A Tunable Transmitter - Tunable Receiver Algorithm for Accessing the Multichannel Slotted-Ring WDM Metropolitan Network under Self-Similar Traffic

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Abstract: This paper presents an algorithm for multichannel slotted-ring topology medium access protocol (MAC) using in wavelength division multiplexing (WDM) networks. In multichannel ring, there are two main previously proposed architectures: Tunable Transmitter - Fixed Receiver (TTFR) and Fixed Transmitter - Tunable Receivers (FTTR). With TTFR, nodes can only receive packets on a fixed wavelength and can send packets on any wavelengths related to destination of packets. Disadvantage of this architecture is required as many wavelengths as there are nodes in the network. This is clearly a scalability limitation. In contrast, FTTR architecture has advantage that the number of nodes can be much larger than the number of wavelength. Source nodes send packet on a fixed channel (or wavelength) and destination nodes can received packets on any wavelength. If there are fewer wavelengths than there are nodes in the network, the nodes will also have to share all the wavelengths available for transmission. However the fixed wavelength approach of TTFR and FTTR bring low network utilization. Because source node with waiting data have to wait for an incoming empty slot on corresponding wavelength. Therefore this paper presents Tunable Transmitter - Tunable Receiver (TTTR) approach, in which the transmitting node can send a packet over any wavelengths and the receiving node can receive a packet from any wavelengths. Moreover, the self-similar distributed input traffic is used for evaluation of the performance of the proposed algorithm. The self-similar traffic performs better performance over long duration than short duration of the Poison distribution. In order to increase bandwidth efficiency, the Destination Stripping approach is used to mark the slot which has already reached the desired destination as an empty slot immediately at the destination node, so the slot does not need to go back to the source node to be marked as an empty slot as in the Source Stripping approach. MATLAB simulator is used to evaluate performance of FTTR, TTFR, and TTTR over 4 and 16 nodes ring network. From the simulation result, it is clear that the proposed algorithm overcomes higher network utilization and average throughput per node, and reduces the average queuing delay. With future works, mathematical analysis of those algorithms will be the main research topic.

Keywords: Slotted – Ring, WDM, MAC Protocol, Multichannel Ring.

1. INTRODUCTION

The explosion in the popularity of the internet and its new multimedia application and services has led to a need for increased bandwidth in the network backbone. In the present time, WDM-based solutions are therefore expected to appear as the next generation access networks in the metropolitan area [1-5]. The WDM technology brings high speed backbone that could support the demand bandwidth of internet or other applications. Moreover, technology of Dense Wavelength Division Multiplexing (DWDM) is now offering an unprecedented bandwidth as currently available systems support up to about 100 wavelengths per fiber, enabling a single fiber to carry several hundred gigabits per second of information.

Multichannel slotted ring network is one solution of the WDM network. It needs medium access control (MAC) protocol to perform accessing and managing processes over channels of the WDM network. Therefore, this article presents a MAC protocol for the multichannel slotted ring WDM network which based on Tunable Transmitter - Tunable Receiver (TTTR) and destination striping approaches which outperforms higher average throughput per node and lower average queuing delay.

Following the introduction, this paper is organized as follows. Section 2 introduces the network architecture and the MAC protocol proposed. Section 2 presents a proposed algorithm. Simulation results are given in section 4. The main conclusions are given in section 5.

2. NETWORK ARCHITECTURE

2.1 The physical architecture

The network architecture illustrated in Fig. 1, is a simple multichannel WDM slotted ring topology with a single fiber and a small number of different wavelengths. The simple case of fixed-size slots is considered. It basically consists of a number of access nodes (AN) each of them having add-and-drop capabilities to access the ring slots. Each AN is used to connect a Gigabit Ethernet (GbE) access network to the ring. Data sent from one access network to another is first received by an AN through the GbE link and is then transmitted through the WDM ring to the destination AN which delivers the data to the intended access network. Each nodes could be has a fixed/tunable transmitter and a fixed/tunable receiver depend on selected MAC protocol. The MAC protocol allows nodes to transmit and receive data on network wavelengths or channels. In this paper, we will only focus on the logical implementation of the network.

