A New Channel Priority Scheduling Technique for WDM Star Networks

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Abstract- **We consider an optical wavelength division multiplexed (WDM) network with broadcast and select architecture. The performance of such a network seriously depends on the resulting scheduling method. Our goal is to improve the performance of the network, in terms of channel utilization and network throughput, using two scheduling techniques: the prediction and the sorting technique. The new proposed algorithm adopts the prediction and the sorting feature, in a different way. Our work includes the presentation of the novel algorithm, the comparison of two ancestors scheduling algorithms with the new one, and the simulation results of each of the three scheduling algorithms.**

Keywords: optical WDM networks, star topology, prediction, service sequence, scheduling.

I. INTRODUCTION

As we live in a network world, the ever growing demands for communication capacity go stronger. The bandwidth required by each individual user has been increased dramatically. Optical technology comes to solve this problem, as optical fibers offer radically higher bandwidths than alternative transmission media [1]. If we want to utilize the optical fiber in a cost-effective way, it would be useful to share all of its huge capacity among several communication stations. Wavelength division multiplexing (WDM) technique offers an excellent way of exploiting the huge bandwidth of optical fibers by introducing concurrency among multiple users transmitting at ‘electronically’ feasible rates [2]. WDM broadcast and select networks [3] comprise a number of nodes and a passive star coupler in order to broadcast from all inputs to all outputs. Transmitters and receivers are connected via two way fibers to the optical star coupler. Each node of the network has a transmitter, in order to send data and a receiver, in order to accept and filter data. Each transmitter and receiver can be fixed or tunable [4]. This paper focuses on the single hop broadcast and select star local area network with one tunable transmitter and one fixed receiver (TT-FR) per node (Fig. 1). It is obviously that a protocol, oriented to WDM TT-FR single hop broadcast and select network, has to provide two sets of appropriate rules for: a) coordination transmissions between all the nodes of the network, and b) determination (or elimination) probable collisions. A very effective way to organize the data sending (transmission) and the data acceptance (receipt) by the protocol is to divide the time into two independent periods. During the first period, known as reservation phase, the protocol accepts the total transmission requests of the nodes of the network and performs a scheduling process in order to define the order of the data transmission of each node to the desired transmission channel. During the second period, known as data phase, happens the real sending of data, according to the method, which have been agreed in reservation phase. This paper presents a novel scheduling technique, which try to improve the performance of the network. Its goal is to decrease as possible the estimation time of the scheduling process, in order to support higher network speeds. At the same time, the proposed algorithm considers each node and each channel individually and serves it according to some criteria and metrics. In other words, simulation results show an improvement in network performance, by changing the order of service and examination of the nodes and the channels while the scheduling process is formed. The improvement that new algorithm brings up is presented through a detailed series of figures.

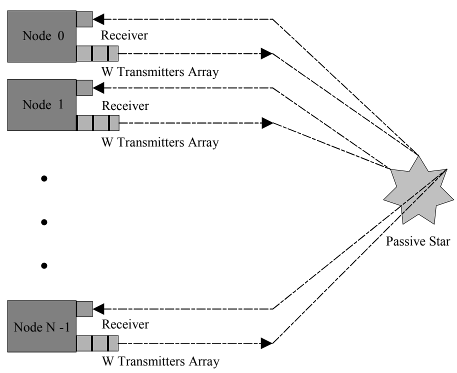

Figure 1. The network consists of N nodes and W channels, connected via a passive coupler.

The paper is organized as follows: Section II analyses the architecture and the structural elements of the network, while Section III analyses the three ancestor protocols. Section IV presents the new proposed algorithm, and is followed by the figures and the detailed comparisons between the performances of the whole three algorithms in Section V. Finally, concluding remarks are given.

