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A Multi-Priority MAC Protocol for WDM Multi-Channel Slotted Ring Networks

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ABSTRACT

This study presents a high performance multiple priority protocol for WDM Multi-channel slotted Ring networks. In the slot ring networks, each node is assumed to have one tunable transmitter and one fixed receiver for data channels, and be able to inspect statuses of slots on all channels. The multiple priority protocol is proposed for transmitting different priority packets on the networks. The protocol modified the header format of slots, which defines the priorities of slots on ring networks and limits which of packets can be transmitted on slots. By cooperating with an appropriate designation method, the capability of transmitting multiple priority packets can be achieved. In the paper, we present a simple designation method to assign the priority of slots. It bases on two thresholds to raise and lower the priority of slots.

Simulation results demonstrate that the packet delay of high priority packets is sure to be smaller than that of low priority packets on multi-channel slotted ring networks with the multiple priority protocol. Moreover, the multiple priority protocol still achieves near optimal channel utilization under balanced traffic load.

KEYWORDS: Wavelength Division Multiplexing (WDM), Slotted Ring, Multi-MetaRing (MMR), Multiple Priority

1. Introduction

In optical networks, Wavelength Division Multiplexing (WDM) [1-2] technology provides one means to utilize the huge potential bandwidth of fiber. WDM is generally used to divide the huge bandwidth of fiber into a number of channels whose rates match the speeds of the electronic interface. Clearly, a network explored by the WDM technology is logically a multiple channel network.

Because of the huge bandwidth of the WDM technology, many papers based on the technology propose new transmission protocols on different topologies, such as ring, star, tree and mesh. Among these topologies, star and tree topologies are usually utilized in local area network (LAN) and access networks. In addition, ring and mesh topologies are used in access networks and metropolitan area networks (MAN). This paper focuses on the ring topology and tries to propose a multiple priority protocol on multi-channel slotted ring networks [3-4].

Nowadays, since Internet is in widespread use, the types of network applications are diversity. A noticeable application is the transmission of multimedia or real-time data, such as video, voice data. In order to let the transmission of real-time data satisfy its deadline, the transmission priority of real-time data must be higher than the priority of non real-time data. Due to the real-time property of multimedia data, the transmission protocols without differentiating between data streams according to their priorities or reserving bandwidth for real-time data are not suitable for transmitting real-time data. In order to provide multi-priority transmission, many multiple priority or reserving bandwidth protocols are proposed for traditional protocols, such as [5-7].

This paper attempts to propose a packet priority protocol for multi-channel slotted ring networks which can be implemented by the WDM technology. In the network, there is one tunable transmitter and one fixed receiver for all data channels at each node. The transmitter can be tuned to any data channel, and then provide the full connectivity of the network. Besides, each node is assumed that it can inspect the header information of slots in all channels. Herein, the header information of slots in each channel can be carried by a different sub-channel implemented by the subcarrier multiplexed (SCM) [8] technology. Alternatively, control packets of one lower-speed data channel can be used to carry the header information of slots in all channels. This proposed protocol provides the priority transmission by means of providing more information in the header of slots.

The rest of this paper is organized as follows. Section 2 outlines the network topology, the multiple priority transmission protocol. This section also explains the header format of slots and the fairness mechanism used in the network. Section 3 then describes the usage of the multiple priority function on the network. Following this, section 4 carries out simulations to evaluate the performance of the network. The final section presents conclusions.

2. The multi-channel slotted ring network

2.1 Network topology

Assume that a WDM slotted ring network is composed of M nodes and W+1 channels. Figure 1 depicts an example of the multi-channel slotted ring network with M=W=4 and one additional control channel. Herein, we assume that the header of slots of all channels is carried on slots of the control channel. The W channels are the data channels used to transmit data packets, while the control channel transmits control packets. Every control packet carries the header of slots of all channels within a slot time. Regardless of normal channels or the control channel, there are a constant number of fixed length slots that synchronously and circularly flow in one direction. Assume that a packet exactly fits into the payload of a slot in all channels. Furthermore, the header of a slot and the slot itself can be transmitted at the same slot time. Or the header can be transmitted before several slot times of the slot in order to have enough time to tune the tunable transmitter. Herein, we assume that the header of a slot is transmitted at the same slot time with the slot.