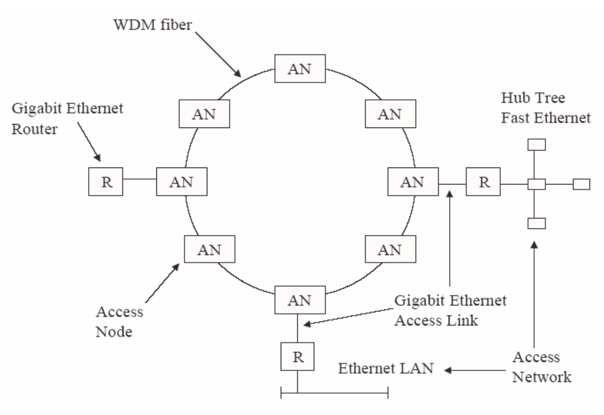

Fig 1. Network architecture

Each node has two FIFO (First-In First-Out) buffers (one for transmission and one for reception), each of which can store up unlimited packets.

2.2 The medium access control protocol

There are two main types of MAC protocol for multichannel slotted ring network which are

With TTFR architecture, wavelengths for transmitters are tunable; the transmitters can then able to send to any wavelength. However, about receivers, each wavelength can be seen as a link dedicated to the corresponding receiver and this implementation therefore requires as many wavelengths as there are nodes in the network. This is clearly a scalability limitation [8]. The main advantage of such implementations is that they avoid receiver collisions.

In FTTR architecture, nodes can receive packets on any wavelengths. If there are fewer wavelengths than there are nodes in the network, the nodes will also have to share all the wavelengths available for transmission. This is not a limitation as the wavelength rate is generally much greater than the node access link rate and therefore a wavelength can be shared for transmission by a high number of nodes. The main advantage of this architecture is that the number of nodes can be much larger than the number of wavelength.

2.3 Empty slot mechanism

Transmitter sends a data packet over an incoming empty slot which becomes a marked slot. After, the marked slot reaches a corresponding receiver. The slot will be emptied or the data on the slot will be stripped by two main mechanisms listed as following.

- Source Stripping, and
- Destination Stripping

In the case of source-stripping operation, the sender is responsible for marking the slot empty after it has completed an entire ring loop. With destination-stripping, the destination marks the slot empty once correctly received and thus makes the slot reusable earlier than in the previous scheme. A restriction is also introduced, which does not allow a node to immediately reuse a slot it just marked empty. This scheme introduces a very simple fairness mechanism where a node cannot starve the entire network if it never releases any of the slots it uses (this does not apply with the destination-stripping implementation).

3. TTTR MAC PROTOCOL

As describes in the introduction section, our proposed algorithm is tunable transmitter and tunable receivers (TTTR), nodes can receive and transmit packets on any wavelengths. In the paper, we propose 3 ideas listed as following to increase efficiency of MAC protocol.

1. Tunable Transmitter and Tunable Receiver, node can receive and transmit packet on any wavelengths.
2. Destination Stripping Operation, the destination marks the slot empty once correctly received and thus makes the slot will be reuse at next node.
3. Use one buffer per wavelength at a receiver node in order to avoid collisions of channel at a receiver.

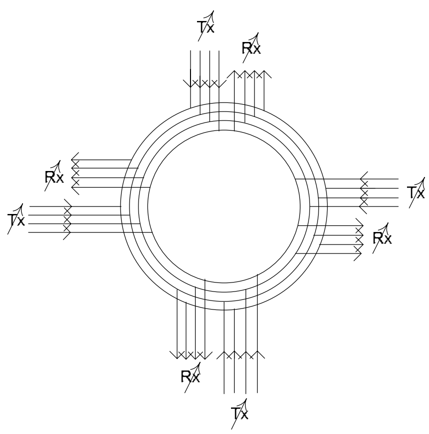

Fig. 2 Tunable Transmitter - Tunable Receiver Architecture

Figure 2 shows architecture of Tunable Transmitter – Tunable Receiver (TTTR). Since transmitters and receivers can send and receiver packet over any wavelengths or channels, this can reduce queuing delay or waiting time at transmitting nodes and then can increase throughput. With this technique, number of nodes can be much larger than the number of wavelengths, hence this overcomes scalability limitation.

Also, the second idea can increase network throughput by using the destination stripping mechanism. The marked slotted would be stripped at the receiving node. Therefore, the slot is empty and can immediately be used at the next node.

The last idea solves problem of impact of receiver collision.

At each receiver, numbers of additional buffers which equal to numbers of channels are added. Therefore, receiver can receive packets from different wavelengths simultaneously. The problem of collision is then solved.

