# Analysis of metropolitan ring network based on optical packet switching

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Here, we present a metropolitan multiple-access ring network based on optical switching over wavelength division multiplexing. An access point to connect local area networks to the metropolitan ring whose key component is an optical switch is introduced. Several simulations have been performed to study the performance of this network that show its viability for a particular set of standard conditions. Several parameters such as packet latency, traffic load or number of access points per wavelength have been analysed to establish the limitations of this architecture.

## 1. Introduction

In this work a CWDM (Coarse Wavelength Division Multiplexing) metropolitan multiple-access ring network based on optical switching of packets according to their wavelength is presented. The basis of the presented network is an access point (AP or node) that connects several local area networks (LANs) to the metropolitan ring, and a Point-of-Presence (POP) for connectivity to the wide area network. The APs transmit packets in any of the ring wavelengths, but only drop packets in one particular wavelength. Thus, instead of a permanent connection between nodes, a media access control (MAC) is necessary to govern access to the wavelengths and detect and avoid collisions between nodes. All-optical packet switching is an active field in optical networks research because it completely eliminates any electronic routing bottlenecks by always keeping the signal in the optical domain. However, all-optical packet switching is still in the research phase and currently optical buffers and routers are too bulky, expensive and complicated. Nevertheless, switching times have been decreasing recently up to the range of tenths of nanoseconds for commercial switches, and more research is presently directed towards further reduction [1]. The main advantage of the optical switch is that packets whose address is not in the node will be incorporated directly into the transmission fibre, because there is no need for opto-electronic conversion and subsequent reconstruction and queuing of these packets before modulating the laser for transmission.

Here, our aim is to assess the viability of a metropolitan ring network based on a modification of HORNET [2], as shown in Figure 1, but using optical packet switching in the APs. The ring implementation we propose is a passive optical network (PON) with 5 to 8 wavelengths with a relatively wide spacing (20 nm), characteristic of coarse WDM (CWDM). Some of these wavelengths are destined exclusively to support traffic external to the MAN. The data payload and address will be encapsulated in packets of fixed length, in order to facilitate a simple media access control (MAC). The proposed MAN ring transmission speed is fixed to 1000Mb/s and the LAN to 100Mb/s, which are the data rates of Gigabit and Fast

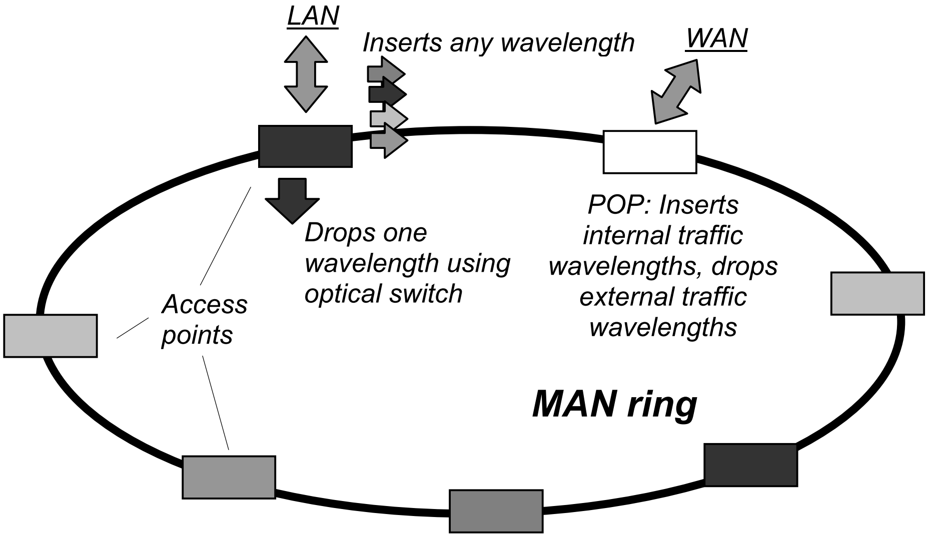


Figure 1. MAN ring proposed: each AP connects a LAN to the ring, POPs provide connectivity to and from the WAN.

