic load. Obviously CANON introduces a topology transformation and a different multiplexing paradigm. Therefore the edge node functionality in each case is different. However the important thing we need to evaluate is the performance of the resulting network architecture given a specific amount of resources. In this study the number of resources is expressed in terms of number of ports and wavelengths per port on network nodes. The basis for comparison is drawn from the minimum number of wavelengths that are required over the core network links to serve the input traffic load in the static case of OCS. Given this figure we demonstrate the performance trade-off that sub-wavelength resource allocation can achieve and benchmark the CANON distributed switching architecture and OBS against static OCS.

For the benchmarking, the Pan-European core topology of S De Maesschalck et al (2003) shown in Figure 1 is used. This core network consists of 16 nodes interconnected in a partially mesh topology consisting of 23 links. For our modelling work, the following statistical characteristics of the incoming traffic were assumed: Poisson inter-arrival times of fixed-sized frames with size equal to 0.125msec and uniform distribution probability destination. For each node, traffic filling four wavelength channels per input link was assumed. For the S-OBS case the burst size has been assumed equal to 5msec. The nodes are based on the  $\lambda$ -S- $\lambda$  configuration presented by A. Stavdas et al. (2008), providing full wavelength conversion. Also at the edge nodes electronic buffers have been assumed for all cases where burstification takes place.

Firstly we study the performance of both S-OBS and OCS. For the OCS scenario, each node needs to have an interconnection with every other node and taking into account the distribution of the four input wavelength traffic load over all destinations and the wavelength conversion capability at each output port in every node, the minimum requirement for the interconnection of the nodes is a (virtual) wavepath of the size of one wavelength for each destination.

On the other hand for the S-OBS two different scenarios have been evaluated. Since S-OBS is a statistically multiplexing protocol with dynamic

reservations, it can be assumed that the over-provisioning made at the OCS case can be limited to cover only the expected demand as would be done in any other case of traditional packet switching networks. Thus the network capacity has been limited to the average expected traffic of the OCS capacity. In order to be more fair a second scenario has been assumed. This time we adjust the capacity of each link taking into account the maximum load of a node. By using this over-provisioned assumption we expect the performance of S-OBS to be improved albeit with higher cost and poor resource utilisation.

This difference in the number of resources of each scenario and thus the cost of each solution can also be seen in Figure 2, with the two scenarios of S-OBS marked as mesh S-OBS lim and mesh S-OBS over respectively.

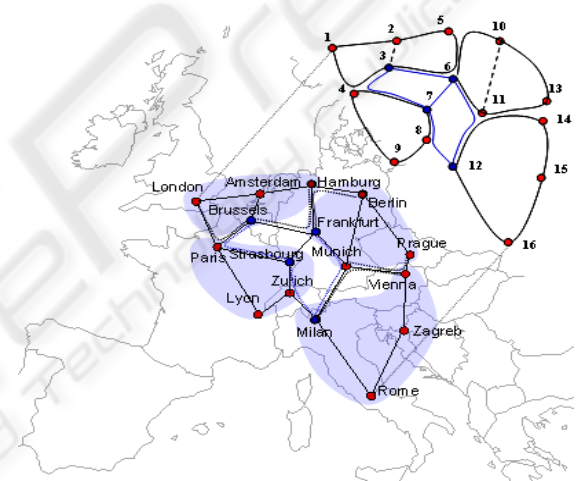


Figure 1: Pan-European core topology.

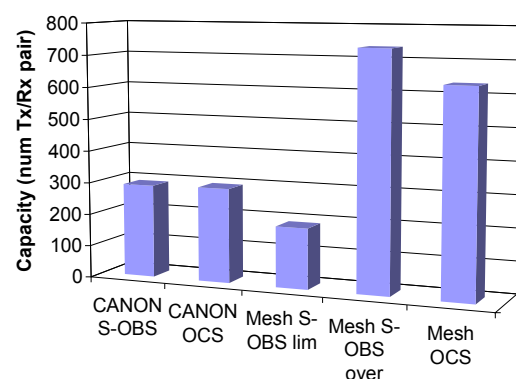


Figure 2: Overall capacity in number of Tx/Rx pair.

In order to evaluate the benefits of CANON, we segmented the same core network into 4 separate clusters as it is indicated by the grey areas Figure 1

without introducing any modification on the existing infrastructure. The resulting topology is shown in the inset of Figure 1 (upper right) showing 4 clusters consisting from 4 MNs (nodes 3, 6, 7, 12) and a number of RNs per cluster. Under the current partitioning, those links which are designated with a dotted line are not in use. It is important note that the algorithm for the segmentation of the network depends only on the distances of the nodes. A better solution may be found by applying more efficient algorithms, though such optimisation is out of the scope of this paper.

