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RESMRing: A Reservation-Based MultiChannel Optical Slotted Ring Network

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ABSTRACT

In this paper, a REServation-based Multichannel optical RING network (RESMRing) is proposed. 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 "normal" channels. There is a control channel used in the network to coordinate all nodes. Moreover, a fair transmission protocol is also proposed to provide transmission fairness between nodes. By the protocol, the network can support multiple type traffics that can have different transmission priorities. In the paper, there are simulation results to evaluate the performance of the network.

Keywords:
WDM, Slotted Ring, Multiple Priority, RESMRing

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 being nice method utilizing bandwidth. But the slot-reused property makes the unfairness between nodes, there are many fairness mechanism are proposed for single and multiple channel rings, ex. MetaRing, ATMR, Orwell and Multi-MetaRing [2-3][7-8]. In this paper, we also propose a quota-based fairness mechanism originating from ATMR protocol for the reservation- based transmission protocol. It will be described in section 3 of this paper.

Because of the huge-bandwidth and real-time requirement of multimedia application, the research in the multiple priority transmission and huge-bandwidth is the hot topic in the research of high-speed network. In this paper, we proposed a multiple priority transmission protocol based reservation mechanism on the WDM slotted ring network, called RESMRing. In the network, every node has a tunable transmitter and a fixed receiver (TT-FR), or one fixed transmitter and one tunable receiver (FT-TR), for the data cells. In the network, a specified channel is used as the control channel to transmit control cells that coordinate the transmission of every node. By means of these control cells, the network provides the capability to transmit these cells with different priorities. In section 3, we will describe it in detail.

This paper consists of five sections. The second section will describe the network architecture. The basic transmission protocol with TT-FR and FT-TR will be described in detail. The third section will describe the control mechanism to explain how to provide multiple priority service in the RESMRing network. In the fourth section, the simulation results will be obtained to evaluate the performance of the network.

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. We assume every ring has k slots, S_1, ..., S_k. 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. The control channel can be implemented by a normal channel or the MSS (Multiple Subcarrier Signaling) [5] 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 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

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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 [5][6] can be used to remove cells on channels.

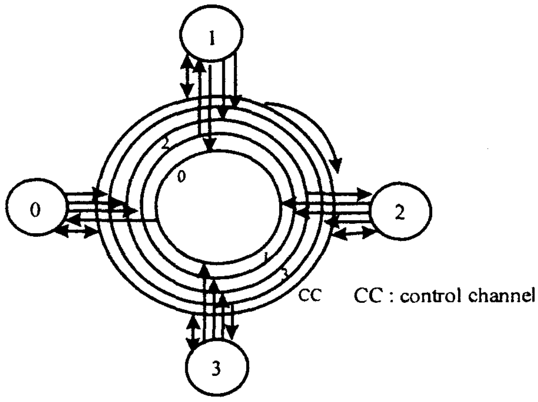

Figure 1. *The architecture of Multi-Channel Ring Network with $W=M=4$.*

For simplicity in network transmission, we adapt the RND (Random) protocol in [4] as the basic transmission protocol for this paper. In TT-FR case, every node selects randomly a nonempty queue and attempts to transmit the head cell of the selected queue in every slot time. If the destination channel is empty, the transmission of the attempted cell will be successful and the source node will removes the cell from the selected queue. Otherwise, the source node remains the cell on the queue. In every slot time, each node simultaneously executes this selection procedure. In FT-TR case, every node also selects randomly a nonempty queue and attempts to transmit the head cell of the selected queue in every slot time. If the source node does not inspect any another cell on other channels to the same destination, the transmission of the attempted cell is successful and the source node removes the cell from the selected queue. Otherwise, the source node remains the cell on the queue. In every slot time, the selection procedure is also executed by every node.

In the network, each node is not only equipped with one tunable transceiver, TT-FR or FT-TR, but also one fixed transmitter and receiver. The later is used to transmit and receive control cells. Besides, every node maintains separate transmitting queues for different priority cells of each transmission channels. The format of control cells and the mechanism of the control channel will be described in detail in next section.

