

# Timescale analysis for wavelength-routed optical burst-switched (WR-OBS) networks

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**Abstract:** The relationship between timing parameters in a WR-OBS network architecture is analyzed with respect to packet loss, delay constraints, and network scalability. A novel burst-aggregation scheme provides low latencies even for high traffic loads.

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OCIS codes: (060.4510) Optical communications; (060.4250) Networks

## 1. Introduction

Future optical packet network architectures are expected to carry and route dynamically varying traffic with different QoS. Whilst packet delay and low packet loss probabilities must be guaranteed, the required network resources should be kept to the minimum. Optical burst-switching (OBS) has been suggested as a TDM approach in a number of different schemes, e.g. Just-Enough Time (JET) [1], to allow access to bandwidth in fractions of wavelengths. Burst sizes in most OBS schemes are in the kB regime (15 kB, equivalent to 3.1  $\mu$ s at 40 Gb/s [1]) which is too short for an end-to-end acknowledgement ensuring QoS. Burst loss resulting from collision of bursts competing for the same link in the core can only be reduced by the assumption of full wavelength conversion.

In this paper, we analyse a wavelength-routed optical burst-switched (WR-OBS) architecture that provides connection guarantees [2] and quantify the key time parameters which must be synchronised in such architecture. The scheme provides a strict separation of burst aggregation in the electronic layer at the network edge and optical transport and wavelength-routing in the core. Under dynamic wavelength-provisioning it is imperative to ensure that the interplay of the timing parameters in different parts of the network is synchronized; this analysis has not been carried out, however, in the context of OBS networks. Three timing parameters key to the operation of WR-OBS networks are identified and investigated: the edge delay for burst aggregation, the round-trip time required for signalling, and the processing time of wavelength requests. Results regarding the scalability of the network are applicable to all schemes using dynamic routing and wavelength assignment (DRWA). Whilst OBS schemes such as JET suffer from severe burst loss for high traffic loads [1], we show that the use of a novel burst-aggregation scheme (unlimited burst size, UBS) not only ensures that the WR-OBS architecture remains operational for higher loads, but in fact reduces achievable latencies in this case [3].

## 2. Network architecture

Packets are aggregated into bursts at the network edge, experiencing an edge delay  $t_{\text{edge}}$  whilst being queued in an edge router. The burst sizes considered here are in the MB regime, corresponding to edge delays in the range of milliseconds which is sufficient for end-to-end reservation of resources across the network [2]. Once pre-defined performance parameters such as the latency or a buffer threshold are exceeded, a wavelength request is sent to the network control node (Fig. 1). A round-trip time  $t_{\text{RTT}}$  is required for signalling between edge routers and the control node. Wavelength requests experience a queuing and processing delay,  $t_q$  and  $t_c$ , before an acknowledgement is returned to the requesting edge router. After receipt of an acknowledgement the burst is sent into the core network on the specified wavelength and route. Wavelength agility at the edge of the network is provided by fast tuneable lasers and key to network operation, as it has been shown that it can eliminate the need for full wavelength conversion in core routers [4]. As end-to-end lightpaths are established, core routers are bufferless, and there is no need to carry out further processing in the core.

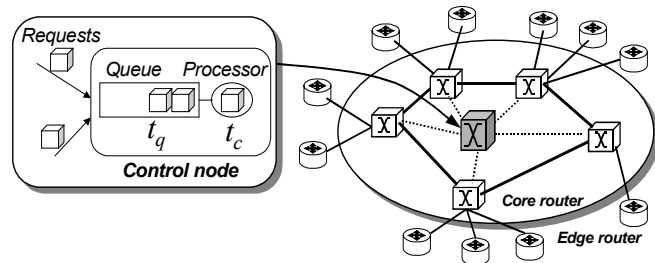


Fig. 1. WR-OBS network architecture with central control node

### 3. Timing parameters

Previous work has shown that for a given buffer size in edge routers the buffer overflow and resulting packet loss depend on the traffic statistics used [2]. Edge delays are on a millisecond timescale, and the allowable edge delay would vary by more than 10 ms for various traffic statistics for a buffer that would hold 40 ms worth of traffic at a data loss probability of  $10^{-6}$ . The correct traffic modelling is under much debate and depends on parameters such as user behaviour and the level of statistical multiplexing. In general it is impossible to obtain a closed expression for the overflow probability or related packet loss without exact knowledge of the statistics involved. The only two parameters readily available in real networks are the mean  $\mu$  and the variance  $V_t$  of the incoming traffic over the period  $t_{\text{edge}}$ . Based on moderate deviations theory [5] the buffer overflow probability for a given process can be approximated by:

$$\gamma = -\log(\text{overflow probability}) = \frac{(B - \mu \cdot t_{\text{edge}})^2}{2 \cdot V_t}$$

