Modeling the High Performance Transmission Control Protocol for Supporting IP Packet 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. An approximate analysis, base on the M/G/1 queuing model, has been developed to evaluate the performance of our protocol. The analytical results show an excellent agreement with simulation results over a broad range of parameters. The results show that the proposed protocol can achieve higher bandwidth efficiency and lower access delay.

1. 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 1999, Stanford University's Optical Communication Research Laboratory (OCRL) [5-8] proposed the hybrid optoelectronic ring network (HORNET) using carrier sense multiple access with collision avoidance (CSMA/CA) protocol. HORNET utilizes the optical-electronic (O/E) and electronic-optical (E/O) conversion to retransmit the bypassed packets back into the channel received, and employs a jamming signal mechanism to resolve the optical packet collisions.

In this paper, we propose a carrier preemption MAC protocol based on carrier sense multiple access (CSMA/CP) schemes to support IP packets directly over the WDM network. We derive the equations of packet average transfer time for the CSMA/CP MAC protocol. To demonstrate the accuracy of the analytical model, this study simulates the network performance. In subsequent descriptions, the WDM ring network architecture for our protocol is presented in Section 2. Our protocol design is illustrated in Section 3. To evaluate the performance of the protocol, the performance analysis is described in Section 4. In Section 5, the simulation results are compared with the analytical results over a broad range of parameter. Finally, a few remarks are given in the conclusions.

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2. Network architecture

We now consider a unidirectional single fiber ring network, which connects a number of nodes N. This ring network is composed of data channels, W, as shown in Figure 1. Each data channel uses one specific wavelength to convey optical signals. Therefore, based on the WDM technology, channels can work independently without mutual interference. Logically, the network can be treated as a multi-ring network. The node structure of the network is shown in Figure 2.

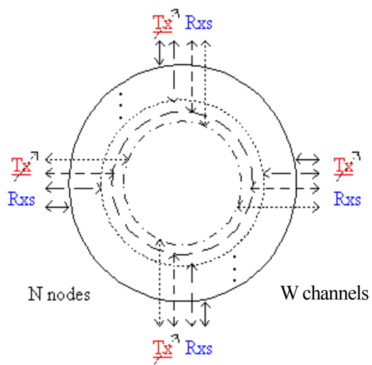

Figure 1.*Logic architecture.*

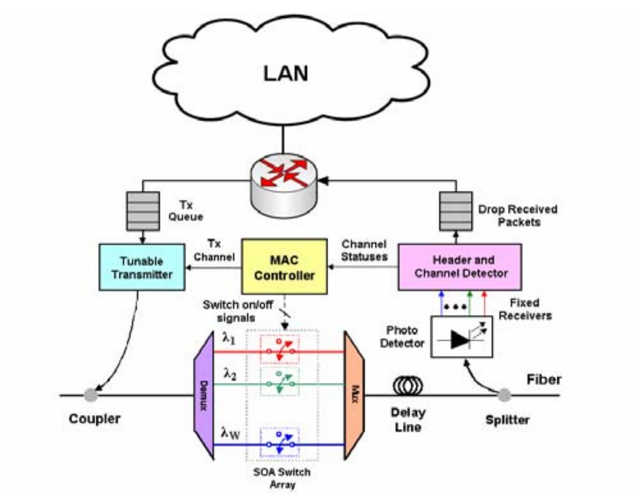

Figure 2.Node structure.

Each node has one tunable transmitter (TT) and W fixed receivers (FRs) dedicated to their particular data channels. 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. If the destination address of received packet does not match the node address, the portion signal of packet in the node will be ignored and most of the delay line will be bypassed to the downstream node. The node then goes back the monitor state. In this network architecture, the destination removal policy is used.

3. Carrier sense multiple access with carrier preemption (CSMA/CP) protocol

To resolve the access collisions in the network shown in Figure 3, each node monitors the wavelengths and tries to find an opening window on channels for packets transmission. Transmitting a packet onto a target channel when another packet (called the carrier) from an upstream node is arriving at the node on the same channel causes a collision. The reason for collisions is that a node does not have enough information to know whether the opening window is long enough to accommodate the packet.

In the carrier preemption scheme shown in Figure 4, a collided packet is immediately fragmented into two parts: one for the part already transmitted and the other one for the part still in queue. For the fragment which has already been transmitted, data frame trailer is appended to its back at once, while the fragment which is still in queue will be transmitted later on the same channel or on other available channels.

