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High Performance Transmission Protocols for WDM Multi-Channel Slotted Rin Networks

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Abstract

This study evaluates a high performance transmission protocol for WDM multi-channel slotted ring networks. The evaluated protocol can utilize the bandwidth of networks efficiently and reduces the implementation complexities that constrain other related protocols such as SRR [3]. The protocol allows every node to inspect the usage statuses of all channels. According to these statuses, a node can select an appropriate channel for transmitting packets from among the free channels through appropriate selection schemes. The evaluated network architecture is similar to HORNET [5]. This study also proposes and evaluates two selection schemes. In addition, to resolve the fairness problem frequently encountered in ring-type networks, a fairness mechanism based on the Multi-MetaRing protocol is used to provide fair access to the network between nodes.

Simulation results demonstrate that the evaluate protocol with the proposed selection scheme can achieve nearly optimal channel utilization under balanced traffic. Moreover, the incorporation of the fairness mechanism also reveals excellent throughputs.

1. Introduction

In optical networks, Wavelength Division Multiplexing (WDM) [1-2] provides one means to utilize the huge potential bandwidth of fibers. It is generally used to divide the huge bandwidth of fibers into a number of channels whose rates match the speeds of electronic interfaces. A network exploiting the WDM technology constitutes logically a multi-channel netwo k.

The WDM networks with a slotted ring topology o simply the WDM slotted rings have simpler network architectures and communication devices [3 -4]. The widely proposed transmission and reception devices in nodes of WDM slotted rings are composed of one tunable transmitter and one fixed receiver (TT -FR), or one fixed transmitter and one tunable receiver (FT -TR). With TT-FR, every node is assigned a fixed channel to receive packets. A transmission node tunes its transmitter to the assigned channel of the de stination and attempts to transmit its packets. The packets in optical carriers propagate opaquely through the ring until the receiver of a destination node extracts it. With FT-TR, every node is assigned a channel to transmit its packets. A destination node extracts packets from the assigned channel of the source node via the tunable receiver.

All optical transmission in WDM multi-channel rings is almost opaque. That is, a node in the rings is nearly blind to catch the network bandwidth. Without access synchronization mechanisms, collisions of packet transmissions may occur frequently, which wastes network bandwidth a lot. To utilize th bandwidth of the rings efficientl , it becomes a big issue. This study evaluates a high performance transmission protocol in which many sub-channels or one dedicated control channel are used to convey the information about the status of slots on the rings and enhance the transparency of bandwidth sharing among nodes. This capability makes all nodes detect the slot usage statuses of all channels and select one from among the transmittable channels according to the slot status. The protocol is not only suitable to the networks based on the TT -FR node structure, but also to the networks based on the FT-TR node structure. Besides, it can operate in all networks regardless of propagation delay. With the inspection capability, this study proposes two different selection schemes as transmission schemes, namely the Random Selection scheme (RS) and the Long-Queue-First-Selection scheme (LQFS), to determine the target destination. The LQFS scheme is incorporated with the Virtual Packet method to avoid starving the queue with low arrival rate.

This investigation describes the protocol of the network with the TT-FR node structure. The rest of this paper is organized as follows. Section 2 outlines the network model and the transmission protocol. Section 3 presents the selection schemes. Following this, section 4 carries out some simulations to evaluate the performance of the network. The final section presents some conclusions.

2. Transmission protocol

Assume that a WDM slotted ring is composed of M nodes and W channels. Figure 1 depicts an example of the multi-channel slotted ring with M=W=4 and one control channel. Herein, packets in the control channel carry the header information of slots in all channels. Alternatively, a different sub-channel implemented by the subcarrier multiplexed (SCM) [6] technology can also carry the header information of slots in each channel. Henceforth, we assume the control channel is used. The W channels are the data channels used to transmit data, while the control channel transmits control packets that are used to coordinate the transmission of all nodes in the network. There are a constant number of fixed l ength slots that synchronously and circularly flows in one direction, regardless of the data or control channels. Assume that a packet can exactly fit into the payload of a slot. For the control channel, control packets send the slot statuses to all nodes in the network. These statuses include whether slots are free and the destination of packets on slots if slots are busy. To avoid the possible collisions on channels, the transmission of data packets must be determined according to these statuses in control packets.

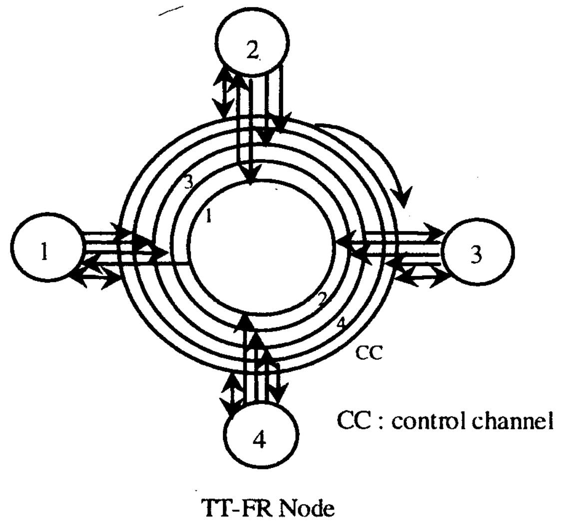

Figure 1. The network topology of the Multi-Channel Slotted Rings with W=M=4.

