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Analysis of Burst Scheduling for Dynamic Wavelength Assignment in Optical Burst-Switched Networks

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Introduction: The approach of optical burst switching (OBS) has recently attracted much attention due to its efficient transport of IP traffic over WDM layer [1]. However, we believe that OBS networks experience some drawbacks because they either trade-off QoS of the high-priority traffic for the severe burst loss rate of the best-effort traffic [2], or assume burst buffering in the optical domain. On the other hand, static routing and wavelength assignment (RWA) used in current WDM networks, leads to high wavelength over-provisioning, as the lightpaths are assigned to each node-pair permanently. That is why we propose a new network architecture, wavelength-routed optical burst switched (WROBS) network [3]. Owing to the centralised control, WROBS requires no processing in the optical core, whilst combining the OBS approach with the dynamic RWA and thus allowing the efficient bandwidth utilisation.

In this paper, we discuss the benefits and limitations of the dynamic RWA in a centralised optical burst-switched network architecture. We present systematic comparison between the performance of the dynamic and static RWA in terms of QoS provisioning and bandwidth utilisation. Additionally, we consider a new component in the WROBS architecture, namely the request scheduler. We demonstrate that its application to the dynamic RWA significantly improves the performance of the WROBS.

Network Model: The architecture consists of N edge-routers located at the ingress of the optical core network. Each edge-router is connected to an optical core router. One of the edge-routers also carries out the function of the control node, or request server, responsible for wavelength assignment to requests arriving from edge-routers [3].

Each request signalled to the request server represents a burst of IP packets aggregated in the edge-router and directed to the same destination. Each edge-router has $C(N\text{-}1)$ electronic buffers where C is the number of traffic classes of service (CoS). One buffer per destination per CoS is assumed, where packets coming from the access layer are aggregated to the bursts. Burst size is limited by a time-out signal which is issued once the defined time of burst aggregation (aggregation delay) has been exceeded. As soon as the time-out signal has been issued, the request for a lightpath is sent to the request server.

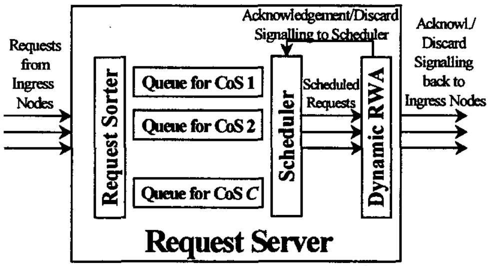

Fig. 1. Request Server Architecture

In the server, requests are sorted according to their (CoS) and directed to queues (Fig. 1). The scheduler is based on earliest-deadline-first (EDF) discipline. If the request has exceeded maximum delay allowed for scheduling, $t_{\mathrm{sched,max}}$, the server drops it and sends a discard signal back to the edge-router. Otherwise, it tries to allocate a lightpath and, if successful, it sends acknowledgement to the edge-router. The latter then sends off the burst over the assigned lightpath through the core network without intermediate optical processing. Once the whole burst has been transmitted, the lightpath is released. If the request is blocked by RWA but it has not exceeded $t_{\mathrm{sched,max}}$, it is sent back to the queue and when the next lightpath is released, the queue is re-ordered so that a request which has spent more time in the queue is served earlier than the one which has spent less time there. As shown below, $t_{\mathrm{sched,max}}$ is one of the most critical parameters affecting the efficiency of the dynamic RWA. In order to clarify the principle of our approach, only one CoS is considered in this paper. We evaluate the QoS provisioning in the WROBS in terms of burst end-to-end delay and the request blocking probability. The results can be easily extended to multiple CoS.

In order to analyse the performance of described network architecture, an event-driven simulator was developed in C++. ARPA Net physical topology was applied which allowed to investigate the algorithms on a realistic network. First-fit heuristic was used for the dynamic RWA component [4]. This heuristic is one of the fastest in terms of the computational complexity, thus we assume zero calculation time of the RWA algorithm. The bursts were aggregated out of packets generated with the ON-OFF Pareto model as in [3]. Uniform traffic loads were assumed. Two network parameters, namely request blocking probability (BP) and maximum request scheduling delay $t_{\mathrm{sched,max}}$ were analysed as a function of the core bandwidth provisioning, W_{DYNAMIC} (wavelength requirement for the dynamic RWA).

Dynamic RWA Efficiency: The efficiency of the dynamic RWA with regards to the static one was evaluated the following way. Wavelength requirement for the static RWA, W_{STATIC} is assumed as an upper bound on the number of wavelengths in the core for blocking-free burst transmission. W_{DYNAMIC} should be lower than W_{STATIC}, otherwise the dynamic RWA leads to poorer bandwidth utilisation and brings no advantage compared to the static RWA. By definition, the static RWA implies zero BP, however, if the BP of 10^{-4} is achieved by the dynamic RWA, it was assumed to be as good in terms of the BP as the static one. This way, the efficiency of the dynamic RWA, E_{DA}, can be introduced as follows:

$$E_{DA} = \frac{W_{STATIC} - W_{DYNAMIC}}{W_{STATIC} - W_{B_{in}}} \Rightarrow E_{DA} = \begin{cases} 1 \text{ if } W_{DYNAMIC} = W_{B_{in}} \\ 0 \text{ if } W_{DYNAMIC} = W_{STATIC} \end{cases},$$

where $W_{B_{in}}$ is the total input bit-rate per node divided by the wavelength bit-rate. In the current analysis both maximum input bit-rate per one buffer and wavelength bit-rate are 10 Gb/s. For ARPA Net, $W_{\mathrm{STATIC}} = 33$ [5].