In addition to these queues, every node has a *reserved-counter* (RC) for each normal channel to record the number of reserved slots. The *channel controllers* (CCTRs) in the figure 2 are used to select cells from different priority queues to transmit on normal channels. Figure 2 shows the TT-FR node architecture for one traffic type. Furthermore, every node has a *reservation table* (RT) and a *reservation register* (RR). RT is used to record the information that is which slot is reserved and which node reserves slots in each transmission cycle. RR is used to record which slot time is reserved by the node and which queue will utilize the slot in each transmission cycle. A transmission cycle is the time that a slot flows through the whole ring once. In section three, the functions of these components will be described in detail.

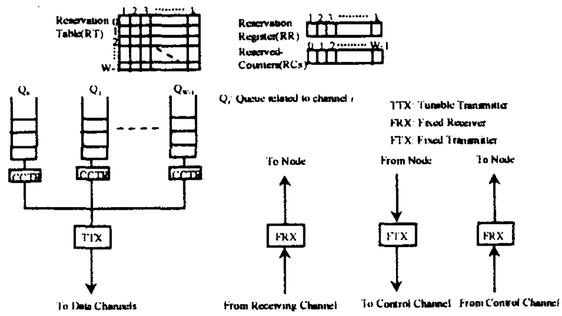

Figure 2. *The TT-FR Node Structure for Single Traffic Type.*

3. Transmission Protocol

3.1 Reservation Protocol

The transmission protocol that we propose is to provide the multiple priority cell transmission. In this protocol, all nodes are coordinated by control cells. The size of control cell is fixed to one slot, and its format is described as shown in figure 3. Every control cell is consisted of a preamble field, a parity field and many Slot-Reservation Frames (SRFs). 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 SRF is consisted of one Channel Number field (CN), one Busy Address field (BA), one Reset Bit field (RS) and many Slot-Reservation Elements (SREs). The CN is used to identify the SRF related to which channel. The BA and RS are used to coordinate all nodes to maintain the fairness between nodes in the controlled channel. In latter section, their roles will be described in detail. The SRE is the basic reservation unit and is consisted of a Reservation Bit (RB), and a Reservation Priority (RP) and a Source Address (SA). RB is used to identify whether the slot is reserved or not. RP records the priority of the queue which cells will be transmitted on the slot. SA records the address of the node that reserves the slot.

Every SRE represents the state of one slot on normal channels. The sequence of SREs is the slot sequence of normal channels. For example, the states of slots of channel 0 are represented firstly, and then the states of slots of channel 1 are represented secondly, and so on. Because there are k slots circulated through the ring, k SREs are needed to represent the states of all slots of one channel. So the number of total SREs used to represent the states of all slots of the network should be $k \times M$ where M is the number of normal channels. The number of control cells is the total number of SREs divides the number of SREs of each control cell.

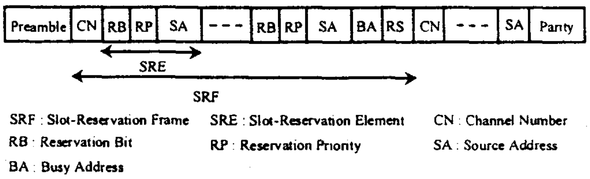

Figure 3. *The Format of Control Cells.*

Because the SREs used to represent the states of the slots of different channels are at different position of control cells, a node always regards the first slot after the slot transmitting the first control cell that represents a channel as S_1 of the channel. This is for specifying the beginning of the transmission cycle in each channel. So, the first slot is the start of a transmission cycle. And the start slot of transmission cycle of every channel is different.

For simplicity, in the following, we only use one traffic type and the TT-FR node architecture to explain the transmission protocol in the network. In the network, when a node detects a control cell, it will check its queue related to the controlled channel. If the queue is not empty, the node will try to reserve slots for transmitting the cells in the queue. Then, it checks serially whether the RBs of SREs representing $S_1 \ldots S_k$ of the channel are false or not. If a RB is false, the node sets the RB of the selected SRE at true, RP at the priority of the queue and SA at itself address. If the RB is true, the node checks next SRE till all SREs representing the channel have been checked. If a node has many cells needed to transmit on a channel, it can reserve many slots on the channel in a reservation cycle. When a node has reserved a slot for a queue, it increases the RC related to the channel by one. When the node received the same control cell again, it checks the SRE to ensure that its reservation is successful. If its reservation is successful, it will set the RB at false and then transmit a cell on a reserved slot from the queue related to the channel. Figure 4 shows the timing diagram that a control cell arrives at a node, then the node reserves S_1 of channel i and transmits a cell on the S_1 of channel i.

