Optical burst and packet switching: Node and network design, contention resolution and Quality of Service

Results from the study in COST 266

Steinar Bjornstad[1,2]

Martin Nord[1,4] ,D.R. Hjelme[2], N. Stol[3]
[1] Internet network architecture
Telenor R&D, Oslo, Norway
Department of: [2]Physical electronics, [3]Telematics
NTNU/UNIK Trondheim, Norway
Steinar.Bjornstad@fysel.ntnu.no,
Dag.Hjelme@fysel.ntnu.no, norvald.Stol@item.ntnu.no
[4]Research Center COM, DTU, Lyngby, Denmark
mn@com.dtu.dk

Franco Callegati, Walter Cerroni,
Carla Raffaelli and Paolo Zaffoni
DEIS - University of Bologna
Bologna, ITALY
wcerroni@deis.unibo.it

Christoph M. Gauger
University of Stuttgart
Institute of Communication Networks
and Computer Engineering
Stuttgart, Germany
gauger@ikr.uni-stuttgart.de

Chris Develder, Jan Cheyns, Erik Van Breusegem, Elise Baert, Didier Colle, Mario Pickavet, Piet Demeester
Dept. of Information Technology (INTEC)
Ghent University - IMEC
Ghent, Belgium
{chris.develder, jan.cheyns, evbreuse, elise.baert, didier.colle, mario.pickavet, demeester}@intec.rug.ac.be

Marko Lackovic
Department of Telecommunications
Faculty of Electrical Engineering and Computing
Unska 3, Zagreb, Croatia
E-mail: marko.lackovic@tel.fer.hr

Davide Careglio, Gabriel Junyent
Universitat Politècnica de Catalunya
Advanced Broadband Communications Labs
Barcelona, Catalunya, Spain
careglio@ac.upc.es, junyent@tsc.upc.es

Mirosław Klinkowski, Marian Marciniak, Marian Kowalewski
National Institute of Telecommunications,
Department of Transmission and Fiber Technology,
Warsaw, Poland
mklinkow@itl.waw.pl, m.marciniak@itl.waw.pl,
M.Kowalewski@itl.waw.pl

***Abstract*—Future network should be able to efficiently serve packet-based networks, such as the Internet. In this paper, based on results from COST 266, we explore characteristics of Optical Burst switching (OBS) and Optical Packet Switching (OPS). Both node design and Metropolitan Area Network (MAN) are discussed. A unique joint comparative performance evaluation of contention resolution in OBS and OPS are presented, as well as methods of Quality of Service (QoS) differentiation in OBS/OPS networks, and their performance.**

Keywords: burst switching, packet switching, contention resolution, node design, Quality of Service, simulation

I. INTRODUCTION

Most existing telecommunication wide area networks (WAN) and Metropolitan Area Networks (MAN) have an SDH based, electronically circuit switched transport core. Connection set-up or tear down may require days or weeks, and switching as well as multiplexing/demultiplexing always requires complex optical/electro/optical (O/E/O) conversions. Nowadays, the operators and vendors are working on an optical control plane, which controls set-up and tear-down of connections. Work on automatically switched optical network (ASON) and generalised multi-protocol label switching (GMPLS) takes place within ITU and IETF, respectively. Resulting Optically

Circuit Switched (OCS) networks can offer explicit transfer guarantees, since circuit establishments are confirmed. However, this generates a delay at least equal to the round-trip time, typically several ms. Even though OCS networks will offer more flexibility than today's solution, the access to the optical bandwidth is still provided with fibre/wavelength granularity.

Future networks should be able to serve a client layer that includes packet-based networks, such as the Internet, which may have a highly dynamic connection pattern with a significant portion of bursty traffic between the communicating pairs. In this case, OCS transport may not be flexible enough. It would require over-dimensioning of the number of connections and of the bandwidth reservation of each connection, to avoid excessive delay and extensive buffering at the ingress routers. Here is when Optical Packet Switching (OPS) and Optical Burst Switching (OBS) come into play, with the goal of reducing delays and improving the utilization of the network's resources through statistical multiplexing. This comes at the expense of not being able to offer explicit transfer guarantees. However, suitable node design and proper dimensioning of network resources may enable support of most services over the same network. Moreover, OPS and OBS may share the WDM layer with an OCS scheme, serving applications with need for explicit transfer guarantees.

