Performance Evaluations with Arbitrary Transceiver Tuning Latencies in Passive Star-coupled DWDM Networks

I-Shyan Hwang*

I-Feng Huang

Ling-Feng Ku*

*Department of Computer Engineering & Science

Yuan-Ze University

Chung-Li, Taiwan, 32026

Abstract

DWDM (Dense Wavelength Division Multiplexing) is a highly promising solution to provide high bandwidth networks. In order to make more efficient use of large bandwidth, two types of DWDM transmission protocols have been designed: reservation-based protocols and pre-allocation protocols. A reservation-based protocol uses at least one control channel to reserve access to the remaining data channels. A pre-allocation protocol uses all channels for data transmission. The reservation-based protocol is considered in this paper due to its more dynamic features, although the switching tuning latency is an inevitable physical limitation factor during data transmission between the different wavelengths (channels). Currently, switching schemes in the range of microseconds or even hundreds of nanoseconds seem to be well within reach. Reducing the tuning time down to a reasonable range is unlikely to be possible in the near future. Unfortunately, the impacts of switching tuning latency on QoS during data transmission have not been studied. Thus, in this paper, we explore the impact of arbitrary tuning latency on transmitting data of variable lengths. Two on-line scheduling algorithms are proposed: The first is *multiple messages scheduling* algorithm that performs best in mean packet delay and channel utilization. The multiple messages per node schedules with an EAT channel assignment algorithm under arbitrary tuning latency. The second is a *receiver-grouping* algorithm that divides the receivers into several smaller groups to reduce the tuning time on the receiver end. We evaluate these two methods by comparing their channel utilization and average packet delay. From the simulation results, the tuning latency indeed affects the system performance. The receiver grouping algorithm proposed in this paper has the shorter average delay when the tuning latency is greater than or equal to 0.3 μ s.

Key words: DWDM, switching tuning latency, QoS, *multiple messages scheduling* algorithm, *receiver-grouping* algorithm.

被動式星狀耦合器光纖網路中
任意長度傳輸延遲之網路效能評估

黃 依 賢*
黃 一 峰
顧 凌 峰*

*元智大學資訊工程研究所

摘　要

波長分割多工技術是一個提高網路頻寬的未來主流技術。為了能夠更有效率的使用這樣大的網路頻寬,學者們即研究波長分割多工技術中的網路傳輸協定。我們可以將這樣的傳輸協定分爲兩類：先置傳輸方式和(Pre-allocation)動態配置傳輸方式(Reservation)。

當資料傳輸時，兩種通訊協定都會遇到同樣的問題，那就是調整更換所需要延遲的時間(tuning latency)。頻道更換在先置傳輸方式中比較少發生，並且已經被部份學者解決。在動態傳輸方式中，頻道更換的機率大，所以延遲時間對於整個系統的效能會有極大的影響。

這一部份的研究往往被忽略。而且就現有的雷射半導體技術來看，頻道更換延遲時間在最近的未來還是無法減少到一個可以接受並且合理的範圍。所以在這一篇論文中,我們將會針對目前光纖元件所產生最大最小範圍內的頻道更換延遲時間，觀察它對於系統效能的影響。此外，我們更提出一個新的方法－

接收端分群(receiver grouping)－來消除接收端的頻道更換的延遲時間，改進封包的平均延遲時間和網路的效能。

經由模擬的結果發現，頻道更換延遲時間對於網路效能的確會有顯著的影響，而接收端分群的方法在頻道數目少以及使用者增加的情況下會明顯的增加網路的效能。

關鍵詞：波長分割多工，交換器延遲時間，服務品質，多重訊息排程演算法，接收器-群組演算法。

I. Introduction

Dense Wavelength-Division Multiplexing(DWDM) [1], developed in Photonic networks, is an effective way for utilizing the high bandwidth of an optical fiber to provide low-loss and high-speed properties. Therefore a truly multi-channel network—with each channel capable of transmitting several Gigabits per second [2]—has become technically feasible for multimedia applications such as medical images and video conferencing. However, these applications need efficient access protocols and scheduling algorithms to provide higher data transmission rate, lower bit error, and minimal propagation delay to a large number of users. Most previous work has divided these access protocols and scheduling algorithms into two main classes [3]: reservation-based and pre-allocation-based techniques. The reservation-based technique uses a fixed channel, that is a fixed wavelength for control policy, with the other wavelengths used for data transmission [4]-[8]. In contrast, pre-allocation-based protocols use all channels for data transmission [9]-[12]. Many scheduling algorithms have been proposed for reservation-based techniques for fixed-length packet transmission and variable-length scheduling algorithms for different traffic characteristics (e.g., bursty) because the reservation-based techniques have more dynamic features than the Pre-allocation-based protocols. However, almost all of the previous works [4,6,7,18] that proposed scheduling algorithms for QoS issues ignored the impacts of switching tuning latency during data transmission among the different wavelengths (channels) through the tunable transmitters and receivers of the star-coupled configuration based photonic networks [8]. Due to the tuning range limitation [14], each channel requires 1-2 *n*m for wide bandwidth, although current technology can only support 3-7 *n*m for large bandwidth devices. This means that the reasonable tunable range can only be 3 to 7 wavelengths with current technology. The channel number is still assumed to be from 4 to 10. The switching tuning latency is an inevitable physical limitation factor during data transmission between the different wavelengths (channels). Currently, switching schemes in the range of microseconds or even hundreds of nanoseconds seem to be well within reach [16], but lowering the tuning time down to a reasonable range is unlikely to be realized in the near future [1,15,16].