In the network, a node has one TT-FR transceiver to transmit and receive data packets and is assigned a particular channel through which packets are received. For the control channel, a node is equipped with one additional fixed transmitter and receiver (FT-FR) to transmit and receive control packets. While the network supports k priorities, every node owns k queues corresponding to one transmittable channel. Every queue stores packets with the same priority and processes packets in a First In First Out (FIFO) order for a channel. At every slot time, each node designates a queue to transmit the head packet of the queue. To transmit a packet, a node tunes its transmitter to the receiving channel of the destination node. The transmitted packet is sent along the ring and waits until the destination node extracts it. When a node tries to send a packet, it must defer the transmission whenever another packet appears in the same channel at the same slot time.

2.2 Transmission Protocol

Figure 2 presents the basic format of a control packet. The packet consists of a preamble field, a checksum field and a number of Channel-Reservation Elements (CRE). The preamble field is used to represent the beginning of a control packet, and the checksum field is used to verify packet accuracy. The number of CREs equals the number of data channels. Basically, a CRE consists of a Channel Number field (CN), a Reservation Bit (RB), a Destination Address (DA) and a Priority Value (PV) as figure 2 shows. The CN is an identifier used to indicate the channel to which the CRE relates. Each CRE stores the header information of the slot of the corresponding data channel at the same slot time. Meanwhile, the RB serves to identify whether the related slot is reserved or not. The DA stores the destination address of the packet transmitted at the slot. Finally, the PV defined the transmission priority of the slot. The transmission priority of a slot is the smallest priority of packets that can be carries by the slot. The usage of the PV fields will be described in detail in the next sub-section and section 3.

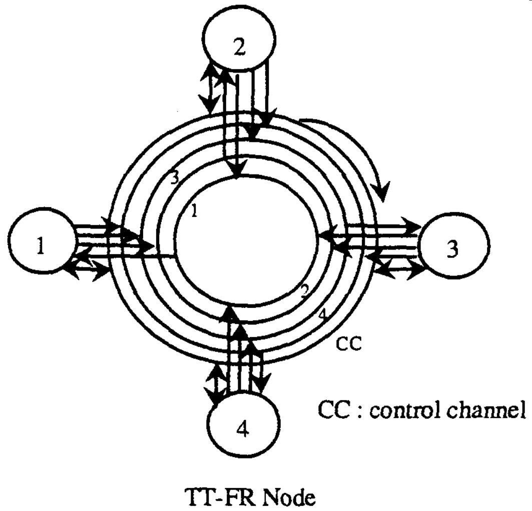

Figure 1. *The network topology of the Multi-Channel Slotted Ring Network with W=M=4.*

