An Adaptive Scheduling Algorithm for Differentiated Services on WDM Optical Networks

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Abstract- **One of the important issues in the design of next generation high-speed networks is to provide differentiated services to different types of applications with various time constraints. In this paper, we study the problem of providing real-time service to either hard or soft real-time messages in conjunction with a normal transmission service to variable-length messages without time constraints in wavelength division multiplexing (WDM) optical networks. We propose an adaptive scheduling algorithm to schedule and manage message transmissions in single-hop passive-star coupler based WDM optical networks. In particular, we develop an adaptive scheme for scheduling message transmissions in order to improve the network performance when both real-time and non real-time messages are transmitted in one single topology. In addition, we have conducted extensive discrete-event simulations to evaluate the performance of the proposed algorithm. This study suggests that when scheduling message transmission in WDM networks, a differentiated service should be considered to benefit the transmission of both real-time and non real-time messages so that the overall performance of the network could be improved.**

I. INTRODUCTION

The recent development in fiber optic technology is making the design of gigabit networks possible. Gigabit networks can provide a very large bandwidth capable of carrying various transmission signals with very different frequencies. The technique of *Wavelength Division Multiplexing* (WDM) is shown to be an effective method to utilize the large bandwidth of an optical fiber. Several system structures of the optical WDM networks have been proposed as in [1, 2]. A typical and simple network is the structure with a single-hop topology, which directly connects the network nodes to a passive star coupler [3]. Based on the hardware structure of a WDM optical network, multiple media access control protocols are needed to schedule the messages to be transmitted through the multiple channels of the optical fiber. In particular, the design of a medium access control protocol that makes efficient use of the channel resources while satisfying the messages and system constraints is highly expected. The protocols and algorithms proposed in this system structure of WDM optical network can be divided into two different categories: the pre-allocation-based techniques as in [3, 4, 5, 6]; and the reservation based techniques as in [7, 8, 9, 10, 11]. The pre-allocation-based techniques assign transmission rights to different nodes in a static and predetermined manner. The reservation-based algorithms reserve one of the available channels as the control channel to transmit global information about messages to all the nodes in the network. The other channels are used to transmit real messages. Reservation-based techniques are more dynamic in nature and assign the transmission rights to the messages based on real-time availability of the receiving node and the channels in the network. Our work in this paper focuses on the reservation-based technique.

One of the important issues in the design of high-speed networks, such as WDM optical networks, is to provide real-time communication service for applications with time constraints. The most important aspect of the time-constrained applications is that a message generated at a source must be received at its destination within a given amount of time. This time is referred to as message *deadline*. If the delay of a message in the network exceeds its time constraint, the message is considered to be lost (useless). There are two types of real-time messages. One is hard real-time message with the property that the time to transmit a message in the network is not allowed to be longer than the message deadline. The potential late messages must be dropped rather than transmitted. The other is soft real-time message with the property that a message delay longer than the deadline can be tolerable. To provide real-time service to time-constrained messages is to

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schedule and manage the transmission of the messages to meet their time constraints as much as possible.

In this paper, we develop a novel scheduling algorithm for reservation-based medium access control protocols in a single-hop passive-star coupled WDM optical network to provide differentiated service to messages with different time constraints. The objective of this algorithm is to balance the network service to all kinds of messages while the messages' time constraints can be satisfied as much as possible.

The remainder of this paper is organized as follows. Section II specifies our system model and the network service. Section III presents our new algorithm. And section IV presents the results from experiments to show the performance of the proposed algorithm. Finally, section V concludes the paper.

II. SYSTEM MODEL AND NETWORK SERVICE

We consider message transmission in a single-hop WDW optical network whose nodes are connected to a passive star coupler via two ways fibers. Each direction of the fiber supports C+1 WDM channels with the same capacity and there exist N nodes in the network. The C channels, referred to as data channels, are used for message transmission. The remaining channel, referred to as the control channel, is used to exchange global information among nodes about the messages to be sent. The control channel is the basic mechanism for implementing the reservation scheme. Each node in the network has two transmitters and two receivers. One transmitter and one receiver are fixed and are tuned to the control channel. The other transmitter and receiver are tunable and can tune into any data channel to access messages on those channels.

