ISCOM 99

ISCOM'99

1999 International Symposium on Communications
November 7-10, 1999
Grand 50 Convention & Exhibition Center, Kaohsiung, Taiwan

Proceedings of the 1999 International Symposium on Communications

November 7 – 10, 1999

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CPMR : A Carrier-Preview Protocol For Multi-Channel Slotted Ring Network

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[Abstract]

In this paper, a Carrier-Preview protocol for Multichannel slotted Ring network with TT-FR or FT-TR transceiver (CPMR) is proposed. In the protocol, the carrier-preview function is achieved by a bandwidth-reserved protocol. In the network, all nodes are equipped with one TT-FR transceiver (one tunable-wavelength transmitter and one fixed receivers), or one FT-TR transceiver (one fixed transmitter and one tunable receiver) for all data channels. There is a control channel used in the network to transmit the slot-reservation information to all nodes. By this control channel, all nodes can detect the transmission status on all channels in next slot-time and let the network equips the carrier-preview function. In this protocol, we use the Multi-MetaRing as the fairness mechanism to provide the fair bandwidth-utilization between nodes. In the paper, there are simulation results to evaluate the performance of the network.

Keywords: WDM, Slotted Ring, CPMR, Multi-MetaRing (MMR), Multiple Subcarrier Signaling (MSS)

1. Introduction

Recently, the development of network communication is so rapidly and the bandwidth provided by ISP (Internet Service Providers) also grows quickly. However, the bandwidth requirement is already more than the growth. Recent years, the Wavelength Division Multiplexing (WDM) [1] technology is explored and makes the huge bandwidth of fiber being exploited. WDM is normally used to divide the huge bandwidth of fiber into a number of channels whose rates match the speeds of electronic interface. The technology provides a solution to achieve the bandwidth requirement.

The WDM network with slotted ring topology, called WDM slotted ring networks, has the simpler architecture and transmission device, and the slot-reused property among these protocols exploited WDM technology. These advantages make it a nice method utilizing bandwidth. The most proposed node architecture is one tunable transmitter and one fixed receiver (TT-FR), or one fixed transmitter and one tunable receiver (FT-TR). These simplest transmission protocols are to randomly select one channel or one destination to transmit cells. [3][4] But these protocols cannot efficiently utilize the network bandwidth because nodes can not sense all carriers in channels until they selects their target channels or destinations. In this paper, we attempt to propose a Carrier-Preview protocol for Multi-channel slotted Ring network (CPMR) to provide all nodes to sense the transmission status of all channels before they select their targets.

In the protocol, we utilize a control channel to transmit the transmission status of all channels to all nodes. By this information, all nodes can detect which channels can be used to transmit its cells and select one available channel to transmit. In the network, the slot-reused property also makes the unfairness between nodes, there are many fairness mechanism are proposed for single and multiple channel rings, ex. MetaRing [5], ATMR [6], Orwell [7] and Multi-MetaRing [2]. In the protocol, we utilize the Multi-MetaRing as the fairness mechanism to make the bandwidth-utilization fairness between all nodes.

This paper consists of five sections. The second section will describe the network architecture. The basic transmission protocol and node architecture with TT-FR and FT-TR will be described in detail. The third section will describe the control mechanism to explain how to provide the carrier-preview function and the fairness mechanism in the CPMR protocol. In the fourth section, the simulation results will be obtained to evaluate the performance of the network. The final section presents the conclusion of this paper.

2. Network Architecture

The proposed network architecture is a WDM slotted ring network consisted of M nodes and $W+1$ channels. Figure 1 is an example as $M=W=4$. In the network, every ring is divided into a constant number of fixed length slots that synchronously and circularly flow in one direction in the ring. Every cell is exactly to fit into the payload of a slot. In the network, one channel is used to coordinate all nodes in the network, called the control channel and other W channels are used to transmit data and priority cells, called normal channels. These cells transmitted on the control channel are called control cells. They broadcast the node reservation information to other nodes in the network. By the reservation information, all nodes can detect the transmission status of next slot-time on normal channels. The control channel can be implemented by a normal channel or the MSS (Multiple Subcarrier Signaling) [3][8] technology.