In the first part of this paper we present a strictly non-blocking node design suitable for OPS/OBS. Then, we show how the node-design can be simplified, with the drawback that it becomes blocking. We then elaborate on how the performance of this blocking node can approximate the performance of a non-blocking node. In the next section we describe alternatives for resolving contention OBS and OPS networks. We compare the performance of OBS and OPS using a proposed simulation scenario. The topic of the next section is how the OPS/OBS layer can support QoS differentiation, preventing over-dimensioning of the network nodes, and offering QoS differentiation to the IP-layer. In the final section we identify the main requirements for Optical MANs (O-MANs), and use them to compare different O-MAN architectures. Finally, we sum up and conclude our work, and point out interesting topics for further studies.

II. OPS/OBS NODE DESIGN

In this section we describe a switch design, suitable for OPS/OBS. The design is shown in figure 1, and can be made strictly non-blocking or, in a simplified version, blocking. The strictly non-blocking design is optimal for asynchronous packet switching, and was proposed in [1]. The input WDM signal of each fibre is demultiplexed to its corresponding wavelengths and fed to the input of the Tuneable Wavelength Converters (TWCs). The outputs of each TWC are then fed to the AWG inputs. By tuning the TWC's output wavelength, packets can be sent to any of the AWG outputs (but only one at a time). The packet will be sent directly to the scheduled output, if vacant. If no output with correct destination is available, the packet will be sent to one of the buffer inputs, if a vacant buffer input can be found. If not, the packet will be dropped.

Buffered packets are clocked out of the buffer and sent back to an AWG input as soon as a wavelength output to the destination becomes available. At the buffer output, the wavelength, and thus AWG output, is selected by tuning a tuneable laser. This type of architecture is called a feedback design, and has the benefit of supporting packet priority, also when FDLs are used for buffering [2], [3]. When a packet is leaving the AWG for the output, the signal is converted to the desired wavelength before it is multiplexed on to the correct output fibre.

The design is suitable for the scenario envisaged by the COST consortium, where node degree is set to typically a maximum of five. However, a drawback with this design is that it does not scale well to a high node degree. The total number of switch inputs s, is given as $s = N \cdot n$, where N is the number of input/output fibres and n is the number of wavelengths in each fibre. The total number of channels needed in the AWG is given as $s+B$, where B is the number of buffer inputs. An AWG with size $(s+B)\times(s+B)$ is therefore required. Since n increases both with the number of fibres and the number of WDM link wavelengths, the maximum switch size is limited by the size of the AWG, which is currently reported to be a maximum of 400 channels [4]. However, a scalable design based on the same principles, scaling to a very high number of wavelengths, and a high node degree, can be found in [1].

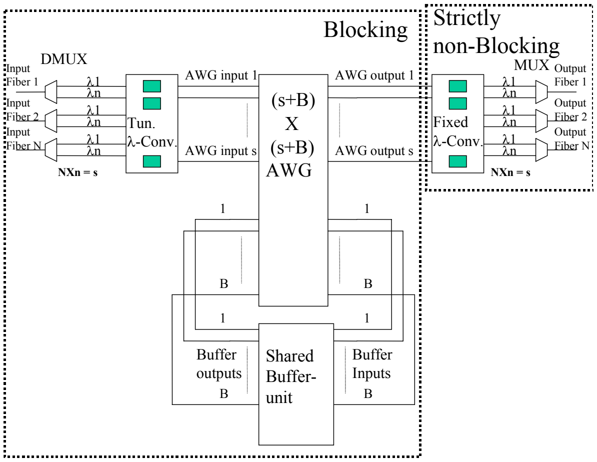

Figure 1. An OPS/OBS node design with shared buffers. A simple design with blocking is shown in the left dotted frame. By adding wavelength converters at the outputs of the AWG (right dotted frame), the design can be made strictly non-blocking.