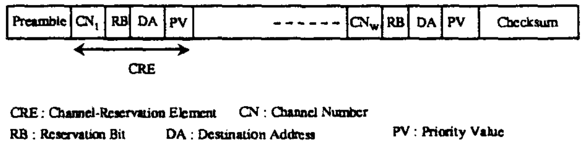

Figure 2. *The Format of Control Packets.*

Initially, the RBs of all CREs are set to false which indicates that the slots of all corresponding channels are not busy. Retrieving a control packet from the control channel, a node can ascertain the status of channels by checking the RBs of all CREs. Because there is only one transmitter for transmitting data packets at each node, it can only exploit a channel at most at one slot time. Basing on the discovered header information and the queue status, each node executes a selection strategy to select a channel to reserve. The evaluated selection strategy is described fully later. When a node designates a destination channel, it sets the RB of the corresponding CRE to true and enters the destination of the transmitted packet into the DA field. Herein, all data queues on the node are assumed to be FIFO queues and the transmitted packet is the head of the selected queue. If the node selects a free channel, the node will transmit its packet via the channel after the processing and tuning delay. Because all nodes in the network inspect all control packets on the control channel, the transmission collision can be avoided. Because a node receives a control packet from the control channel at every slot time, it always checks the corresponding CRE of its assigned channel to ascertain whether the DA of the CRE matches its own address or not. If the node is the destination of an incoming data packet from the assigned channel, it sets the RB of the corresponding CRE to false and will receive and remove the packet from its assigned channel.

Although nodes can preview the status of all slots, the unfairness problem is still existent in the networks. In order to avoid the starvation of low priority nodes in an overloaded channel, this paper adopts the Multi-MetaRing mechanism [5] as the fairness mechanism. In this paper, we will not describe the mechanism on the networks in detail. Readers can refer to the paper [5] for more information.

2.3 The Selection Strategy

In this paper, we use the strategy, named the longest queue first selection with virtual packet (LQFS-VP), as the selection strategy because it provides the high network throughput. A strategy determines the target queue from among the available queues. The available queues are those queues which are nonempty and whose corresponding channels are free.

To implement the LQFS selection strategy, every node needs to check all internal queues and statuses of all channels at every slot time, and then select its target queue. First, nodes find available queues with priorities equal to or higher than those of slots at the corresponding channels of these queues according to values of PV fields in CREs. Then, nodes discover these queues with the longest queue length from among these available queues. If there is only one queue, the queue is the target. Otherwise, if there is more than one queue with the longest queue length, nodes randomly select one queue from among them. When a node decides its target queue, it sets the RB of its target channel related to the selected queue to true in order to transmit the head packet of the queue on the channel.

Because the LQFS strategy always prioritizes the packets of the longest queues, certain queues may be starved in some conditions. For example, one queue may have very few packets inside itself while all the other queues are heavily loaded in one node. Under the LQFS strategy, the transmission probability of the packet in the light load queue would tend to be very low. It means that the packet in the queue will never be transmitted until the starvation is over. To avoid starvation, a new scheme, the Virtual Packet scheme, is added into the LQFS strategy.
Note that a virtual packet is not a real packet. It cannot be transmitted and is added to the queues to extend them. Additionally, every node has one counter, called the slot counter, for each queue. When a node transmits a packet, the slot counters of all queues inside the node are increased by one, except for the queue whose packet is transmitted. If one packet leaves from a queue, the slot counter of the queue is reset to zero. When the value of the slot counter of a queue is equal to the number of queues in a node, the node generates a virtual packet for the queue and resets the slot counter to zero. With this scheme, queues with fewer packets have an opportunity to transmit their packets after a while. After transmitting a packet from a queue, the virtual packets between the transmitted packet and the next real packet are removed from the queue. The LQFS strategy combined with the Virtual Packet scheme is called the LQFS-VP strategy.

3. The Multiple Priority Protocol

This paper assumes that there are k priorities, 0...k-1, supported in the network. Zero is the least priority and k-1 is the highest priority. Therefore, each node has k queues for one channel and totally has $W \times k$ queues. From the transmission protocol section, it can be found that nodes depend on the PV fields of control packets to select their queue at every slot time. In order to set PV fields of CREs in every control packet, in this paper, a simple designation method of priorities of slots is presented. In this method, nodes will check the inter-transmitting interval between neighboring packets of every priority queues. The inter-transmitting interval of a packet is defined as the interval from the transmission moment of its last packet to the event of transmitting the packet itself. Every node has two thresholds of inter-transmitting time for every priority queues as the criterion of raising and lowering priority values of slots. The two thresholds are a high threshold (HT) and a low threshold (LT), $HT \geq LT$.