For these reasons, we intend to resolve this problem based on reservation protocols. In this paper we focus our attention on the impact of arbitrary tuning latency. We propose a new method named **receiver grouping** to reduce the tuning latency of the receiver ends [20]. The advantage of receiver grouping is that by reducing the tuning latency in the receiver ends, all the receivers have to do is to park its receiving channel to the dedicated channel. This method divides all the destination nodes into numbers of small clusters that are equal to the number of data channels. The amount of destination nodes is evenly distributed in each cluster. Each cluster can only receive data using only one channel assigned to the system, and other clusters cannot occupy the dedicated channel. Each node in its cluster parks its own receiver on the dedicated channel, which means that a fixed receiver is adopted for data reception instead of a tunable receiver. Thus, the switching latency in the receiver ends is eliminated.

The rest of this paper is organized as follows. Section 2 describes the system architecture and medium access protocol. Section 3 illustrates the receiver grouping algorithm. In Section 4, the mean packet delay and channel utilization are compared for the receiver grouping algorithm and multiple messages per node algorithm [6]. Conclusion and future work is given in Section 5.

II、System Architecture and Protocol Assumptions

1、System Architecture

The proposed WDM network architecture is based on a star-coupled configuration with tunable transmitters and receivers, as shown in Fig. 1. The virtual WDM passive star network is shown in Fig. 2. Figure 2 depicts a single hop, passive star WDM network. Each node is connected to the star coupler via a two-way fiber. The network interface unit is CC-FTFR-TTTR [17] and the number of wavelengths and network stations is W+1 and M.

In a single-hop, passive star-coupled WDM network, two access protocols and scheduling algorithms can be classified into two main classes: the first is reservation-based and the second is pre-allocation-based techniques. Preallocation-based protocols pre-assign the channels to the nodes, where each node has a home channel it uses either for all data packet transmissions or all data packet receptions. The reservation-based technique uses a fixed channel, i.e. a fixed wavelength for control policy, with the other wavelengths (data channels) used for data transmission. Every time there is a request for data transmission, the source node issues its traffic demand on the control channel. The control channel then adopts control policies, such as a TDMA scheme [5,6,8] or a slotted ALOHA [4] or other random access protocols [7] as its media access protocol. The TDMA protocol is considered in this paper since it has higher throughput [5] when the load is heavy.

Fig. 1 Star-coupled configuration based WDM network with tunable transmitters and receivers

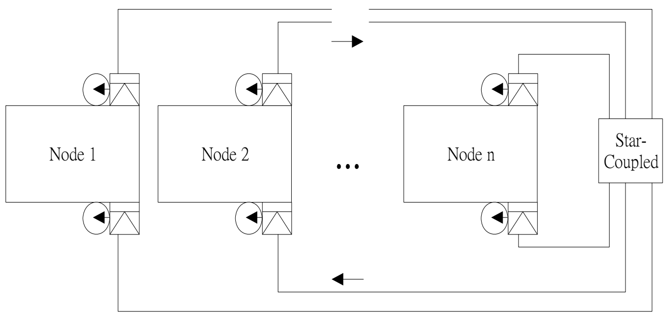
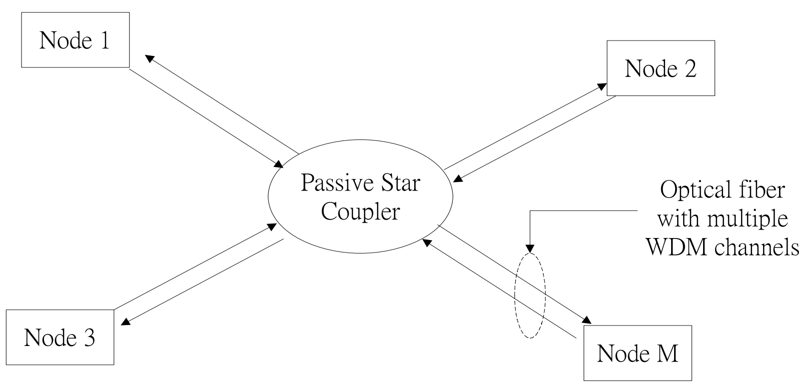


Fig. 2 Virtual WDM passive star network



2、Protocol Assumptions

The medium access protocol we propose here is similar to [5,6]. Before we describe the access protocol, we introduce the system assumptions and terminology used throughout the paper.