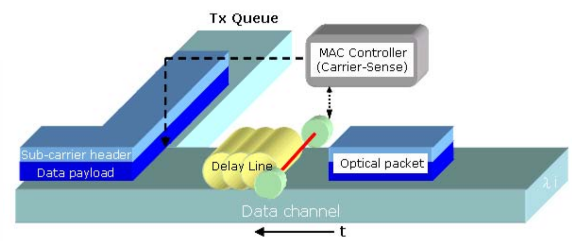

Figure 3.Carrier sense (Channel i).

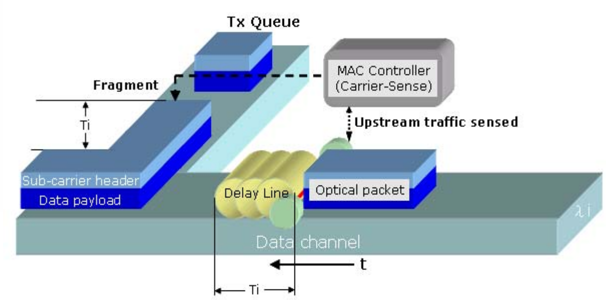

Figure 4.Carrier preemption (Channel i).

4. Network performance

When a new packet arrives, it must wait $n_G \cdot d$ seconds for each item ahead of it and wait $n_G \cdot d$ more for its own service. The steady-state duration of all the whole vacation intervals is equal to $\lambda_i TQE[n_G]E[d]$, and we obtain the average queue-waiting delay.

$$TQ = E[\alpha] + \lambda_i TQE[X] + \lambda_i TQE[n_G]E[d]$$
$$= \frac{L}{2 \cdot R} + \lambda_i TQE[X] + \lambda_i TQE[n_G]\frac{L \cdot \rho_{Bi}}{R \cdot (1-\rho_{Bi})} \quad (1)$$

which can be reduced to

$$TQ = \frac{L}{2 \cdot R \cdot (1 - \lambda_i E[X] - \lambda_i E[n_G]\frac{L \cdot \rho_{Bi}}{R \cdot (1-\rho_{Bi})})} \quad (2)$$

Because the packet transfer delay is comprised of the queue-waiting delay, transmission delay and propagation delay, the average packet transfer delay is

$$D = TQ + S + \tau' \quad (3)$$

where τ' is the average propagation delay from a source node to a destination node, which is often expressed as τ / 2. The average transmission delay is

$$S = E[X] + E[n_G]E[d]$$
$$= E[X] + \frac{E[n_G] \cdot L \cdot \rho_{Bi}}{R \cdot (1 - \rho_{Bi})} \quad (4)$$

Thus, the average transfer delay is given by

$$D = TQ + S + \tau / 2 \quad (5)$$

In order to analyze the multiple WDM ring networks, it is assumed that the bridge traffic load from the upstream source is equally distributed among W rings. To simplify the analysis, let the circulation of slots on W rings be synchronized [9-10]. That is, a node can observe W mTU on different rings at the same time. Since the bridge traffic load from the upstream source is uniformly distributed among the W rings, the average bridge traffic load of each ring, ρ_B, can be expressed as

$$\rho_B = \rho_{Bi} / W \quad (6)$$

The probability that the packet at the head of a queue cannot get an empty mTU among the currently passing W mTUs is $(\rho_B)^W$. Therefore, the probability that the packet has to wait i mTUs before it can be sent out is $(\rho_B)^{W \cdot i}(1 - (\rho_B)^W)$.

Let $E[d_B]$ be the average time required to find the arrival of an empty mTU, then we have

$$E[d_B] = \sum_{i=0}^{\infty} i\frac{L}{R}(\rho_B)^{W \cdot i}(1-(\rho_B)^W) = \frac{L \cdot (\rho_B)^W}{R \cdot (1-(\rho_B)^W)} \quad (7)$$

Since for each packet in the queue the arriving packet has to wait for $L/R + d_B$ times, the average queue-waiting delay in the queue faced by arriving packet is

$$TQ = E[\alpha] + \lambda_i TQE[X] + \lambda_i WE[n_G]E[d_B] \quad (8)$$

Therefore, we have

$$TQ = \frac{E[\alpha]}{1 - \lambda_i E[X] - \lambda_i E[n_G]E[d_B]} \quad (9)$$

The average transmission delay is

$$S = E[X] + E[n_G]E[d_B]$$
$$= E[X] + \frac{E[n_G] \cdot L \cdot (\rho_B)^W}{R \cdot (1 - (\rho_B)^W)} \quad (10)$$

Thus, the average transfer delay is given by

$$D = TQ + S + \tau / 2 \quad (11)$$

5 Results and discussions

In this section, we will present the analytical and simulation results of packet transfer delay of the network. To evaluate the performance of the WDM ring network, the following parameters have been listed below.