In the network, every node has one TT-FR transceive for transmitting and receiving data packets and owns an internal queue corresponding to eac data channel. Because the receiver in each node is set to a fixed wavelength, each data channel is designated to a fixed destination node. Therefore, when a packet is generated in a node for one destination, it is entered into a queue corresponding to that destination.

At every slot time, each destination node checks its assigned channel and the statuses stored in control packets of the control channel. If nodes find the packets in the slots of their assigned channel destined for themselves, they receive and remove the packets from the slots. If not they bypassed these slots. In addition, after checking incoming slots and receiving their packets, nodes check all channels on which slots are empty and then selects a queue according to their selection schemes introduced in the following section and then tunes its transmitter to the designated channel corresponding to the queue for transmitting their head packet. The transmitted packets are sent along the ring and wait until the destination nodes extract it.

Although nodes can inspect statuses of slots in all channels, 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 (MMR) mechanism [3] as the fairness mechanism. In this paper, we will not describe the mechanism on the networks in detail. Readers can refer to the paper [3] for more information.

3. Selection schemes

The simplest scheme for channel selections is to randomly select a target queue from availabl e queues. This scheme is called the random selection scheme (RS). The available queues are those internal queues in nodes which are nonempty and whose corresponding channels are empty. At any slot time, a node checks the slot statuses of all channels and all internal queues inside itself according to the incoming control packet. Subsequently, the node finds out a set of non-empty queues with their corresponding channels having available slot at this slot time, and then randomly selects a queue from the set. The major advantage of RS is its simpler operations. However, this simplicity may lower the throughput of multi-channel ring networks. With the RS scheme, a node cannot obtain the best selection without affecting the transmission of other nodes. That is to say, it may select the channel that is necessary for its downstream nodes. Therefore, using the RS scheme cannot utilize the network bandwidth completely.

To increase network throughputs, another selection scheme, namely the longest queue first selection (LQFS) scheme, is considered. Under balanced traffic conditions, the longest queue of nodes is always the queue with the lowest priority in the network. By prioritizing the longest queue, the network throughput can be improved because empty slots can be used as much as possible before they are wasted. Under unbalanced traffic, the longest queue of nodes should be the queue corresponding to the channel with the highest load. By prioritizing the longest queue, the highest load channel can be used as much a possible and then lower the packet delay of packets on the channel. Therefore, by selecting the longest queue, the network performance can be improved. To implement this scheme, every node needs to check all internal queues at every slot time and search the longest qùeue whose corresponding channel is not reserved. If there is more than one longest queue, the node needs to randomly select one queue.

Since the LQFS scheme always prioritizes the longest queue in every packet transmission in a node, other queues may starve in some situations. For example, suppose a queue is lightly loaded while all the other queues are heavily loaded in one node. With LQFS, the transmission probability of the head packet in the lightly loaded queue would tend to be very low. It means that the packet will never be transmitted until this lightly loaded queue becomes the longest queue at last. To avoid this starvation, an additional method, the Virtual Packet (VP) method, is combined with the LQFS scheme.

The LQFS scheme combined with VP is abbreviated to LQFS-VP. In LQFS-VP, some virtual packets are added into those lightly loaded queues to avoid the possible starvation conditions. Note that virtual packets are not real packets. They are not transmitted and only added to the lightly loaded queues to extend their queue length. Additionally, a counter, called the slot counter, is associated with each internal queue in a node. It is used to count the number of successfully transmitted packets from the corresponding internal queue in a node after last reset. When a node transmits a packet, the slot counters of all nonempty queues inside the node are increased by one, except for the queue that transmits the packet. If a packet is transmitted from a queue, the slot counter of the queue is reset to zero. When the value of the slot counter of a queue reaches to the number of queues (i.e., a threshold) in a node, the node generates a virtual packet for the queue and resets the slot counter to zero. With this scheme, lightly loaded queues can extend their queue length gradually, and then obtain an opportunity to transmit packets. After transmitting a packet from a lightly loaded queue, the virtual packets between the transmitted packet and the next real packet are removed from the queue.

4. Simulation Results

This stud uses the SIMSCRIPT language to implement the simulation program. The simulation obtained the throughput and delay results of the network under a balanced traffic condition. This condition indicates that the incoming traffic of e very node is equal to the outgoing traffic 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 fo 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 scheme. In the simulation, the length of every real packet and virtual packet is same and fixed. Herein, the out-of-band control channel or subchannels are not considered when computing the network throughput.