(**1**) **Wavelength channels**: We denote that we have W+1 wavelengths (channels) in each fiber, which are numbered λ_0 ,λ_1 ,λ_2 ,λ_3 , …,λ_W. Wavelength λ_0 is reserved for the control channel, while the remaining W wavelengths are data channels.

(**2**) **Network stations**: There are a total of M stations in our network. Basically, M may be much larger than W, based on the current status of WDM technology.

(**3**) **Transmitter and receivers per station**: In the multiple messages per node algorithm, a pair of fixed transmitters and receivers is used for the control channel, and a pair of tunable transmitters and receivers is used for data channels. This is denoted as the CC-FTFR-TTTR network interface. In the receiver grouping algorithm, a fixed receiver is adopted for data channels.

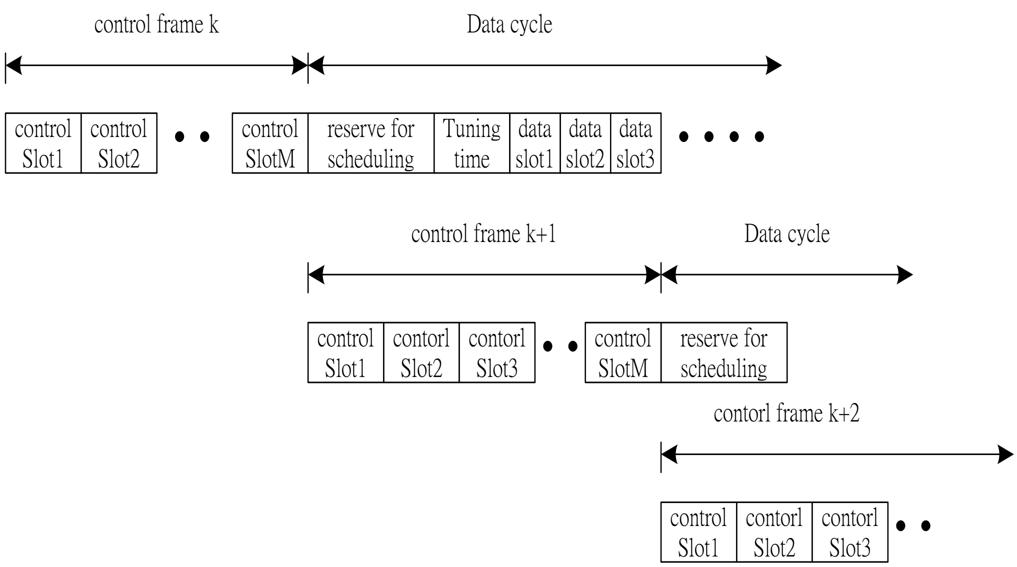
(**4**)**Tuning times**:Tuning latency is assumed to be a constant of **T** time units.

(**5**)**Propagation delay**:In our single hop, passive star topology, we assume a round-trip propagation delay between a node and PSC is **R** time units, which is the same for all nodes.

(**6**) **Synchronization**:All stations in the network are synchronized using a common clock, and synchronization on the data channels and control channel can be independent. Timing jitters can be reduced using a common clock.

Figure 3 depicts the control channel structure and data channel structure. Each node has the privilege to transmit its control packet on the corresponding control slots. This is a time division multiplexed access (TDMA) method, and a control frame consists of M control packets. In each control slot, the corresponding node broadcasts its control packet to any other stations in the network. The control packet contains the destination address and how many messages it intends to transmit.

