Supporting Multiple Classes of Services in IP over WDM Ring Network

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Abstract

In our previous paper [1-2]*, we proposed a novel carrier preemption MAC protocol based on carrier sense multiple access schemes has been designed to supporting IP packets over all optical WDM MAN ring networks. Since the traditional IP provides the best effort service only, the issue of supporting IP packets with QoS transfer has become a crucial issue for multimedia transmission. We do so by addressing the priority-aware QoS model.*

1. Introduction

A Wavelength Division Multiplexing (WDM) [3-5], first developed during the late 1980s, provides tremendous bandwidth, up to OC-192 (10Gb/s), and has total bandwidth on an optical fiber exceeding 20 Tbps. WDM-based solutions are therefore expected to appear in the next generation of access networks in metropolitan area networks. In addition to avoiding transmission collisions among nodes attempting to use the same network wavelength, an MAC protocol is necessary to arbitrate access to the wavelengths and detect or avoid collisions between nodes. Unfortunately, most of the research efforts in this area assume that connection is for a single class of traffic. In recent research, the WDM ring average delay analysis has been extended to multi-class services. In this paper, we will introduce service quality differentiation into the WDM ring network. The rest of this paper is organized as follows. The CSMA/CP MAC protocol are presented in Section 2. In Section 3, an approximate queue model for priority-aware QoS is presented to evaluate the performance. In Section 4, the numerical results are obtained from our analysis. Concluding remarks are made in Section 5.

2. NETWORK ARCHITECTURE AND MAC PROTOCOL

The optical fiber is composed of W data channels (λ_1, λ_2, λ_3,…, λ_w) as shown in figure 1. The node structure of the network is shown in Figure 2. 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. Receivers continuously monitor sub-carrier headers to detect whether or not the channel is available at that time, and inspect the header information. The data packet will be passed to the local area network (LAN) if its destination address does match this node address. Meanwhile, the MAC control scheme is signaled to activate the semiconductor optical amplifier (SOA) filter to filter the most of the optical signal of the received packet within the delay line interval. When the optical signal arrives at the delay line, it will be delayed for a fixed interval to process the address recognition and adjust the switch array of the SOA Filter to drop the optical signal if necessary. If the destination address of the received packet does not match the node address, the portion signal of the 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.

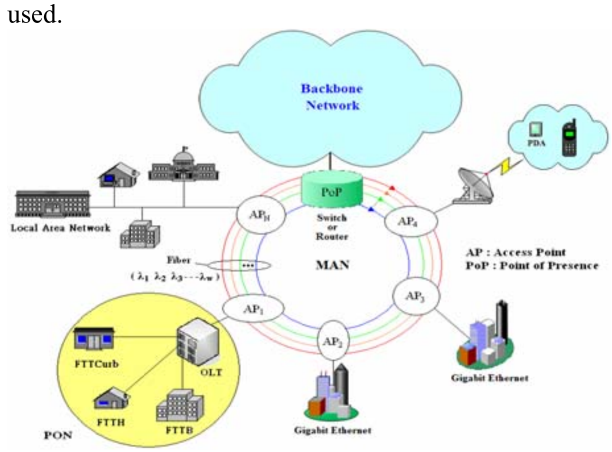

Figure 1. Network architecture for the WDM ring Network

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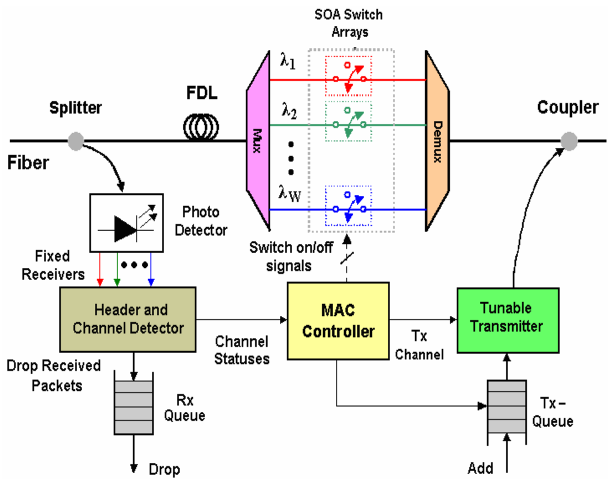