Figure 2 displays the throughputs of the network without the MMR protocol versus the traffic load per channel under the balanced traffic load. The figure compares the throughputs of three different transmission protocols, namely, the random transmission protocol (RND) [3], the evaluated transmission protocol with the RS scheme, and with the LQFS-VP scheme. The RND protocol is the simplest MA protocol for multi-channel slotted ring networks in which every node randomly selects its target queue from the nonempty queues. Under the normalized traffic load of every channel being 1.0, the throughput per channel for RND, the evaluated protocol with RS and with LQFS-VP approach 0.66, 0.93 and 0.99 separately. Obviously, the evaluated transmission protocol wit LQFS-VP obtains the best network throughput.

Table 1. The simulation model.

Number of Nodes	16
Number of Channels	16
Propagation Delay Between Neighboring Nodes	1 slot time
Packet Length	1 slot
Traffic Distribution	Poisson
Node Architecture	TT-FR
Buffer Size Per Queue	5000 packets
Simulation Time	1000000 slot times

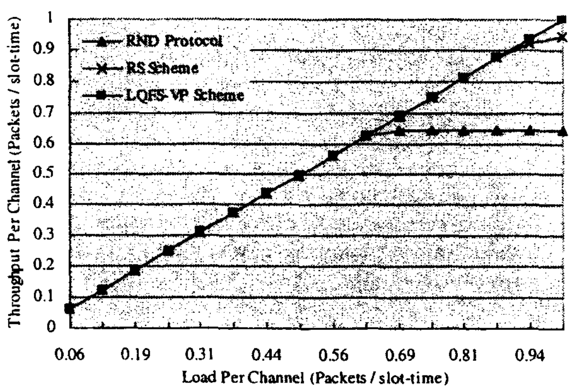

Figure 2. The channel throughput versus the traffic load per channel under balanced traffic for different protocols.

Figure 3 presents the average packet delay of the network under a balanced traffic load. Under heavy loads, the packet delay of the evaluated protocol is smaller than the RND protocol. This is because the ins pection capability delays the network saturation point. Also, it shows that the evaluated protocol with LQFS-VP also performs better than that with RS in packet dela s.

Table 2 displays the throughputs of different protocols under an overload condition, namely a total network load of sixteen packets per slot time. Each item in the table represents the throughput of a channe for these protocols. The table lists the throughput results when the number of channels equals sixteen, eight, four, and two. From the table, the evaluated protocol improves the throughput much more than RND as the number of channels increases. However, for two channels, the evaluated improves slightly the throughput. This phenomenon is due to the slot-reuse property that increases the throughput for RND when there are few channels. With sixteen channels in this case or with one node assigned a n individual assigned channel, the slot-reuse property does not affect the throughput because no another node shares the bandwidth of the receiving channel of each node.

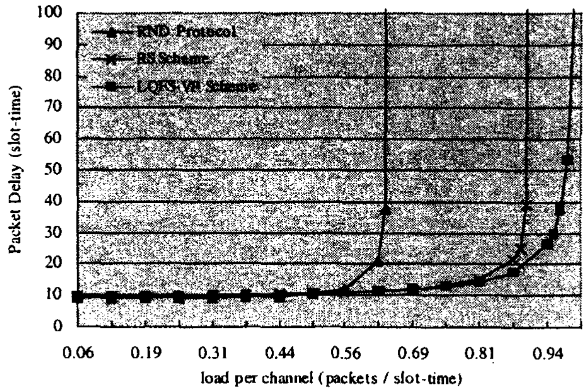

Figure 3. The average packet delay of the network under balanced traffic load for different protocols.

Table 2. The channel throughput in balanced traffic for different protocols, while the number of nodes is 16.

Protocol / Channel No.	RND Protocol	RS Scheme	LQFS-VP Scheme
16	0.644	0.944	0.99
8	1.002	1.32	1.364
4	1.408	1.637	1.667
2	1.76	1.87	1.88

Table 3 summarizes the channel throughput of the proposed selection schemes with and without MMR under an overload condition. Herein, the quota used in MMR is assumed to be one thousand. From this table, the fairness mechanism slightly reduces the channel throughput. This is because the transmission of fairness control messages occupies a little channel utilization.

Table 3. The channel throughput in balanced traffic for proposed protocols with and without the MMR mechanism with network load of sixteen packets per slot time.

Protocol / Channel No.	RS Scheme	RS Scheme with MM	LQFS-VP	LQFS-VP Scheme with MM
16	0.94	0.93	0.99	0.99
8	1.32	1.29	1.36	1.36
4	1.64	1.63	1.67	1.66
2	1.87	1.86	1.88	1.87

5. Conclusions

This study evaluates a high performance transmission protocol with two selection schemes that show very good network throughput. The protocol is based on the WDM slotted ring networks in which every node can inspect slot statuses of all channels. Because of the inspection capability, a node can determine the destination channel in advance, improving the network utilization significantly. Notably, it has been show that the evaluated protocol with the proposed selection scheme, LQFS-VP, provides a nearly optimal throughput. Additionally, this study adopted the fairness mechanism, Multi-MetaRing, with the proposed protocol to provide transmission fairness between nodes.

Simulation results revealed that the network throughput is improved with the proposed protocol. Moreover, the averaged packet delay is also reduced. The simulation results showed that the protocol with the proposed selection scheme achieves very high network.

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