Ethernet respectively. However, we want to point out that we are not studying a ring network based on Ethernet because it supports variable size packets while we are studying only fixed length ones. As default we choose 4 wavelengths for the traffic within the MAN and one wavelength for the transport of the external traffic. The proposed architecture consists of 10 AP nodes per wavelength for the 4 channels devoted to internal traffic, and 2 POPs that drop the packets whose destination address is out of the ring. We assume that there is no synchronisation between the nodes in such a way that they work with an unslotted approach. A similar study for a slotted network would be straightforward.

## 2. Network access point description

The AP node is shown schematically in figure 2, where packets from different channels travelling within the ring are reaching the node, which is composed mainly of three stages whose functions are explained next.

### 2.1. Packet-manager

For every wavelength, the manager detects empty spaces large enough to insert a packet, and determines the packet destination only for those packets in the AP's own wavelength. We are not concerned here with the exact procedure used to obtain packet addresses, which can be implemented using multiple technologies, because for our study only the address reading speed will be relevant. In any case, for long enough packets the reading speed will be negligible.

### 2.2. Optical drop

This is the key point in our work. Here, packets travelling in the node's own wavelength are routed by an optical switch using the address information from the packet manager. Thus, the packet is dropped if its address belongs to the LAN connected to the AP, or sent back to the ring if the packet is destined to an AP node downstream sharing the same wavelength. Switching time has been chosen

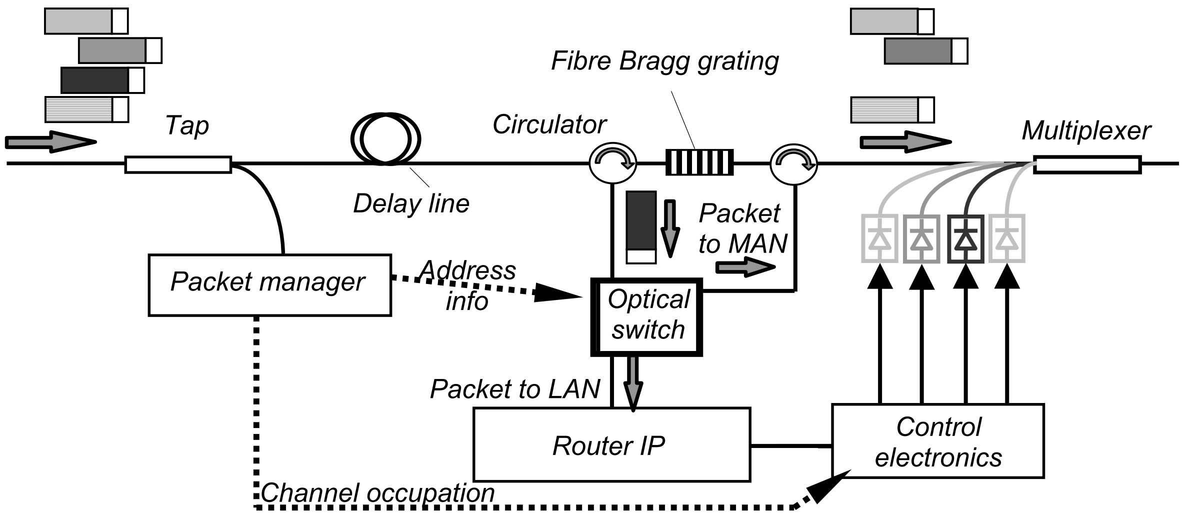


Figure 2. Access Point proposed design: every packet crossing the node suffers a delay introduced in order to avoid collisions with those packets added by the node. Additionally, packets belonging to the node's own wavelength cross the optical switch and are redirected either to the router (i.e. dropped) or again to the MAN ring.

to be 1 $\mu$s, a value found for commercially available optical switches [3]. When crossing this stage of the node, all packets must suffer a delay equal to its duration to avoid collisions with inserted packets. Moreover, an additional delay has to be considered in order to avoid collisions in the switch with other packets travelling at the node's own wavelength. This delay corresponds to the switching time plus a guard time that has been chosen to be 10% of the switching time. Thus, the total delay for every packet crossing the node is:

$$t_{delay\ line} = t_{packet} + t_{switch} + 0.1t_{switch}$$

## 2.3. Optical add

It inserts packets into the fibre from the LAN for all the ring wavelengths. Packets that cannot be transmitted are queued to wait for a vacancy signalled by the information coming from the packet-manager. For this last stage, we propose a laser array with fixed wavelengths, instead of a tunable transmitter as in HORNET that allows an independent treatment of each channel wavelength. As every laser in the array can transmit simultaneously, packets in different wavelengths can be stored in different queues and only need to wait for an empty space in its own channel in order to be transmitted. Thus, queuing time is clearly reduced in this approach at the cost of reducing flexibility and wavelength scalability.