As a node transmits the head packet of a priority queue, it will calculate the inter-transmitting interval of the queue again. If the interval of a queue is larger than its HT, after the transmission slot time, the node will seek a CRE of the corresponding channel the value of whose PV field is lower than the priority of the queue. If the CRE exists, the node will push the current value of the PV field of the CRE into its priority value stack and set the field into the priority of the queue. On the contrary, if the interval of a queue is smaller than its LT, the node will seek a CRE of the corresponding channel the value of whose PV filed is same as the priority of the queue. If the CRE exists, the node will pop a value from the priority value stack and set the PV field of the CRE into the popped value.

In order to avoid setting consecutively priorities of slots on the same channel and the inter-transmitting interval of packets varies severely, for a channel, nodes check again the inter-transmitting interval of packets for a queue only after setting the priority of a slot on the corresponding channel of the queue.

4. Simulation Results

This study adopts the SIMSCRIPT language to implement the simulation program. The simulation obtained the throughput and delay results of the multi-priority protocol under balanced traffic. Balanced traffic means that the incoming traffic of every node is equal and the outgoing traffic from a node is distributed equally to other nodes. Here, the packet delay is defined as the interval between the moment that the last bit of a packet is received and the event that generated the packet. Table 1 shows the assumptions for the simulation parameters. In the table, the buffer size per queue is the maximum length of queues that stores the real packets and virtual packets in the LQFS-VP selection strategy. Because there are only two priorities, the high priority and the low priority, in the simulation, merely high priority queues own the HT and the LT. This simulation maintains one extra channel as the control channel. The bandwidth of the extra channel is not considered as the network bandwidth when the average channel throughput is computed.

Table 1. *The simulation model.*

Number of Nodes	16
Number of Channels	16
Propagation Delay Between Neighboring Nodes	1 slot time
Traffic Distribution	Poisson
Priority Levels	2
Node Architecture	TT-FR
Buffer Size Per Queue	3000 packets
Simulation Time	200000 slot times

Figure 3 displays the throughput of multi-channel slotted ring networks with the multi-priority protocol and without the protocol under different conditions of threshold values for high priority queues. These conditions for the networks with the priority protocol include 1) HT=5, LT=2, 2) HT=10, LT=5 and 3) HT=15, LT=5. Another assumption is that the traffic load of high priority packets is four tenth of the total traffic load. The figure shows that the multi-priority protocol lowers the network throughput little because the protocol makes slots not carry low priority packets. Another phenomenon is that the smaller the threshold values, the lower the network throughput because the smaller the threshold values, the more slots that can not be utilized by low priority packets.

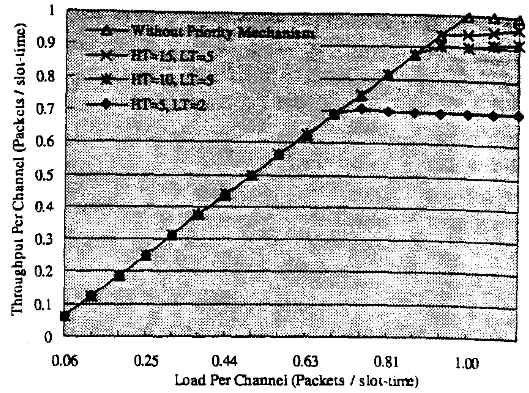

Figure 3. *Throughput of multi-channel slotted ring networks with the multi-priority protocol and without the protocol.*

Figure 4 presents the average packet delay of high priority packets of the network under the same simulative conditions in figure 3. In addition, figure 5 shows the average packet delay of low priority packets. These figures show that with the priority protocol high priority packets still hold low packet delay even though the total traffic load is over the bandwidth of the network when the traffic load of high priority packets on a channel is lower than the bandwidth of the channel. However, due to the limitations of priorities of slots, the lower the threshold values, the longer packet delay of low priority packets in the network.