In the network, every node has one TT-FR transceiver or one FT-TR transceiver for transmitting and receiving data cells. In TT-FR case, every node is assigned a particular channel, called the *receiving channel* by which cells are received. Every transmitting node transmits a cell by tuning its transmitter to the channel of the destination receiver. The transmitted cell will propagate along the ring until the

This work was supported by the National Science Council, Taiwan, ROC: The project number is NSC89-2213-E-151-001.

destination node extracts it. In FT-TR case, every node is assigned a particular channel, called the *transmission channel* on which cells are transmitted. Every transmitting node transmits a cell by its transmission channel. When the destination detects that the cell is on the transmission channel, it tunes its receiver to the channel. Then, the receiver extracts the cell from the transmission channel. When a node attempts to transmit a cell, it will defer the transmission when it finds another cells with same destination on the slot time. The inspection capability can be achieved by the MSS technology. The add/drop multiplexer [9][10] can be used to remove cells on channels.

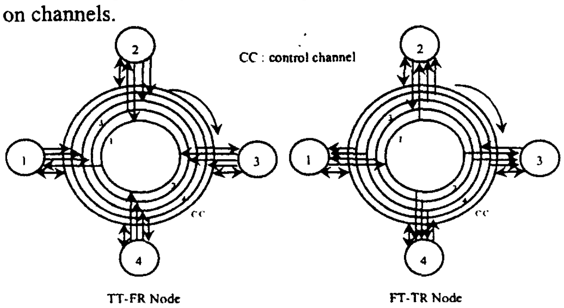

Figure 1. *The network topology of Multi-Channel Slotted Ring Network with W=M=4.*

In this network, each node is not only equipped with one tunable transceiver, TT-FR or FT-TR, but also one fixed transmitter and receiver (FT-FR). The later is used to transmit and receive control cells. Figure 2 depicts the node architecture with the TT-FR transceiver and a FT-FR transceiver. The node architecture with the FT-TR transceiver is similar to the architecture with TT-FR. In this paper, the node with the TT-FR transceiver is called a TT-FR node, and the node with the FT-TR transceiver is called a FT-TR node. The differences between them are that the receiver of the latter is tunable and transmitter is fixed. In the architecture shown in figure 2, the FT-FR transceiver is responsible for receiving control cells into the controller and transmitting control cells to fiber. The controller is responsible for recording and updating the transmission status of all normal channels. By the extractor and combiner, the focused wavelength can be extracted from or combined into fiber. The cell filter is used to filter the data cells and SAT messages from incoming cells. The SAT message is used to coordinate the fairness between nodes. The format of control cells and the mechanism of the control channel will be described in detail in next section.

In the TT-FR node architecture, every node owns a queue corresponding to all transmittable channels. In the FT-TR node architecture, every node owns a queue corresponding to all destinations. Because of the difference between two node architectures, the transmission protocols of two node architectures also are different. We will describe the detail of these transmission protocols in the next section.

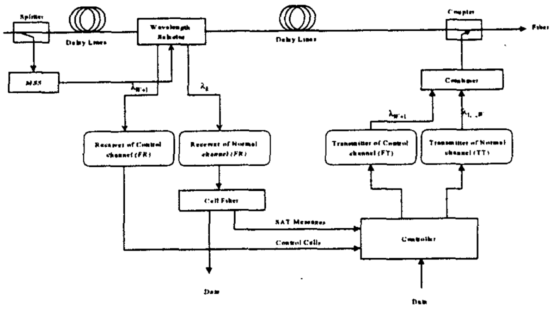

Figure 2. *The TT-FR Node Structure*

3. Transmission Protocol

The transmission protocol that we propose is to provide the carrier-preview function. By the carrier-preview function, all nodes can preview the transmission status of next slot, then decide which slot can be used to transmit its cell. In this protocol, all nodes are coordinated by control cells. This function is implemented into the controller of figure 2. Because the transmission protocols used on TT-FR and FT-TR node architecture are different, we describe the two protocols separately.

3.1 TT-FR Reservation Protocol

In TT-FR reservation protocol, the size of control cell is fixed to one slot. In TT-FR case, every control cell records the transmission status of every channel in next slot. The format of every control cell is described as shown in figure 3. A control cell is consisted of a preamble field, a parity field and many Channel-Reservation Elements (CRE). The number of CREs is equal to the number of channels. The preamble field is used to represent the beginning of a control cell, and the parity field is used to verify the accuracy of a cell.

