Analysis of Wavelength-Routed Optical Burst-Switched Network Performance

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Abstract: This paper studies a novel scalable network architecture combining optical burst switching (OBS) with dynamic wavelength allocation to guarantee quality of service (QoS). All processing and buffering functions are concentrated at the network edge and bursts are assigned to fast tuneable lasers and routed over a bufferless optical transport core using dynamic wavelength assignment. Different burst aggregation mechanisms are evaluated for a range of traffic statistics in terms of delay and packet loss rate. New network performance parameters in an analytical model quantify the advantages of dynamic wavelength allocation. The results define the operational gain achievable with dynamic wavelength assignment compared to quasi-static wavelength-routed optical networks.

1. Introduction

In future telecommunication networks traffic with different performance requirements will be merged in the same physical layer and will require new, traffic-adaptable architectures. Although static wavelength-routed optical networks (WRONs) [1] are relatively simple to design and operate, they are not easily adaptable to dynamically varying traffic. In contrast, optical burst-switched (OBS) networks [2-3] have been proposed which can adapt to dynamic traffic variations by packet aggregation at the network edge. However, most OBS schemes assume one-way reservation of network resources and thus can not take into account QoS differentiation, or suffer from high packet loss rates (PLR) [4]. As an alternative a wavelength-routed OBS network architecture, WROBS, has been proposed to achieve deterministic latencies, and together with the initial design parameters was described in [5]. In this work new analysis and results are reported on the burst aggregation process at the network edge, the trade-offs in the design of edge delay, core-to-input bitrate ratio and the round trip time, which allow to predict bandwidth utilisation and dynamic wavelength allocation gain. These results help to define the bounds on the round-trip time required for lightpaths assignment under dynamic network control.

2. Network Architecture and Burst Aggregation

The analysis in this work extends that proposed in [5] and is based on the WROBS architecture shown in Figure 1, where electronic edge routers are connected to an optical core. The optical core is assumed to be transparent by using dense wavelength-division multiplexing (DWDM) transport and active or passive routers to avoid the processing of header information and temporary buffering in the core routers. Packets are pre-sorted in the edge-routers according to their class of service (CoS) and destination into separate buffers, aggregated to bursts, and dynamically assigned to an available wavelength; this occurs either when packets are dropped due to buffer overflow, or when a timeout signal dictates the release of time-critical packets to meet latency requirements.

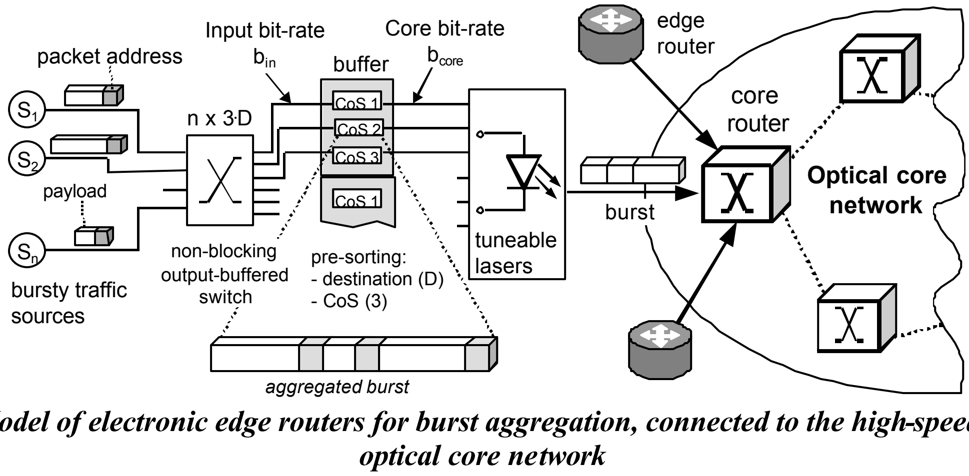

Fig. 1. Model of electronic edge routers for burst aggregation, connected to the high-speed DWDM optical core network

The incurred delay in the edge router, t_{edge}, is, thus, both deterministic and adjustable to meet the specific latency requirements of different traffic classes.

