Modelling of Control Plane in OBS Networks

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ABSTRACT
In this paper we address the problem of control plane operation and its impact on the performance of optical burst switching networks (OBS). In a poorly-engineered network the congestion in control plane may delay excessively the processing of control packets in an electronic core-node controller and as a result lead to the loss of data bursts. In order to approach this outcome effectively a queuing model of control plane operation has to be studied. First we discuss several factors that have an impact on the control plane operation. Then for an exemplary OBS system we propose two queueing models which show some relations between its parameters.
Keywords: control plane, network design, optical burst switching, queuing system.

1. INTRODUCTION

Optical burst switching (OBS) [1] is a promising solution for reducing the gap between transmission and switching speeds in future networks. In the edge node, client packets are aggregated and assembled into optical data *bursts* which are further transmitted through WDM links and switched all-optically in core nodes. A *burst control packet* (BCP) is transmitted in a dedicated control channel and delivered with some *offset time* prior to its data burst *payload*. In this way the electronic *controller* of core node has enough time both to reserve a wavelength in the output link and to reconfigure dynamically the switching matrix. The offset time is introduced either in the edge node [1] by delaying the transmission of burst payload, we refer to it as a *conventional* OBS, or in core nodes [2] by means of additional fixed-length fibre delay element, in an *offset time-emulated* OBS architecture. When the burst transmission is finished in a node the output wavelength is released for other connections.

Due to the separated transmission of burst control packets and data payloads both opto-electronic control and all-optical data planes can be seen as two parallel networks, namely a *data* and a *control* network. The burst is lost if either its control packet or its payload is lost; it occurs, in principle, due to resources occupancy in congestion states. Both burst contention resolution mechanisms and scheduling algorithms deal with the problem of congestion in data plane (see e.g. [3], [4]). The congestion in control plane is solved by packet queuing in electronic buffers of the controller.

The burst losses can be also due to early burst payload arrivals. This effect arises if an *effective processing delay* the control packet undergoes in the controller is larger then a *delay budget* given by the offset time; in such case the burst is lost. The effective processing delay is determined by the queuing delay and processing time of control packet as well as the switch setup time. While control packets experience variable queuing delays, depending on the congestion situation, the effective processing delays vary as well. As a result the determination of appropriate delay budget and setup of offset times that would prevent burst losses is not a trivial task. Notice that excessive over-provisioning of offset times is undesired in OBS networks since it both results in extended burst delays and puts constraints on the application of fibre delay elements in the offset time-emulated OBS.

Although there are some studies that consider the impact of congestion in control plane on OBS node/network performance (see e.g. [5], [6]) few of them address the problem of *sufficient* offset time provisioning. In [7] an initial discussion on some factors which constitute the processing delay budget is provided. In [8] a control packets scheduling algorithm reducing the effect of insufficient offsets is proposed. Finally, in [3] an M/M/1 queuing model is used to compute an approximation for the complementary distribution of the control packet processing delay. Since the results presented in these works are very preliminary the study has to be continued.

In order to address thoroughly the problem of sufficient offset time provisioning the operation in control network has to be analysed. In particular one has to study a queuing model of control plane taking into actual system parameters. In this study we provide a discussion on several factors that have impact on the control plane operation. Moreover we investigate two queuing models of an exemplary OBS node controller. It allows us estimating the delay budget that have to be provided to the bursts in order to achieve a target burst loss probability.

This work has been partially funded by the e-Photon/ONe+ project (FP6-IST-027497) and the MEC (Spanish Ministry of Education and Science) under the CATARO project (Ref. TEC2005-08051-C03-01).

1-4244-1249-8/07/$25.00 ©2007 IEEE

2. CONTROL PLANE IMPACTING FACTORS

Before elaborating a model of OBS control plane one has to identify both the model objectives and its impacting factors. In particular, the fidelity of model depends on the phenomenon one wants to study. Some control-plane stability constraints in OBS (see [5], [6]) can be obtained with a simple algebra based on basic system parameters. On the other hand a more complex queuing analysis has to be applied when elaborating a model which involves time dependencies. There are many factors that influence the control plane operation and performance; below we list the main of them.