Fig. 3 Timing sequence of control channel and data channel



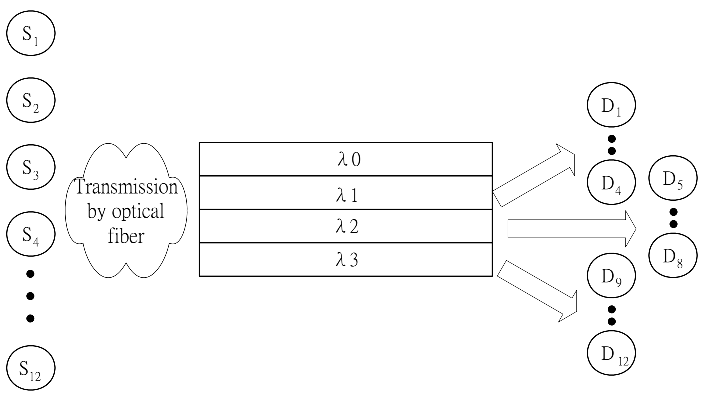
After receiving the last control slot M of this control frame, an identical scheduling algorithm is invoked by each node to determine in which wavelength and when to transmit messages. For example, station 1 (node 1) can only access the control channel on time slot 1 and send its own control packet, then after a round-trip propagation delay time R, it (and all other nodes) receives the control packet. Station 1 does not invoke the scheduling algorithm until the entire control frame has been received. Under our assumption, the time duration for the control frame is F. Once the message is scheduled, after T time units, the sending node's transmitter will tune to the selected data channel before the scheduled transmission time, and then at the scheduled transmission time it will transmit the message. After another round-trip propagation delay, when the message arrives at its destination the receiver at the destination node should be tuned to the same data channel to receive the message. All of the algorithms are executed independently at each node so that each node will reach the same unique schedule. In addition, this protocol allows us to transmit variable-length messages and the duration of data slot is equal to the transmission time of a fixed-length data packet.

III、Receiver Grouping Algorithm

The method we used to reduce the tuning latency of the receiving ends is a method referred to as **receiving grouping**. We divided the receivers into a number of clusters and each node in its own cluster parks its receiver on the dedicated channel. Suppose that there are 12 stations and 4 wavelengths numbered λ_0, λ_1, λ_2, λ_3 in our passive star network as shown in Fig. 4. As we described above, λ_0 is used as a control channel, and the remaining wavelengths are used as data channels. The difference between this and the common reservation scheme is that we dedicate λ_1 as the receiving channel for stations1 to 4, and λ_2 as the receiving channel for stations 5 to 8, and so on. The advantage of receiver grouping is to reduce of the tuning latency in the receiver ends because all the receivers need to do is park their own receiving channel to the pre-assigned dedicated channel.

However, the disadvantage is channel utilization sacrifice. For example, if station 1 and station 4 have a large traffic demand such as isochronous data [13], while the traffic demand in stations 5 to 8 is much less, such as data transfer, then the utilization of λ_1 is greater than that in λ_2 and most of time λ_2 remains idle. The number of stations that can receive data on a dedicated channel must be taken into account. If too many stations receive data using a common data channel, that will lead to a large packet transmission delay. The number of stations that can be used to receive data by applying a common data channel is the main issue investigated in this paper.

Fig. 4 Receiver-grouping



In the following, we illustrate the general transmission and reception procedure for the receiving grouping algorithm. When an entire control frame is received, the scheduling algorithms determine the data channel and time duration over which the message is transmitted/received. First we determine which group the messages belong to by inspecting the destination nodes of each message. Second, we schedule those messages by invoking the Shortest Job First algorithm, which was previously shown to have the shortest average delay per packet [5].

Finally, all of these messages are delivered to their destinations using the dedicated data channel. These steps are summarized in terms of the receiver grouping algorithm as follow:

```
receiver grouping algorithm
begin
    if we receive an entire control frame then
      repeat put all of these message in the proper group
             based on their destination
      until there are no messages left
      goto shortest job first scheduling
    else keep on receiving
end
```

IIII、 Simulations

We compared our receiver grouping method with the multiple messages per nodes (on-line scheduling), shown by Hamidzaedh [5] to have better performance, and we measured the network performance using a simulation program. This is in contrast to most of the previous studies, in which a delay-throughput graph was adopted as the network performance evaluation [5,6,19]. Generally speaking, the definition of delay is that the time from the packets generated by the source nodes to the packets received by its destination nodes. The definition of throughput is the average number of packets successfully received by each station in network system per unit time. However, the throughput could represent the load in a network system only when the length of packets is fixed. Under our assumption, we focus our discussion on variable length messages, and an average-throughput graph is not suitable for our evaluation. We adopted channel utilization as a system parameter to evaluate network performance. Here, the definition of channel utilization is the ratio of the number of transmission packets per unit time to the network transmission rate.

1、System Parameters Assumption

Our system parameters include the number of nodes (M), number of channels (W), packet length, arrival rate (λ), channel capacity (C) and tuning latency (T). The number of nodes are 50, 100, 200 and 400 of which, 50 and 100 nodes were adopted from [5] and [6]. In order to determine what situations our receiver grouping is the most appropriate, 200 and 400 nodes were chosen in this simulation. The numbers of data channels were also adopted from [5] and [6]. Due to the tuning range limit [14], each channel requires 1-2 *n*m for wide bandwidth and current technology can only support 3-7 *n*m for large bandwidth devices. This means the reasonable tunable range can only be 3 to 7 wavelengths with current technology, so the channel number is assumed to be from 4 to 10.