The CRE is consisted of a Reservation Bit (RB), a Channel Number field (CN), a Destination Address (DA). The CRE is the basic reservation unit and represents the transmission status of the corresponding channel. The transmission statuses include that whether the next slot carries a cell or not, the destination node address of the transmitted cell if the next slot carried a cell. The RB is used to identify whether the slot is reserved or not. The CN is used to identify the CRE related to which channel. DA records the address of the destination of the cell transmitted on the next slot.

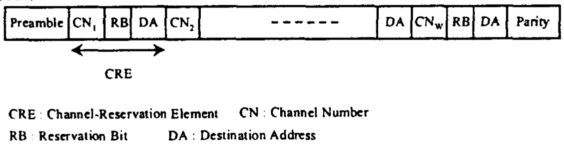

Figure 3. *The Format of Control Cells.*

In initial state, the RBs of all CREs are false that indicates that the next slots of all corresponding channels are not reserved to transmit a cell. When a node retrieves a control cell from the control channel, it will seek which channels in next slot time is not reserved. It can obtain the information by checking the RB of every CRE. If there are many channels that are not reserved and their corresponding queues in the node are not empty, the node will randomly select a channel to reserve. When a node attempts to reserve a next slot time of a channel, it modifies the RB of the corresponding CRE into true and writes the destination of the transmitted cell on the DA. If all data queues on the node are FIFO (First In First Out) queues, the transmitted cell is the head cell of the selected queue. When a node reserves a channel, it writes the channel number to its reserved-channel register (RCR). Otherwise, the RCR is equal to zero. In the next time slot, the node will transmit its cell on the reserved channel. Because every node only has one transmitter, it just can reserve a channel at one time slot.

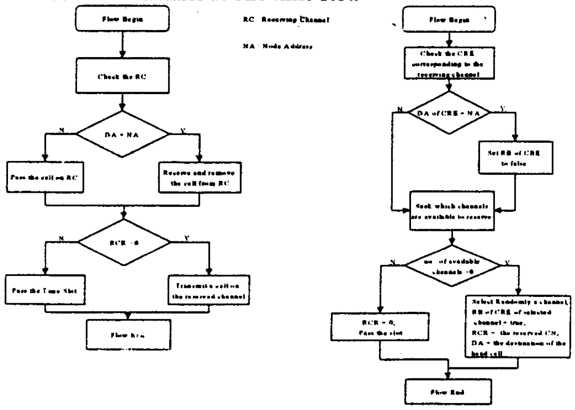

Figure 4. *The protocol flow of a TT-FR node at one time slot.*

When a node receives a control cell from the control channel, it will check the corresponding CRE of its receiving channel whether its DA is itself. If it is the destination of the transmitted cell in the reserved slot, it modified the RB of the corresponding CRE into false. By the process of reserving and releasing slot, every node can preview which channels can be used to transmit its cell in next time slot. Figure 4 shows the action flow of every node at one time slot. The left side of the figure is the flow of the protocol for all normal channels. The right side of the figure is the flow for the control channel.

3.2 FT-TR Reservation Protocol

In the FT-TR protocol, the format of its control cell is same as the cell format in TT-FR protocol. In it, the initial state also is that the RBs of all CREs are set to false. However, the protocol flow is different from the protocol flow of TT-FR nodes. When a node receive a control cell, it will check whether there is one CRE which DA is its node address. If it is existent, it will set the RB of the CRE to false. If there are cells in itself queues waiting to transmit, it will check its transmission channel whether its next time slot is reserved or not. If the channel is not reserved, it will check all CREs in the control channel to find which nodes are not the destinations of cells of other nodes in the next time slot. It also checks which queues corresponding to all possible destinations are not empty. If there are many possible destinations which corresponding queues in the node are not empty and are not reserved, the node randomly selects a destination to reserve. When a node reserves a slot to transmit a cell to a selected destination in next time slot, it writes the selection destination node number to its reserved-destination register (RDR). Otherwise, the RDR is equal to zero.

