A Novel Multimedia Network backbone Architecture base on Proportional Delay Differentiation

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Abstract

This paper proposes a novel multimedia network backbone architecture that supports all-optical transmission and Quality of Service (QoS). A new Media Access Control (MAC) protocol for this network named CSMA/CP (Carrier Sense Multiple Access/Carrier Preemption) is used to directly transport variable size IP packets on the DWDM ring network without encapsulating IP packets to SONET; it improves the transport efficiency of network. In addition, this network also provides the survivability function to increase reliability for restoring any node or fiber failures. In the thesis, the system model of the network is built, analyzed, and simulated. Simulation results show the proposed MAC protocol is able to take higher node throughput and lower packet latency. Finally, the proportional delay differentiated mechanism is added for this system to support Differentiated Services (DiffServ).

1. Introduction

Wavelength Division Multiplexing (WDM) [1-2], first developed during the late 1980s, provides tremendous bandwidth, up to OC-192 (10Gb/s), and has total bandwidth on an optical fiber exceeding 20Tbps. WDM-based solutions are therefore expected to appear in the next generation of access networks in metropolitan area networks. However, harnessing this unprecedented bandwidth in the metropolitan network environment will require a WDM transmission protocol to efficiently transport IP packets across the data centric WDM-based MANs.

The ring topology is chosen as an all-optical metropolitan backbone. 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.

This paper proposes a proportional delay differentiated 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 [3] and the proportional delay differentiated mechanism to support all-optical and transferring of the IP packets of the nodes in the WDM ring networks; the new MAC protocol is named proportional delay differentiated CSMA/CP. 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. The rest of this paper is organized as follows. The multimedia network backbone architecture and proportional delay differentiated CSMA/CP MAC protocol are presented in Section 2. In Section 3, an approximate proportional delay differentiated queue model based on an M/G/1 queue with vacations is presented to evaluate the ring performance. In Section 4, the numerical results are obtained from our analysis and simulation. Concluding remarks are made in Section 5.

2. Multimedia Network Backbone Architecture

The architecture of a WDM ring network is based on a unidirectional single fiber ring topology; it consists of a number of access nodes (ANs) and W data channels, as shown in Figure 1. Each AN contains two kinds of network interfaces: (1) the LAN interface is used for the transmission between AN and its access network; (2) the optical link interface is used to access this WDM MAN ring in the optical domain. Each AN is also equipped with a tunable transmitter and W fixed receivers; each receiver makes use of a particular data channel which has a unique specific wavelength. Every AN can simultaneously receive data from any wavelength, and channels work independently without interference with each other. Logically, the network can be treated as a multi-ring network.

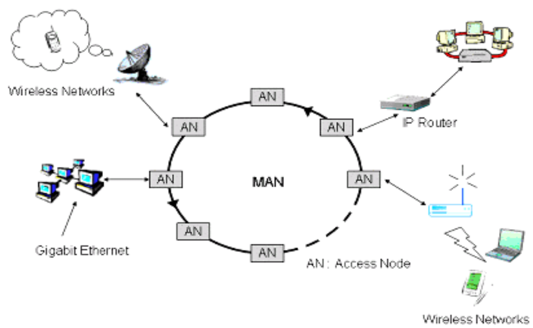

Fig.1. Network architecture for the WDM ring network

2.1. Structure of the Access Node

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.

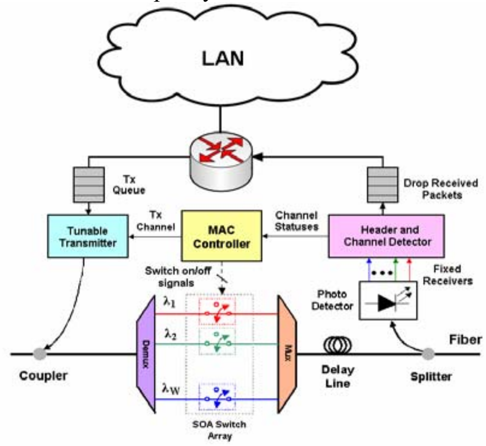

Fig.2. Structure of access node.