II. NETWORK EXAMINATION

The network comprises N nodes and W channels. Each node disposes a tunable transmitter, which provides the transmission of data to the appropriate channels. Moreover, the node has a fixed receiver, which allows receiving data in the particular channel, which is dedicated to each node. The interconnection of the nodes is accomplished through a passive device that allows transparent and immediate transfer of data from the transmitters to the receivers. Each node receives data on a specific channel, known as home channel. So, if a node wants to transmit data to a receiver node, tunes the laser to the appropriate channel, namely the destination's home channel. In the specific network we have N nodes and W channels; hence N/W nodes share the same home channel. A packet is generated at a node is queued in the channel queue, corresponding to the destination's home channel. We suppose that the time is divided in time frames. Each frame is composed of a reservation phase and a transmission phase. Also, each frame consists of a number of timeslots, during which the reservation and the packet transmission take place. In pre-transmission co-ordination based protocols the algorithm accepts the time demands of each node of the network and stores them in a transmission frame, called traffic demand matrix, $D = [d_{N,W}]$. The total requests of each node are collected and stored, by the scheduling algorithm, in a specific storage structure, know as traffic demand matrix $D = [d_{N,W}]$. This storage matrix shows the global information of the network for each frame [5]. The matrix has N rows and W columns, as N is the number of the nodes and W is the number of the channels. Hence, the cell in the i row and j column contains the amount of time (usually in timeslots), which i node requests to transmit on the j channel, as j channel is the home channel of the destination node. As each frame starts, all nodes run the same distributed scheduling algorithm, based on the same information. So, the algorithm can be able to decide how transmissions and receptions should be made for the next frame. In order to understand better the usage and the operation of the demand matrix a specific example is considered:

$$D1 = \begin{bmatrix} 3..2..2 \\ 1..2..3 \\ 2..2..4 \end{bmatrix}$$

It is clear that in the specific example the network contains three nodes and three channels. The first node requests three timeslots for the first channel, two timeslots for the second channel and two channels for the third channel. With the same manner, the second node requests one node for the first channel, two timeslots for the second channel, and three timeslots for the third channel. Lastly, the third node needs two timeslots for the first channel, two timeslots for the second channel and four timeslots for the third channel. In the continuance of this work we will use the specific demand matrix to compare a set of scheduling algorithms.

III. PREVIOUS WORK ON ONLINE SCHEDULING ALGORITHMS

Online interval-based scheduling (OIS) [6] is a typical simple online protocol. This scheme incorporates online scheduling on the basis of available time intervals on channels and for each examined node that requests reservation. As we said before each node runs at the same time the same distributed scheduling algorithm. The entire demand matrix is not necessary, hence the construction of the scheduling matrix begins immediately after the first set of requests (by the first node) is known. In order to be able to function properly the algorithm, each node maintains a list of time intervals that are available on every data channel. If we assume that node N_1 requests t_1 timeslots to transmit packets using channel W_1, the OIS algorithm searches for an available time space, equal to t_1 in order to reserve for this node. When OIS finds a suitable timeslot beginning at time t, it reserves channel W_1 from time t to $t + (t_1\text{-}1)$. Of course, the algorithm is not allowed to assign more nodes at the same interval, in order to keep the schedule collision free. The same idea is implemented for the requests of the rest nodes. It is obvious that OIS cannot reserve another channel for node N_1 that overlaps with the above reservations. If the algorithm concludes that the scheduled transmission does not result in any collisions, it includes it in the scheduling matrix that is being constructed. As a result, at any given timeslot the request table (scheduling matrix) of OIS comprises of the nodes that are scheduled to transmit and the wavelengths they will transmit in. We examined the main idea of OIS, whose operation will become clear if we consider the same example demand matrix D1 used in before. The application of OIS would result in the scheduling matrix of Figure 2. It is obvious that the total amount of demands is equal to twenty one. The first node asked for seven, the second node asked for six and the last one asked for eight. OIS constructed a schedule scheme that composes ten timeslots for each channel. So, the total timeslots are thirty. We can observe, also, that nine timeslots remains idle, so the total percentage of idle timeslots is 9/30, 30%.

