Performance Comparison of Static and Dynamic Optical Metro Ring Network Architectures

Abstract: Four static and dynamic optical ring network architectures are analysed in terms of end-to-end delay, throughput and wavelength requirements, for implementation in future metropolitan area networks.

Introduction
Metropolitan Area Networks (MANs) must be designed to accommodate increasing volume of data-centric traffic and dynamically varying traffic patterns. While static networks are relatively simple to design and manage, they cannot adapt efficiently to traffic changes and require increased capacity provisioning for resilience to network failures than dynamic approaches \cite{1}. Thus, there is a trade-off between the simplicity of design and operation of static networks and the adaptability of dynamic networks which requires study. In this work four optical ring network architectures with different degrees of dynamic behaviour were studied: (1) static wavelength-routed optical network (WRON), (2) slotted, (3) optical burst switching with just enough time signalling mechanism (OBS-JET) and (4) wavelength-routed optical burst switching (WR-OBS). The results allow to identify the architecture which has the optimal performance with minimum resource requirements for MAN applications.

Description of architectures

Static WRON ring: The ring topology is that of one bi-directional link between adjacent nodes, and one lightpath is established between each source-destination node pair with a total of $N(N-1)/8$ quasi-static lightpaths in a N-node ring. Using the algorithm proposed in \cite{2} for lightpath allocation, the minimum number of wavelengths required is $W = (N^2 - 1)/8 \cdot$

Slotted Ring: The ring topology consists of a single unidirectional link between every pair of adjacent nodes. Data directed to node $j$ must be transmitted using $\lambda_j$ during a pre-allocated slot. Thus, in an $N$-node ring, $N$ wavelengths are required and, assuming uniform traffic, $\lambda_j$ is divided into $(N-1)$ slots.

OBS-JET ring \cite{3}: The ring is equipped with one bi-directional link between adjacent nodes. Bursts of data (electronically aggregated at the network edge) are transmitted through the optical core after a control packet that configures switches on a hop-by-hop basis. As bursts are assumed to be in the range of tens of kilobytes, there is no time for end-to-end path reservation. As a result, bursts can be dropped at any point along the path to the destination due to channel contention. To decrease the loss probability, full wavelength conversion is used in every network node. The analysis in this work used fixed routing and First-Fit with Void Filling wavelength allocation scheme \cite{4}.

WR-OBS ring \cite{5}: The ring topology is that of one bi-directional link between adjacent nodes. Bursts of data are sent through the optical core only after an acknowledgement for an allocated lightpath is received from a control node. End-to-end lightpath reservation implies bursts in the millisecond range and that QoS requirements, such as latency and jitter, can be guaranteed. In this work, the centralised WR-OBS architecture described in \cite{6} was considered.

Performance comparison: results and discussion

The four architectures were evaluated in terms of their mean end-to-end delay, throughput and the required number of wavelengths under the assumption of uniform traffic. Data units of fixed size were assumed to arrive at the network following a Poisson process, except for the WR-OBS architecture, where the packet level traffic was assumed to arrive as an exponentially distributed ON-OFF process and the aggregation procedure was simulated \cite{6}.

Figure 1: Mean end-to-end delay vs. offered load per node pair.

All networks were assumed to have a diameter of 150 km, with nodes (ranging from 8 to 20) equally spaced around the ring, and with transmission bit-rate of 100 Gbit/s per wavelength, for example using 100GbEthernet \cite{7}. The wavelength requirement in the...
WRON and in the slotted ring is determined by the number of nodes. For OBS and WR-OBS, unless otherwise stated, the number of wavelengths considered was that required by a static WRON with the same number of nodes. The first two architectures were studied analytically using queuing theory, while simulation was used for the burst switching scenarios. **Mean end-to-end delay** is defined as the time elapsed since the first bit of a data unit is received in the edge router buffer, and until its successful receipt at the destination node. As shown in **Figure 1**, the static WRON architecture exhibits the lowest end-to-end delay, closely followed by OBS-JET (assuming 1 ns for header processing time), for traffic loads under 0.9. The slotted ring architecture exhibits higher delay than static WRON and OBS-JET, mainly due to the longer paths (as uni-directional links are employed). In these three cases the propagation times dominate the end-to-end delay with respect to other contributions (buffering/queuing and transmission delay), and thus the end-to-end delay does not vary as load increases except in the static WRON and slotted ring cases for loads over 0.9, when queuing delays are comparable to propagation times. Finally, WR-OBS exhibits the longest mean end-to-end delay due to the end-to-end reservation process, but still well under the 100ms established for time-critical data /8/.

**Throughput** was defined as the amount of information successfully delivered per unit of time per node pair. In **Figure 2**, throughput for an 8-node ring is plotted normalised to the bit rate (similar figures were obtained for different number of nodes). Static WRON exhibits the maximum achievable throughput, followed closely by the WR-OBS. OBS-JET exhibits a lower throughput than WR-OBS for loads in excess of 0.4, in spite of using full wavelength conversion in each node. Finally, the slotted ring architectures showed the lowest throughput for all traffic loads due to the reduced bandwidth per connection.

**Wavelength requirements**: In an N-node ring, static WRON and slotted architectures require \(\left\lceil \frac{(N^2 - 1)}{8} \right\rceil\) and \(N\) wavelengths, respectively. In the dynamic networks the required number of wavelengths depends on the blocking (loss) probability target and on the offered load. In **Figure 3** wavelength requirement for the 8-node ring with target loss probability of \(10^{-3}\) is depicted.

![Figure 3: Required number of wavelengths vs. offered load per connection (8 nodes)](image)

WR-OBS wavelength requirement is roughly the half of OBS-JET to achieve the same blocking probability and, for loads under 0.7, it requires fewer wavelengths than static WRON (and slotted). This level of resource efficiency in WR-OBS is achieved by using advanced scheduling methods in the control node /9/.

**Summary and conclusions**

The performance of four different optical metro ring architectures, in terms of their delay, throughput and number of wavelengths, has been evaluated for the first time. It has been shown that WR-OBS networks as applied to rings are a promising architecture for MANs as they are able to achieve high throughput while saving resources when compared to other solutions. For example, in an 8-node metro ring, for loads under 0.7, WR-OBS throughput is optimal and wavelength requirement is the lowest (8 at the most). Although the delay is higher than in other architectures, it is still low enough to satisfy time-critical applications in MANs as the short metro distances ensure that the end-to-end reservation process takes only a few milliseconds.

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