A. Blocking in OPS/OBS nodes

A very basic node design consists of having the demultiplexed WDM signals connected to an AWG via TWCs, similar to Figure 1 but without the fixed output wavelength converters at the switch's outgoing ports. This is a very simple switch architecture. However, it has the drawback that it is blocking: without the output wavelength conversion, the converters at the input can only use the same wavelength set as in the input fibre. Consequently, this switch architecture is internally blocking. Important in such a switch design is how the output ports of the AWG are combined into the output fibres [5]. If this is done properly and intelligent choices on the wavelength conversion are made at the input, the performance of this blocking node can approximate the performance of a non-blocking node. In asynchronous mode, however, it is a lot harder to emulate a non-blocking node using this architecture. The problem is that once a decision is taken for a TWC this cannot be reverted, but when a future packet arrives it might become clear that another choice would have been better. Thus a possible way of improving performance is using a windowed scheduling mechanism [6]. This scheduling in the switch increases the time separation of header and payload by an extra FDL at the input. In this way there is a form of prediction of which packets will block each other, so that the converter decision for these overlapping packets can be coupled, which will result in a lower blocking probability. Simulation results for this switch design are presented in Figure 2, showing that in slotted mode we can reach the same performance as a non-blocking node, while for asynchronous operation the windowing approach only partially alleviates the internal blocking.

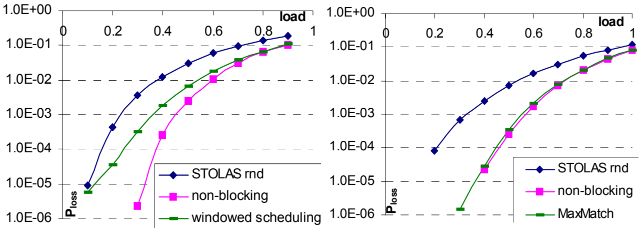

Figure 2. Packet loss simulations for a blocking optical packet switch (3 fibres in and out, 15 wavelengths per fibre) in slotted (left) and asynchronous mode (right). A non-blocking node is shown as reference, STOLAS rnd is performance using no specific TWC assignment algorithm. In slotted operation, MaxMatch TWC assignments allow to emulate a non-blocking node. In asynchronous mode windowed scheduling improves the performance, but the there still exists a serious gap with the ideal non-blocking node.

III. CONTENTION RESOLUTION IN OPS/OBS- A COMPARISON

Optical burst and packet switching inherently rely on statistical multiplexing in order to achieve good utilisation in presence of bursty traffic. As a consequence, temporary overload situations called contention situations occur and have to be resolved. A reservation or transmission conflict, which leads to burst or packet loss, exists if the wavelength on the designated output fibre is blocked by a different burst or packet. Such a contention situation can be resolved in one or several of the following three domains:

Wavelength domain: By means of wavelength conversion, a burst or packet can be transmitted on a different wavelength channel of the designated output fibre.

Time domain: A burst or packet can be delayed until the contention situation is resolved by applying a buffer.

Space domain: In deflection routing, a burst or packet is sent to a different output fibre of the node and consequently on a different route towards its destination node. Deflection routing results in only limited improvement for variable length bursts or packets [7] and has not been investigated within the COST 266 action. Furthermore, deflection routing may cause that packets arrive out of order at the egress node. Space domain can be exploited differently in case of multi-fibre networks, i.e. several fibres are attached to an output interface. In this case, a packet or burst can also be transmitted on a different fibre of the designated output interface without wavelength conversion.

In the following sections, we discuss contention resolution in wavelength and time domain, and present results of a joint comparative performance evaluation.

A. *Wavelength conversion*

WDM not only provides increased transmission capacity, but also allows for highly effective contention resolution. If wavelength converters are employed, all wavelengths on a fibre (or within a certain waveband) can be considered a bundle of channels shared by all bursts or packets to be transmitted over this fibre (waveband). In teletraffic theory, it is well known that a bundle of *n* parallel servers each with capacity *c* have a smaller blocking probability and thus a higher utilization than a single server of capacity $n \cdot c$. This is called *economies of scale.*

B. *FDL Buffer Architectures*

Since traditional queuing is not feasible in all-optical burst or packet switches, contention resolution in the time domain may be provided by using Fibre Delay Lines (FDLs), which imitate conventional queuing by delaying packets that are forced to go through an optical fibre of a given length. In this paper we assume that the output wavelength is reserved at packet arrival, therefore both *feed-forward* as well as *feedback* buffer [8] configurations are equivalent to an output queue.