In every time slot, a node always checks whether the RDR in itself is not zero or not. If it is true, the node put the head cell of the queue corresponding to the selected destination to its transmission channel. The selected destination is recorded in RDR. If the RDR is zero, it will pass the time slot. When the node transmitted its cell, it resets its RDR to zero. The flow of the protocol is described in figure 5. The left side of the figure also describes the flow to receive and transmit a cell on normal channels. The right side of the figure describes the flow to reserve a destination and remove the reservation for being reused by other nodes.

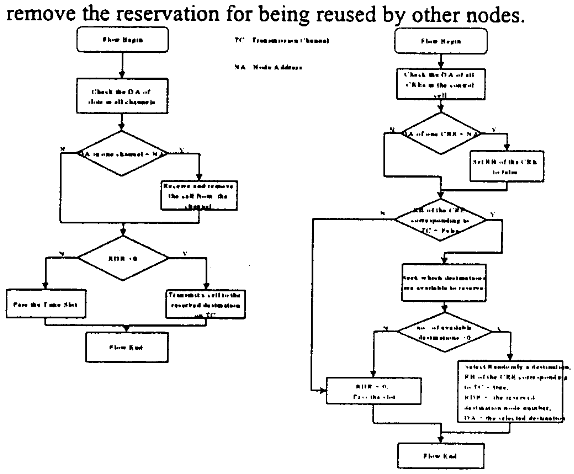

Figure 5. *The protocol flow of a FT-TR node at one time slot.*

3.3 Fairness Mechanism

In these proposed protocols, they have a severe drawback, that is the fairness problem. This problem leads that each node in each channel does not transmit its cell fairly. The reason of the problem is that the position of a node on a channel affects the transmission ability of the node on the channel. For example, in the TT-FR network at figure 1, node 1 has the lowest priority to transmit its cells in channel 2. Because it can only transmit its cells when node 3 and node 4 don't have cells to transmit on the channel. In the same reason, the node 3 has the highest priority to transmit its cell in channel 2. The property at slotted-ring network is also called the cyclic-priority property [4].

Because the fairness problem arises in multichannel slotted ring networks with spatial reuse, in this paper, we adapt a fairness mechanism to guarantee the bandwidth shared fairly between nodes. The fairness mechanism had been proposed in [2]. The mechanism is originated from the MetaRing. Because the modified mechanism is suited to the multi-channel slotted ring network, the author called it as

Multi-MetaRing (MMR). The mechanism on this proposed protocol is described as following. In MMR, the fairness of a network is achieved by a control message, SAT (SATisfied) messages. The message rotates in the opposite direction with respect to the data traffic it is regulating. Every node for every channel (TT-FR) or every destination (FT-TR) is assigned a maximum number of cells to be transmitted (called Quota, Q) between two successive SAT visits.

Normally, when a node receives an SAT message corresponding to a channel or a destination, it forwards the SAT message on the ring with no delay, unless it is not satisfied. When the node does not exhaust its transmission quota and the queue corresponding to the channel or the destination is not empty since the last time it forwarded the SAT, it is not satisfied. When a node is satisfied, it forwards the SAT message to its upstream node. In CPMR, the number of SAT messages is related to its node type. In the TT-FR network, the number of SAT message is equal to the number of channels. Every SAT message coordinates the data traffic on a channel. In the FT-TR network, the number of SAT message is equal to the number of nodes and every SAT message coordinates the data traffic to a node.

4. Simulation Results

In this paper, we use the simulation results to evaluate the performance of the CPMR network. The simulation program is programmed in SIMSCRIPT language. The followings are the simulation model in the simulation program. In these simulation results, the throughput and delay results of the network in balanced traffic are obtained. In the network, the balanced traffic means that the traffic load of every node is equal and is distributed evenly to other nodes. Here, the cell delay is defined as the interval between the moment that the last bit of a cell is received and the event that the cell is generated. Table 1 shows the simulation assumptions.