The burst aggregation was analyzed for traffic with the same mean bit-rate (10 Gb/s), but different packet length and packet inter-arrival time statistics as a function of the edge delay for a buffer size of 48.8 MB (400 Mbit) as shown in Figure 2:

I) Pareto packet length, Pareto inter-arrival distribution.
II) Fixed packet length, Pareto inter-arrival distribution.
III) Fixed packet length, Poisson inter-arrival distribution.

In all cases the minimum packet length was 0.5 kB, the mean 5 kB, $\alpha = 1.5$ for the Pareto distribution [5]. The Pareto distribution describes traffic burstiness in data networks, and the Poisson distribution is an established traffic model in circuit-switched networks.

The largest variance of both burst size and edge delay distribution was observed for case I, resulting in significant packet loss and reducing the allowable edge delay accordingly. To maintain a mean PLR < 10^{-6}, t_{edge} < 28 ms is required for case I, whereas the same PLR can be achieved for edge delays up to 38 ms in case III. The results indicate that the burst sizes in the WROBS scheme are not only considerably larger compared to other OBS schemes [2-3] with a few MB of size, but that the mean burst-size behaviour can be approximated by a continuous bit-rate (CBR) model.

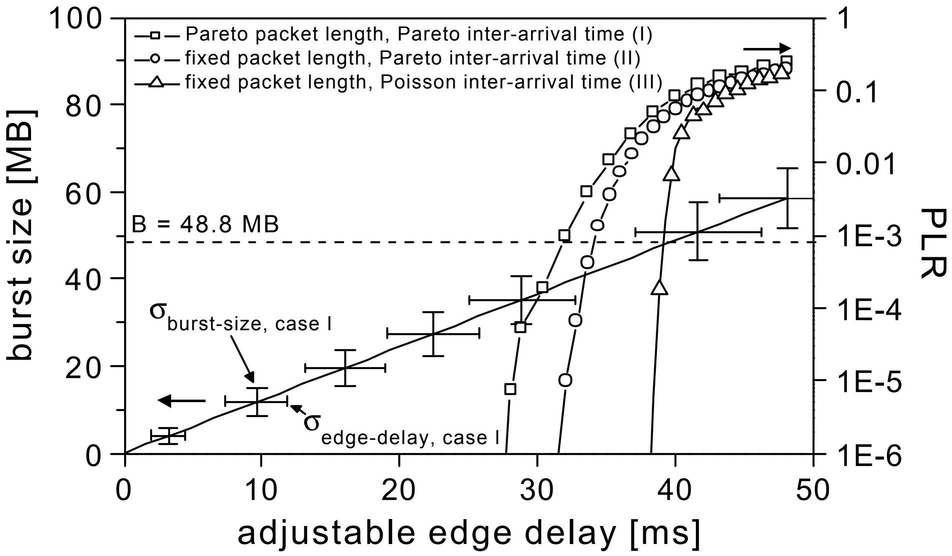

Fig. 2. Burst size, edge delay distribution and resulting PLR for three different traffic statistics

3. Network Modelling Results

A uniform distribution of packets addressed to other edge routers and no loss of packets in the output-queued switch are assumed. The time duration before a burst is assigned to a free wavelength and released into the network is defined as the edge delay t_{edge}. As described in the previous section, a CBR traffic model was assumed, for which the burst size L_{burst} increases linearly with the edge delay $L_{burst} = t_{edge} \cdot b_{in}$. The wavelength holding time t_{WHT} denotes the period for which a given wavelength is assigned, typically in milliseconds $t_{WHT} = t_{RTT} + (t_{edge}/A)$, where $A = b_{core}/b_{in}$ is the bit-rate ratio. t_{RTT} is the time required for the lightpath set-up, including propagation delays. In these calculations a value of 5 ms was assumed, based on a network with a 1000 km diameter. The equivalent bandwidth used by a lightpath is defined as bandwidth-per-wavelength, $BPW = L_{burst}/t_{WHT}$. For high resource utilization in the physical layer it is important that a given lightpath is used as efficiently as possible, the bandwidth utilization U can thus be defined as $U = BPW/b_{core}$.