In a DWDM network contention resolution may also exploit the wavelength domain, by sharing the wavelength pool of a fibre and then by transmitting contending packets on different wavelengths in the FDL. Thus, when a packet needs to be forwarded to an output fibre specified in the routing table, the Wavelength and Delay Selection problem (WDS) arises. In fact, these two actions are somewhat correlated, because the need to delay a packet is related to the availability of the wavelength selected. The WDS problem becomes also more complex in case of asynchronous, variable-length optical packets, since some gaps may appear between queued packets inside the FDL buffer due to the discrete number of available delays [9]. In order to solve the WDS problem under these traffic assumptions, a few resource allocation policies have been proposed [10] [11]. Here we consider *Random Non-Full queue* (RNF): the wavelength is chosen randomly excluding those that will be busy beyond the maximum available delay (full queues). *MINimum Length queue* (MINL): the wavelength that will be free as soon as possible (the shortest queue) is chosen. *MINimum Gap queue* (MING): The choice this time falls on the wavelength that introduces the smallest gap between the current packet, and the last one queued. In case all queues are full, no choice is made and the packet is lost.

In OBS, the Just Enough Time (JET) reservation scheme offers the flexibility to reserve newly arriving bursts in gaps left by already reserved bursts. Thus, JET provides another solution for the problem of gaps induced by FDL buffers [12]. Also, regarding the WDS, the sequence in which wavelength conversion and buffering are applied can be exploited to trade-off wavelength converter and FDL buffer usage [13].

C. *Electronic Buffering*

Since FDLs give fixed delays, random access is not possible: in contrast to electronic memory, FDLs cannot provide access to a specific data packet at an arbitrary access time. As an alternative to FDLs, the use of simple electronic FIFO memory with few opto-electronic interfaces is suggested in [1]. When using electronic memory, fast random access with respect to time in a FIFO buffer can be obtained. A random access in space to a random storage unit is more complicated since addressing the storage unit before readout of the data is then needed. However, since FIFO buffering is used, access to a random storage unit in the buffer is not required. Like when using FDLs, data-format transparency is obtainable in electronic memory. However bit rate transparency is more complicated, since clock recovery circuits recognizing the bit rates is then needed.

D. *Comparative performance evaluation*

In a common evaluation scenario, the impact of different WDS algorithms and individual FDL delays in an FDL buffer have been compared for OBS and OPS both assuming asynchronous operation and variable length bursts or packets. Then, both approaches have been compared to OPS with electronic buffers based on the number of buffer interfaces.

Bursts and packets arrive at a node with 4 input and output fibres according to a Poisson process with an offered load of 0.8. Burst and packet length is negative exponentially distributed with mean 100 kbit (bursts) and 4 kbit (packets) which translates into an average transmission time h=10 µs (bursts) or h=0.4 µs (packets) for a 10 Gbit/s line-rate. Unless stated differently, 16 wavelengths are assumed on each fibre and FDL. For the FDL buffer, the length of FDL i can be calculated as $i.b$ with respect to a basic delay b. For OBS, JET is applied for fibre and FDL reservation. FDL reservation is performed at time of burst arrival (*PreRes* in [12]).

Comparing FDL based OPS/OBS contention resolution schemes by simulation we have found that the RNF choice gives the worst performance since such policy does not detect the wavelengths immediately available, which do not insert gaps in the buffer. More intelligent mechanisms, such as MINL and MING, provide a strong improvement. In particular MING outperforms MINL because it aims, first of all, at reducing the gaps, leading to a more efficient buffer utilization and therefore shorter queues overall, as well as better performance.

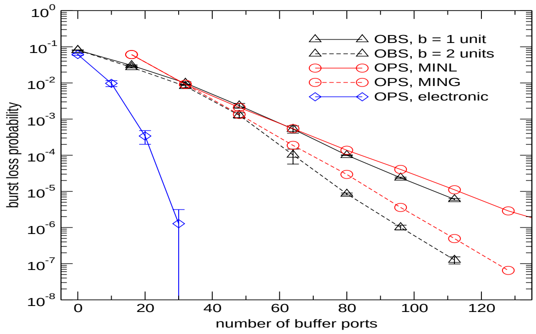

Figure 3. Burst/Packet loss probability versus number of buffer ports

Figure 3 depicts the impact of the number of buffer ports for FDL and electronic buffers. For FDL buffers, the number of buffer ports is the product of number of wavelengths and number of FDLs in the buffer. Basic delay of FDL buffers is chosen to be the one found optimal in case of OPS, and one and two times the mean burst transmission time in case of OBS, respectively. It can be seen that increasing the number of buffer ports greatly reduces blocking for all scenarios. While all results for FDL buffers show comparable trends, electronic buffers need a significantly smaller number of buffer interfaces.