- **Network architecture** - depending on the use of either the conventional OBS or the offset time-emulated OBS or their hybrid solution the offset time may either vary or do not inside the network. As a result the delay budget of bursts entering the node is either variable or fixed.
- **Node controller architecture** - a simple controller can consist of a single *processor* unit with a *buffer* handling all the burst control packets in a centralized way. More advanced controllers can use distributed, pipelined and parallelized operation onto multiple processors. Such architectures speed-up the processing of control packets.
- **Functions and algorithms** - the main functions performed by the controller processors are *forwarding* of burst control packets, *resources reservation* (with contention resolution and QoS functions) for incoming burst payloads and configuration of the switching matrix. These functions may be realized with algorithms of different complexity and performance. The algorithm implementation can be either *memory*-based, where the processing time depends on the seeking time in the memory map, or *combinatorial*, where the processing time is constant. Both selection and implementation of algorithms influence the service time distribution of the controller.
- **Processing technologies** - several alternatives can be employed in the processor implementations, starting from relatively slow processors of general purpose, through the field programmable gate arrays (FPGA) and network processors (NP), to the fastest but also the less flexible application-specific integrated circuits (ASIC) (see e.g. [9]). The first three technologies allow for both memory-based and combinatorial algorithm implementations, while the ASIC may be limited only to combinatorial solutions.
- **Queuing discipline** - either simple first-in, first-out (FIFO) or more advanced disciplines, for instance with ordering the burst control packets according to their offsets, can be used in the buffers.
- **Data plane-related parameters** - the number of both node input/output ports and data wavelengths has an impact on the amount of burst control traffic arriving to the controller.
- **Characteristics of burst control traffic** - the arrival process of burst control packets depends on the burst traffic load, the burst assembly algorithm, in particular on the distribution of both the payload and the control packet lengths, the number of control channels and the transmission rates in both control and data channels.

3. QUEUING MODEL OF CONTROL PLANE

In general, OBS control network is a network of node controllers connected by control channels. Each controller can be seen as a queuing system. There is some burst control traffic offered to the controller. The arrival process of control packets is closely related to the arrival process of data bursts; therefore according to [10] it can be modelled as a Poisson process.

Construction of accurate queuing model of a controller may be difficult, if not impossible, task. The controller service time distribution largely depends on its features (discussed in the previous section). In particular, the controller architecture could be represented as a queuing network of buffer-processor systems; some approximation techniques like for instance a two-moment analysis [11] could be applied here.

The operation of OBS controller can be seen as a queuing with reneging [12]. In particular, a burst control packet, when accepted to the queue, leaves the system non-served if its delay budget is lower than the effective processing delay. The delay budget is equal to actual offset-time of the burst. In a well-designed system this offset should be long enough in order to reduce the probability of burst losses due to their reneging.

In this work we concern on a simple controller with one processor unit and one FIFO buffer handling all burst control packets arriving to the node. The processing times of the processor are either *exponentially* distributed (EXP) or *deterministic* (DET) with a mean equal to T_p. We assume that the delay budget τ, which is provided to all the bursts entering the node, is constant (like in the offset time-emulated OBS).

For each processing time distribution we consider a different queuing model, namely:

- for EXP – M/M/1 queue with reneging, where all control packets are accepted to the queue; the packet is lost if period τ expires before it is served.
- for DET – M/D/1/K queue without reneging, where control packets are accepted to the queue only if there is free space; when accepted all those packets are served. The system (queue and server) capacity $K=[\tau/T_p]$ guarantees that all the packets entering the queue are served before period τ. K gives also an upper bound on the loss probability of a M/D/1 queue with reneging.

The burst loss probability function $P(\tau)$ and its inverse form $\tau(P)$ are presented in Table 1. In particular, we base on fine approximation of M/D/1/K queue proposed by [13], whilst we have exact results for M/M/1 queue with reneging [14]. In the notation ρ is the processor load ($\rho=\lambda T_p$, where λ is the intensity of control packet arrival). In case of the M/D/1/K queue we will consider τ to be a multiple of T_p ($\tau=KT_p$).

Table 1. Performance of queuing models.

