Performance of a Medium Access Control Protocol for a WDMA/TDMA Photonic Ring Network

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Abstract: We present the results of computer simulation of a new medium access control (MAC) protocol for a photonic ring network based on a combination of wavelength- and time-division multiple access (WDMA/ TDMA). The simulations show that the proposed protocol offers maximum throughput in excess of 90% of total network capacity, although for delay-sensitive traffic it is necessary to limit the offered traffic to around 70% of capacity. Our protocol thus allows at least twice the throughput of the next best existing alternative, slotted ALOHA.

1. Introduction

Wavelength division multiplexing (WDM) is rapidly becoming the technology of choice for high-capacity optical networks because it provides a graceful upgrade path to accessing the enormous fibre bandwidth, as well as advantages in terms of scalability and network management [1]. *MAWSON* (*m*etropolitan *a*rea *w*avelength *s*witched *o*ptical *n*etwork) is a WDM optical network demonstrator, suitable for LAN- to MAN-scale applications, which is currently under development by the Australian Photonics Cooperative Research Centre [2]. The *MAWSON* network is based on a passive optical network (PON) in a ring topology, and its design addresses issues of flexibility, compatibility and cost associated with smaller-scale networks.

This paper first describes the basic architecture and characteristics of the *MAWSON* network. Then the design and operation of a novel TDMA/WDMA medium access control (MAC) protocol which has been developed for *MAWSON* is discussed. Finally, results of computer simulation of the protocol are presented, which demonstrate that the new protocol shows significant performance improvements over existing alternatives.

2. Network Architecture

A four-node, four-wavelength *MAWSON* ring is illustrated in Figure 1. The PON itself consists of a fibre-optic ring with a WDM add-drop multiplexer (ADM) located at each access point. Each ADM drops a single, fixed wavelength, but allows any wavelength, or any number of wavelengths simultaneously, to be added. In the demonstration network the ADMs are implemented using simple passive-optical components [2]. When connected to a *MAWSON* access point, a node will only receive information which was transmitted on the dropped wavelength. It is assumed that each node is equipped with a WDM laser-array transmitter (see, for example, [3]) which is capable of transmitting at all wavelengths used in the network.

From the perspective of the MAC protocol, the significant characteristics and limitations of the passive-optical ring architecture are as follows. Each node in the network can reach any other node simply by transmitting at the wavelength corresponding to the ADM to which the destination node is connected, i.e. at the physical layer, wavelength acts as an address. Each node receives only one wavelength: it cannot receive information transmitted on any other wavelength, nor can a node sense activity on wavelengths other than that which it receives. Thus a protocol such as that proposed in [4], which depends upon a carrier-sense capability, is not appropriate. A node can transmit information on any one or more of the available wavelengths (i.e. multicast/broadcast facility is available), however it *cannot* simultaneously transmit *different* information on different wavelengths.

3. The Reservation/Allocation Protocol

Since a transmitter cannot sense the transmission channel, it cannot *a priori* avoid transmitting when another node in the ring is transmitting, leading to a collision. The retransmission cost when a collision occurs leads to a reduction in performance which can be seen in systems which allow collisions, such as those which use ALOHA, or slotted ALOHA [5] for medium access control. The aim of an efficient MAC protocol is to avoid loss of capacity by limiting access to the medium so as to either avoid or limit the impact of collisions. Further aims of the present protocol are: to be scalable (in the number of nodes); to attain high throughput, low delay and packet-loss; and to be fair. The protocol proposed here is a collision-free protocol which uses allocation by the receiver to prevent collisions. Each node which wishes to transmit to a particular receiver must *request* bandwidth, and wait for an *allocation* before transmitting. The protocol will thus

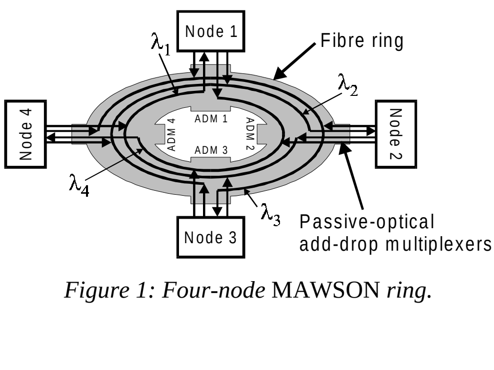

Figure 1: Four-node MAWSON *ring.*

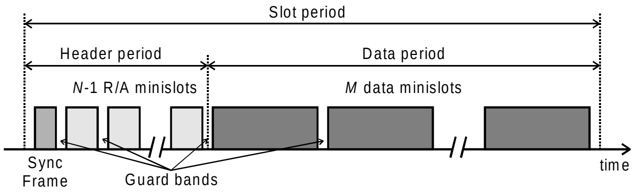

Figure 2: Request/allocation protocol slot structure.

be referred to as the *request/allocation protocol* (RAP).