IV. QUALITY OF SERVICE IN OBS/OPS

Introduction of multimedia applications in the Internet, which may have strict real time and information loss demands like a high quality video component, have increased the need for service quality differentiation. We expect IP to be the converging protocol layer, but the IP protocol itself does not support QoS differentiation. When implementing an OBS or an OPS layer, the quality of the service offered will be influenced by the amount of resources, like buffering and wavelength converters, spent in the network nodes. An OPS layer should therefore be able to support QoS differentiation, preventing over-dimensioning of the network nodes and delivering QoS differentiation to the IP-layer.

Based on ITU-T recommendation Y.1541 [14] that defines some provisional IP network QoS class definitions and [15] where a packet loss ratio of 10^{-6} is used for the highest priority QoS class, we expect that a packet loss through an OBS/OPS node better than 10^{-6} should be sufficient to service even the most demanding video-services.

A. *Quality of Service in Optical Burst Switching*

In order to provide service differentiation directly in the optical layer, several approaches have been proposed and investigated for optical burst switching. They take advantage of burst reservation, burst assembly or a combination of both and can be classified based on their key mechanism as follows [16].

- Differentiating offset values
- Preemption (composite burst switching)
- Intentional dropping of (low priority) bursts
- (Re-)scheduling in core nodes
- Access control and bandwidth reservation

In offset-based schemes, the burst control packet is separated from the data burst by an offset time. In the JET reservation scheme, the exact arrival- and end time of the corresponding burst are considered for reservation. Using the delayed reservation principle, bursts are reserved only from the expected arrival time. When the principle is applied in the JET scheme, bursts can be reserved between two already reserved bursts. This increases utilization. Service differentiation is achieved by allowing early reservation of high priority bursts by assigning an extra offset time [17] - called *QoS offset*. Therefore, high priority bursts make their reservation in a rather lightly loaded system, and have a smaller loss probability. On the other hand, low priority bursts experience the total system load, and has a higher loss probability.

The impact of QoS offsets on differentiation of loss probability has been analysed in [17] and [18]. Figure 4 depicts the impact of the QoS offset on the burst loss probability of the high priority class. As the mean and the distribution of low priority bursts have significant impact, the QoS offset is normalized by its mean burst length, and different burst length distributions of the low priority class are included.

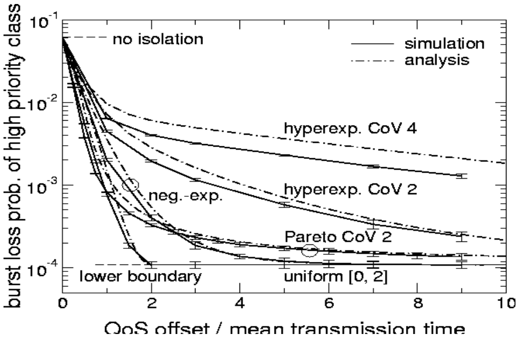

Figure 4. Impact of QoS offset on burst loss probability of high priority bursts

Offset-based QoS has the same total blocking probability with or without service differentiation, i.e. the overall performance is not reduced significantly ([17] reported a slight increase in overall loss rate for low loads). However, this scheme has two severe drawbacks [18]: First, the loss probabilities of high and low priority classes are highly dependent on burst characteristics. Second, basic offset adaptation in core nodes can change the differentiation in offset, which leads to undesirable subclasses as they introduce unfairness [19].