Because every node only has one tunable transmitter, it must avoid reserving two slots which arriving itself at the same slot time. The requirement can be achieved by a RR. The register has k fields. Every field represents a slot time on a transmission cycle and which queue will employ the slot. Because every control cell is transmitted in fixed slots on the control channel, the positions of slots of every channel are also fixed for other channels. By it, a node can calculate easily the positions of slots of all channels. If one field of RR shows that a slot time is reserved, it means that the slot time that the field corresponds to is reserved and the node can not reserve the same slot-time slot on other channels.

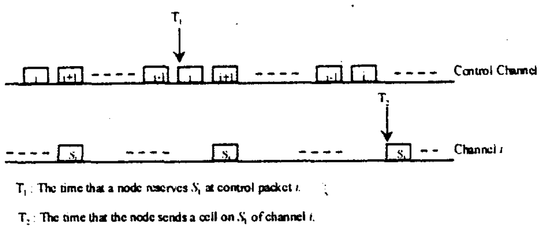

Figure 4. *The timing diagram that a node reserves a slot.*

Because the control cells are broadcast to all nodes in the network, every node can know in which duration reserved slots of all channels are not used. By this capability, every node still can attempt to transmit its cells on these reserved slots when they arrive. The method is that when the destination of a cell wanting to transmit on a slot is arrived more quickly than the source node reserving the slot, the node can attempt to transmit the cell on the slot.

Of course, for a node, it can also transmit its cells on unreserved slots. Every node can know the reservation status of each slot on a channel from its RT that records the reservation status of slots of all channels when control cells pass through itself. So, when a slot arrives at a node, the node will decide whether it can transmit its cell on the slot or not. In this paper, when a node attempts to transmit its cells on unreserved slots, we consider the RND protocol described in the above as the transmission protocol. In the network, on every slot, the selectable channels in RND protocol are these channels that slots can be used and the cell number of the queues corresponding to them are larger than the RC related to them.

In the above, we describe the transmission protocol in one traffic type case. In multiple priority traffic type case, we just modify the protocol slightly to suit the case. When a node has multiple priority traffic loads, it has different queues for each priority traffic load of every channel. It also needs different RCs for different priority traffic types. When a node receives a control cell, it will reserve slots for cells in high priority queues, then reserve slots for cells in low priority queues when all cells in high priority queues are reserved slots. When a node attempts to transmit cells on useable slots, it also transmits the low priority cells only after serving the high priority cells.

3.2 Fairness Mechanism

Because the fairness problem arises in slotted ring networks with spatial reuse, in this paper, we propose a fairness mechanism originating from ATMR protocol [2] to guarantee the bandwidth sharing fairly between nodes. Every node is allocated a quota for each queue, equal to q. When a node attempts to reserve a slot or transmit a cell by RND protocol on a channel, it needs to check the number of transmitted cells of the queue related to the channel. If the number is smaller than q, the attempt is allowed, otherwise, it is prohibited. When the reservation is completed or the transmission is successful, the number of transmitted cells increases by one.

In the mechanism, an active node that has cells to transmit on a channel and whose transmitted cells is smaller than quota on the channel always overwrites its node address into the BA field of the control cell that represents the channel. Inactive nodes that have nothing to transmit or whose transmitted cells are equal to the quota on a channel do not overwrite the BA field. By the rule, a node that finds its node address on an incoming control cell automatically detects that the other nodes in the network are all inactive on the corresponding channel. As soon as the last active node that detected the inactive state of the other nodes on the corresponding channel, it sets the RS field of the control cell at true. Inactive nodes detect that the RB field of a control cell is true, they will reset their quota on the corresponding channel. When the node that set the RB field of the control cell receives the control cell, it sets the RB of the incoming control cell at false.

4. Simulation Results

In this paper, we use the simulation results to evaluate the performance of the network. The simulation program is programmed in SIMSCRIPT language. Table 1 shows the simulation assumptions in the simulation program. In these simulation results, the throughput of the network in balanced traffic is obtained. The average cell delay of the network on the balanced and unbalanced traffic is also obtained. The cell delay of every queue in the network on the heavy load is presented. 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. The throughput of every queue in the network on the overloaded load is shown finally. Because of the limitation of this paper size, we do not present the simulation results of multiple priority.