In simulation section, the self-similar traffic distribution is used in the algorithm, for the purpose of better performance over long duration than short duration of the Poison distribution.

4. SIMULATION RESULTS

The simulation model and results are shown as followings.

4.1 Simulation model

We use the network topology with network parameters shown in Table 1 as simulation model. There are some assumptions for the simulation:

1. Input traffic is used by self similar traffic with Hurst parameter, H = 0.8.
2. Length of packet and slot is constant.
3. Not consider addressing neither capabilities nor optical and electronic issues.
4. Node interval is equally the same.

Table 1 Network Parameter

Fiber Length (FBL)	138,240 meters
Wavelength Rate (WVR)	OC-48 2.5 Gb/s
Light Velocity in Fiber (LV)	2×10^8 m/s
Fiber Delay = FBL/LV	691.2 µs
Number of Wavelengths per Fiber	4
Slot Size (S) ≈Ethernet MTU	12,000 bits
Nb of Slots per Wavelength = (FBL*WVR)/(LV*S)	144

$$\text{Average Throughput per node} = \frac{\sum_{i=1}^{n}\left(\frac{R_n}{T_n}\right)}{n} \qquad (1)$$

Where N = total nodes in network

R_n = packet was sent to complete destination node of node n

T_{out} = total packet time was sent to complete destination node of node n

$$\text{Average Queuing Delay} = \frac{\sum_{i=1}^{p}\left(t_{out_i} - t_{in_i}\right)}{p} \qquad (2)$$

Where P = total packet was sent

T_{In} = packet time was sent to queue wait for sent

T_{out} = packet time was sent from queue

According to performance comparison, average throughput per node (Mbps) and average queuing delay (second) are evaluated. Eqs.(1) and Eqs.(2) express formulas of average throughput per node and average queuing delay, respectively.

Extensive MATLAB simulations were carried out to study the performance of our proposed routing algorithm. Flowchart of the program can be shown in Figure 3.

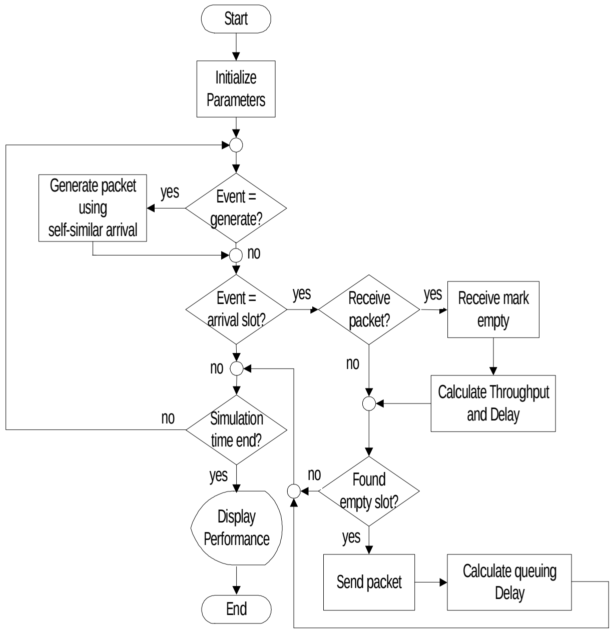

Fig. 3 Flowchart of simulation

4.2 Results

There are 4 and 16 nodes scenarios in order to evaluated scalability of the proposed mechanism. The tunable transmitter – fixed receiver, fixed transmitter – tunable receiver, and tunable transmitter – tunable receiver approaches are shortly called TTFR, FTTR and TTTR, respectively.

In the first scenario, the simulation is tested over 4 nodes/4 channels network. Each channel have capacity of 2.5 Gbps. Therefore total bandwidth of the network is 10 Gbps. Result o of the simulation of this scenario is shown in Figure 4 and 5. From the first figure, the TTTR perform the best performance of average throughput per node. The TTFR has the lowest throughput. And the FTTR has throughput of middle level compared among TTTR and TTFR. Since the transmitters and receivers are tunable and the destination stripping is used. Therefore, more empty slot in the network available. This makes throughput of TTTR the highest. Also, the queuing delay performance of TTTR is the lowest comparing to FTTR and TTFR approaches.

To test the scalability of TTTR algorithm, the second scenario has increase nodes to 16 nodes. Since nodes and wavelengths must be equal in TTFR, then TTFR is not be tested. Again from figure 6 and 7, the TTTR has the highest performance compared to FTTR.