B. *Quality of Service in Optical Packet Switching*

1) Fibre Delay Line buffering

When using feed-forward buffers it is not possible to change the order of packets coming out of the delay lines, thus making pre-emption based techniques not applicable. Therefore, mechanisms based on a priori access control of packets to the WDM buffers are necessary [20]. We here demonstrate how to improve the WDS policies mentioned earlier in order to differentiate the QoS by allowing different degrees of choice to different policies. The objective is to apply reservation of the resources managed by the WDS policies, i.e. the available wavelength and delay, in order to privilege one traffic class over the other. The following alternatives have been investigated:

Time-threshold-based technique: the resource reservation is applied to the time domain, and a delay threshold T_{low} lower than the maximum available delay is defined. The WDS policy for low-priority packets cannot choose delays that are above threshold; therefore, a low priority packet cannot be accepted if the current buffer occupancy is greater than T_{low}, leaving the remaining buffer space to high priority packets which see the whole buffer capacity.

Wavelength-based technique: the resource reservation is applied to the wavelength domain. The WDS algorithm for high priority packets can send packets to any wavelengths of a fibre, while low priority packets are allowed to access only a subset (w_{low}) of the wavelength resources.

These two concepts have been applied to the MING WDS policy earlier discussed, leading to two new QoS-oriented policies named MING-D and MING-LIM which use the time-threshold-based and the wavelength-based technique respectively. As an example, in Figure 5, the performance of the MING-D policy is shown for the same node configuration as discussed earlier, providing a good separation between the high-priority class (grey curves) and the low-priority class (black curves).

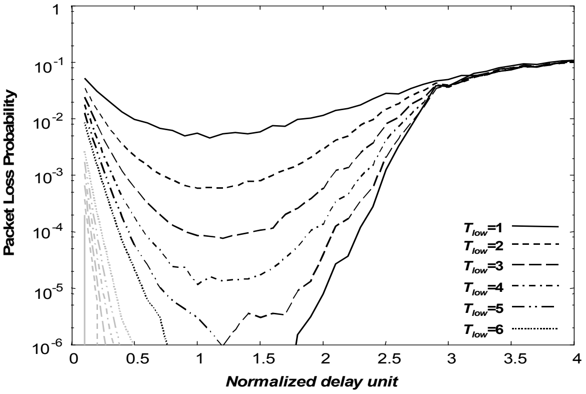

Figure 5. Service differentiation with the MING-D policy

2) Electronic buffering

By reserving parts of the buffer inputs in a feedback buffer for specified service classes, service differentiation can be achieved. As argued in [21], we expect two service classes to be sufficient, therefore we have chosen to evaluate the packet loss when the buffer resources are divided into two different blocks of inputs, allowing two service classes. If the packet belongs to the High Class Transport bearer service (HCT), any available buffer input can be used. If the packet belongs to the Normal Class Transport bearer service (NCT), only a limited number of buffer inputs can be used, if one of them is available. If no buffer input is available, the packet will be dropped.

In our simulations the share of traffic belonging to the HCT class will be set to 10 and 50 % respectively, and the number of wavelengths in the links to 32.

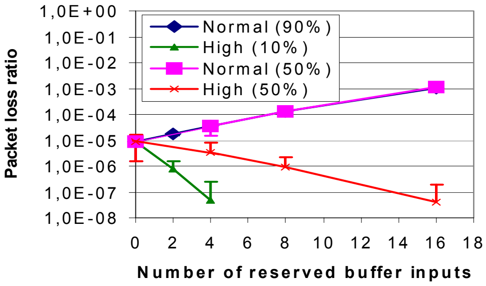

Figure 6. Packet loss as a function of number of buffer inputs reserved for HCT packets, 32 available wavelengths, load 0.8, 8 input/output fibres, variable length poisson packet arrival. A total of 42 buffer inputs are available. Curves are given for 10 % HCT (High) and 90 % NCT (Low) traffic and the two traffic classes having equal share of traffic (50 %). The two curves for the NCT traffic are coinciding and are therefore seen as only one curve. The error bars marks the limits within a 95 % confidence interval. Where only the upper limit is given, the lower limit is lacking. Higher precision can be achieved, making simulation time excessively long.

In Figure 6, the total number of buffer inputs is set to 42. Number of reserved buffer inputs is varied from 0 to 16 The share of HCT traffic is set to 10% and 50 % of the total traffic load, while the rest of the traffic consists of NCT traffic. The figure shows clearly that reserving buffer inputs gives a decrease in packet loss ratio for the HCT packets, while the NCT packets pays the price with a higher packet loss ratio. It is also confirmed that when the fraction of HCT traffic is increased to 50 %, the number of buffer inputs reserved for the HCT traffic has to be increased significantly in order to obtain the same packet loss ratio as for the case when HCT traffic load is 10 %.