Table 1. *The simulation model.*

Number of Nodes	10
Number of Channels	10
Propagation Delay Between Neighboring Nodes	1 slot-time
Number of Traffic Type	1
Traffic Distribution	Poisson
Node Architecture	TT-FR / FT-TR
Quota Per Queue	1000 cells
Buffer Size Per Queue	1000 cells
Simulation Time	1000000 slot-times

In figure 6, the throughput versus the traffic load per channel under balanced traffic is shown. In the figure, the throughputs of four different transmission protocols, randomly selection (RND) with TT-FR nodes, CPMR with TT-FR nodes, RND with FT-TR nodes, CPMR with FT-TR nodes are compared. The throughput per channel of RND approaches 0.66, and the throughputs of CPRM approach 0.93. Obviously, CPMR achieves the improvement in network utilization.

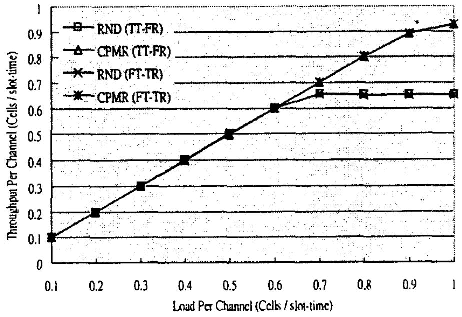

Figure 6. *The channel throughput versus the traffic load per channel under balanced traffic for different protocols.*

In figure 7, the average cell delay of the network under balanced traffic load is shown. Under light load, the cell delay in CPMR approaches the cell delay in random selection protocol. The addition part of cell delay in CPMR is created by CPMR protocol because in the protocol every cell must reserve a slot before it is transmitted. However, under the same heavy load, the cell delay in CPMR is smaller than that of RND protocol. This is because the carry-preview function defers the network saturation point.

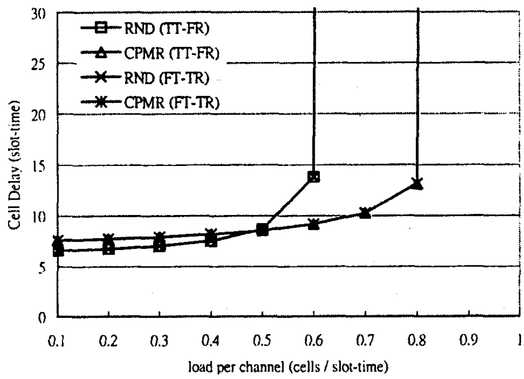

Figure 7. *The average cell delay of the network under balanced traffic load for different protocols.*

In Table2, the throughput of different protocols at the heavy load is shows as the total network load is 10 cells per slot-time. In the table, each item is the throughput of each channel in these protocols. Here we list these throughput results as the channel number is equal to 10, 5, 2. From the table, as the channel number is more, it can be found that CPMR improves the throughput very much as comparing with random selection protocols. However, as the channel number is 2, the CPMR just improves the throughput a little. The reason is that the slot-reused capacity makes the high throughput for random selection protocols at little channel number case. When the channel number is 10 in this case, that is one node is assigned a individual receiving channel or transmission channel, the slot-reused capacity does not affect the throughput because for each node no another node shares the bandwidth of its receiving channel or transmission channel.

Protocol / Channel No.	RND (TT-FR)	RND (FT-TR)	CPMR (TT-FR)	CPMR (FT-TR)
10	0.653	0.653	0.927	0.926
5	1.064	1.078	1.390	1.285
2	1.667	1.685	1.999	1.741

Table 2. *The channel throughput in balanced traffic for different protocols as network load is 10 cells / slot-time.*

In Table 3, the channel throughput of our proposed protocols with and without fairness mechanism as the total load of network is 10 cells / slot-time is shown. From this table, we can find that the fairness mechanism reduces slightly the channel throughput. This is because the transmission of fairness control messages, SAT messages, will reduce the channel utilization for data cells. It is interesting that CPMR+MMR with FT-TR node architecture has better throughput than that without the fairness mechanism as the number of channels is smaller than the number of nodes.