Each node is equipped with multiple fixed receivers, and each takes care of a dedicated data channel; hence the receivers would detect more than one available data channel at a time. However, there is only one tunable transmitter in a node to transmit a packet on a specified wavelength at a time; this paper uses the random selection strategy to make the decision for the channel selection. The packets to be transmitted are added into the transmission queue before sending; as the packet is transmitted onto an available data channel, it is propagated in an optical carrier form and its control header is propagated in a sub-carrier frequency multiplexed tone. They are mixed into the optical fiber first, afterward the mixed signal will be sent to the downstream nodes.

2.2. CSMA/CP MAC Protocol

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. The carrier sensing scheme is used by the receiver to inspect the sub-carrier signaling of the transmitted packets in an optical fiber. Each node monitors wavelengths under the carrier sensing scheme as shown in Figure 3(a) 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 3(b). 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.

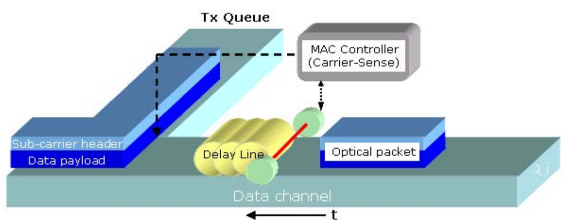

Fig.3 (a) Data payload and its header are sent in wavelength *λi.* The optical packet arrives and accesses the node and the receiver senses the carrier, which will inform the MAC controller

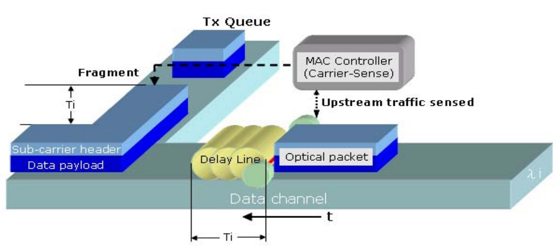

Fig.3 (b) Delay line will postpone the upstream carrier Ti ns, the frame will be fragmented at the exact position.

To support the carrier preemption scheme, a frame format is designed, as shown in Figure 4. A collided packet is fragmented into two fragments, as depicted in Figure 5. The front fragment that has just been transmitted is appended into a frame trailer and the rear fragment for later transmission is inserted into a frame header.

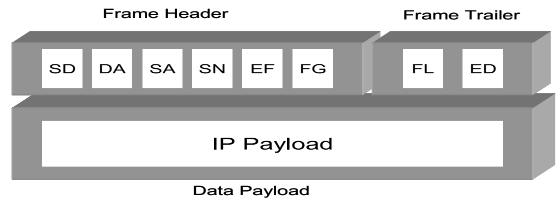

Fig.4.The frame format.

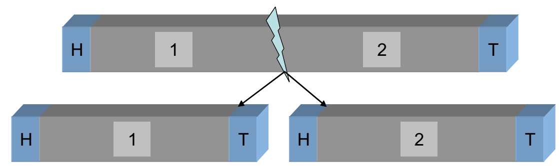

Fig.5. Fragmentation of data frame.

2.3. Proportional delay differentiated CSMA/CP MAC Protocol

We improved the WTP [4] scheduling reducing the computation of average waiting time instead of average delay time. The implementation for WTP-Like algorithm is shown in Figure 6. In **De_queue** procedure, it selects a queue *j* for transmission such that

$$j \leftarrow \arg\max_i \{B_i(t) \cdot r_i / \lambda_i(t)\} \tag{1}$$

En_queue Procedure ( )
$\{B_i(t) \leftarrow B_i(t) + 1\}$; /* for each corresponding delay class*/
De_queue Procedure ( )
$\{ j = \max_i \{ B_i(t)\ r_i / \lambda_i(t)\}$;
transmit from delay class j; /* select a packet to transmit from a queue */
$B_j(t) \leftarrow B_j(t)-1$; }

Fig.6. WTP-Like algorithm

3. Approximate Performance Analysis

We derive the formula by the formula in the CSMA/CP [5-6] and TDP (Time-Dependent Priority) [4] scheduling. The average waiting time in different class is obtained by M/G/1 queuing model. The derived formula is given by follows.