The nodes are assumed to generate messages with variable length, which can be divided into several equal-sized packets. The basic time interval on the data channels is the transmission time of one packet. The nodes are divided into two non-disjoint sets of source nodes s_i and destination nodes d_j. A queue of messages to be transmitted is assumed to exist at each source node s_i.

A Time Division Multiple Access (TDMA) protocol is used on the control channel to avoid collision of the control packets belonging to different nodes. According to this protocol, each node can transmit a control packet during a predetermined time slot. The basic time interval on the control channel is the transmission time of a control packet. N control packets make up one control frame on the control channel. Thus, each node has a corresponding control packet in a control frame, during which that node can access the control channel. Figure 1 illustrates some of the basic concepts in our model.

The procedure of messages transmission and reception in this system model works as follows: A node has to transmit a control packet on the control channel in its assigned time slot before sending a message to its destination node. After one round-trip propagation delay, the destination node and the other nodes in the network receive the control packet. Then the distributed scheduling algorithm is invoked at each node to determine the data channel and transmission time slots of this message transmission. Once the message is scheduled, the sending node's transmitter will tune to the scheduled data channel and sends this message at the scheduled time. The receiver of this message destination node should tune to that channel to be ready to receive the message. After the propagation delay, the message will arrive at the destination node and it is received.

The service provided by the network to the messages is not only to transmit the real-time messages within their time constraints but also to transmit non real-time messages with less message delay.

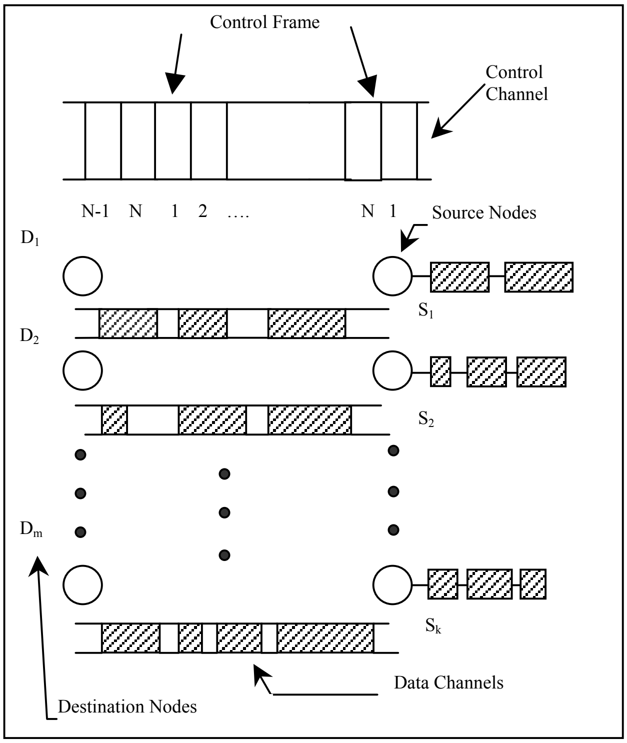

Fig.1. The system model of the network.

III. SCHEDULING ALGORITHM

Briefly, a scheduling algorithm of a MAC protocol has basically two functions: the resources assignment and the message transmission ordering. The technique to assign data channels and transmission time slots to selected messages may vary based on different WDM optical network models. We adopt *Earliest Available Time Scheduling* (EATS) in [9] as our basic channel assignment mechanism.

We have the following two principles when the new scheduling algorithm is considered. First, the new algorithm has to benefit the transmission of the messages with time constraint as much as possible. With it, we expect the message loss rate or messages tardy rate to be as low as possible. The other is that the messages without time constraint will also receive efficient transmission service with low average message delay. With these considerations in mind, the new scheduling algorithm should first schedule the messages based on their time constraints. Then, the messages without time constraints could be scheduled during the time when the real-time messages have to wait for transmission.

To schedule the transmission of messages based on time constraints, we adopt the *Minimum Laxity First* (MLF) scheme. By scheduling messages with minimum laxity first, the MLF algorithm could schedule and transmit tight time-constrained message first to reduce the messages loss rate.