We propose the interface between the AP node and the LAN to be performed by a router that can carry out part of the processing, such as:

- Encapsulation of data and address into fixed length packets, for data coming from the LAN with destinations in other AP nodes.
- Wavelength assignation to each packet based on its destination address.
- Data and address recovery from the dropped optical packets.

In this way, most of the electronic processing will be performed at the router level and will make the node design much simpler.

The POP node is identical to the AP node, except that it does not need a switch since all the packets that reach POP nodes in the external wavelengths have external destinations and thus, have to be necessarily dropped.

## 3. Simulation results

We have studied the viability of the optical switch configuration simulating the proposed network for some fixed parameters, called standard conditions, and analysing the variance of the queuing time at the worst positioned node. Through several simulations, this evaluation criterion is shown to be a suitable indicator of the network saturation and instability.

The standard conditions are defined as follows: the number of nodes per wavelength is 10, and there are two POPs in the ring. MAN data rate is 1Gb/s and packets are inserted from the LAN to the router in the AP at a data rate of 100Mb/s following a Poisson distribution. Traffic load from the LANs is 50% for all nodes, and the ratio of MAN external-to-internal traffic is 50%. Packet length is fixed to 1500 bytes, which represents a packet time within the MAN of 12 $\mu$s. The packet addresses are supposed to be uniformly distributed among wavelengths and nodes. We choose the inter-node distance as 2 km and thus, network perimeter for the default conditions is 80 km. Simulation time has to be chosen to let the network reach a stationary regime, and for the standard conditions it has been found to be 0.1 s.

Packet latency is made up of four different times

$$t_{latency} = t_{insert} + t_{fibre} + t_{nodes} + t_{extract}$$

where $t_{insert}$ results from adding the time the packet spends at the router for transmission and the time a packet is waiting to be transmitted by the laser array (queuing time: $t_{queue}$); $t_{fibre}$ accounts for the mean number of hops within the ring from source to destination node; $t_{nodes}$ accounts for the mean number of nodes, that the packet must cross before reaching its destination. As explained before, the delay a packet suffers when crossing a node is $t_{delay\ line}$ for every packet and $t_{delay\ line} + t_{switch}$ for those belonging to the node's own wavelength, as they are susceptible of being dropped. Finally, $t_{extract}$ accounts for the time necessary to extract the packet from MAN to LAN by the router. Time for packet extraction and insertion at the router is not critical, since the above-mentioned conditions assure the correct management of packets in both ways (transmission: LAN – MAN and reception: MAN – LAN). Router processing time has been taken as 40 $\mu$s as estimated from real router *Nucleox Plus 60* [4].

The variance of the queuing time at the worst positioned node ($t_{queue}$) is the parameter that accounts directly for the instability of the network. Specifically, we consider that unstable behaviour of the network is indicated by the variance of the queuing time growing without bounds in any of the wavelengths and at any of the nodes. We considered that variance is permitted to grow up to 0.05 ms$^2$ with peaks of 0.1 ms$^2$.

Average latency for the standard conditions and only one wavelength devoted to external traffic is about 0.6 ms for internal wavelengths and 0.3 ms for the external traffic wavelength. In these conditions the network is stable for all nodes and wavelengths, which means the network is able to manage all packets without saturation.

Thus, we set out to analyse the limits of this network by simulating conditions different from the standard. In particular, we want to know the maximum number of nodes and the maximum LAN load that the network is able to support. In addition, in most working environments the external-to-internal traffic ratio is not 50% as we set in the standard conditions and before physical implementation of the network, an estimation of this ratio using real traffic data should be done. However, in order to have a general idea of the ring behaviour under different external-to-internal traffic ratios, we have studied the maximum number of nodes and the maximum LAN load for different values of this parameter. In particular, we have simulated the network for very low (10%), low (30%), medium (50%), high (70%) and very high (90%) external-to-internal traffic ratios.