$$\rho_i = \lambda_i \cdot E[X_i] \tag{2}$$
$$\gamma = E(n_G)E(d)$$
$$\beta_{ik} = \lambda_i \cdot W_i \cdot E[X_i] + \lambda_i \cdot W_i \cdot E(n_G) \cdot E(d)$$

$$\text{for all } i \le k \tag{3}$$

$$\beta_{ik} = \lambda_i \cdot W_i \cdot \frac{b_i}{b_k} \cdot E[X_i] + \lambda_i \cdot W_i \cdot \frac{b_i}{b_k} \cdot E(n_G) \cdot E(d)$$

$$\text{for all } i > k \tag{4}$$

$$\alpha_{ik} = \lambda_i \cdot W_k \cdot \left[1 - \frac{b_k}{b_i}\right] \cdot E[X_i] + \lambda_i \cdot W_k \cdot \left[1 - \frac{b_k}{b_i}\right] \cdot E(n_G) \cdot E(d)$$

$$\text{for all } i < k \tag{5}$$

$$\begin{aligned} W_k &= R + \lambda_i \cdot W_i \cdot E[X] + \lambda_i \cdot W_i \cdot E(n_G) \cdot E(d), (i < k) \\ &+ \lambda_i \cdot W_i \cdot \frac{b_i}{b_k} \cdot E[X_i] + \lambda_i \cdot W_i \cdot \frac{b_i}{b_k} \cdot E(n_G) \cdot E(d), (i > k) \\ &+ \lambda_i \cdot W_k \cdot \left[1 - \frac{b_k}{b_i}\right] \cdot E[X_i] + \lambda_i \cdot W_k \cdot \left[1 - \frac{b_k}{b_i}\right] \cdot E(n_G) \cdot E(d), (i \le k) \\ &= \frac{R + \sum_{i=1}^{k-1} (\rho_i + \lambda_i \cdot \gamma) \cdot W_i + \sum_{i=k+1}^{P} (\rho_i \cdot \frac{b_i}{b_k} + \lambda_i \cdot \gamma) \cdot W_i}{1 - \sum_{i=1}^{k} (\rho_i + \lambda_i \cdot \gamma) \cdot \left[1 - \frac{b_k}{b_i}\right]} \end{aligned} \tag{6}$$

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. We show the case with the control parameter $b_1 = 8$, $b_2 = 4$, $b_3 = 2$, $b_4 = 1$ for four priority class. It shows the performance between each class has a proportional delay differentiated relationship from the results of figure 7 and Table II and class 1 packets get the best quality of service. A novel multimedia network backbone base on proportional delay differentiation supports the multimedia transmission which has demand of different bandwidth.

5. Conclusions

The proposed proportional delay differentiated CSMA/CP MAC protocol adds the proportional delay differentiated 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 proportional delay differentiated CSMA/CP MAC protocol. Both transfer delay improves with the number of wavelengths and quality-of–service (QoS) improves with the proportional delay differentiated scheme used in the multimedia network backbone, consistent with current WDM technology trends.

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

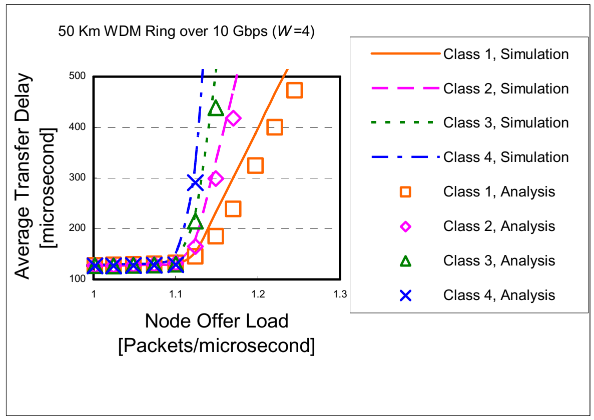

Fig.7. Average transfer delay versus offered load for proportional delay differentiated service.

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