# A Carrier Preemption Access Control Protocol for Supporting IP Packets over WDM Ring Networks

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***Abstract***

*In this paper, a carrier preemption access control protocol based on carrier sense multiple access schemes has been investigated for supporting IP packets over all optical WDM ring networks. The intention of our protocol design is to reduce the communication overhead of IP packets over optical networks for local/metropolitan area. To facilitate spatial reuse on the bandwidth of all optical ring networks, a special design is made for the carrier preemption scheme. Simulation has been done to evaluate the performance of our protocol. The simulation results display extraordinary good network efficiency.*

## I. Introduction

With the explosion of information traffic due to the Internet, electronic commerce, computer networks, voice, data, and video, the need for a transmission medium with the bandwidth capabilities for handling such a vast amount of information is paramount. Recently, the channel bandwidth of commercial WDM (Wavelength Division Multiplexing) communication systems has reached to OC-192 (10 Gbps), and the total bandwidth of an optical fiber exceeds 1 Tbps. This indicates that WDM is the solution for bandwidth insatiability.

Due to the widespread services and tremendous user population on Internet, the traffic of IP packets dominates the utilization of data networks. However, they are now transferred, switched, and manipulated through complex protocol stacks, such as IP/ATM/SONET/WDM, IP/ HDLC/SONET/WDM, and so on. How to merge and collapse the middle layers to reduce cost, complexity, and redundancy has become an important research issue [1-3]. Additionally, since many WDM systems have been deployed in wide area networks (WANs), the bottleneck of communications will be pushed ahead from backbone networks to local access networks. As a result, applying WDM to local and metropolitan area networks (LANs /MANs) gains much research interests [2-4].

In the literature, a number of research works were done for WDM ring networks. Cai et al. proposed the MTIT access protocol for supporting variable size packets over WDM ring networks based on fixed transmitters and fixed receivers (FTs-FRs) architecture [2]. To achieve all optical communications, MTIT adopts the source removal policy [5] for dropping packets from networks to prevent packet re-circulation. Shrikhande et al. developed HORNET as a testbed for a packet-over-WDM ring MAN [3]. To facilitate signal regeneration and destination removal [5], HORNET utilizes opto-electronic and electro-optic conversion, which may constrain the transmission rate of the network. Marsan et al. proposed SRR, an almost optimal MAC protocol based on TDM access, for all optical WDM multi-rings with tunable transmitter and fixed receiver (TT-FR) [4]. Due to strict TDM access, packet transmissions to a node is constrained to via a data channel. This scheme is lacking of the flexibility of utilizing channels, whereas adopting destination removal can free channels to other nodes. In sum, all optical communications and spatial reuse [5] owing to destination removal are two requirements for achieving high network efficiency.

To support IP packets directly over WDM ring networks and satisfy the above two requirements, we investigate a carrier preemption access control protocol based on carrier sense multiple access schemes. The access mechanism for our protocol uses the architecture of tunable transmitter and multiple fixed receivers (TT-FRs). In subsequent descriptions, the WDM ring network and the node structure for our protocol are presented in Section 2. Our protocol design is illustrated in Section 3. To evaluate the performance of the protocol, the simulation experiment and results are described in Section 4. Finally, a few remarks are given in the conclusions.

## II. Network Architecture

Let us consider a single and unidirectional fiber ring network, which connects a number of nodes. The ring network is composed of *W* data channels as shown in

Figure 1. Each data channel makes use of one specific wavelength to convey optical signal. Therefore, based on the WDM technology, channels can work independently without mutual interference to each other. Logically, the network can be treated as a multi-ring network.