For a given buffer size  $B$ ,  $\mu$  and  $V_t$ , the only variable parameter is  $t_{\text{edge}}$ . An adaptive burst assembler can therefore be designed (Fig. 2) [5] which can accommodate a large variety of traffic statistics for a given value of  $\gamma$  ( $\gamma_{\text{target}}$ ). Mean and variance are measured during the burst aggregation process and used in a feedback control loop to estimate the buffer overflow. The performance of this controller is shown for negative exponential input traffic with mean 5 Gb/s, arriving at a buffer of 100 kbits (Fig. 3). For a targeted overflow probability of  $10^{-6}$  the control algorithm operates more conservatively and prevents any overflow. Doubling the mean and the variance of the arriving traffic at  $t = 25$  ms results in instantaneous buffer overflow. Within a few burst aggregation cycles, depending on the control used, the burst size is adapted to the new traffic parameters, successfully preventing buffer overflow. The edge delay drops by more than a factor of 2 from  $15 \mu\text{s}$  to  $6 \mu\text{s}$  in order to accommodate for the increased variance. The results show that the control provides a reliable estimation of the edge delay whilst preventing buffer overflow even for fast traffic changes.

Key network parameters of the WR-OBS architecture were evaluated [2]. For reservation of network resources a round-trip time delay  $t_{\text{RTT}}$  between the requesting edge router and the control node is required.  $t_{\text{RTT}}$  adds to the wavelength-holding time for which a lightpath is reserved for burst transmission, and results in an overhead that in turn limits the network performance. The wavelength re-use factor (RUF) was introduced as a key parameter with  $\text{RUF} = t_{\text{edge}}/t_{\text{WHT}}$ . Its value depends on both  $t_{\text{RTT}}$  and  $t_{\text{edge}}$  (Fig. 4), here with a variable  $t_{\text{RTT}}$  and  $t_{\text{edge}} = 10, 20$  and  $50$  ms for a core-to-input bit rate ratio of 20. For  $t_{\text{RTT}} \geq t_{\text{edge}}$  the network would require more wavelengths than a static WRON, but if  $t_{\text{edge}} < t_{\text{RTT}}$  wavelengths savings are achieved, which depend on the RWA algorithm and topology, and could be up to a factor of 20 for the example shown.

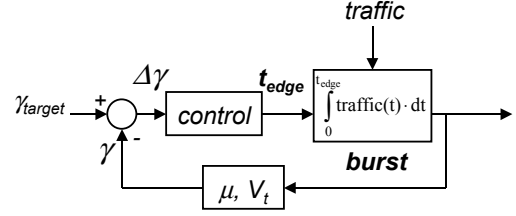


Fig. 2. Adaptive burst assembly based on estimation of the buffer overflow

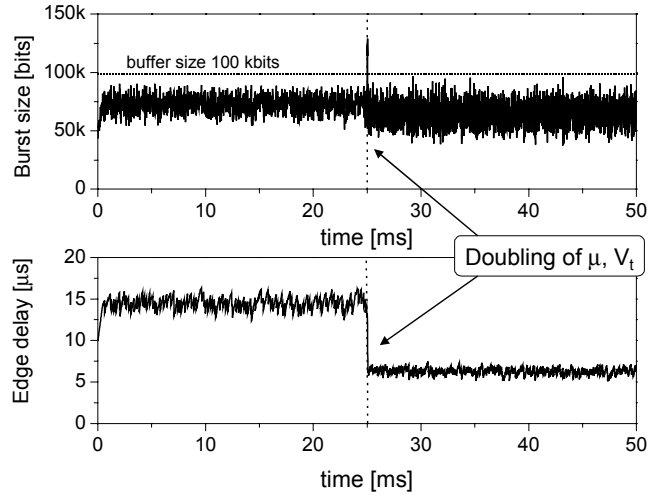


Fig. 3. Burst size and edge delay (aggregation time) as function of time. Mean and variance double at  $t = 25$  ms

