All-Optical IP-over-DWDM MAN Ring Network with CSMA/CP MAC Protocol

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Abstract - *This paper proposes a Carrier Sense Multiple Access with Carrier Preemption (CSMA/CP) MAC protocol for the DWDM Metropolitan Area Network (MAN) Access ring networks. In the network, each node is equipped with one tunable transmitter and multiple fixed receivers. This protocol provides variable size IP packets directly over all-Optical DWDM MAN ring networks and gives the more efficient bandwidth utilization among nodes. Simulation results show the proposed MAC protocol getting the excellent performance.*

Keywords: IP-over-DWDM, MAN, All-optical, CSMA/CP, Ring Network.

I. Introduction

The explosive growth of new multimedia applications and services are driving the demand for bandwidth, it is growing at a rapid pace in the near future. Therefore, Dense Wavelength Division Multiplexing (DWDM) technology is developed to support tremendous bandwidth. Recently, the channel bandwidth of commercial DWDM communication systems has reached to OC-192 (10Gbps), and the total bandwidth of an optical fiber exceeds 20 Tbps. Because of the technical and economic feasibility, DWDM networks will become the Internet transport infrastructure in core and MANs.

In most of the existing backbone networks, SONET systems are used for transporting IP traffic. However, SONET network is designed to offer the circuit-switched service, it is suitable for Constant Bit Rate (CBR) date traffic, such as voice service. Hence, it is underutilized and inefficient bandwidth utilization for the burst data-traffic of MAN.

Hence, many researches are proposed to address and resolve the transport problems of SONET in MANs. For example, the Hybrid Optoelectronic Ring Network (HORNET) with CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) protocol for supporting the variable size IP-packets over DWDM was proposed by the Stanford University's Optical Communication Research Laboratory (OCRL) [1-3]. HORNET utilizes the optical-electronic (O/E) and electronic-optical (E/O) conversion to retransmit the passed packet into the network on the particular receive channel and employ jamming signally mechanism to handle the optical packet collision. The data/packets regeneration may minimize the number of erbium-doped fiber amplifiers (EDFA's) and reduce amplifier noise accumulation, however the O/E conversion may also constrain the transmission rate of the high speed DWDM backbone network.

This paper proposes a novel network with CSMA/CP (Carrier Sense Multiple Access with Carrier Preemption) protocol to transmit IP packets directly over the DWDM network instead of encapsulating them into SONET frames. It is a all-optical network that eliminates all O/E conversion. For achieving all-optical, the DWDM network is implemented by the Sub-Carrier Multiplexing (SCM) technique to mix the sub-carrier frequency multiplexed tones as packet headers and employ RF detection techniques to monitor the availability of wavelengths [1][4][10].

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 and compares the proposed architecture to the presented single fixed receiver architecture in open literature.

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 (ANs) and W data channels as show in Fig 1. Each access node is composed of two interfaces: the Gigabit Ethernet interface is used for transmission between the access nodes and the access networks; the Optical-Link interface is used to access the DWDM MAN ring in optical domain. Each node is also equipped with a

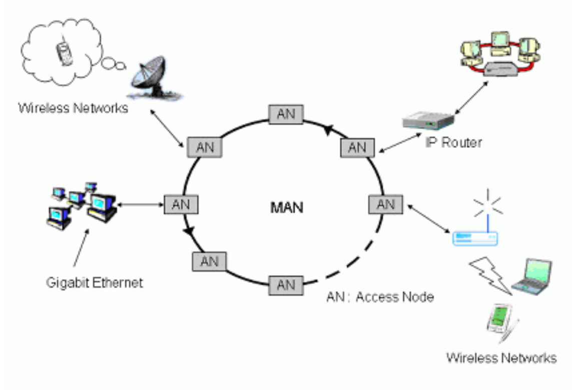

Fig 1. *Network architecture for MAN ring networks.*

tunable transmitter and multiple fixed receivers; each receiver takes case of a particular data channel which owns a unique specific wavelength. Nodes can simultaneously receive data from any wavelengths (or receivers). Channels can works independently without mutual interference to each other. Logically, the network can be treated as a multi-ring network.