	Packet loss probability	**Delay budget**
M/M/1 with reneging	$P=\frac{(1-\rho)e^{\tau(\rho-1)/T_p}}{1-\rho e^{\tau(\rho-1)/T_p}}$	$\tau=\left(\frac{\ln\left(\frac{P}{1-\rho(1-P)}\right)}{\rho-1}\right)T_p$
M/D/1/K	$P=\frac{\rho^{\left(\frac{2\tau/T_p-\sqrt{\rho}}{2-\sqrt{\rho}}\right)}(\rho-1)}{\rho^{\left(2\frac{\tau/T_p+1-\sqrt{\rho}}{2-\sqrt{\rho}}\right)}-1}$	$\tau=\left(\frac{\left(\ln\left(\frac{P}{1-\rho(1-P)}\right)-\ln(\rho)\right)\left(2-\sqrt{\rho}\right)}{2\ln(\rho)}+1\right)T_p$

4. RESULTS

The node under study has $N=4$ input/output ports. The transmission bit rate of data channel is $r_b=40$ Gbps. We consider fast switch operation with the switching time $T_S=0.1\mu$s. The analyzed mean processing times are T_p={10 µs, 1 µs, 200 ns} (the same as reported in [9]). We assume the number of control channels is high enough to carry entire control traffic and to have the packet contention effect in control channel negligible.

4.1 Traffic Intensity and Stability Constraint

In Fig. 1A we present the intensity of control packet arrival λ_c in the function of mean data burst length L_b for the systems with different number of data wavelengths k per port. The burst traffic load ρ_b is such that the target burst loss probability in data plane $P_{Tb}=10^{-4}$; with the Erlang B-loss formula we find it equal to ρ_b = {0.06, 0.33, 0.62} per wavelength, respectively for the system with k = {4, 16, 64}. As we can observe the intensity of control packet arrival increases with the number of wavelengths and is inversely proportional to the burst length.

Moreover for different processing times T_p we plot the boundary $\lambda_c=1/T_p$ of the control-plane stability constraint $\rho=\lambda_c T_p<1$ (see [6]). Taking this into account, for each pair of k and T_p we can find the minimum mean burst length which assures the stability of controller operation. Note that with shorter T_p (what means faster processor operation) this limit can be lowered.

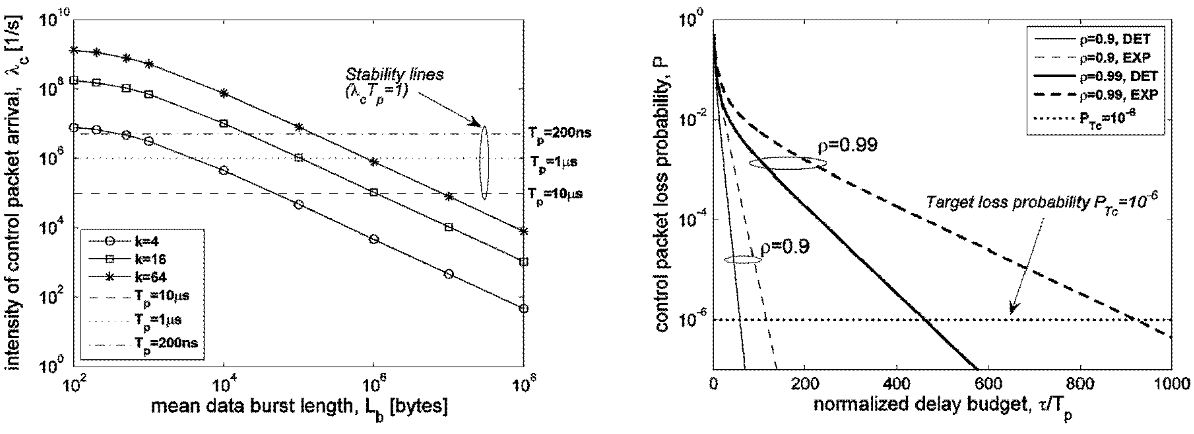

Figure 1. A) Intensity of control packet arrival; B) Loss probability of control packets.