In order to implement RAP, time is divided into uniform slots. The overall slot structure on wavelength *j* for an *N*-node network is illustrated in Figure 2. The slot is divided into a header period and a data period, with both header and data periods being divided into "minislots." The header begins with a *sync* frame which is used in a broadcast mode to synchronise all nodes to the start-of-slot. The rest of the header period is used for request and allocation (R/A) minslots. There is one R/A minislot for each node $i \neq j$ on wavelength *j*, i.e. the R/A minislot for node *i* on wavelength *j* is used by node *i* to request data minislots on wavelength *j*, and to allocate data minislots on wavelength *i* to node *j*. The R/A minislots are preallocated to avoid collisions. The data period in each slot is divided into *M* data minislots, each of which may be separately allocated for transmission of data. The guard bands between minislots allow for factors such as differential propagation delays between wavelengths, and errors in timing between nodes.

Each node maintains separate buffers for each possible destination node, and sends a request when the buffer receives a packet to be transmitted. The node requests enough data minislots (up to the maximum available) to transmit all of the packets currently stored in a buffer. When a node receives requests it performs allocations in a round robin fashion, i.e. it cyclically allocates one data minislot to each node *in sequence* until all of the minislots or all of the requests are used up. Note that this allocation procedure is inherently fair.

4. Simulation Results

Computer simulations of the performance of RAP have been carried out. The bit-rate assumed in the simulations is 100 Mb/s per node/wavelength (the bit-rate to be used in the prototype network). Note that at higher bit-rates the performance of RAP can only improve, as the time per slot occupied by R/A minislots is reduced. Simulations showed that good performance is obtained over a wide range of offered traffic using eight data minislots per slot. Acceptable delay and packet-loss performance are obtained for loads of up to 70% of capacity (i.e. 70 Mb/s per node/wavelength). This represents a significant improvement over the next best existing alternative, slotted ALOHA, with maximum throughput around 36%.

In order to demonstrate the scalability of the protocol, the maximum attainable throughput for the network is plotted as a function of total ring length in Figure 3 for the cases of 3, 10 and 30 nodes, with throughput of slotted ALOHA shown for comparison. The dependence of throughput on total ring length in the new protocol can be explained as follows. The most natural and efficient choice for the slot period is to make it equal to the total ring propagation delay, since this allows the nodes to process traffic and avoid collisions without ever having to leave any wavelengths idle. Further, the R/A minislots occupy a fixed time period per slot which increases with the number of nodes. Thus longer rings imply longer slots, and a greater proportion of time per slot devoted to data transmission, leading to a greater maximum throughput. The results in Figure 3 show that maximum throughput can exceed 90% if the ring length is at least 1 km per attached node. Thus for small networks, additional fibre might have to be included to provide a form of optical buffering. However, for larger networks, the buffering may be inherently provided by the transmission fibre alone.

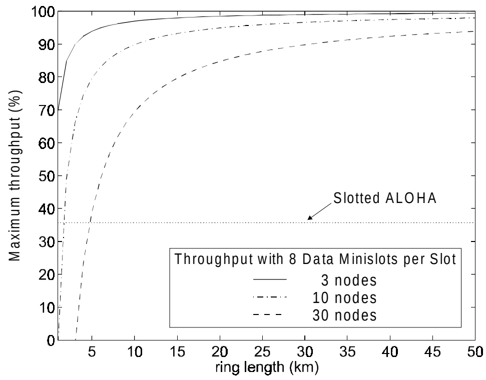

Figure 3: Maximum throughput as a function of ring length.

5. Conclusion

A MAC protocol for the *MAWSON* photonic ring network has been presented. Simulation results show that the protocol is efficient: for current parameters it introduces around 10% overhead and it is scalable to beyond 30 nodes, with moderate delay at loads up to 70% of maximum. Furthermore, it is intrinsically fair. Prototype network nodes implementing the proposed protocol at 100 Mb/s per wavelength are currently being developed.

6. References

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