Figure 2. The node structure of the network

To avoid packet collisions and use bandwidth more efficiently, this paper uses a CSMA/CP MAC protocol that is based on carrier sense multiple access and carrier preemption schemes. Each node monitors wavelengths under the carrier sensing scheme as shown in Figure 3 and tries to find an opening on channels for packet transmission. It is possible that another packet (called a carrier) from upstream arrives on the same channel when the node is still transmitting its packet, thus a collision occurs. The reason for the collision is the node does not have enough information to know whether the opening on the channel is long enough to accommodate the transmitted packet. Under the carrier preemption scheme, the transmission of a collided packet will be immediately fragmented into two parts: one will be continuously transmitted and the other is added to a queue as shown in Figure 4. The transmitter can continue to transmit the former when the arrival carrier passes into the delay-line. It is noted that the CSMA/CP scheme is done in the electrical domain of the node, but the data packet is transmitted in the all-optical domain of the network. The carrier passes through the delay-line after T_i *ns* (nanosecond), just as the transmitter finishes the former transmission. The queued fragment will be transmitted later on the same or another available channel.

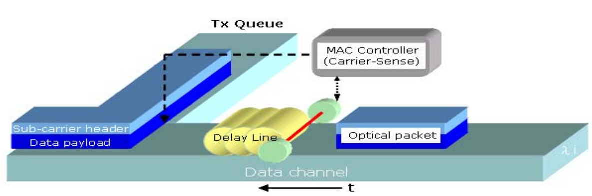

Figure 3. Data payload and its header is sent in wavelength λi. The optical packet arrives and accesses the node and the receiver senses the carrier, which will inform the MAC controller

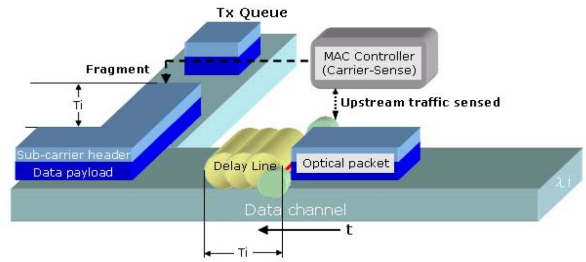

Figure 4. Delay line will postpone the upstream carrier *Ti ns*, the frame will be fragmented at the exact position

The first approach proposed to replace the best effort model is Integrated Services (Intserv) [6-10]. Using resource reservation and admission control (through protocols like RSVP), an application's request for a certain level of performance can be guaranteed. But per-flow state information should be kept inside each router along the way in order to fulfill the service requirement of each flow. As a result, this approach encounters a scalability problem in its deployment. In order to overcome the scalability problem of Intserv, a relatively new approach: Differentiated Service (Diffserv) [11-15] has been proposed. Instead of providing end-to-end per-flow performance guarantees, Diffserv provides local (per hop) service differentiation for aggregated traffic with the same QoS requirement (per class). This goal is achieved by defining packets' Per-Hop-Behavior (PHB) at each router. No state information about each flow is kept in the core of the network due to its per-class QoS model. In particular, two models of Diffserv have been identified: absolute service differentiation and relative service differentiation. The latter is receiving more attention because of its simplicity and its ability to be deployed incrementally [16].

Since the traditional IP provides the best effort service only, the issue of supporting IP packets with QoS transfer has become a crucial issue for multimedia transmission. Today, while the network bandwidth has grown dramatically, the kind of applications transferred are mostly high-bandwidth demanding multimedia transmissions. It is predictable that the end-to-end QoS will be an important area of study in the next generation Internet.

This paper proposes a priority-aware MAC protocol of core metropolitan area network in the next generation Internet, which is an OPS network that all-optically and directly transfers IP packets over a WDM ring network. It uses the concept of CSMA/CP MAC protocol and the priority mechanism to support all-optical and priority-aware transferring of the IP packets of the nodes in the WDM ring networks; the MAC protocol is named priority-aware CSMA/CP.