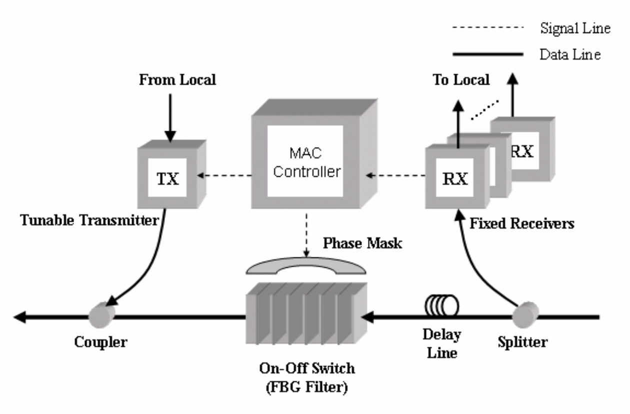

Fig 2. *Structure of Access Nodes*

The node structure 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 receivers 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 does match the node address. Meanwhile, the MAC control 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 multiple fixed receivers where each takes case of a data channel; hence the receivers may detect more than one available data channels at the same time. 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 access any wavelength and statistically shares the bandwidth of each data channel. A logical architecture is shown in the figure 3 for the case of four wavelengths and four nodes.

To avoid packet collision and efficiently govern the unprecedented bandwidth, this paper proposed a novel carrier preemption Medium Access Control (MAC) protocol that is based on carrier sense multiple access scheme. The carrier sensing

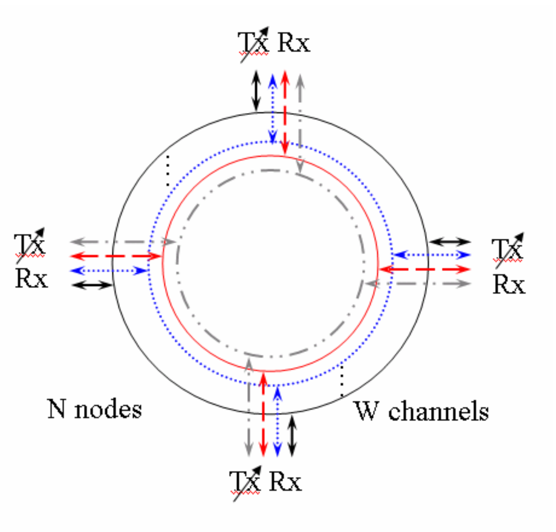

Fig 3. *Logical Architecture*

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 packets 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 that nodes do not have enough information to know whether the opening window is long enough to accommodate the packet.

In the carrier preemption scheme, a collided packet which transmission does not finish will be immediately fragmented into two parts: one should be transmitted and the other must still be in queue is shown in Fig 4. The transmitter can continually transmit the former when the arrival carrier passes into the delay-line. Until the carrier through delay-line after Ti nano-seconds, the transmitter just finishes the former transmission. For the fragment in queue, it will be transmitted later on the same channel or on other available channels.

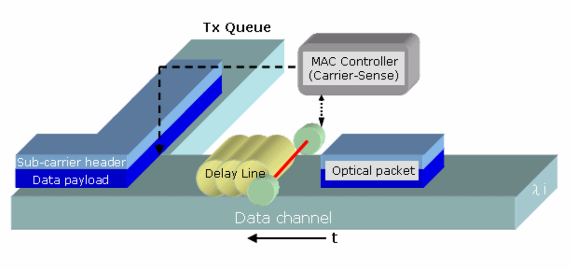

Fig 4. (a) *Carrier Sense (channel i)*

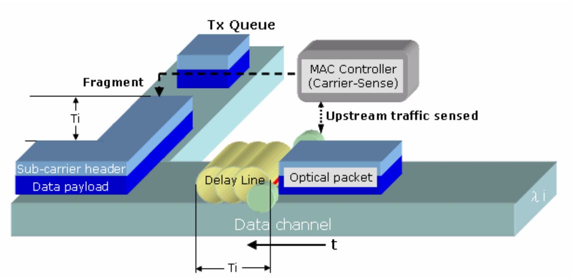

Fig 4. (b) *Carrier Preemption (channel i)*

To support the carrier preemption scheme, the frame format is designed as shown in Fig. 5. It is adopted as the solution of the addressing capabilities and fragmentation mechanisms [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) field record address information in the network. The sequence number (SN) expresses 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 define different service class for the data payload. Fig. 6 shows how the packet is fragmented into two parts if packet collision happened. Each packet must append frame header either being transmitted or being fragmented.

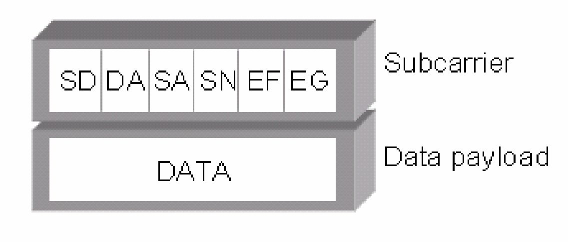

Fig 5.*The frame format*

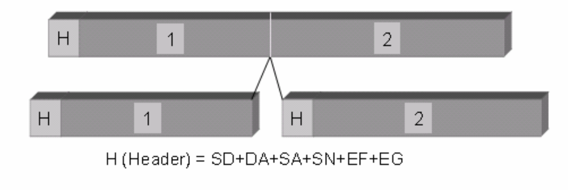

Fig 6. *The data frame fragmentation*

III. Simulation and Results

This study adopts the SIMSCRIPT language to implement the simulation programs. Fig. 7 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.