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
Quota Per Queue	1000 cells
Buffer Size Per Queue	2000 cells
Simulation Time	200000 slot-time

In the network, the balanced traffic means that the traffic load of every node is equal and is distributed evenly to other nodes. The unbalanced traffic is a client-server traffic type. This means that there are one node as the server and other nodes as clients in the network. We assume that the generated traffic of the server is one-three of total traffic load and distributed evenly among all clients. The half of traffic load generated by each client is directed to the server, and the other half of the traffic is uniformly distributed among other clients. Here, we assume that node 0 is the server node.

In figure 5, the throughput versus the traffic load per channel under balanced traffic is shown. In the figure, the throughputs of three different transmission protocols, pure RND, RESMRing without fairness mechanism and RESMRing with fairness mechanism are compared. The throughput per channel of pure RND approaches 0.63, and the throughputs of RESMRing without fairness mechanism approach 1. The throughput of RESMRing with fairness mechanism approach 0.9. The throughput decrease due to the fact that all nodes in inactive state must wait for the reset signal. Obviously, from this figure, RESMRing achieves the improvement in network utilization.

In figure 6, the average cell delay of the network under balanced traffic load is shown. Under light load, the cell delay in RESMRing approaches the cell delay in RND protocol. This is because the most of cells are transmitted on unreserved slots. Under the same heavy load, the cell delay in RESMRing is smaller than that of RND protocol. This is because the most of cells in heavy load are transmitted on reserved slots. So, by means of the transmission flexibility, we can defer the network saturation.

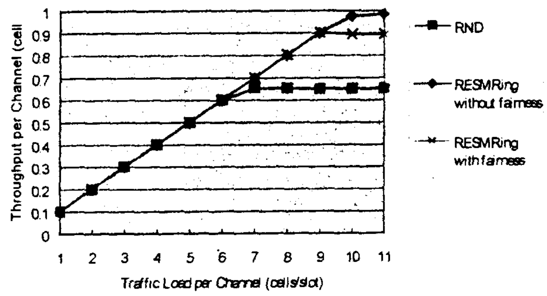

Figure 5. Throughput vs. traffic load per channel.

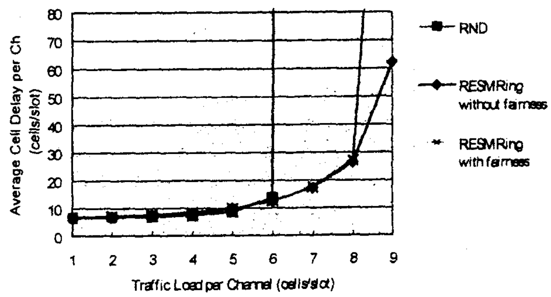

Figure 6. Average cell delay vs. traffic load per channel.

In figure 7-8, the throughputs of different queues of the network with unfairness mechanism under balanced and unbalanced traffic load are shown. The total generated traffic load in balanced traffic load is 11. The total generated traffic load in unbalanced load is 3.5. This load also is an overload for the server node and the server channel. In figure 9-10, the throughputs of different queues of the network with fairness mechanism under balanced and unbalanced traffic load are shown. We can find that every node shares fairly the network bandwidth in the network with fairness mechanism. We also can find that the network bandwidth is shared fair by every queue in the overload channel. So, the fairness property of the network with fairness mechanism in network throughput can be proven from these figures.

In figure 11-12, the average cell delay of different queues of the network without fairness mechanism under balanced and unbalanced traffic load is shown. In these figures, the cell delay does not include the transmission latency. The total generated traffic load in balanced traffic case is 9.0. The load is high load for every queue. The total generated traffic load in unbalanced load is 2.97. The load also is high load for these queues that the server owes and these queues related to the server in client nodes.

