A CSMA/CP MAC Protocols for IP over WDM Metropolitan Area Ring Networks

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Abstract - To solve the explosively growth of the Internet demands, Metropolitan area networks (MAN) use SONET to provide huge bandwidth. However, the SONET network is suitable for Constant Bit Rate (CBR) traffic. Therefore, it cannot effectively handle the burst-natured Metropolitan area networks Traffic. This paper proposed a novel MAN network architecture and protocol by using the wavelength division multiplexing (WDM) technique to efficiently share the network bandwidth among every network nodes. The proposed novel network architecture adopts Carrier Sense Multiple Access with Carrier Preemption (CSMA/CP) that is a Media Access Control (MAC) protocol to handle the variable size IP packet transport on WDM MAN ring network. This paper also shows the simulation results to verify the proposed MAC protocol is able to take more efficiently utilization and lower packet latency. Further developments are proposed to improve the efficiency and add new capabilities such as QoS.

I. Introduction

Today, the new multimedia applications and services have caused the bandwidth demands explosive increase in the metropolitan area network backbone. Hence, WDM (Wavelength-Division Multiplexing) technology is developed to offer unprecedented bandwidth to meet the rapidly growing Internet traffic in metropolitan networks. Recently, the WDM technology offer channel bandwidth of commercial system has reached to OC-192 (10 Gbps), and the total bandwidth of an optical fiber exceeds one Tbps. The WDM-based solutions are therefore expected to appear as the next generation access networks in the Metropolitan Area Network (MAN). But harnessing the unprecedented bandwidth in the metropolitan network environment will require WDM network to be efficiently transport IP packet cross the data centric WDM-based MAN.

Conventional transport IP-Dominant packets over WDM in MAN backbone are to employ SONET framed techniques. However, SONET transport packets between the interconnect nodes in MAN must establish a permanent connection that is only optimized for continuing data traffic or voice traffic, not suitable for the burst-natured traffic of MAN. In the open literature, the Stanford University's Optical Communications Research Laboratory (OCRL) developed the hybrid optoelectronic ring network (HORNET) based on a tunable transmitter and a fixed receiver (TTFR) [1-3]. Each HORNET node drops a fixed wavelength and transmits data on any open wavelength while it is determined by Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) MAC protocol. Due to HORNET uses optical-electronic and electronic-optical conversion to retransmit the passed packet into the network on the fixed received channel and employ jamming signally mechanism to handle the collision avoidance, which may constrain the transmission rate of the high-speed backbone network.

This paper proposes and evaluates a novel network architecture and Media Access Control (MAC) protocol. In order to support IP packet directly over WDM ring network instead of using SONET frames and without any O/E processing. The access of networks is implemented by Sub carrier Multiplexed (SCM) header techniques [4][7], to inspect the header information from sub carrier frequency multiplexed tones of optical packets for achieving all-optical WDM network. Moreover, this paper will propose a carrier preemption access control protocol based on carrier sense multiple access schemes to place packets on the WDM ring network that avoids the collision between the transmitting flow and the channel flow. This protocol allows the network to utilize the high capacity bandwidth of multi-wavelength network more efficiently.

Eventually, we present simulation results that verify the network architecture is able to take lower queuing delay and higher throughput, and investigate the effects of various system parameters. Following the introduction, this paper is organized as following: Section II introduces the network architecture and the proposed MAC protocol. Section III presents the simulation model and simulation results to demonstrate the system performance such as transmission delay and queuing delay. It also studies the effect of various system parameters.

II. System architecture

A. The network architecture

The proposed network architecture is based on a single unidirectional fiber ring topology; it consists of a number of access nodes (AN) and W data channels as shown in Fig.1.