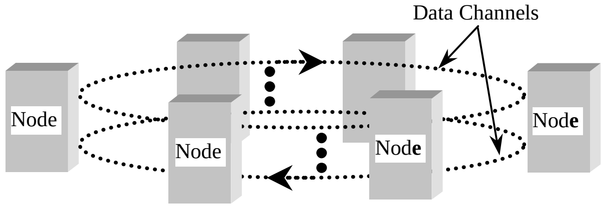


Figure 1: Logical architecture of a WDM ring

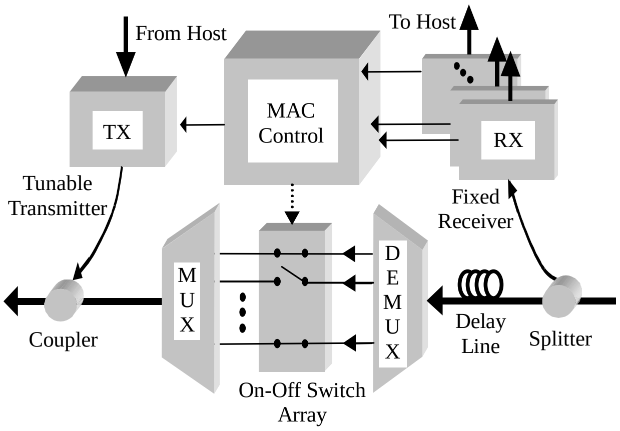


Figure 2: The node structure

The node structure of the network is shown in Figure 2. Each node has one tunable transmitter and *W* fixed receivers with one for each data channel. For the optical signal sent from upstream nodes, a splitter is used to tap off a small portion of the optical power from the ring to the receivers. Every receiver detects the optical signal carried in its corresponding wavelength within the output branch from the splitter for node address identification. If the destination address in the incoming packet header matches the node address, the packet data is sent to the host. Meanwhile, the MAC control scheme is signaled to activate the open of the on-off switch for the corresponding data channel to remove the received packet carried in the major portion of the optical signal through the delay line. If the destination address is irrelevant to the node address, the detected packet is ignored and the process of scanning next new packet is started.

As for the portion of optical signal through the delay line, optical carriers will be delayed a period of delay time for the operation time of address recognition, MAC control scheme, and on/off switching to remove received packets. After through the delay line, the optical signal will be de-multiplexed by the DEMUX (see Figure 2) into *W* data channels according to their separate wavelength. The output of the DEMUX is connected to an on-off switch array with *W* input ports and *W* output ports. If a switch for one specific channel is opened, it means that the node is ready to remove the packet in that channel from the ring to prevent the re-circulation of packets. Otherwise, optical signal flows through the closed switches directly to the MUX. The MUX of nodes is used to multiplex the separate wavelength into its output fiber link. With the combination of a delay line, a DEMUX, an on-off switch array, and a MUX in nodes, the destination removal policy [5] can be realized in our ring network.

The packets ready to be transmitted are placed in the transmission queues of a node transmitter before sending. In order to avoid the head of line (HOL) blocking problem [3-4] occurred in the mechanism of single transmission queue for ordinary packet transmissions, the transmission mechanism with multiple queues is adopted in the transmitter of nodes, where one queue is used for each destination node. When the receivers detect a few idle data channels, the tunable transmitter that is signaled can tune to the transmission wavelength corresponding to a data channel, pick a packet from a transmission queue according to some transmission selection strategies, and then send the packet onto the target channel. Since each node is equipped with a receiver for each data channel, a packet can be transmitted via any available data channel to its corresponding destination node. As a packet has been transmitted onto an available data channel, the optical carrier of the packet is then coupled with the optical carriers from the MUX by the coupler. The integrated carriers are then sent to the downstream nodes. For the transmission selection strategies, they are part of the MAC control scheme and will be discussed in the later section.