timeslots

	0	1	2	3	4	5	6	7	8	9
W_0	N_0	N_0	N_0	N_1	N_2	N_2	---	---	---	---
W_1	N_1	N_1	---	N_0	N_0	---	N_2	N_2	---	---
W_2	N_2	N_2	N_2	N_2	---	N_0	N_0	N_1	N_1	N_1

frame

Figure 2. The final scheduling matrix constructed by OIS/POSA

The basic problem with OIS is the large amount of time, of the schedule computation period of each frame. As we mentioned before, each frame is composed by a reservation phase and a data phase. According to OIS, the transmission data have to wait for the algorithm to finalize the schedule for each frame. In order to decrease the delay that a ready node experiences while waiting for OIS to compute the schedule, predictive online scheduling algorithm (POSA) [7] attempts to eliminate the duration of the schedule computation process by predicting the nodes' requests for the next frame. In this direction POSA makes use of a hidden Markov chain and after an initial learning period of several frames, POSA attempts to predict the requests of the nodes for the subsequent frame based on their requests for the previous frame. Because the algorithm does not wait for the nodes to send their requests in order to compute the schedule but starts working based on the predictions, a significant amount of time is saved. The predictor uses two different algorithms, the learning algorithm and the prediction algorithm. During each frame of data, the predictor first runs the learning algorithm and then the prediction algorithm. The first algorithm is responsible for informing and updating the data of the history queue, while the second one is responsible for predicting the demand matrix as accurately as possible. Finally, we must pinpoint that POSA uses the same algorithm as OIS to construct the scheduling matrix. This fact means that if we consider the same demand matrix D1, as output of the predictor of POSA then the constructed scheduling matrix will be the same as Figure 2.

Check and sort-predictive online scheduling algorithm (CS-POSA) [8] is an extension of POSA. Its aim is to extend POSA, while maintaining the pipelining of the schedule computation and the full operation of the predictor. The extension of CS-POSA is based on shifting of the schedule computation of the nodes or in other words, on guiding the order of checking and programming of the nodes. POSA ignores the variety of the traffic among the nodes building the transmission scheduling matrix starting from the predicted requests of the first node, then the second one and so on until the last one. This is due to the fact that POSA uses OIS to construct the scheduling matrix examining one after the other the requests of the first to the last node. CS-POSA, on the contrary, does not always blindly follow the same service order, i.e., from the first to the last. It examines the cumulative workload, i.e., the sum of the requests of each node to all destinations and based on it, it processes them in a declining order. Shifting is based on the workload of each node, which means that the CS-POSA comprehends better not only the general traffic of the network but also the specific workload in each node. Before CS-POSA constructs the schedule matrix, it takes the two following steps. In the first step CS-POSA adds each row of the traffic matrix D in a new vector S that will register the total amount of requests by each node. So, vector S consists of the total amount of the requests of the whole nodes for the whole transmission channels. In the second step CS-POSA grades vector S in a declining order. In case those two nodes are found with the same total number of requests, then the selection is random. In this way, vector S changes in the ordered vector S'. If we consider the same demand matrix D1, as output of the predictor of CS-POSA then the constructed scheduling matrix will be the same as figured in Fig. 3. Like OIS/POSA, CS-POSA constructed a schedule scheme that composes ten timeslots for each channel and a total thirty for all channels. CS-POSA leaves nine timeslots idle, so the total percentage of idle timeslots is 9/30, 30%.