3. Analysis of priority- aware CSMA/CP

We derive the formula by the formula in the CSMA/CP [1-2]. From the behavior of a priority-aware queue model, the model can be categorized as a non-preemptive priority M/G/1 queue model [17]. Figure 5 shows model of corresponding priority k in access node i. Note that the $\rho_{i,k}$ is the product of $\lambda_{i,k}$ (individual class k arrival rate in node i and $\sum \lambda_{i,k} = \lambda_i$) by E[$X_{i,k}$] (the mean service time of class k in node i). The notation γ is the product of E[n_G] by E[d].

Consider the mean waiting time $W_{i,1}$ of the highest priority queue, we obtain:

$$
\begin{aligned}
W_{i,1} &= \alpha + \lambda_{i,1} \cdot W_{i,1} \cdot E[X_{i,1}] + \lambda_{i,1} \cdot W_{i,1} \cdot E[n_G] \cdot E[d] \\
&= \frac{\alpha}{1 - \lambda_{i,1} \cdot E[X_{i,1}] - \lambda_{i,1} \cdot E[n_G] \cdot E[d]} \\
&= \frac{\alpha}{1 - \rho_{i,1} - \lambda_{i,1} \cdot \gamma}
\end{aligned} \quad (1)
$$

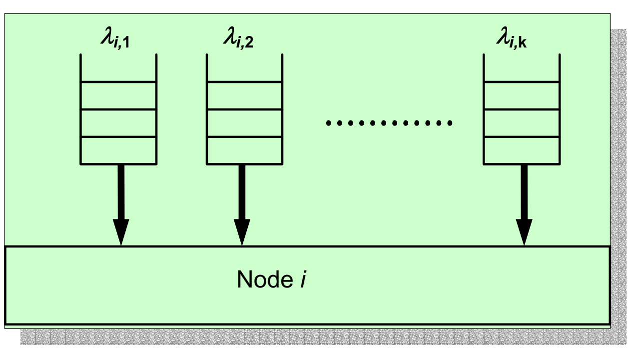

Figure 5. Queuing model of corresponding priority *k* in access node *i*

For the second priority queue, we have a similar expression for the mean waiting time $W_{i,2}$, except that we have to count the additional waiting time due to packets of higher priority that arrive while a packet is waiting in queue. Using the expression (1) obtained earlier, we finally have:

$$
\begin{aligned}
W_{i,2} &= \alpha + \lambda_{i,1} \cdot W_{i,1} \cdot E[X_{i,1}] + \lambda_{i,1} \cdot W_{i,1} \cdot E[n_G] \cdot E[d] \\
&\quad + \lambda_{i,2} \cdot W_{i,2} \cdot E[X_{i,2}] + \lambda_{i,2} \cdot W_{i,2} \cdot E[n_G] \cdot E[d] \\
&\quad + \lambda_{i,1} \cdot W_{i,2} \cdot E[X_{i,1}] + \lambda_{i,1} \cdot W_{i,2} \cdot E[n_G] \cdot E[d] \\
&= \frac{\alpha + \lambda_{i,1} \cdot W_{i,1} \cdot E[X_{i,1}] + \lambda_{i,1} \cdot W_{i,1} \cdot E[n_G] \cdot E[d]}{1 - \lambda_{i,2} \cdot E[X_{i,2}] - \lambda_{i,2} \cdot E[n_G] \cdot E[d] - \lambda_{i,1} \cdot E[X_{i,1}] - \lambda_{i,1} \cdot E[n_G] \cdot E[d]} \\
&= \frac{\alpha + \rho_{i,1} \cdot W_{i,1} + \lambda_{i,1} \cdot W_{i,1} \cdot \gamma}{1 - (\rho_{i,1} + \rho_{i,2}) - (\lambda_{i,1} + \lambda_{i,2}) \cdot \gamma} \\
&= \frac{\alpha}{(1 - \rho_{i,1} - \lambda_{i,1} \cdot \gamma)(1 - (\rho_{i,1} + \rho_{i,2}) - (\lambda_{i,1} + \lambda_{i,2}) \cdot \gamma)}
\end{aligned} \quad (2)
$$