## III. Design of the MAC protocol

In our network, all nodes can access any wavelength and statistically share the bandwidth of each data channel. A media access control (MAC) protocol is therefore necessary to govern access the wavelengths and handles access collisions between nodes. Our MAC protocol is based on the scheme of carrier sense multiple access. The carrier sensing mechanism for finding transmitted packets in optical fiber can be based on sub-carrier signaling [2-4] or receiver monitoring. For sub-carrier signaling, each wavelength is associated with a sub-carrier frequency. When a node transmits a packet, it multiplexes the corresponding sub-carrier frequency. The nodes determine the occupancy of all wavelengths in parallel by monitoring the sub-carriers in the RF domain. In addition, since each receiver extracts the optical signals from the corresponding data channel (or wavelength), receiver monitoring can be another approach to determine the occupancy of all wavelengths. It seems natural that the receivers are associated with the auxiliary function to monitor the status of the optical ring network. Nowadays, the cost of such receivers is still so high that is not economical to manufacture, but it may be realized later.

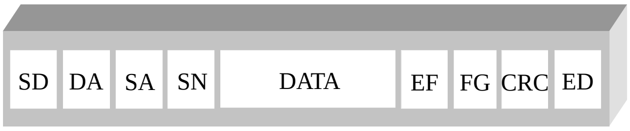


Figure 3: The frame format

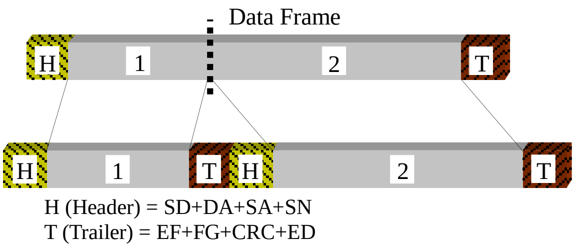


Figure 4: The data frame fragmentation

To resolve the access collisions in our network, a carrier preemption access scheme is proposed in conjunction with the carrier sense multiple access mechanism to form our MAC protocol, which is called the Carrier Sense Multiple Access with Carrier Preemption (CSMA/CP) protocol. Based on the protocol, each node monitors the wavelengths and tries to find an opening on channels provided that there are packets for transmission. Given that a packet is being transmitted onto a target channel while the node detecting another packet arriving on the same channel at its input, a dilemma of ring access (an access collision) has occurred. The cause for access collisions is due to the fact that the node cannot know if the opening is long enough to accommodate the packet. By the carrier preemption scheme, a collided packet is immediately fragmented into two parts: one for already transmitted and the other one for still in queue. For the fragment of already transmitted, a data frame trailer is appended to its back at once. For the fragment of still in queue, it will be transmitted later on the same channel or on other available channels. To guarantee the correctness of the protocol operations, the delay line inside nodes must be used to delay the incoming packet and to sustain the time for packet fragmentation. In addition, the delay line should be long enough to cover minimum packet length so that unnecessary fragmentation can be avoided.

To support the carrier preemption scheme, the frame format adopted is shown in Figure 3. For the start delimiter (SD) and the end delimiter (ED), they mark a physical data frame conveyed in data channels for packets or fragments. The source address (SA) and the destination address (DA) serve as the address information in the network. The sequence number (SN) is used to record the serial number in a sequence of fragments and the end fragment (EF) is used to indicate the last fragment. To prevent the possible transmission errors in midway, the cyclic redundancy check (CRC) is employed. The flag (FG) field is reserved for extended protocol functions. To demonstrate the action of packet fragmentation, a collided packet is fragmented into two fragments as depicted in Figure 4. The front fragment that has just been transmitted is appended a frame trailer and the rear fragment for later transmission is inserted a frame header.

## IV. **Simulations**

For the simulation model, it is shown in Figure 5. There are four processes used in the model: GEN, INS, RX, and CHK.