The packet lengths we discuss here are multiples of that in Gigabit Ethernet. We used 1518 bytes as our packet length because 1518 bytes is the maximum transfer unit in Gigabit Ethernet. There is no need for fragmentation or reassemble when a packet is conveyed between the data link layer and transport layer. In our system, each stations each time generated L packets. L is a system design parameter, if L is small, the number of times we evoke the scheduling scheme increases, and system performance becomes lower. However, if L is large, for example, when it is larger than 10, it indicates we need to transfer a frame whose entire length is at least 15180 bytes. Because of the feature of timing jitter, the frame length must be confined to a reasonable range. In this paper, the range of L is distributed uniformly from 0 to 10, where 0 means that there is no traffic demand generated at this time.

Based on those four types of station numbers, the arrival rate in 50 nodes,100 nodes,200 nodes and 400 nodes are 6.006 pkt/μs, 6.6635pkt/μs, 6.2506 pkt/μs, and 6.741 pkt/μs, respectively. The definition of arrival rate in this paper is the arrival number of packets starting between the packets have been scheduled and their arrival to the data channels.

In previous studies [5,6,19], the channel bandwidth was not discussed. Since the WDM network can achieve multi-gigabit/second even terabit/second, we assumed that the bandwidth of each channel is 9620.928 Mbps, which equal to optical carrier level 192 (OC-192). Using our assumption, the duration for transmitting a packet whose length is 1518 bytes at OC-192 is approximate to 1.22 microseconds, and the control slot is assumed approximate to 50 nanoseconds.

Finally, we introduce the tuning time of transmitters and receivers. Currently, switching schemes in the range of microseconds or even hundreds of nanoseconds seem to be already achievable [16,21]. In this study, the optical switching speed that used to evaluate the network performance is ranged from 10 nanoseconds to 1000 nanoseconds. The tuning latency which is smaller than 100 nanoseconds can be negligible. For convenience, we adopted three tuning time 0.1 microseconds, 0.5

microseconds and 1 microseconds to evaluate our system performance.

In the next section, the simulation results are measured and analyzed [20]. The simulation is divided into three categories, tuning latency = 0.1 μs, tuning latency = 0.5 μs, and tuning latency = 1 μs. In each sub-category, we evaluate "average delay-number of frames" graph by employing four channels, seven channels, and ten channels, respectively. Additionally, in each sub-category, the utilization and average delay of variable channel number will be examined.

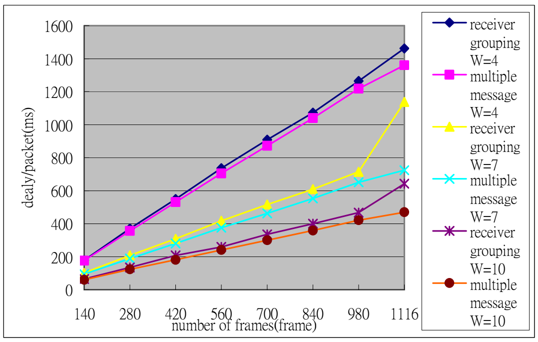
2、Simulation Ⅰ

For simulation Ⅰ, Fig. 5(a) depicts the effect of varying channel numbers on the frame delay under the receiver-grouping and multiple messages per node algorithms. With M= 50,W=1, 4, 7 and T=0.1 μs. This graph describes how many numbers of frames have been received successfully and the delay time for each frame.

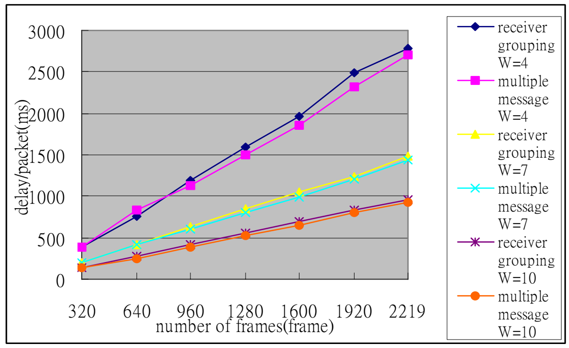
The graphs show that if the channel numbers increase, the frame delay time would drop gradually. This feature can also be observed in Fig. 5(b) with M=100, Fig. 5(c) with M=200, and Fig. 5(d) with M=400, respectively. The difference among them is that as the number of node increases, the delay time also increases, besides, the average delay distance between two the methods becomes closer in Fig. 5(c), Fig. 5(d). This indicates that if the user population increases, the increase in average delay in multiple messages per node method is faster than in receiver grouping method. From Figs. 6(a), we can see that multiple messages per node has a longer delay time of each frame for M=400 nodes, W=4,7 and T=0.1 μs.

Fig. 5 Effect of delay time versus number of frames of varying channels with T=0.1 μs for (a) M=25, (b) M=50, (c) M=100, and (d) M=200 nodes, respectively.