The derivation is similar for the general priority queue (class k >1). The formula for the mean waiting time in queue is:

$$
W_{i,k} = \frac{\alpha}{\left(1 - \sum_{l=1}^{k-1} \rho_{i,l} - \left[\sum_{l=1}^{k-1} \lambda_{i,l}\right] \cdot \gamma\right) \cdot \left(1 - \sum_{l=1}^{k} \rho_{i,l} - \left[\sum_{l=1}^{k} \lambda_{i,l}\right] \cdot \gamma\right)} \quad (3)
$$

4. Numerical Results

The parameters of network are shown in Table I. The CASI SIMSCRIPT II.5 simulation tool is used to simulate the network model.

Table I Network parameters

Number of nodes (N)	16
Number of channels (W)	4
Ring distance	50*Km*
Propagation delay of the fiber	5 μs / *Km*
Channel speed	OC-192 (10 *Gbps*)
Size of the delay line	80 *ns*
Average IP packet size	512 *bytes*

In the assumption, there are 16 access nodes with attached to four wavelengths (W=4), and IP packets are divided into four classes. The total traffic is divided equally to each class, i.e. a quarter of the total packet amount. Figure 6 presents the different performance for each class under the priority-aware model, where Class 4 packets get the worst quality of service and Class 1 packets get the best quality of service. The performance between each service class has a notable diversity. Moreover the agreement between the simulation results and the analytical results is excellent.

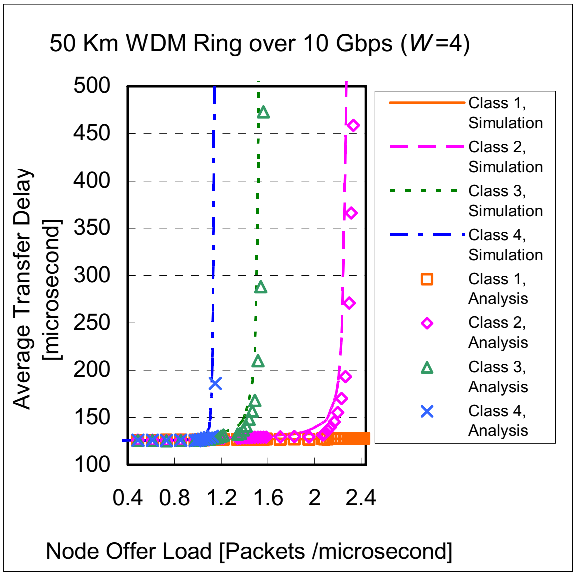

Figure 6. Average transfer delay under different class (*k*=1, 2, 3 and 4) using priority-aware CSMA/CP model

5. Conclusions

This investigation describes a novel MAC scheme applicable to all optical WDM ring networks. By facilitating spatial reuse of network bandwidth, the CSMA/CP MAC protocol displays excellent characteristics of high throughput and low delay for all optical communications. The proposed priority-aware CSMA/CP MAC protocol adds the class-based priority scheme into the CSMA/CP MAC protocol. This novel protocol may differentiate traffic, so when used to implement IP links it is able to help the access nodes implement the quality-of-service-aware (QoS-aware) communication needed in a network that carries multimedia traffic. It also derives the approximate equations for the average packet transfer delay for priority-aware CSMA/CP MAC protocol. For verification, a simulation program obtains simulated results for the network, and the results closely resemble the analytical values, and this demonstrates the good performance of the network. It is also observed that the throughput characteristic of the network is almost proportional to the number of channels in the network. Transfer delay improves with the number of wavelengths and quality-of–service (QoS) improves with the class-based priority scheme used in the ring, consistent with current WDM technology trends. The characteristic of the ring network is the priority-aware property that introduces the unfairness between nodes, moreover the proposed priority-aware scheme does handle the priority between nodes (i.e. global priority-awareness). Those problems could be left for future research.

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