Each access node is composed of two interfaces: Gigabit Ethernet interface and Optical–Link interface. Gigabit Ethernet interface is used for transmission between the

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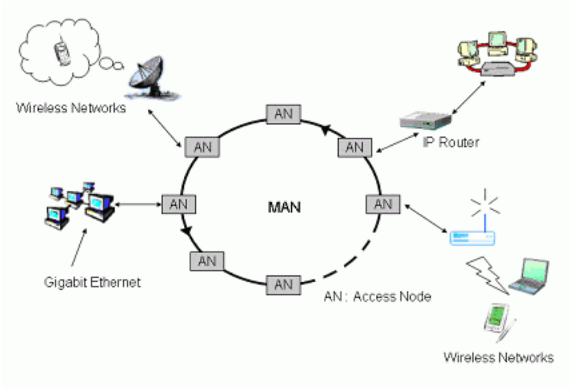

Fig 1. *Network architecture for MAN ring networks*

access node and the gigabit access networks, the Optical–Link interface is used to access the WDM MAN ring in optical domain. Each node is also equipped with a tunable transmitter and a fixed receiver to allow them to transmit packet onto any usable wavelength and receive data from a unique specific wavelength.

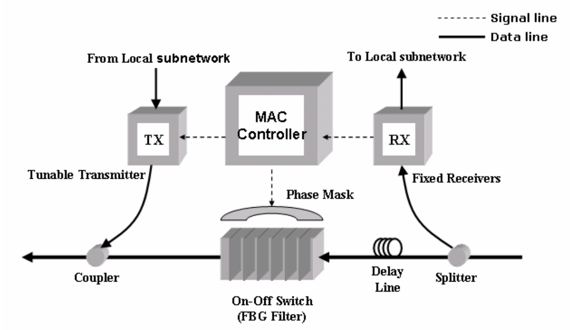

Fig 2. *The Structure of Access Node*

The structure of the access node is shown in Fig.2. The optical signal sent from upstream nodes will be tapped off a small portion of optical power from the ring to receive by the splitter. Every receiver continuously monitors the sub-carrier frequencies carried in all opened wavelength to detect whether the wavelengths are transmittable or not, and to inspect the header information. According to the information, the data packets will be passed to the local network if their destination addresses do match the node address. Meanwhile, the MAC scheme is signaled to activate the Fiber Bragg Grating (FBG) Filter for filtering the received packet that carried in major portion of the optical signal through the delay line. If the destination address does not match to the node address, the retrieved packet is ignored; the node then continuously scans the next packets.

When the optical signal goes through the delay line, it will be delayed a period of delay time for the operation of address recognition and the adjusting of phase mask for the FBG Filter in order to drop the specified wavelength. In this network architecture, the destination removal policy is used.

The transmitting packets are added into the transmission queue before sending. Each node is equipped with one fixed receiver that scans data channels in round robin manner; hence the receiver may detect more than one available data channel. However, there is only a tunable transmitter to transmit packet on a specified wavelength at a time; this paper uses the random selection strategy to make the decision for it. As packets will be transmitted onto the available data channel, the optical carrier of packets and the sub-carrier frequency multiplexed tones are coupled into the optical fiber first, and then sent to downstream nodes.

B. CSMA/CP protocol

In the network architecture, each node has the ability to transmit on any available wavelength and receive from the unique wavelength; its logical architecture is shown as in Fig.3.

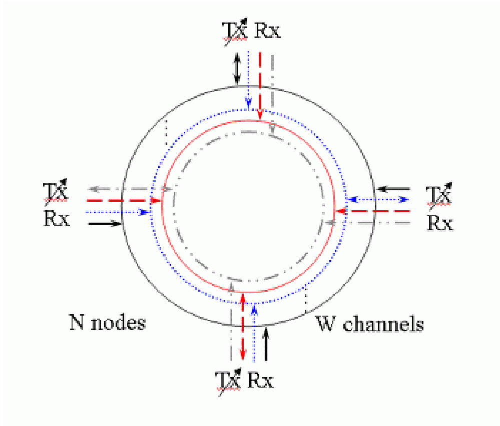

Fig 3. *Logical Architecture*

To avoid packet collision and govern the extraordinary bandwidth efficiently, this paper proposes a novel carrier preemption MAC protocol based on carrier sense multiple access schemes. The carrier sensing mechanism is used by receiver to inspect the sub-carrier signaling of transmitted packets in optical fiber. Each wavelength is associated with a sub-carrier frequency. Nodes detect the availability of wavelengths by monitoring the sub-carrier in RF domain.