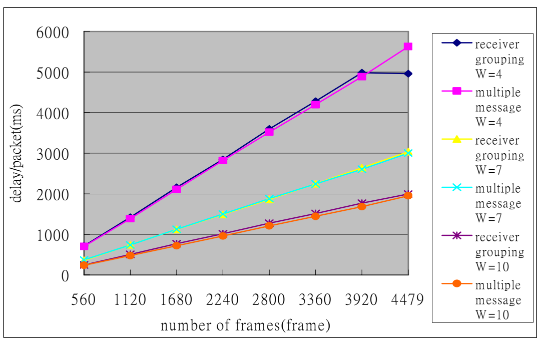
(a)



(b)



(c)



(d)

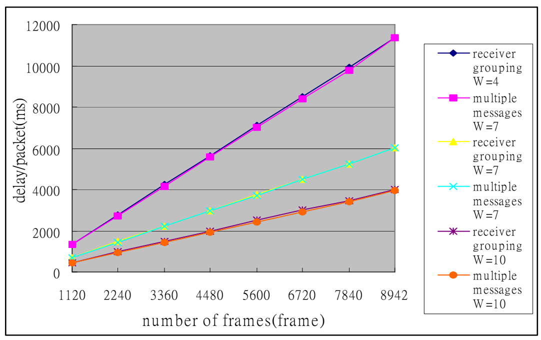
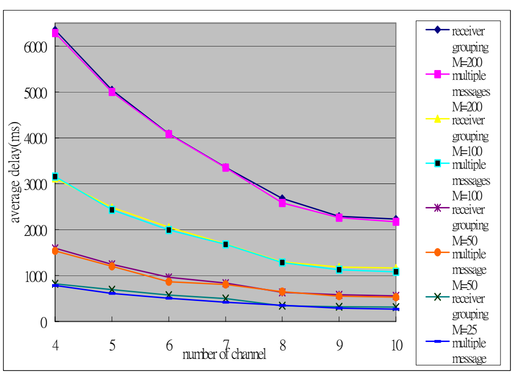
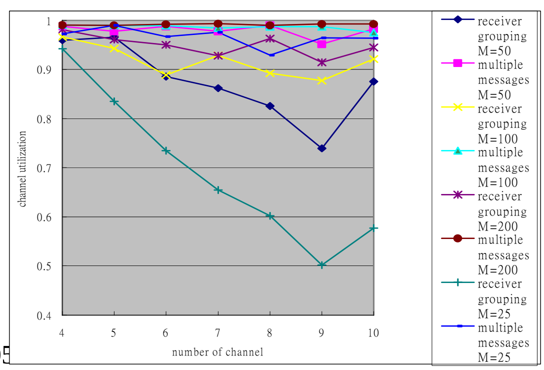


Fig. 6 (a) Effect of delay time versus varying channels (b) effect of utilization with varying channel for the different nodes M=50, 100, 200, 400 nodes and T = 0.1 μs

(a)



(b)



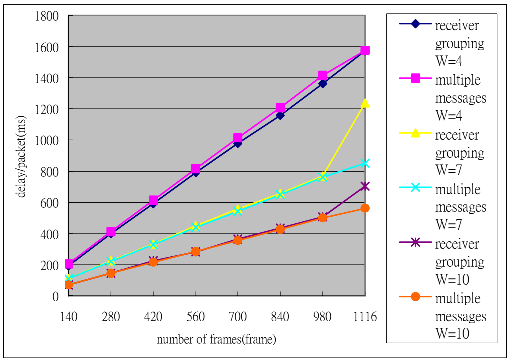
The channel utilization was adopted as our system parameter because it could reflect the efficiency of scheduling algorithm, and the network throughput. However, owning to the nature of receiver-grouping algorithm, each time in each node there is a random generation for the probability of the decision at which destination node to transmit. This leads an unfair load at each channel and poor channel utilization. Fig. 6(b) illustrates the effect of utilization whit varying channel under M=50, 100, 200, 400 nodes and T = 0.1 μ s.

Fig. 6(b) shows that the receiver grouping algorithm indeed suffered from the destination node random distribution, especially in M=50 nodes. However, as the user population grows, the channel utilization in both algorithms also increases. The channel utilization of the receiver grouping with varying channel number all exceeded 90 % for M =200 and 400 nodes. That indicates that the probability of choosing which destination node to transmit has a uniform distribution with a heavy offered load.