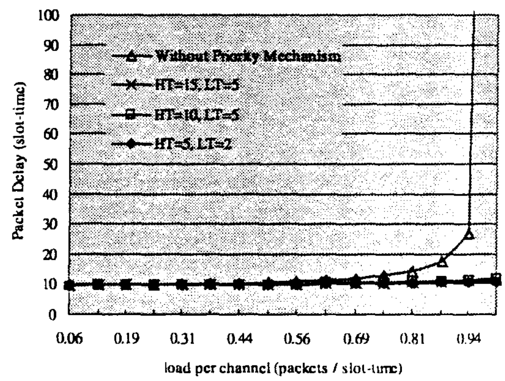

Figure 4. *Average packet delay of high priority packets of the network with the multi-priority protocol and without the protocol.*

Figure 6 presents the packet delay of high priority packets under different threshold values versus the proportion of traffic load of high priority packets to the total traffic load. The simulative traffic load is 100%, that is, sixteen packets per slots. The figure shows that the packet delay of different conditions is similar when the proportion is 20% and 40%. However, when the proportion grows, the packet delay of high priority packets under the condition of low threshold values is smaller than that under the condition of high threshold values. Therefore, from the results shown in the figures, some conclusions can be obtained. First, in order to gain higher network throughput and lower packet delay of low priority packets, the threshold values should be set to larger value when the proportion of traffic load of higher priority packets is small. Second, it is worthless that the HT and LT are set to too small because the packet delay of high priority packets will never be lower than HT. In addition, it also leads too much slots to be set to high priority when threshold values is so small under heavy traffic load.

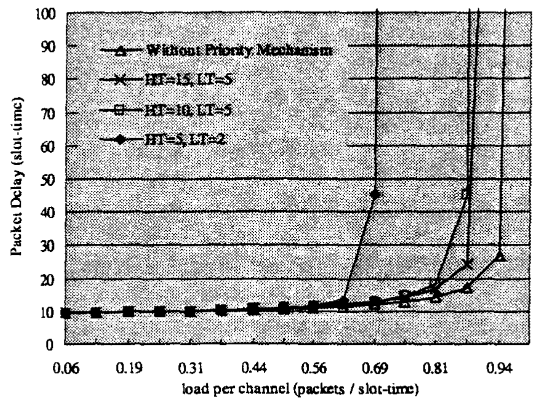

Figure 5. *Average packet delay of low priority packets of the network with the multi-priority protocol and without the protocol*

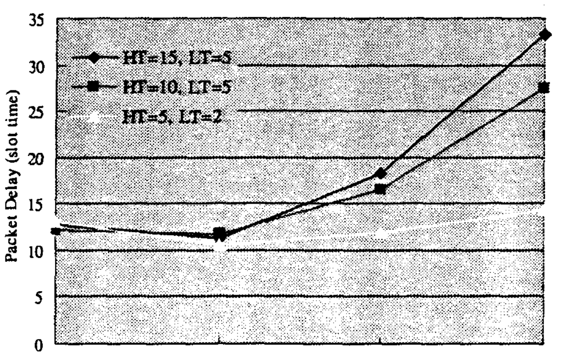

Figure 6. *Packet delay of high priority packets under different threshold values versus the proportion of traffic load of high priority packets to the total traffic load.*

5. Conclusions

This study proposes a multiple priority protocol for multi-channel slotted ring networks that is simple to implement and only sacrifice little throughput. The protocol provides the multiple priority capability for the network by modifying the format of control packets of the basic protocol. In the protocol, we propose a simple designation method using two thresholds. By assigning proper values to thresholds, the aims of high network throughput and low packet delay of high priority packets can be achieved.

Simulation results reveal that the multiple priority protocol still gain the high network throughput when the packet delay of high priority traffic is largely unaffected by low priority traffic, even when total traffic load is grown to overload conditions. The results in this paper show that the multiple priority protocol is suitable for transmitting multimedia and real-time data.

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