## 3.1. Number of nodes per internal wavelength

We have obtained the queuing time variance as a function of the number of AP nodes for different external-to-internal traffic ratios in order to establish the limits before network saturation. The other parameters are those given by the standard conditions described before. In particular, LAN traffic load is 50% and there are only two POP nodes, as in the default conditions. The fact that the traffic inserted from the WAN into the ring is determined by the number of POPs, independently of the number of APs, sets a minimum number of AP nodes in the ring for an appropriate operation of the network. For networks with less than 3 nodes per wavelength (12 APs), the traffic percentage destined for each of them is very high, and a bottleneck at the router would appear when dropping packets to the correspondent LAN, whose velocity is ten times lower than that of the MAN ring. Thus, the variance is plotted in Figure 3 versus number of nodes per wavelength, from the minimum of 3 nodes to 20 nodes. As the wavelengths devoted to internal and external traffic have different behaviour, they are plotted separately in Figure 3(a) (internal wavelengths) and Figure 3(b) (external wavelength). The arrows in the figures mark the points where the variance is greater than 0.05 $ms^2$, indicating network saturation. For the wavelength dedicated to external traffic, the AP before a POP node represents the worst possible case as it is at this point where the

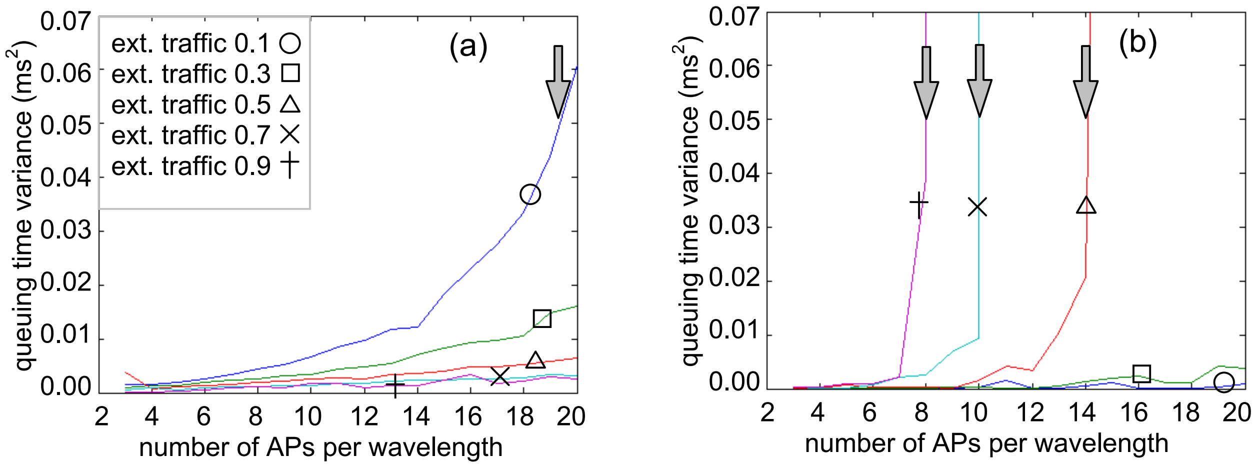


Figure 3. Queuing time variance versus number of nodes per internal wavelength, for the internal wavelengths (a) and for the external wavelength (b).

external wavelength reaches its maximum occupation and its queue is the first to saturate. For the other wavelengths, there is not a particular node that reaches saturation before the others. Thus, the variance plotted in figure 3(a) represents an average among queuing time variances for the queues of the internal wavelengths at all AP nodes.

To facilitate the analysis, the maximum number of nodes for each wavelength and each value of external to internal traffic ratio have been summarised in Table 1. Results show that for low external to internal traffic ratios, the network is always stable. For higher ratios, however, the external wavelength poses the limit, as it is unable to manage all the packets generated from more than 13 nodes. The traffic over the internal wavelengths only becomes unstable when more than 19 APs per wavelength are deployed at 10% of external traffic (maximum internal load).

| external to internal traffic ratio | maximum number of APs per wavelength | |
|---|---|---|
| | internal wavelengths | external wavelength |
| 0.1 | 19 | > 20 |
| 0.3 | > 20 | > 20 |
| 0.5 | > 20 | 13 |
| 0.7 | > 20 | 9 |
| 0.9 | > 20 | 8 |

Table 1. Maximum number of APs for different external-to-internal traffic ratios.