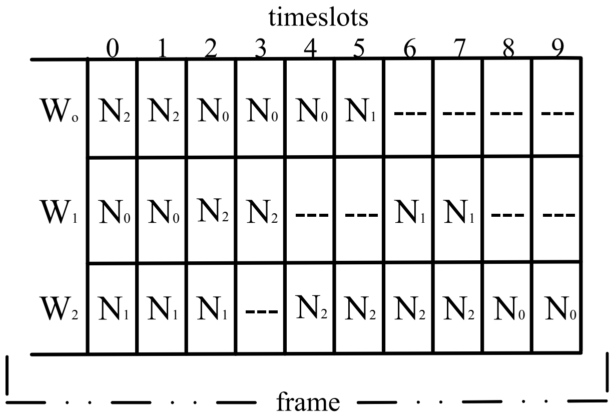

Figure 3. The final scheduling matrix constructed by CS-POSA

IV. LENA ALGORITHM

In order to reduce the idle timeslots of the final scheduling matrix, we can form a different sequencing mechanism. According to load eclectic navigated algorithm (LENA), a set of noteworthy rules are maintained and a set novel set of rules are utilized. The list of maintained rules is below:

Rule 1. LENA adopts from OIS the simplicity of its algorithm and the absence of any complex procedure or manufacture. So, LENA keeps the protocol's complexity in low levels.

Rule 2. LENA adopts from POSA the prediction scheme. So, LENA reduces the time required per frame, by pipelining the schedule computation phase of each frame with the reservation and the data transfer phases.

Rule 3. Lastly, LENA adopts the shifting of the schedule computation of the nodes based on the sum of the requests of each node to all destinations. The new rules that LENA proposes are:

New Rule 1. After the finishing of the service sequence of the nodes LENA prioritizes the requests of the channel with the greatest total of requests. The algorithm begins the manufacture of scheduling matrix with the channel that contains the most requests. That means that the algorithm does not chooses the channels from the first one to the last one, but selects each time the channel with the most time requests for the specific node.

New Rule 2. LENA imports also a new improvement, which has to do with the selection of two or more nodes with the same sum requests. If a set of nodes has the same number of total requests (for all channels) then LENA selects the node that will find to have the bigger number of request (the max request). In order to understand better the need for studying and co-estimating the individual workload in each channel separately, a specific example is examined. Let us consider that the same demand matrix D1 is predicted by the predictor of LENA:

$$D1 = \begin{bmatrix} 3..2..2 \\ 1..2..3 \\ 2..2..4 \end{bmatrix}$$

First of all LENA adds each row of the traffic matrix D1 in a new vector S that will register the total amount of requests by each node:

$$D1 = \begin{bmatrix} 3..2..2 \\ 1..2..3 \\ 2..2..4 \end{bmatrix} \quad S = \begin{bmatrix} 7 \\ 6 \\ 8 \end{bmatrix}$$

So, vector S consists of the total amount of the requests of the three nodes for the three transmission channels. Vector S is a mirror of the activity that each node has. Then LENA grades vector S in a declining order. According to New Rule two, in case those two nodes are found with the same total number of requests, then the node with the max request is preferred. In this way, vector S changes in the ordered vector S':

$$S' = \begin{bmatrix} 8 \\ 7 \\ 6 \end{bmatrix}$$

This denotes that the requests of node N_2 (eight timeslots at total) will be first examined, then those of node N_0 (seven timeslots at total) and finally those of node N_1 (six timeslots at total). In this context LENA starts the construction of the scheduling matrix, by examining the requests of Node N_2.