As $b_{core} \gg b_{in}$ can be assumed for a high-speed optical core, $t_{WHT} \ll t_{edge}$. In this case the time required to transmit a burst and, therefore, the time for which a given wavelength is used is much shorter than the edge delay. In the case of dynamic wavelength allocation an unused wavelength can be assigned to another edge router, and the resultant increase in the wavelength re-use is denoted by a wavelength re-use factor, RUF, defined as:

$$RUF = \frac{t_{edge}}{t_{WHT}} = \frac{A \cdot t_{edge}}{A \cdot t_{RTT} + t_{edge}} = A \cdot U \tag{1}$$

It is plotted in Figure 3 for 0 ms $\leq t_{edge} \leq$ 200 ms, $0 \leq A \leq 100$, and t_{RTT} = 5 ms. These results clearly show that with this network approach different types of traffic could be accommodated: low delays, required for time-critical types of traffic, are achievable, but with low values of utilization, U, especially for large bit-rate ratios. It is possible to design a network with U > 80 % for A > 10 and delays > 50 ms. From Figure 3 it can be seen that RUF reaches maximum values with both increasing t_{edge} and A. For comparison, Figure 3 shows also the equivalent to the case of a statically wavelength-routed optical network where RUF = 1. For values of RUF < 1 the network would theoretically require more wavelengths than in a static WRON, and this represents the region of network instability where the total input load exceeds the network throughput.

The time to set up a lightpath is t_{RTT}, required for signalling between edge routers and the network control element, either central or distributed. To ensure that RUF > 1 as defined in (1),

$$t_{RTT} < (A-1) \cdot t_{edge}/A \Leftrightarrow t_{RTT} < t_{edge} \quad \text{for } A >> 1.$$

The variation of RUF is plotted against t_{RTT} for given edge delays (10, 20, 50 ms) and A = 20 in Figure 4. An important result is that for A >> 1 as in high core bit-rate networks, a high re-use factor is achieved only for t_{RTT} of a few milliseconds. It is important to note that in order to achieve efficient wavelength re-use, the lightpath set-up time must be as small as possible, and for a fixed t_{edge}, the upper bound in RUF is given by RUF_{max} = A.

The proposed architecture can, therefore, accommodate traffic with wide range of delay requirements over the same network. Very delay sensitive traffic, such as voice, would only be queued at the edge for 10 - 20 ms before being assigned to a free wavelength with the penalty of a relatively low re-use factor (< 5) as shown in Figure 3. Less delay sensitive traffic such as data can be routed over the network in parallel, but with longer edge delays allowing for a higher re-use of wavelengths than in the case of latency-sensitive traffic.

The lower bound for the required edge delay is the round-trip time t_{RTT} as shown in Figure 4. Providing, therefore, the acceptable t_{edge} significantly exceeds t_{RTT}, high values of A > 10 allow to improve network design, although a high bit-rate does not necessarily improve bandwidth utilization if

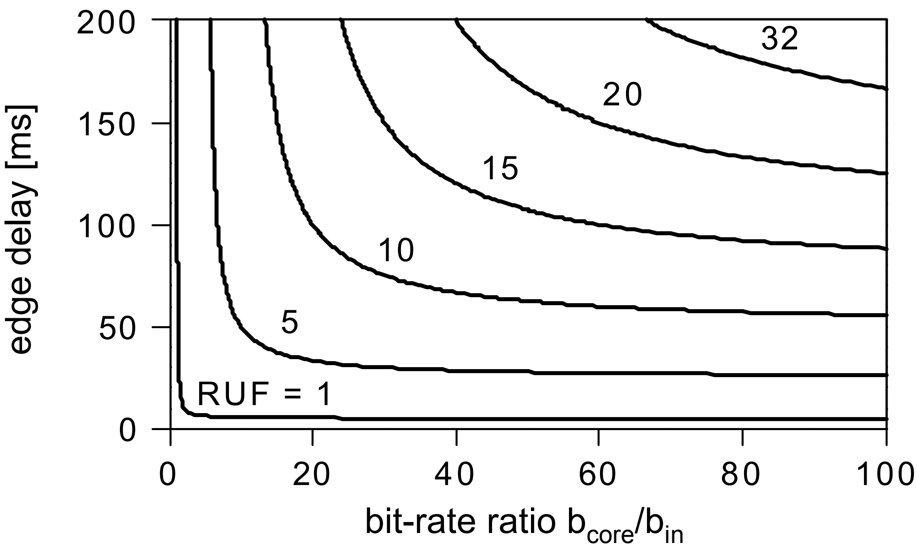

Fig. 3. Wavelength re-use factor (RUF) as a function of edge delay, t_{edge}, and bit-rate ratio A for round-trip time t_{RTT} = 5 ms