From both scenarios, it is clear that the proposed algorithm, TTTR, overcomes higher network utilization and average throughput per node, and reduces the average queuing delay. And it achieves scalability limitation of number of nodes per wavelength.

Fig. 4 Average throughput per node (4 nodes)

Fig. 5 Average queuing delay (4 nodes)

5. CONCLUSIONS

In multichannel WDM ring, there are two main previously proposed architectures: Tunable Transmitter - Fixed Receiver (TTFR) and Fixed Transmitter - Tunable Receivers (FTTR). With TTFR, nodes can only receive packets on a fixed wavelength and can send packets on any wavelengths related to destination of packets. Disadvantage of this architecture is required as many wavelengths as there are nodes in the network. So, it has the worst in scalability problem. In contrast, FTTR architecture has advantage that the number of nodes can be much larger than the number of wavelength. Source nodes send packet on a fixed channel (or wavelength) and destination nodes can received packets on any wavelength. However both TTFR and FTTR bring low network utilization, because transmitting node have to wait for an incoming empty slot on and receiving node have to wait for corresponding wavelength that data can be received.

Therefore, this paper presents an algorithm for multichannel slotted-ring topology medium access protocol (MAC) using in wavelength division multiplexing (WDM) networks, called Tunable Transmitter - Tunable Receiver (TTTR) approach. With the approach, the transmitting node can send a packet over any wavelengths and the receiving node can receive a packet from any wavelengths. Moreover, the self-similar distributed input traffic is used for evaluation of the performance of the proposed algorithm. The self-similar traffic performs better performance over long duration than short duration of the Poison distribution. In order to increase bandwidth efficiency, the Destination Stripping approach is used to mark the slot which has already reached the desired destination as an empty slot immediately at the destination node, so the slot does not need to go back to the source node to be marked as an empty slot as in the Source Stripping approach.

MATLAB simulator is used to evaluate performance of FTTR, TTFR, and TTTR over 4 and 16 nodes ring network. From the simulation result, it is clear that the proposed algorithm overcomes higher network utilization and average throughput per node, and reduces the average queuing delay. And it achieves scalability limitation of number of nodes per wavelength. About future works, mathematical analysis of those algorithms will be the main research topic.

Fig. 6 Average throughput per node (16 nodes)

Fig. 7 Average queuing delay (16 nodes)

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REFERENCES

[1] N. Ghani, S. Dixit, and T. Wang, "On IP-over-WDM Integration," IEEE Commun. Mag., vol.38, no.3, pp. 72-84, March 2000.

[2] M. Kuznetsov, N. Froberg, S. Henion, H. Rao, J. Korn, K. Rauschenbach, E. Modiano, and V. Chan, "A Next-Generation Optical Regional Access Network," IEEE Commun. Mag., vol.38, no.1, pp.66-72, January 2000.

[3] D. Stoll, P. Leishing, H. Bock, and A. Richter, "Metropolitan DWDM: A Dynamically Configurable Ring for the KomNet Field Trial in Berlin," IEEE Commun. Mag., vol.39, no.2, pp.106-113, Feb. 2001.

[4] A. Hill, and F. Neri, IEEE Commun. Mag. "Optical Switching Networks: From Circuits to Packets", vol.39, no.3, pp. 107-108, March 2001.

[5] J. Cai, A. Fumagalli, and I. Chlamtac, "The Multitoken Interarrival Time (MTIT) Access Protocol for Supporting Variable Size Packets Over WDM Ring Network," IEEE J. Sel. Areas Commun., vol. 18, no.10, pp. 2094-2104, Oct. 2000.

[6] M. Marsan, A. Bianco, E. Leonardi, A. Morabito, and F. Neri, "All- Optical WDM Multi-Rings with Differentiated QoS," IEEE Commun. Mag., vol. 37, no. 2, pp. 58-66, Feb.1999.

[7] C. S. Jelger and J. M. H. Elmirghani. Performance of a slotted MAC Protocol for WDM Metropolitan Access Ring Networks under Self–Similar traffic. In Proc., IEEE International Conference on Communications, volume 5, pages 2806–2811, April 2002.

[8] A. Bononi, "Scaling WDM Slotted Ring Networks," in Proc. Conf. On Information Sciences and Systems, Princeton, vol. 1, pp. 659, March 1998.