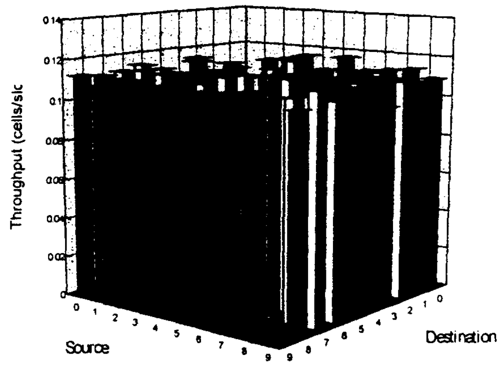

Figure 7. *Throughput of the network without fairness mechanism under balanced traffic, total load = 11 cells/slot.*

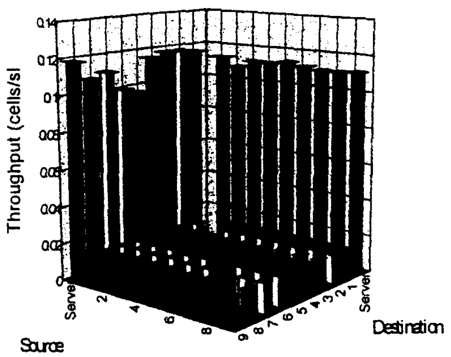

Figure 8. *Throughput of the network without fairness mechanism under unbalanced traffic, total load = 3.5 cells/slot.*

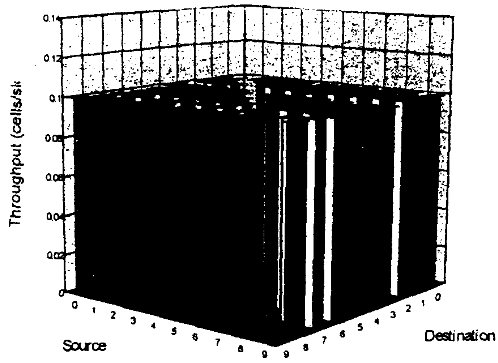

Figure 9. *Throughput of the network with fairness mechanism under balanced traffic, total load = 11 cells/slot.*

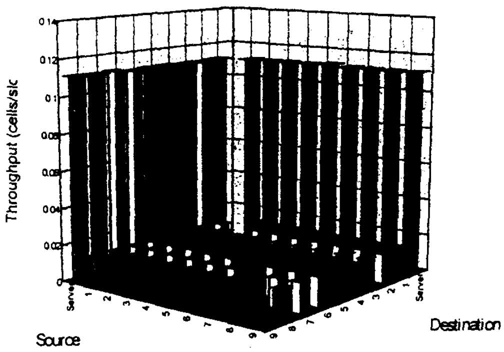

Figure 10. *Throughput of the network with fairness mechanism under unbalanced traffic, total load = 3.5 cells/slot.*

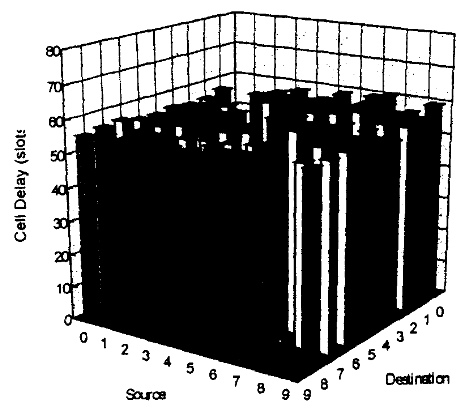

Figure 11. *Cell delay for balanced traffic, total load = 9 cells/slot.*

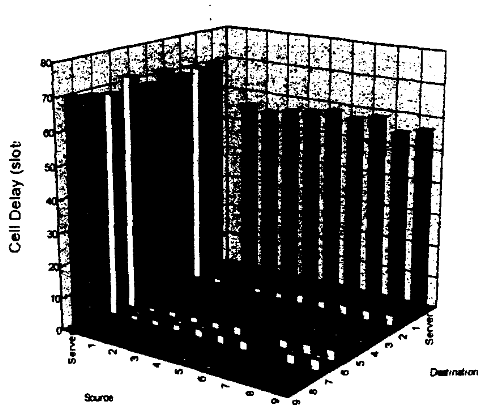

Figure 12. *Cell delay for unbalanced traffic, total load = 2.97 cells/slot.*

5. Conclusion

In the paper, we propose a fair and efficient protocol that provides the capability to transmit priority cells. The protocol is based on the WDM slotted ring network and utilizes a control channel to coordinate all nodes for reserving slots. In the network, every cell can transmit on reserved slots or unreserved slots. In order to avoid the unfairness between nodes under overload traffic, we adopt a fairness mechanism originating from ATMR protocol to guarantee the fairness between nodes. Because of the flexibility of the transmission protocol, the network has low cell delay in light load and high throughput in heavy load. The simulation results show the property and prove the fairness property.

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