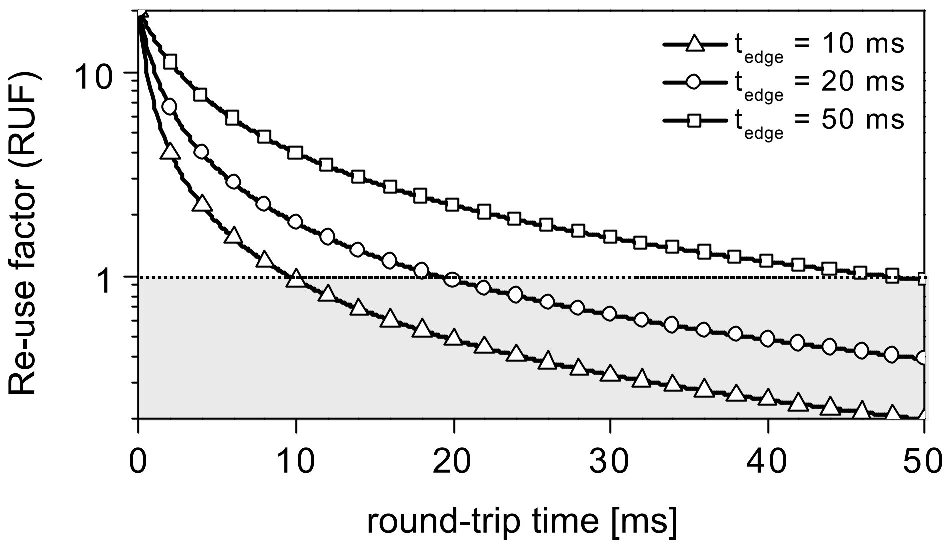

Fig. 4. Re-use factor RUF as a function of the round-trip time (t_{RTT}) for t_{edge} = 10, 20, 50 ms and bit-rate ratio A = 20. Shaded region: network requires more wavelengths than static WRON

the signalling overhead dominates the lightpath set-up time. It should be noted that the round-trip time is a lower bound on the lightpath set-up time and whether it can be achieved depends on the efficiency of the routing and wavelength assignment (RWA) algorithms.

4. Summary

New analysis of optical burst-switched networks is reported which allows to quantify performance parameters key to network design. It was shown that for the limiting case of CBR traffic an analytical model for the edge router can be derived, and that this architecture allows to achieve a range of edge delays to satisfy the latency requirements of different traffic types. Bandwidth utilization and wavelength re-use were introduced. These allow to quantify accurately the gain with dynamic wavelength allocation, which has the two-fold benefit of reducing wavelength requirements and enabling the network to respond to variable traffic demands. For the proposed network architecture wavelength re-use factors greater than 25 and 10 could be achieved for edge delays up to 170 ms and 50 ms, respectively. The time required for lightpath path set-up, t_{RTT}, is a lower bound on the achievable edge delays and must be minimised by fast RWA algorithms. The results are applicable to the design and the dimensioning of WROBS networks and the optimization of RWA algorithms.

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References

[1] S. Baroni, P. Bayvel, R.J. Gibbens, S.K. Korotky, "Analysis and design of resilient multifiber wavelength-routed optical transport networks," J. Lightwave Technol. **17**, 1999, pp. 743-758

[2] J.S. Turner, "WDM Burst Switching for Petabit Data Networks," OFC 2000, paper WD2-1, 2000, pp. 47-49

[3] M. Yoo, C. Qiao, S. Dixit, "QoS Performance of Optical Burst Switching in IP-over-WDM Networks," IEEE J. Select. Areas Commun. **18**, 2000, pp. 2062-2071

[4] K. Dolzer, C. Gauger, J. Späth, S. Bodamer, "Evaluation of Reservation Mechanisms for Optical Burst Switching," AEÜ Int. J. Electron. Commun. **55** (1), 2001, pp. 1-8

[5] M. Düser, E. Kozlovski, R. I. Killey, P. Bayvel, "Design Trade-Offs in Optical Burst Switched Networks with Dynamic Wavelength Allocation," Tech. Dig. ECOC 2000, paper Tu 4.1.4, 2000, pp. 23-24