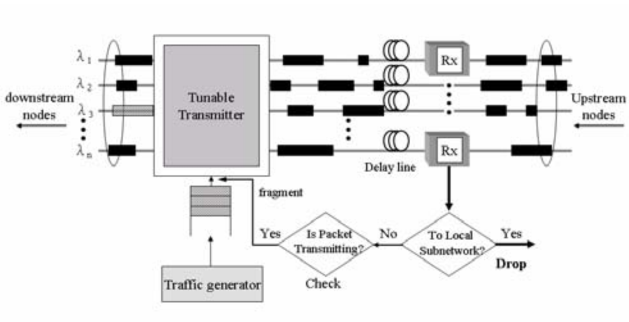

Fig 7. *Simulation Model of the access node*

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. The transmission-delay is measured from the time the packet is completely stored in the transmit buffer of a source node to the time the packet is completely received by the receive buffer of a destination node.

To evaluate the performance of the DWDM ring network, the assumption for the simulation parameters have shown in Table 1.

Table 1 *Network Parameters*

Number of nodes	16
Number of channels	1, 2, 4, 8
Ring distance	50 km
Channel speed	OC-192 (10Gbps)
Size of the delay line	80 ns
Average IP packet size	512 bytes

Figure 8 shows the relation of the average transfer delay versus the number of packets per node in a 10Gbps DWDM ring with various numbers of channels. Under the steady state network condition, the higher the number of channels in the DWDM ring obtains the higher the node throughput. The means the throughput characteristic of the network depends on the aggregated transmission capacity of the network. We also compare the single receiver case of this network, as the number of channels increased the difference of performance is increased.

In constant total bandwidth case, the average transfer delay will be small changed between the networks with various channels as shown in Fig 9: eight-channel of 1.25 Gbps DWDM ring, four-channel of 2.5 Gbps DWDM ring and single-channel of 10Gbps DWDM ring. The reason

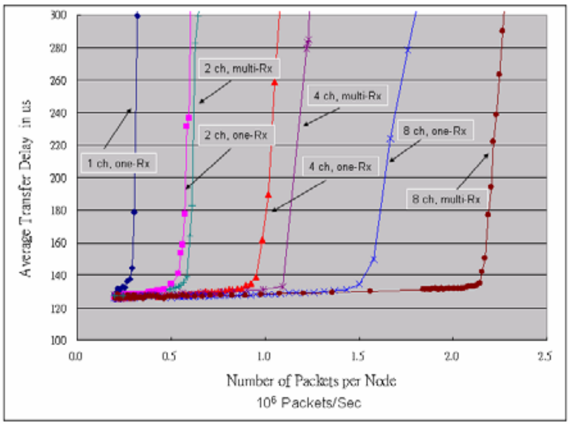

Fig 8. *Average transfer delay for various the number of channels*

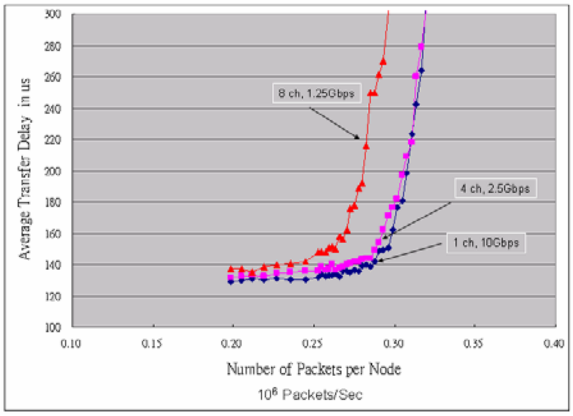

Fig 9. *Average transfer delay for various channel speeds and the number of channels*

of the difference in the node latency is each node only has a tunable transmitter. In single channel case, the transmitter only transmits optical packet in fixed channel without any tuning operation. However, in multiple channel case the tunable transmitter has to be tuned to other channel and use the random selection policy to choose the available channel. The tuning time and the selection times will increase the additional transfer delay.

IV. Conclusions

This paper proposes a novel MAC protocol for all optical DWDM ring networks. The protocol supports the transmission of IP packets directly over DWDM networks. Meanwhile, this novel network architecture accommodates an arbitrarily number of nodes and each node can operate independently. Simulation results show the excellent characteristics of high throughput and low latency in the way of all optical communication.

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