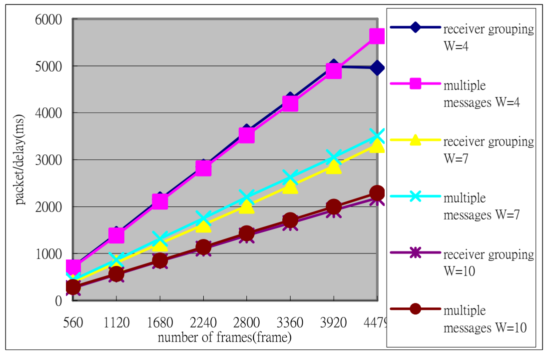
3、Simulation Ⅱ

Since the simulation phenomena in each sub-category is quiet similar to each other, i.e. the curves representing M=100, 200, 400 nodes are similar, so we will show the simulation result by observing M=100, 200, and 400 nodes in simulation Ⅱ and simulation Ⅲ, respectively.

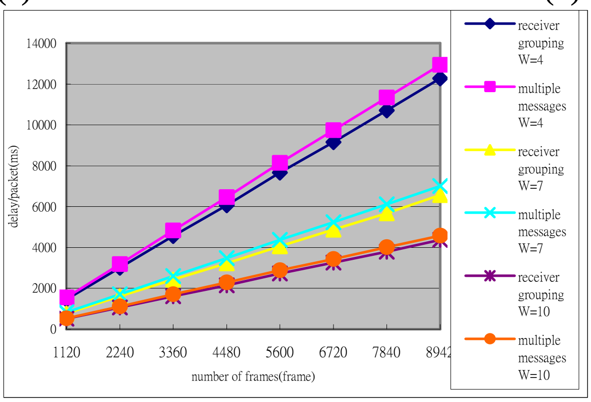
Fig. 7 Effect of delay time versus number of frames of varying channels with T=0.5 μs for the different nodes (a) M=100, (b) M=200, and (c) M=400, respectively.



(a)

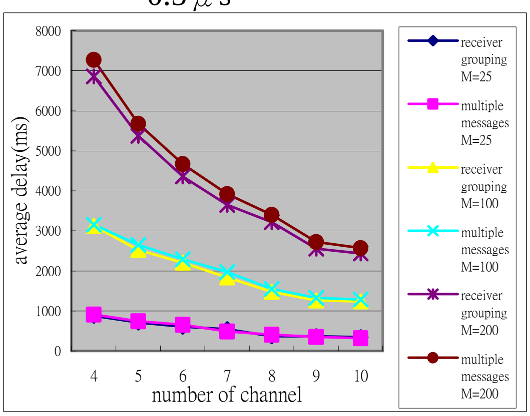


(b)

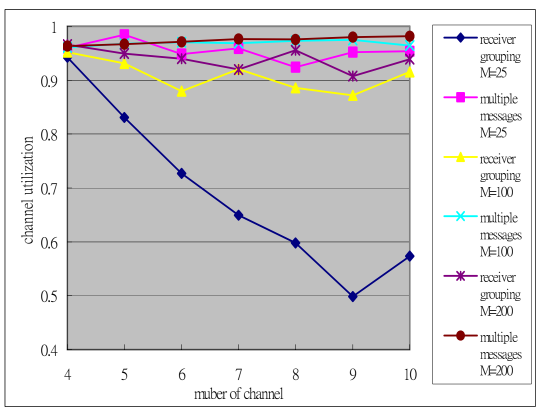


(c)

Fig. 8 (a) Effect of delay time versus varying channels (b) effect of utilization with varying channel for the different nodes M=100, 200, 400 nodes and T = 0.5 μs



(a)



(b)

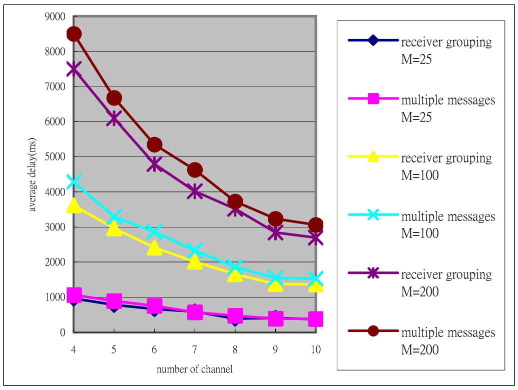
Fig. 7 shows that the receiver grouping algorithm provides a shorter delay time than that of multiple messages per node algorithm for M=100,200, 400 nodes. Fig. 7 also shows that when the tuning latency equals to 0.5 μ s, multiple messages per node algorithm suffered from transceiver's arbitrary tuning time. Comparing our simulation results in simulation Ⅰ with simulation Ⅱ, the difference between Fig. 6(a) and Fig. 8(a) is that Fig. 8(a) has longer average delay in both methods, and the curves turn down in an identical trend in both Figures.

With channel utilization, receiver grouping method still perform worse under tuning latency=0.5 μ s. However, we determined that the two methods perform a similar channel utilization with M=200 and 400.