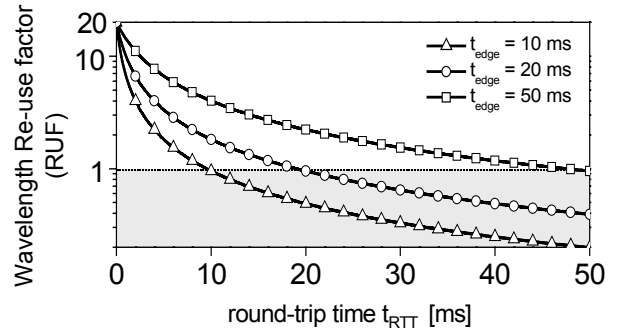
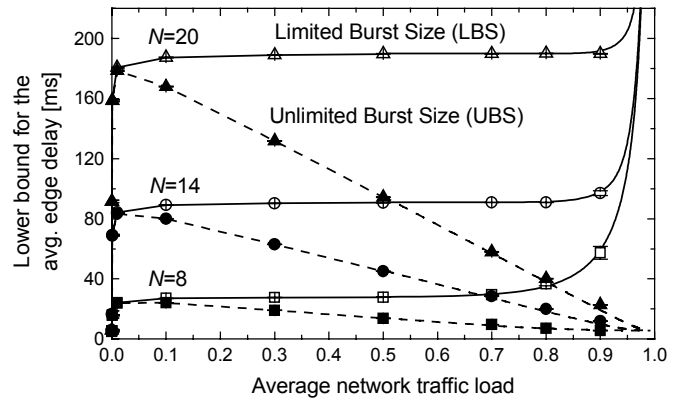


Fig. 4. Wavelength re-use factor (RUF) as a function of the round-trip time  $t_{\text{RTT}}$  for edge delays 10, 20 and 50 ms and a core-to-input bit rate ratio of 20

The processing time of DRWA algorithms is another key factor. Wavelength requests arriving at the control node experience a queuing and processing delay,  $t_q$  and  $t_c$ , before returning to the edge router with an acknowledgement that provides information about the route and the wavelength the burst will take in the core network. For simplicity, a centralized control scheme is assumed here with a single processor fed by requests from a single queue (Fig. 1). The minimum achievable edge delay also depends on the burst aggregation scheme used. The burst size is either known when a request is submitted [1], or when the acknowledgement is received (limited burst size scheme, LBS [3]). However, they suffer from increasing edge delays. Packets arriving while a burst is being transmitted are not aggregated into this burst, but are assigned to the following burst, for which a new request must be submitted. The related overhead for reservation limits both network diameter and admissible load, resulting in excessive burst loss for high loads with all known OBS schemes.



**Fig. 5. Lower bound of the average edge delay as a function of the network load for  $N = 8, 14$  and  $20$  routers. The unlimited burst size (UBS) scheme (dash) reduces latency with increasing load compared to the limited burst size (LBS) scheme (solid). Symbols denote simulation results for LBS (open) and UBS (solid)**

Acknowledging this shortcoming, we introduced the concept of the unlimited burst size (UBS) [3]. Once a lightpath is established between two edge routers, it will be open not only for the burst it was originally assigned for, but also for all subsequently arriving packets, and the connection is only terminated when no packet remains in the queue in the edge router. A comparison in terms of the minimum achievable average  $t_{edge}$  for LBS and UBS is shown in Fig. 5. Simulation results (and analytical for high traffic loads) are shown for networks with  $t_{RTT} = 5$  ms, and  $N = 8, 14$  and  $20$  edge routers, as a function of the average traffic load, assuming a bursty traffic model with uniform mean load and a DRWA algorithm with mean  $t_c = 500$   $\mu$ s. For LBS, the lower bound for the edge delay is given by  $t_{edge} > t_c \cdot N \cdot (N-1)$ , except for very low traffic loads, where the lower bound decreases towards  $t_{RTT} + t_c$ . It is also shown that edge delays deteriorate with increasing network load. A faster algorithm would reduce the lower bound, but at some point the edge delay would become limited by the network diameter. For UBS, although the edge delay has the same lower bound for low traffic loads, it significantly reduces with increasing load. This is because UBS adapts very well to traffic, as a lightpath is not released while there is data in the buffer. Hence, the arrival rate of requests to the control node decreases, and so do the waiting time in the control node queue and  $t_{edge}$ . The lower bound is reduced to  $t_{edge} > t_{RTT} + t_c$  for a fully loaded network. This finally links all three timing parameters investigated in this paper. In the limit, the dynamic lightpath assignment of WR-OBS transits into a static WRON. The advantage is two-fold: The UBS scheme not only keeps the WR-OBS scheme operational for higher loads than limited size schemes, but in effect latencies are reduced with load, increasing the performance of the network.

**In summary**, the relationship of three timing parameters in the WR-OBS network architecture has been identified and investigated, to quantify the limits on the operation of a dynamic network. An adaptive burst assembler at the network edge provides an accurate estimation of the maximum edge delay whilst preventing buffer overflow, depending only on the mean and variance of incoming traffic. The round-trip time defines the achievable wavelength re-use under dynamic network operation, which could be as large as 20 for the example shown. The processing and queuing latency in the network control node links all three parameters and imposes a lower bound to the edge delay for a given number of edge routers. The unlimited burst size (UBS) scheme not only overcomes the main limitation of many OBS approaches – excessive burst loss for high network loads, but also reduces latency with increasing load, potentially ensuring adaptive network operation over a wide range of loads.

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