Table 3. *The channel throughput in balanced traffic for proposed protocols with and without fairness mechanism as network load is 10 cells / slot-time.*

Protocol / Channel No.	CPMR (TT-FR)	CPMR+MMR (TT-FR)	CPMR (FT-TR)	CPMR +MMR (FT-TR)
10	0.927	0.900	0.926	0.901
5	1.390	1.325	1.285	1.370
2	1.999	1.754	1.741	1.788

In figure 9-10, the average throughput results of different queues of the TT-FR network with fairness mechanism and without fairness mechanism are shown. In figure 11-12, the average throughput results of different queues of the FT-TR network with fairness mechanism and without fairness mechanism are shown. The network load is 10.0. The load is high load for every queue. These figures show that these lower-priority nodes at one channel have lower network throughput than these nodes with higher priority in these networks without fairness mechanism. However, in these networks with fairness mechanism, the fairness between nodes can be achieved.

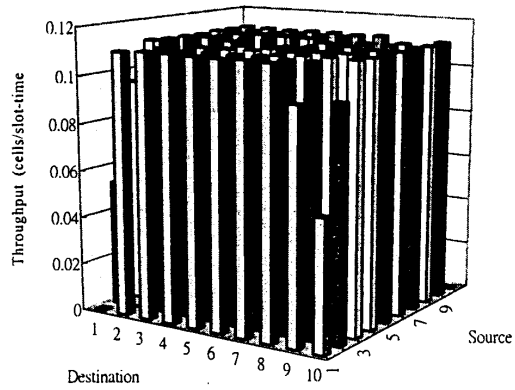

Figure 9. *Throughput for CPMR (TT-FR) without fairness mechanism.*

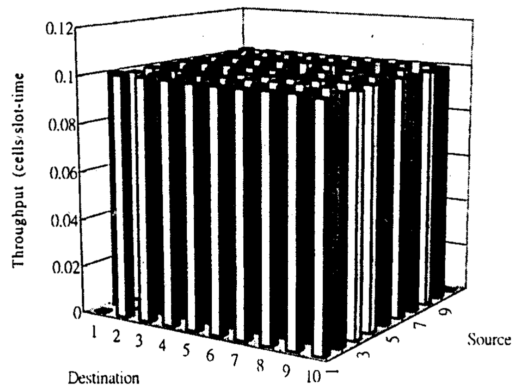

Figure 10. *Throughput for CPMR (TT-FR) with fairness mechanism.*

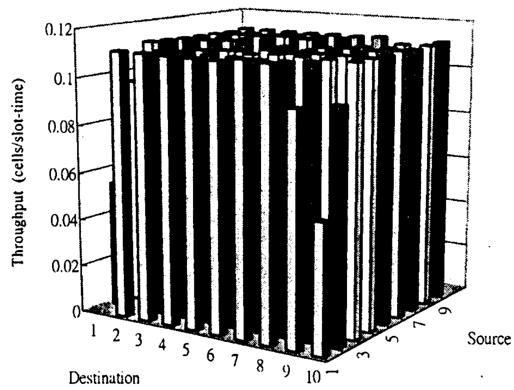

Figure 11. *Throughput for CPMR (FT-TR) without fairness mechanism.*

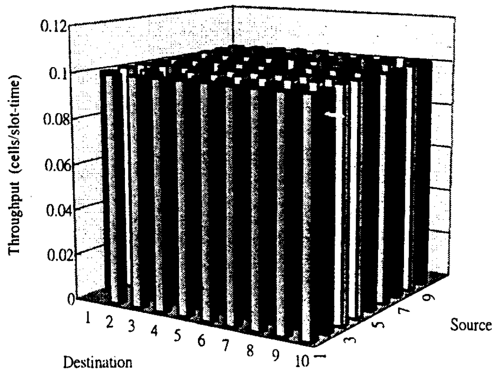

Figure 12. *Throughput for CPMR (FT-TR) with fairness mechanism.*

5. Conclusion

In the paper, we propose a CPMR protocol to improve the network throughput. The protocol is based on the WDM slotted ring network and utilizes a control channel to coordinate all nodes for previewing the transmission status of next time slot. Under this protocol, every cell can be only transmitted on reserved slots. Because of the preview function, the network throughput can improve very much. Here we also adapt the fairness mechanism, Multi-MetaRing, in the proposed protocol to provide the transmission fairness between nodes.

From these simulation results in this paper, we can find that the network throughput improves very more than that without the proposed protocol. The cell delay also achieves the improvement. Another result is that under the protocol throughput and cell delay of the TT-FR protocols are better than that of FT-TR protocols as number of channels is smaller than number of nodes.

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