When the number of reserved buffer inputs is set to 4 and the fraction of HCT traffic is set to 10%, packet loss ratio is approximately three orders of magnitude higher for the NCT traffic than for the HCT traffic. The obtained PLR of $< 10^{-7}$ satisfies the demands for the HCT class, while PLR of $< 10^{-4}$ satisfies the demands for the NCT class. Assuming a 50/50 split of the traffic load between the two QoS classes, PLRs that satisfy the QoS demands are obtained by reserving 8 buffer inputs.

3) *QoS in optical MPLS networks*

In the first phase of building optical packet networks, QoS mechanisms can be based on MPLS, which offers resource reservation with proper control algorithms to support Class of Services and Traffic Engineering, enhancing network efficiency.

a) *MPLS control unit*

An MPLS controller should perform the following functions: (i) Building and maintaining the Label Information Base (LIB), (ii) MPLS signalling with support for CR-LDP and RSVP Tunnels for Label Distribution, (iii) forwarding which includes processing of incoming packets, forwarding decisions, packet shaping and packet scheduling. Edge nodes should also be equipped with adaptation functions for incoming/outgoing traffic.

QoS tasks in an MPLS controller consist of the packets classification in edge nodes, differentiated packets servicing in core nodes and Traffic Engineering that performs operations on traffic vectors such as merging, comparing, summarising and subtracting flows as well as LSP admission control and traffic load management.

b) *Support for QoS*

MPLS offers connection-oriented forwarding techniques to the connectionless optical packet network by establishing of Label Switched Paths (LSPs). In effect, this allows optical network to reserve resources, such as buffers or wavelengths over predetermined paths for service differentiation, providing QoS guarantees. Currently two main MPLS features for supporting QoS are used, differentiated servicing [22, 23] and Traffic Engineering. The MPLS Class of Service (CoS) feature enables support for differentiated types of services across an MPLS optical network. The differentiated services model defines a variety of mechanisms for classifying traffic into a small number of service classes. Once packets are classified at the edge of the network, specific class-based forwarding rules are applied in each node.

c) *Traffic Engineering – QoS in network*

MPLS Traffic Engineering is a process of routing data traffic in order to balance the traffic load on the various links and nodes in the network. It assures e.g. better utilization of available bandwidth, accommodation of high class traffic load to buffering capabilities in nodes, routing around failed links/nodes (reliability) and capacity planning.

V. OPTICAL PACKET SWITCHING IN METRO NETWORKS

Ingress traffic level estimates predict that in a few years time the traffic volume will be a few Terabit/s, when access is mainly based on copper technology, and tens of Terabit/s, if a mass deployment of FTTH takes place [24]. Whereas core and access networks are currently experiencing huge innovations, the metro networks are mostly SONET/SDH over WDM rings that carry the increasing amount of data traffic very inefficiently. This results in the so-called *metro-gap*. The gap creates a clear network bottleneck preventing the client benefits. Therefore researchers world-wide make big efforts to investigate new packet-based technologies (e.g. Resilience Packet Ring [25]), which currently experience a migration from access to Metro Area Networks (MANs). Indeed, packet-based transport technology, a natural fit with the now ubiquitous IP traffic, appears to be one of the best choices for overtaking the metro-gap in a cost-effective manner.

a) MAN main requirements

We identify the main requirements that a MAN has to meet in order to bridge the metro-gap:

- *Flexibility*. Capability of handling different granularities of bandwidth and to support a wide range of protocols.
- *Cost-effective*. Compared to the current technology, CAPEX and OPEX costs must be reduced by an considerable amount.
- *Upgradeability*. Ability to incorporate new technologies in an easy and non-disruptive manner must be present.
- *Scalability*. Ability to remove and add network devices in an easy and non-disruptive way.
- *Efficiency*. High throughputs and short delays should be provided.
- *Fairness*. Starvation of nodes through a regulation of the bandwidth usage must be avoided.
- *Multicasting*. Multicasting in order to efficiently support applications such as videoconferences or distributed games should be allowed.
- *Quality of Service*. Rapid provisioning capabilities and service guarantees to mission-critical data and delay-sensitive applications must be supported.
- *Reliability*. The network elements must offer a high degree of reliability. This mandates that critical sub-systems are fully protected and capable of in-service upgrades.