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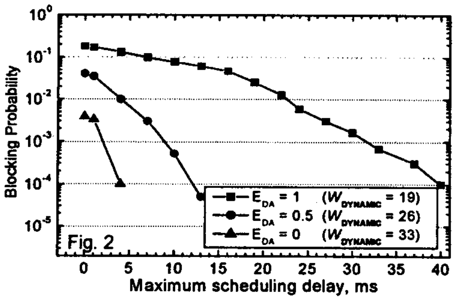

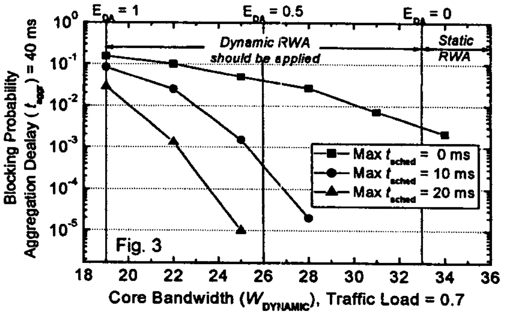

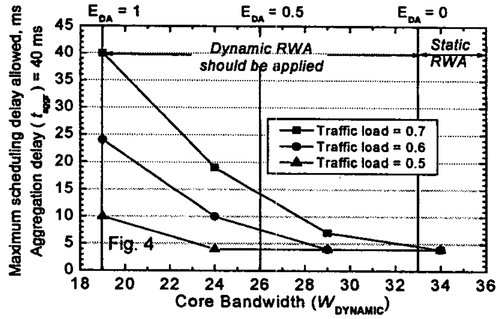

Fig. 2. Blocking Probability vs. $t_{\text{sched,max}}$ for different E_{DA}, aggregation delay $t_{\text{aggr}} = 40$ ms, Traffic Load = 0.7

Fig. 3. Blocking Probability vs. wavelength requirement for different $t_{\text{sched,max}}$, dynamic RWA should be used if wavelength requirement < 33

Fig. 4. Trade-off between $t_{\text{sched,max}}$ and core bandwidth for different traffic loads, blocking probability of 10^{-4} is reached for all curves

Results and Discussion: The burst end-to-end delay, i.e. the time elapsed from when a burst is aggregated until it is delivered to the destination, is influenced by several parameters including two controllable ones: the burst aggregation delay, t_{aggr} (set to 40 ms throughout our analysis), and the time allowed for the request to be buffered at the scheduler, $t_{\text{sched,max}}$.

The decrease in $t_{\text{sched,max}}$ significantly adds to the blocking probability, as shown in Fig . 2. It shows that when $t_{\text{sched,max}} = 0$, the BP of no less than 10^{-2} is reached even for $E_{DA} = 0$ (i.e. when $W_{\text{DYNAMIC}} = W_{\text{STATIC}}$). This indicates that the dynamic RWA has very limited capabilities when not supported by the request scheduling in the central node. In contrast, if $t_{\text{sched,max}}$ of 40 ms is allowed (which represents the case of $t_{\text{sched,max}} = t_{\text{aggr}}$), the BP is 10^{-4} for $E_{DA} = 1$, i.e. in this case the dynamic RWA totally outperforms the static one, because no wavelength over-provisioning is required in this case at all.

Fig. 3 shows how the core bandwidth over-provisioning influences the BP under the different values of $t_{\text{sched,max}}$. Again, it can be observed that with $t_{\text{sched,max}} = 0$, no over-provisioning for $E_{DA} > 0$ can achieve the desired BP, whilst with $t_{\text{sched,max}} = 20$ ms, the BP = 10^{-4} is achieved for 24 wavelengths, i.e. for $E_{DA} > 0.5$. It should be noticed that further increase in $t_{\text{sched,max}}$ will lead to significant end-to-end delays (exceeding 100 ms) and is not allowed for QoS-sensitive traffic.

The relationship between $t_{\text{sched,max}}$ and W_{DYNAMIC} with the BP $\leq 10^{-4}$ is shown in Fig. 4 which demonstrates the trade-off between the core bandwidth over-provisioning and QoS in terms of end-to-end delay. Based on this graph, optimal values of W_{DYNAMIC} and $t_{\text{sched,max}}$ can be chosen depending on the particular QoS requirements. The relationship shows that $t_{\text{sched,max}}$ as small as 14 ms decreases the wavelength requirement twice, i.e. $E_{DA} = 0.5$ is reached.

It must be said that the BP and $t_{\text{sched,max}}$ can be improved by applying more sophisticated scheduling and RWA heuristics. Thus, our model represents the worst case for the analysis of QoS provisioning. However, as demonstrated above, even in this case a fairly small time, allowed for the scheduling delay, brings significant reduction of the wavelengths required to satisfy the desired blocking probability.

Summary: Wavelength-routed OBS network architecture was considered. The request scheduler residing in the control node was proposed and analysed in terms of QoS provisioning. It is shown that the desired blocking probability can be achieved with no or little core bandwidth over-provisioning at the expense of the request scheduling with maximum delays not exceeding the aggregation delay (10-40 ms for ARPANET under the assumptions made). Therefore, the dynamic RWA should only be used in combination with the request scheduling in the control node. This way, it significantly outperforms static RWA in terms of the wavelength requirement whilst reaching the negligible blocking probability and small end-to-end delays.

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