To schedule the transmission of messages without time constraints, we have to seek available time periods during the scheduled real-time message transmission. We have the following observations on the transmission of real-time messages. After the real-time messages have been scheduled to transmit on certain channels in certain time slots to their destination nodes, some of them could be blocked just because there may be more than two consecutive messages going to the same destination node in a very short time period. In the specific case, the first message will be scheduled for transmission in one channel and be received at its destination. If the trailing messages go to the same node as the first one, they have to wait until the previous message has been received, although there are enough channels available at the time. As a result, the utilization of the transmission channels is quite low and succeeding messages will be blocked so that the average message delay for the non real-time messages will be very high. This observation implies that we can use the period of time, when the real-time messages are being blocked to wait for their destinations to be free, to schedule the transmission of the messages without or with time constraints. The condition for this scheduling to be successful is that the transmission time of these messages should be less than the time during which the blocked real-time messages are waiting for their destinations to be free. Since the global information of the states of the receivers and channels are available to every source node, this idea is feasible and can easily be implemented.

With the transmission channel and time slots assignment technique, we combine our real-time scheduling scheme with the insertion scheduling technique, which inserts non real-time message transmissions in a tolerant time period, to form a new scheduling algorithm, named *Minimum Laxity First with Time Tolerance Scheduling Algorithm* (MLF-TTS). With the MLF-TTS algorithm, our initial objective could be achieved, that is to schedule the transmission of real-time messages to meet their time constraints as much as possible while the transmission of messages without time constraints could also be benefited. Compared with the simple MLF scheduling algorithm, we can expect that the average message delay for the messages without time constraints could decrease while the message loss rate or message tardy rate could be kept as low as those of the MLF algorithm. Unlike the scheduling algorithms, which aim to only decrease the average message delay, the MLF-TTS can be expected to significantly increase the real-time performance of the WDM MAC protocol.

We assume that there are M nodes and C data channels. The messages have variable lengths, l, following an Exponential distribution. The real-time messages have time constraints with laxity, p, following an Exponential distribution too. The messages can be transmitted from source node i to destination node j, where $i \neq j$ and $i, j \in M$. The *Receiver Available Time* (RAT) Table can be expressed as an array of M elements, one for each node. $RAT[i] = w$, where $i = 1, 2, ..., M$, means that node i will be free after w time slots. The *Channel Available Time* (CAT) Table can be expressed as an array of C elements, one for each channel. $CAT[j] = v$, where $j = 1, 2, ..., C$, means that channel j will be available after v time slots.

The MLF-TTS Algorithm
Begin:

  Wait for a control packet on the control channel return;
  Sort the real-time messages represented in the control frame based on their laxities;
  Sort the non real-time messages based on their lengths;
  Assign the transmission priority to different messages

with real-time messages taking higher priorities;

S1: Assign transmission channel to the current highest priority message until all messages are scheduled;

Search $CAT[i]$ for a channel with the earliest available time;

Use the earliest available channel k, to transmit the selected message;

Calculate $r = RAT[j] + T$, $t1 = \max(CAT[k], T)$, $t2 = \max(t1 + R, r)$;

where T is the transmitters' tuning time, R is the propagation delay.

Schedule the message transmission time at $t = t2 - R$;

Test whether the message laxity can be exceeded;

If waiting time, t_{ws}, + transmission time (message length), l_s + R > message laxity, p_s ;

drop it if it is a hard real-time message,

degrade it to non real-time with the lowest priority if it is a soft real-time message;

return to S1 to schedule another message;

If waiting time, t_{ws}, + transmission time (message length), l_s + R < message laxity, p_s

update $RAT[j] = t2 + l_s$, $CAT[k] = t2 - R + l_s$;

where $t_{ws} = t$- current time.

Search the current least visited node by $\min(RAT[j])$;

Search the candidates with destination to $\min(RAT[j])$;

S2: Select one message to schedule by testing availability of time tolerance until all are considered;

If waiting time, t_{we}, + transmission time (message length), l_e + R > waiting time, t_{ws}, ;

return to S2;

If waiting time, t_{we}, + transmission time (message length), l_e + R < waiting time, t_{ws},

assign the same channel to the message for the destination node $\min(RAT[j])$,

update $RAT[\min(RAT[j])] = t_{we} + l_e + R$;

return to S1;

End.