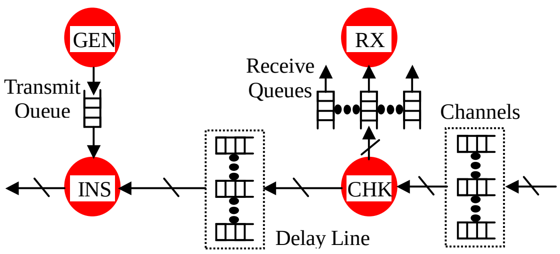


Figure 5: The simulation model

GEN is responsible for generating variable length IP packets based on uniform and non-uniform traffic load. INS is responsible for coordinating the transmission of packets in transmission queue and the shift of packets from the delay line. INS is also to perform the function of packet fragmentation for the collided packet. RX is the receiver process that receives packets and fragments and combines fragments belonging to the same packet together. CHK is responsible for checking the destination address of incoming packets. To simulate the delay line and the input fiber link of nodes under the condition of multi-channels, two sets of *W* queues are used for them. The simulation experiments are based on the codes by SIMSCRIPT II and are replicated corresponding to variance reduction technique with different sequences for pseudo random numbers. The results are obtained with 95% confidence level. For simulation parameters, they are listed below.

- Number of nodes 16 (separated by 5 km)
- Number of channels 8
- Network length 80 km
- Channel speed 10 Gbps (OC-192)
- Size of the delay line 80 nano-second (ns)
- Average IP packet size 512 bytes

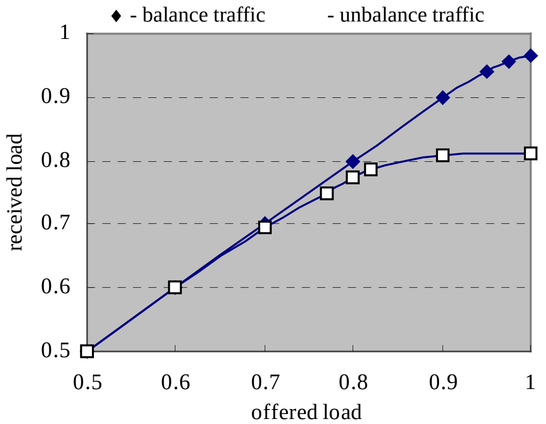


Figure 6: Throughput rate

The performance rate of offered load versa received load to each node is shown in Figure 6. To ease the comparison, the offered load and the received load are normalized with respect to the double of channel speed, since the spatial reuse property facilitates the double of channel utilization under balance traffic condition [5]. The balance traffic is obtained by distributing the output load of every node to other nodes uniformly. For the unbalance traffic, it is a client-server model, where node 16 is set to be the server and other nodes are clients. From Figure 6, it can be seen that the saturated rates for the balance and unbalance traffic is 97% and 82% respectively, which is nearly as good as the results from Marsan [4].

Since the propagation delay of signals is fixed through fiber links, we are interested in the performance of access delay. Figure 7 shows the relationship of throughput versa access delay scaled by nano-second. It shows that the access delay is quite lower under both the balance and unbalance traffic. Without considering propagation delay, our protocol is very suitable to various applications [2-4].

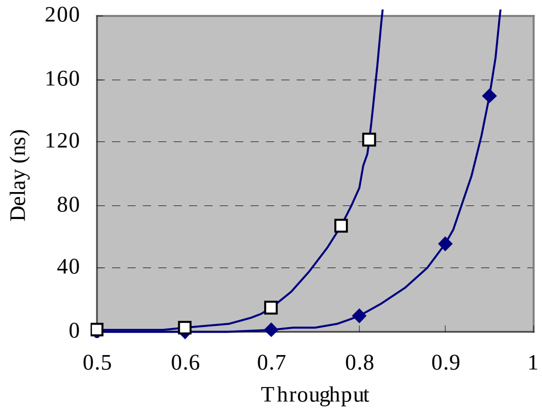


Figure 7: Throughput vs access delay

## V. Conclusions

In summary, we have investigated a novel MAC protocol for all optical WDM ring networks. The protocol supports the transmission of IP packets directly over WDM. Meanwhile, the investigation has been made about how to merge and collapse the middle layers between IP and WDM for next generation optical LANs/MANs. On facilitating spatial reuse of network bandwidth, our protocol displays the excellent characteristics of high throughput and low delay in the way of all optical communications.

## Acknowledgements


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