It is important to notice that these requirements are better met by packet-based technology than by circuit-based technology such as SONET/SDH rings.

b) Optical MAN

OPS solutions appear to be a good candidate for future MAN architectures (Optical MANs, O-MANs). Besides the fact that it is a packet-based technology, it can also provide high throughput avoiding any electronic bottleneck conversion, and cut the cost through a simplification of the structure.

Many research centres/universities are currently proposing viable approaches towards O-MANs by developing networking concepts and technologies, thereby pushing in the described direction.

Several proposals are mainly based on simple star, bus or ring topologies where usually an ad-hoc MAC protocol arbitrates the packets in a non-conflictive manner. The feasibility of some of these is demonstrated in several test-beds. For instance, HORNET (Hybrid Opto-Electronic Ring NETwork) is a WDM time-slotted ring developed at the Stanford University [26]. Another example is DBORN (Dual Bus Optical Ring Network) [27], developed at the Alcatel Research & Innovation. It is based on a unidirectional ring organized around a Hub that generates a logical dual bus structure through a spectral separation of upstream and downstream flows.

On the other hand, there are some studies on novel advanced optical architectures based on multiple trees, rings, and/or buses interconnected among one or more bufferless switches. The main aim is to overtake any throughput limitation, reaching tens of terabit/s. In particular, within the COST 266 action, a multiple trees interconnected metro network has been studied [28]. A centralised array wavelength grating (AWG) provides a static wavelength routing among four trees (each one used 32 wavelengths at 10 Gbps), while a network controller manages the network resources through a proper multi-class scheduling algorithm. The maximum throughput of this network reaches 1.28 Tb/s, thereby removing the metro-bottleneck.

VI. CONCLUSION AND OUTLOOK

The COST 266 action has studied optical burst and packet switching with respect to performance and complexity. Node designs, contention resolution strategies and QoS architectures in OBS have received special attention.

This work, and recently published papers on OPS/OBS, shows an emerging trend towards asynchronous packet- and burst switching. Comparative concept studies show that OPS and OBS share several properties. Some important differences remain, like the control signalling scheme as well as the finer granularity, but higher overhead in OPS.

Key design parameters, as well as a detailed node design for OPS/OBS networks, are described. In order to achieve a sufficiently low burst or packet loss rate in the described node designs, contention resolution schemes must be employed, both in OBS and OPS. In combination with the wavelength dimension, both FDL and electronic buffering are compared for OBS and OPS in a common scenario. It is shown that both buffering technologies are able to significantly reduce loss probability. Despite the fact that electronic memory has the potential of using fewer buffer interfaces, their deployment may be obstructed, since they require costly O/E/O interfaces.

For OBS, a classification of several QoS schemes is given and offset-based QoS is studied in more detail. For support of control and QoS differentiation, OPS can use MPLS reserve resources and provide QoS guarantees, such as buffers, or wavelengths over predetermined paths.

Finally, how to overcome the inefficiency in metropolitan area networks (MAN) has been investigated. In the MAN environment, the advantage of OPS solutions is highlighted, and the main requirements have been identified and described. Network architectures that are currently under development in research/university centres are described. A new advanced architecture that has been studied within the COST 266 action and DAVID project, that overcomes the electronic throughput limitation, is described.

A. Further work

Performance of a node depends on the available resources, which are the result of several trade-offs between performance and complexity. In addition, client layer requirements, technology status, as well as the topology and transmission systems of existing WDM networks, influence network design.

Further work on node and network design should therefore include network and end-to-end client layer performance studies, comparing the OCS and OBS/OPS techniques. Important parameters in this context are throughput, performance (delay, loss rates and QoS differentiation), signal quality and CAPEX/OPEX. Scalability is an issue gaining increased importance as the need for large networks increases. Further work on node and network design should therefore also take into account the need for network scalability. Topics suitable for further studies are e.g. the influence of contention resolution schemes and end-to-end QoS schemes on general performance of OPS/OBS networks, for both backbone and metropolitan environments. How these schemes can be combined with a GMPLS control scheme should also be investigated.

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