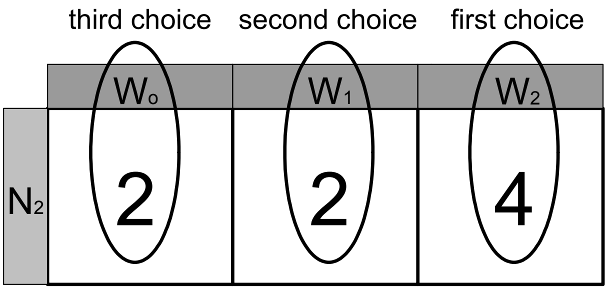

Figure 4. The selection order of channels for node N_2

At this point the algorithm applies the New Rule one. According to this it is examined in which channel have been requested most requests. In the particular example we observe that in channel W_2 have been assembled most requests for node N_2 and the transmission time for them are equal to four timeslots. Then are examined the other two channels and we observe that their demands are equal with 2 timeslots, so the selection is random (Fig. 4). It is easy to understand that LENA directs (navigates) the selections of data requests, according to the demands of each channel, starting with the channel in greatest demand and finishes with the channel in less demand. After this procedure LENA adopts OIS algorithm to form the final scheduling matrix. In the same manner, LENA continues with the set of demands, which belongs to node N_0. Hence, the channel W_0 will be selected (three timeslots), channel W_1 could be follow (two timeslots), and LENA could be finish with node N_0, by selecting the demands of W_0 (two timeslot).Finally, LENA finishes the construction of the scheduling matrix, by servicing the requests of Node N_1. Again, channel W_2 (three timeslots) will be selected first, channel W_1 (two timeslots) will follow and the last selection will be the channel W_0 (one timeslot).

The final scheduling matrix is figured in Fig. 7. LENA constructed a schedule scheme that composes nine only timeslots for each channel and a total twenty seven for all channels.

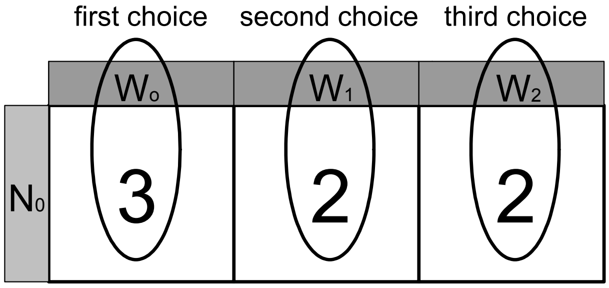

Figure 5. The selection order of channels for node N_0

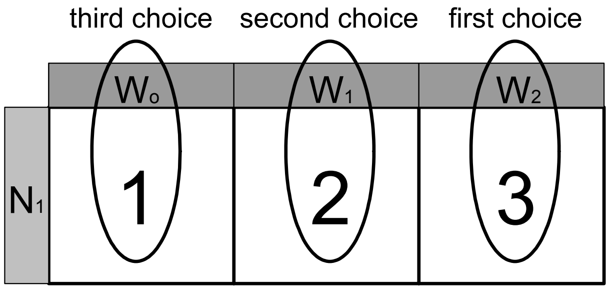

Figure 6. The selection order of channels for node N_1

Apart from this, LENA leaves only six timeslots idle, so the total percentage of idle timeslots is 6/27, 22%.

timeslots	0	1	2	3	4	5	6	7	8
W_0	N_0	N_0	N_0	N_1	---	---	N_2	N_2	---
W_1	N_1	N_1	---	---	N_2	N_2	N_0	N_0	---
W_2	N_2	N_2	N_2	N_2	N_0	N_0	N_1	N_1	N_1

frame

Figure 7. The final scheduling matrix constructed by LENA

V. SIMULATION RESULTS

This section presents the simulation results. Three algorithms, which utilize the prediction method, POSA, CS-POSA, and LENA have been studied and compared in the context of utilization, throughput, and throughput-delay, under uniform traffic. In the results of the simulation, it is assumed that N is the number of nodes, W is the number of the channels and K is the maximum value over all entries in the traffic matrix. In other words K is the maximum value of demand timeslots for each pair of node-channel. The speed of the line has been defined at 2.4 Gbps. Also, it should be mentioned that the tuning latency time is considered to be equal to zero timeslots for simplicity reasons. The simulation took place in a C environment. We consider two network models. The first model consists of 8 channels and 5 different numbers for nodes from 10 to 50 (10, 20, 30, 40, and 50). The second model consists of 16 channels and the same set of nodes. For both models the value of K remains analogous of both the values of nodes and channels, for scalability reasons. So K is equal to NW/8. The first graph (Fig. 8) shows the channel utilization for the first model and the second graph (Fig. 9) shows the channel utilization for the second model. It is obvious that LENA keeps higher values, in context of channel utilization, for every set of channels. The results of the comparison between the three algorithms are presented in the two next graphs. The first one (Fig. 10) shows the network throughput for 8 channels, while the second one (Fig. 11) shows the network throughput for 16 channels. In both figures LENA is superior than POSA and CS-POSA, while the greatest difference reaches 3 Gbps with POSA and CS-POSA. Finally, the last two graphs (Fig. 12 for 8 channels and Fig. 13 for 16 channels) show the relationship between network throughput and mean time delay of the packets, for both models. It is very important the fact that LENA improves the network throughput and meanwhile reduces a little the mean time delay for both models.