4.2 Delay Budget vs. Burst Size

Firstly, we study the impact of delay budget τ (normalized to the processing time T_p) on the loss probability P of control packets, for the system with different processor (controller) load ρ = {0.9, 0.99} and processing time distribution (EXP or DET). As we can observe in Fig. 1B, P decreases if either τ increases or ρ decreases. When having deterministic processing times we need smaller τ to achieve a certain level of loss probability than in case of exponentially distributed processing times; however, this difference is reduced with lower ρ. The dotted line delimit a minimum τ which guarantees a target loss probability in the control plane $P_{Tc}=10^{-6}$; for instance for EXP and $\rho=0.9$ such τ is equal to about 100 times of T_p.

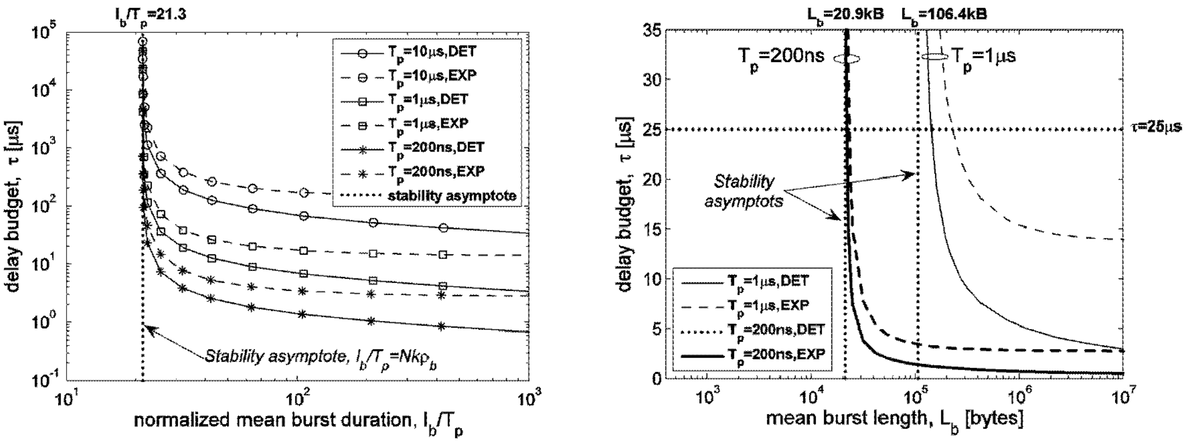

Figure 2. Delay budget vs.: A) normalized mean burst duration, B) mean burst length.

In Fig. 2A we investigate the impact of normalized mean burst duration l_b/T_p on delay budget τ in the system with $k = 16$ (where the total number of data wavelengths $Nk = 64$), different T_p, and target loss probabilities $P_{Tb} = 10^{-4}$ (that is achieved with $\rho_b = 0.33$) and $P_{Tc} = 10^{-6}$. We can see that if l_b/T_p approaches the stability asymptote ($Nk\rho_b = 21.3$) we have $\tau \to \infty$ for all curves.

Finally, in Fig. 2B we plot a reference (dotted) line $\tau = 25$ µs corresponding to the offset provided by a feasible fibre delay unit (see [2]). With such target τ we can find a lower bound on mean burst length L_b which preserve the system performance. In particular it is about 20 kbytes in the case of fast processing ($T_p = 200$ns) and a few hundreds of kbytes under moderate processing times ($T_p = 1$µs). Notice that for $T_p = 200$ ns the limiting value of mean burst length is very close to the one determined by the stability constraint.

5. CONCLUSIONS

In this paper we address the problem of congestion in the control plane in OBS networks. In order to approach this issue a queuing model of control plane operation has to be studied. Since several factors have an impact on the control plane operation the elaboration of such model may be a difficult task.

This paper gives some preliminary results for an exemplary OBS system with one processor performing in the node controller. Depending on the distribution of processing times we model such system either as M/M/1 queue with reneging or as M/D/1/K queue without reneging. The obtained results show that by appropriate setup of the minimum mean burst length the congestion in control plane can be effectively limited. Moreover for the analysed system with moderate processing times we show that a feasible fibre delay element can both effectively provide the offset times and concurrently preserve the system performance. The future study will concern on more advanced controllers, in particular, on the controllers with distributed operation onto multiple processors.

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