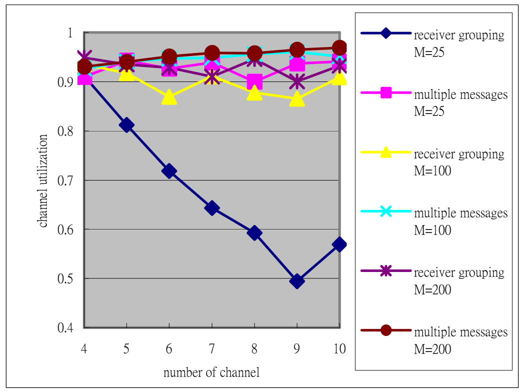
4、Simulation Ⅲ

Fig. 9(a) and (b) depict that the receiver grouping performs a shorter delay time than multiple messages per node algorithm for M=100, 200, 400 nodes and T=1 μ s. We can conclude that receiver grouping method is suitable for large user population with fewer data channels. The multiple messages per node method is suitable under any circumstance, however, when the tuning latency grows, receiver grouping have a better system performance. Fig. 9(a) and Fig. 9(b) depict the features that we mentioned above. Fig.10 depicts the smallest tuning latency that receiver grouping has shorter average delay than multiple messages per node algorithm under varying network stations is T = 0.3 μ s.

Fig. 9 (a) Effect of delay time versus varying channels (b) effect of utilization with varying channel for the different nodes M=100, 200, 400 nodes and T = 1.0 μ s.

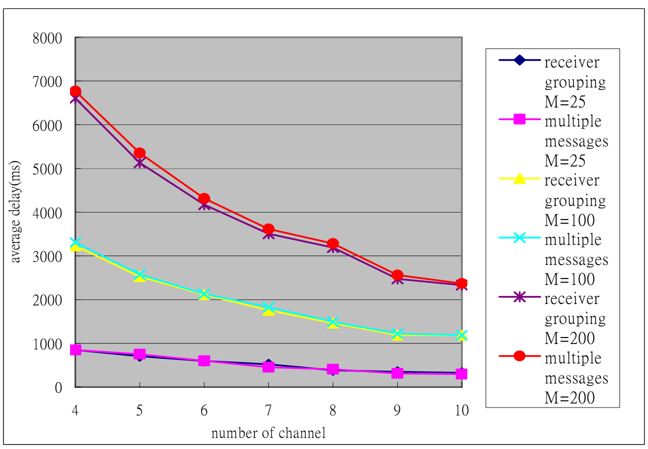


(a)



(b)

Fig. 10 Effect of delay time versus varying channels of receiver grouping and multiple messages per node for the different nodes M=100, 200, 400 nodes and T=0.3 μ s



5、Conclusion and Future Work

We have showed tuning latency does impact in passive star coupler WDM network regardless whether they are scheduled with receiver grouping algorithm or multiple messages per node algorithm. Consequently, when the tuning latency equal or less than 0.1 microsecond (100 nanoseconds) and the number of stations is reduced to 50 or even lower, receiver grouping perform longer packet delay time and worse system performance. However, as the tuning latency grows above 0.3 μs and the number of stations becomes higher than 100, receiver grouping method performs better average packet delay time, and the receiver grouping still behave worse than multiple message per node most of the time. As we mentioned before, both receiver grouping method and multiple messages per node method have their own drawbacks. The ones for multiple messages per node method are the arbitrary tuning latency at its transceiver end and its higher cost. The drawback for the receiver grouping method is the random destination nature. However, we have showed receiver grouping achieve better channel utilization in the circumstance of M=100,200, T=0.5 μs,1 μs, and 4 data channels. Accordingly, we conclude that receiver grouping is suitable especially for the large user population and few data channels. This feature coincides with our network environment today. This study indicated that receiver grouping algorithm has better mean packet delay when the tuning latency is larger than 0.3 μs. The future works can be focused on:

（1） he random destination feature causes transceiver conflict, which is a nature drawback to all the scheduling algorithm [22]. Since the media access protocol for the receiver grouping algorithm is a pre-transmission scheme, we can predict which channel is heavily loading and which is lightly loading or staying idle after a small period of time. Thus, we define a threshold value, when the workload difference between adjacent channels exceed the threshold, the adaptive algorithm would be evoked and dispatch the workload in each channel fairly. The adaptive receiver grouping algorithm can possibly to achieve a better channel utilization and system throughput.

（2） Quality of service (QoS) is also an important issue in WDM networks. We plan to classify our traffic demand into two types: isochronous data and asynchronous data. Isochronous data has the following characteristics 1. Uniform in time, 2. Recurring at regular equal interval, and 3. Delay sensitive. Due to these features, we assume the isochronous data has higher priority. We will investigate the performance based on priority scheduling and satisfy these three factors: 1. Guaranteed bandwidth, 2. Bounded packet delay, and 3. Recurrence in time in our system.

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