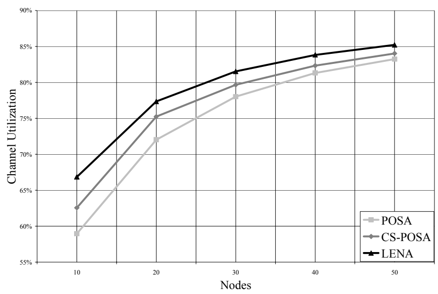

Figure 8. Channel utilization for 8 channels.

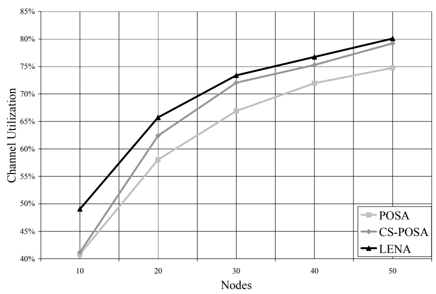

Figure 9. Channel utilization for 16 channels.

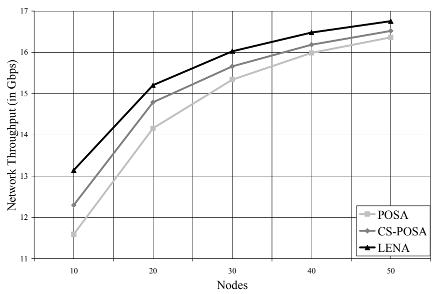

Figure 10. Network throughput for 8 channels.

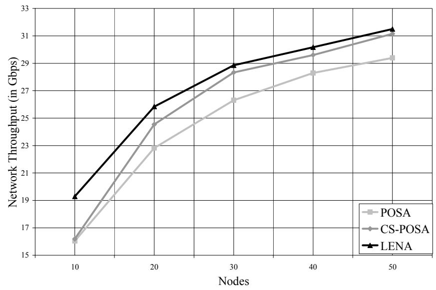

Figure 11. Network Throughput for 16 channels.

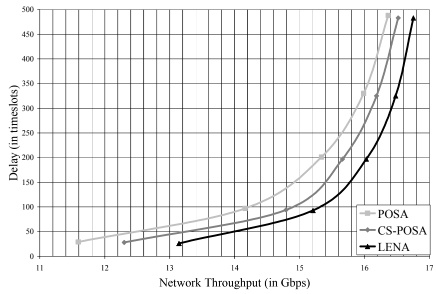

Figure 12. Throughput vs. Delay for 8 channels.

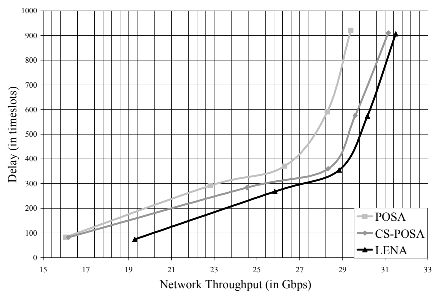

Figure 13. Throughput vs. delay for 16 channels.

VI. CONCLUSIONS

We presented a novel technique for scheduling in WDM star networks. This method changes the way of processing of each channel and leads to an improvement, in terms of channel utilization, network throughput and mean time delay, which is proved by simulation results.

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