By following the CANON solution, different network capacities can be assumed for the two hierarchical sections of intra and inter-cluster. Additionally the traffic can also be distinguished in traffic destined to other clusters, and traffic destined to nodes inside the ring. For the latest, one wavelength is assumed sufficient while for the rest of the traffic the capacity of the ring is limited to the required number in order to serve the average expected traffic. For the inter-cluster, as before, the two different approaches of OCS and S-OBS are being used to serve the inter-cluster interconnection. Following the same principle of the mesh OCS case, in CANON-OCS, each MN needs a virtual wavepath for each destination cluster but this time each wavepath is provisioned only with the minimum number of wavelengths required to serve the load. Likewise, for the S-OBS case we limit the capacity of each link to in order to serve the average expected traffic taking also into account the routing.

In CANON, as explained earlier, only the MNs are considered as  $\lambda$ -S- $\lambda$  switches while the RNs are OADMs. The same traffic profile as before is used and the frames have the same duration of the S-OBS burst of 5msec.

### 3.2 Result Evaluation

Figure 3 shows the loss probability of all simulated scenarios. As expected no losses occur in the OCS scenarios in contrast with the S-OBS. As it can be seen in Figure 3 the mesh S-OBS solution with the limited capacity even for the lowest traffic loads suffers from network collisions and thus severe losses. Moreover when the over-provisioned solution for the mesh S-OBS network is used, the performance improves but even for moderate loading the loss probability still remains unacceptably high (even though full wavelength conversion is employed at all core nodes). On the other hand when CANON is applied, a more reliable system is shown and only for the highest traffic

loads there are losses that are more than an order of magnitude less than what is achievable with mesh S-OBS.

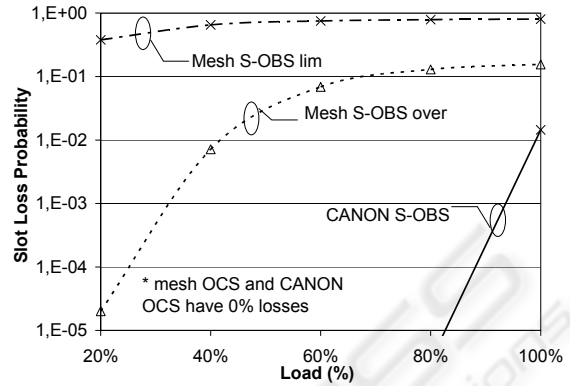


Figure 3: Overall capacity in number of Tx/Rx pair.

Even though the simulations have a specific traffic profile, in theory the maximum capacity of the network would have been achieved only if all links were loaded at 100% at the same time. Thus the throughput of each scenario over this theoretical maximum capacity of the network is a metric that combines the results of both Figure 2 and Figure 3 and it is shown in Figure 4. Even though a mesh OCS solution guarantees transmission QoS, it demands an extremely high capacity which usually remains under-utilized. On the other hand both of the scenarios for the S-OBS case have poor performance since they both suffer from severe losses. Additionally in the case of the over-provisioned network, the high cost reduces even more the performance.

Finally, CANON is a solution that combines both performance and cost. In the first case the loss probability of CANON S-OBS is close to the guaranteed performance of OCS due to the statistical multiplexing enforced by CANON, while even when OCS is used for the inter-cluster communication, the new architecture enforced by CANON keeps the demanded network resources close to the values of the S-OBS case. Thus, as shown in Figure 4, both CANON solutions have similar performance. Moreover both CANON solutions not only outperform the mesh scenarios and if we also take into account the different switching technologies that CANON uses in the intra-cluster segment we can also deduce that the overall cost of CANON (monetary cost, power consumption,...) is much lower than the compared solutions.

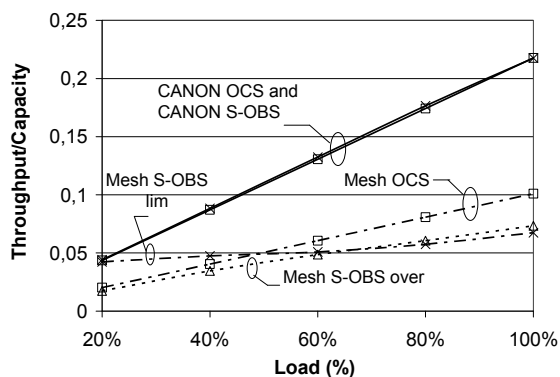


Figure 4: Throughput over theoretical maximum capacity.

## 4 CONCLUSIONS

We demonstrated that using the existing infrastructure of the Pan-European network, CANON can efficiently combine statistical multiplexing gains and improved blocking performance, compared to a mesh S-OBS solution, while keeping the overall cost of the implementation considerably lower than the pre-provisioned mesh OCS case. S-OBS suffers from extensive loss probability resulting in almost complete blocking even at light traffic load values and even under resource over-provisioning. CANON on the other hand can provide the same level of QoS guarantees as OCS (practically lossless operation), limiting over-provisioning by employing the OCS model only in the inter-cluster network and utilizing statistical multiplexing that results from the distributed traffic aggregation inside the local network clusters. Even in the fully dynamic case when OBS is employed for MN interconnection over the mesh inter-cluster topology, the cost (in terms of resources) and performance trade-offs are much better than in the case of S-OBS.

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