IV. EXPERIMENT RESULTS

In this section, we present the results of a set of performance-comparison experiments to evaluate the performance of our proposed scheduling algorithm. In the experiments, we study the performance of the network when integrated traffic (including messages with or without time constraint) with varying message arrival rates. The number of nodes is 50, and the number of channels is 4. Round-trip propagation delay is another parameter, which is set to 10 time units. Message length is a random variable following an Exponential distribution. A Poisson message arrival rate across all nodes is considered which ranged from 0.002 to 0.005 messages per unit time as its mean for each node. Destination nodes for messages are chosen according to a uniform probability distribution. The message time constraint is expressed as messages laxity, which is a random variable following an Exponential distribution. Metrics of real-time performance in the experiments are the *message loss rate* for hard real-time messages transmission, the *message tardy rate* for soft real-time messages transmission. The candidate algorithms for the performance-comparison experiments are *Shortest Message First* (SMF), MLF and our new MLF-TTS scheduling algorithms.

Figure 2 presents the real-time performances of the network using different algorithms for the transmission of the integrated messages. As shown in Figure 2, the performances of the MLF algorithms are much better than those of the SMF algorithms and the MLF-TTS algorithm. However, although the message loss rate of the MLF-TTS algorithm is not as exactly low as that of the MLF algorithm, it has improved the real-time performance of the network a lot. The improvement in terms of the message loss rate by the MLF-TTS algorithm can reach up to more than 30% of that of the SMF algorithm when the traffic is quite heavy. This is obviously because the MLF-TTS algorithm basically follows the principle of the MLF algorithm. And the insertion of scheduling other message's transmission will not violate the MLF principle. So it has achieved almost the same real-time performance as that of the MLF algorithm.

Figure 3 illustrates the relationship between the system throughput and the message arrival rate.

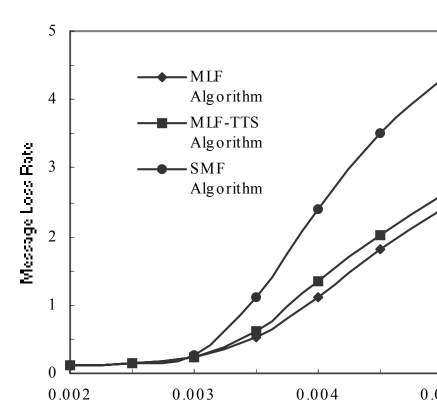

Fig.2. Message loss rate vs. average arrival rate.

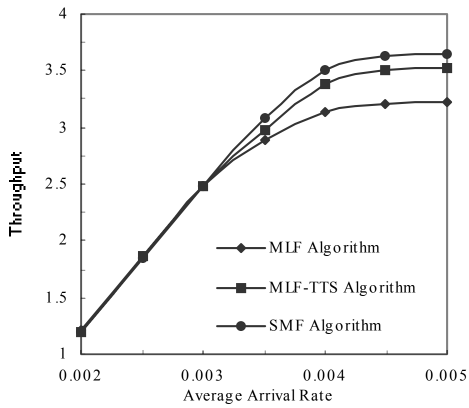

Fig.3. Throughput vs. average arrival rate.

It reveals that the SMF algorithm performs better than the MLF algorithm and the MLF-TTS algorithm. However, the MLF-TTS scheduling algorithm has reached almost the same performance in terms of throughput as that of the SMF algorithm. This is because the MLF-TTS algorithm always tries to take advantage of the unused time slots by inserting another scheduling of message transmission so that the channel utilization can be improved.

V. Conclusion

In this paper, we proposed a novel reservation-based scheduling algorithm, named MLF-TTS, for providing differentiated service to messages with and without time constraints in single-hop passive-star coupled WDM optical networks. Using this scheduling algorithm, we can balance the transmission service to either hard or soft real-time messages and the transmission of non real-time messages. The results of our experiments showed that our scheduling algorithm can achieve almost the same real-time performance as that of simple real-time scheduling algorithm; however, the performance of transmission of non real-time messages can also be improved simultaneously.

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