To solve the access collisions in the network, each node monitors the wavelengths and tries to find an opening window on channels for packet transmission. Transmitting packet onto a target channel while the other packet (called carrier) from upstream node is arrived at the node on the same channel, and a collision is occurred. The reason for collision happens is node does not have enough information to know whether the opening window is long enough to accommodate the packet.

In the carrier preemption scheme, the transmission of the collided packet does not finish and will be immediately fragmented into two parts: one should be transmitted and the other must still stay in queue. The transmitter can continually transmit the former when the arrival carrier passes into the delay-line. Until the carrier through delay-line, the transmitter just finishes the former transmission. For the fragment in queue, it could be transmitted later on the same channel or transmitted on other available channels at once.

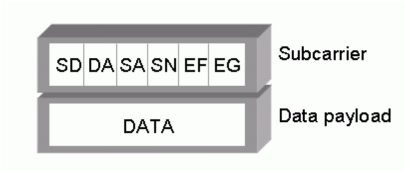

Fig 4. *The frame format*

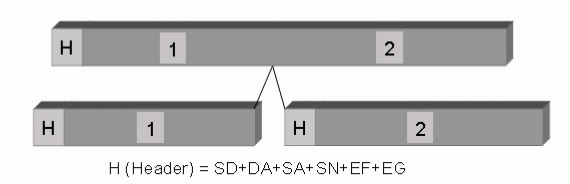

Fig 5. *The data frame fragmentation*

To support the carrier preemption scheme, the frame format is designed as shown in Fig. 4. It is adopted as the solution of the addressing capabilities and fragmentation mechanisms in [5]. Basically, it consists of a start delimiter (SD), which labels the data frame, which is conveyed in data channel either for packets or fragments. The destinations address (DA) and the source address (SA) fields record the address information in the network. The sequence number (SN) demonstrates the serial number in a sequence of fragments, and end fragment (EF) field is used to indicate the last fragment. Finally, the flag field (FG) is reserved for extended protocol functions such as defined different service class for the data payload. Fig. 5 shows how the packet is fragmented into two parts when the packet collision happened. Each packet must append frame header either being transmitted or being fragmented.

III. Simulation and Results

This study adopts the SIMSCRIPT language to implement the simulation programs. Fig. 6 shows the simulation model of the access node. In the model, the upstream traffic is generated by the upstream nodes instead of using the traffic generator. Each node checks the destination address of the packet on each wavelength from the upstream nodes. If destination address matches the node address, the packet is received, and calculated its transmission latency. Otherwise, the packet will be added into the delay-line queue by the CHK module.

The CHK module is also responsible to fragment the transmitting packet to avoid collision by using the carrier preemption scheme. The simulations are processed under various parameters for the symmetric traffic. The symmetric traffic means that the arrival traffic of every node is equal, and their destinations are even to other nodes.

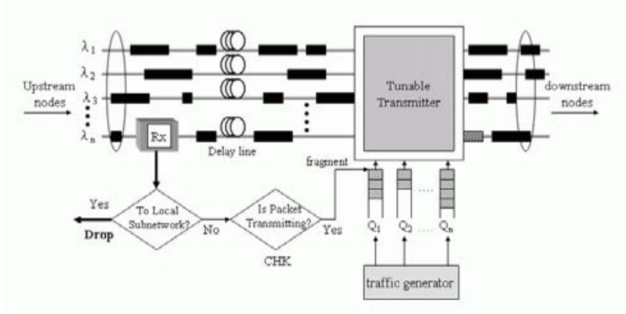

Fig 6. *Simulation Model of the access node*

The queuing-delay is defined as the average queuing time when the packet is generated to the transmit queue. Fig. 7 presents average queue delay against AN (Access Node) traffic offered load for various number of channels. The number of channels is larger; the average queuing-delay is more reduced. In the curve of four nodes share the same wavelength, the average queuing-delay just few microseconds before the node offered load reach to 95%. The best condition is the number of nodes equal to the number of channels. It is easy to reach for the rapid evolution of WDM technology. Table 1 shows the assumptions for the simulation parameters.