In order to illustrate the behaviour of the network when its dimensions are scaled, the mean packet latency versus number of nodes is plotted in Figure 4(a) for internal wavelengths and Figure 4(b) for the external wavelength. Figure 4(a) shows a linear dependence of packet latency with the number of nodes, related to the increase in the number of hops before the packet reaches its destination node. Under stable operation of the network, the contribution of the queuing delay to the packet latency can be neglected, but when a node becomes unstable packet latency grow without limits due to the queuing delay, as it can be seen in Figure

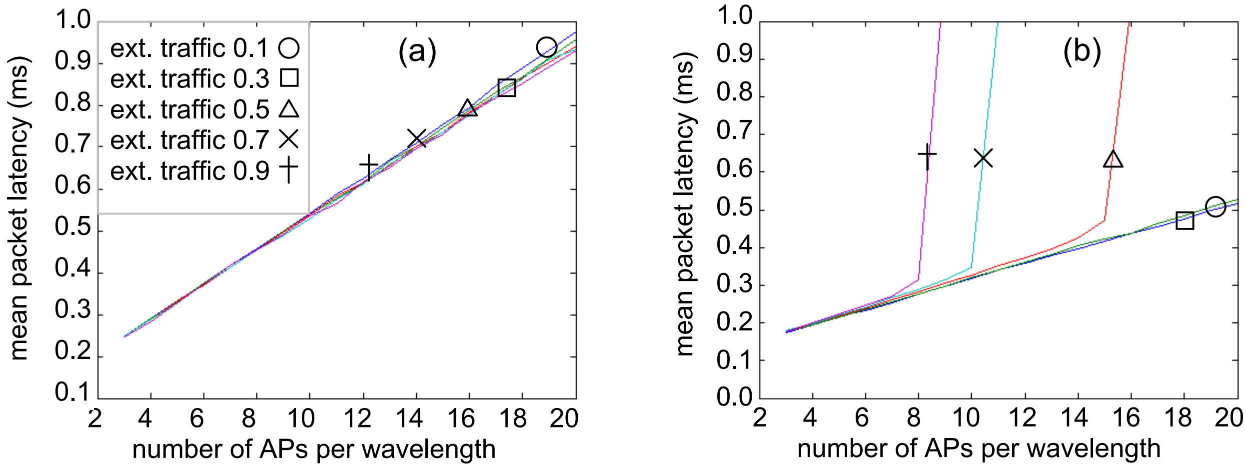


Figure 4. Mean packet latency versus number of nodes per internal wavelength for different external-to-internal traffic ratios for the internal wavelengths (a) and for the external wavelength (b).

4(b). This effects happen for a number of nodes greater than the maximum value established in Table 1 for each external-to-internal ratio condition.

### 3.2 Traffic load from the LANs

The maximum traffic from the LAN that a network with 10 nodes per wavelength is able to manage has been analysed for different external-to-internal traffic ratios by obtaining the point of saturation on the basis of an increase of the variance as described before. Table 2 shows the limits for external and internal wavelengths for the five traffic ratios.

| external to internal traffic ratio (%) | maximum traffic load from LAN (%) | |
|---|---|---|
| | internal wavelengths | external wavelength |
| 10 | 88 | —— |
| 30 | —— | —— |
| 50 | —— | 70 |
| 70 | —— | 50 |
| 90 | —— | 38 |

Table 2. Maximum traffic loads from LANs for different external-to-internal ratios.

These results indicate that in the default conditions, a traffic load from LAN greater than 70% will saturate the external channel when using only one wavelength to carry external traffic. A possible solution to avoid saturation in networks with high external traffic rates is to use two wavelengths to carry external traffic. In this case, the traffic load from the LANs will be limited either by the internal wavelength channels to a load lower than 88% for the highest internal traffic or by the external wavelengths, to a load lower than 81% for the highest external traffic.

The average latency of the packets before saturation is the same as that calculated for standard conditions.

## 4. Conclusions

We have proposed a metropolitan ring network based on optical packet switching. We have studied the performance of such a network for some defined standard conditions and found that for optical switching times of 1 $\mu$s, which is a standard value for commercial optical switches, the network is able to support relatively high traffic load from the connected local area networks. This load is generally lower for external traffic at moderate and high external to internal traffic ratios. To avoid this limitation, we propose introducing a second wavelength to carry external traffic. Further work is directed to analyse the behaviour of this network by varying other parameters such as the number of wavelengths serving internal or external traffic, ring velocity or variable packet size.

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