— Number of nodes 16
— Number of channels 1,2,4,8
— Network distance 30 km, 50 km, 100 km
— Channel speed 1.22 Gbps, 2.5 Gbps, 10 Gbps
— Size of the delay line 800 bits
— Average IP packet size 512 bytes (β = 0.000244)
— Propagation delay of the fiber is 5 μs/km

Figure 5 charts the average transfer delay versus the number of packets per node in a 10 Gbps four-channel WDM ring. Under the steady state network condition, the higher the number of channel in the WDM ring, the higher the node throughput (See Figure 6). This means the throughput characteristic of the network depends on the aggregated transmission capacity of the network, e.g., the performance of the network that has eight-channel 10 Gbps is superior to than four-channel 10 Gbps. Under the steady state network condition, the average transfer delay characteristic of the network with a shorter distance is better than that of a long distance WDM ring network (See Figure 7).

6 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 characteristic of high throughput and low delay in the way of all optical communications.

A novel technique has been devised to analyze the average transfer delay of a packet in the WDM ring network. For verification, we also simulate the network using CASI Simscript II.5 and obtain the simulation result. The analytical results show an excellent agreement with the simulation results over a broad range of parameters. Both throughput and transfer delay improve with the number of wavelengths used in the ring, consistent with current WDM technology trends.

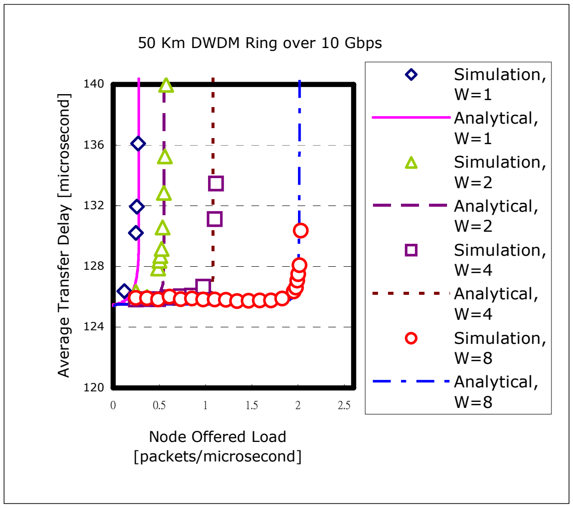

Figure 5.Average transfer delay versus offered load per node, when the number of channels equals 1,2,4 and 8.

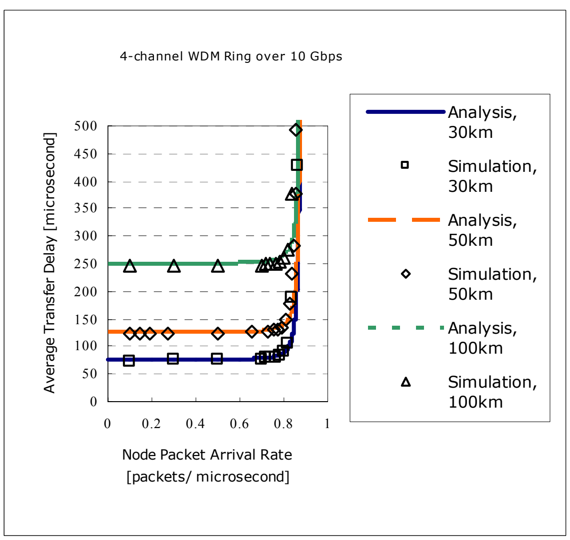

Figure 6.Average transfer delay for various WDM ring distances in a four-channel 10 Gbps WDM ring.

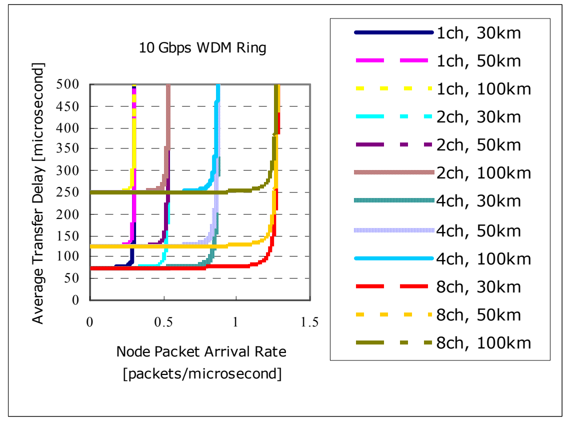

Figure 7.Average transfer delay for various WDM ring distances and number of channels in a 10 Gbps WDM ring.

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