Number of nodes	20
Network length	100 km
Channel rate	OC-192 (10Gbps)
Size of the delay line	32 ns
Average IP packet size	512 bytes

Table 1. *Simulation parameters*

Fig.8 shows the network throughput against the access link load for each node in various numbers of channels. The curve of one node per wavelength shows the best performance. The maximum throughput for each node can reach to 95% access link load.

The packet fragmentation will cause overhead raised because the additional header consumes the optical bandwidth. For reducing the overhead, the minimum fragment should be decided. The length of delay-line should be long enough to cover the length of minimum fragment to avoid unnecessary fragmentation. Fig.9 shows the average queuing- delay against nodes offered traffic load for various delay-line length. The delay-line length can be treated as the minimum transmittable units. The less fragmentation is the longer delay-line length. However, the increased delay-line length will cause the longer average transmission delay. In figure 9, three MTU kinds (1, 2 and 3) are experimented, and their queuing-delay distinction does not obvious. Therefore, in order to reduce the transmission delay, the delay-line optimum length should be equal to the Ethernet MTU. In the 10Gbps per wavelength case, amount to 40 Bytes / 10G = 32 ns.

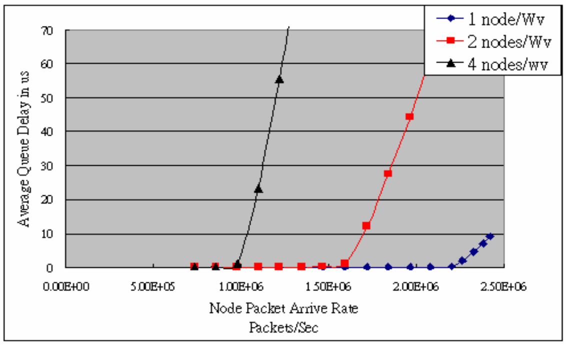

Figure 7. *Display the average queue delay against AN traffic offered load*

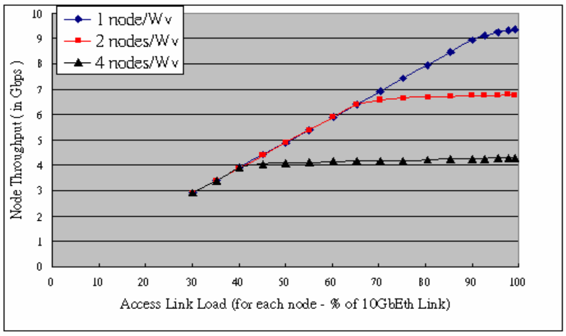

Figure 8. *Displays the node throughput against access link load*

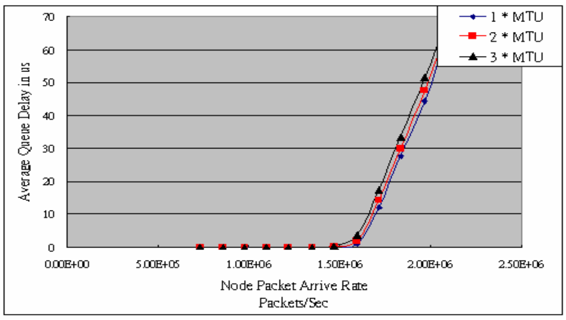

Figure 9. *Displays average queue delay against AN traffic offered load for various delay-line length.*

IV. Conclusion

This paper proposes a WDM-metropolitan ring network architecture that uses a CSAM/CP MAC protocol to efficiently support variable-length IP traffic, and without any O/E conversion. Under this protocol, the network can accommodate a variable number of nodes, and each node can operate independently. Hence, any new nodes can join the network at anytime. Simulation results show that the novel network has excellent performance: high throughput and low latency. In the future, we will improve the overall network efficiency more, and add QoS functionality such as multi-priority services in the selection strategy.

Acknowledgment

We would express thanks to the National Science Council (NSC) in Taiwan R.O.C. for supporting this project; The project number is NSC 90-2213-E-151 -014-.

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