A New Prediction and Channel Sorting Based Scheduling Algorithm for WDM Star Networks

P.G.Sarigiannidis, G.I.Papadimitriou, *Senior Member, IEEE,* and A.S.Pomportsis

Department of Informatics, Aristotle University, Box 888, 54124 Thessaloniki, Greece

This paper introduces a new packet scheduling algorithm for WDM star networks, named CS-POSA. This algorithm utilizes Markov chains in order to predict the transmission requests of the network nodes and thus reduce the calculation time of the final scheduling matrix. The resulting protocol is pre-transmission coordination-based without packet collisions. The proposed algorithm pipelines the schedule computation process and introduces a new order in which nodes' requests are processed. This innovative feature is shown to increase network throughput with negligible impact on the mean delay and the delay variance.

Introduction

The constantly increasing demands for high speeds in audio, image, and video transmission, within LAN (local area network), MAN (metropolitan area network), and WAN (wide area network) are met by the enormous bandwidth of optical fiber technology. There are, however, issues to be resolved that relate to the co-operation of optical and electrical technologies. While the WDM (wavelength division multiplexing) technique has unlocked an even greater portion of the optical bandwidth, it has also created a need for new protocols, network architectures and technologies that will enable the efficient exploitation of this enormous capacity [1]. Also, WDM technology, within a single optic fiber [2-4] may result in gigabit-per-second data rates in independent channels that transmit simultaneously data flows to a single or multiple users. In this context, broadcast-and-Select networks [5] consist of a number of nodes and a passive star coupler that broadcasts all inputs to all outputs. Every node can select at a given time among the channels available to perform transmission. This paper focuses on the Broadcast-and-Select Star local area network with one tunable transmitter and one fixed receiver (TT-FR) per node (Fig. 1).

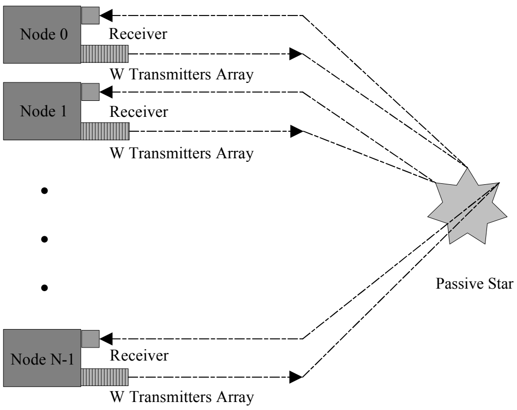

Fig.1 A Broadcast-and-Select Network with tunable transmitters and fixed receivers.

The way in which available channels are accessed by networks nodes is controlled by a MAC (medium access control) protocol. The objective is to coordinate the nodes that wish to transmit and receive data so as to maximize network throughput while trying to eliminate collisions. The two types of collisions that can occur are channel collisions and receiver collisions [6]. In the former case two or more nodes contend for the same transmission channel while in the latter case two or more transmit to the same receiving node in different wavelengths. Because in the network considered the receiver of each node is fixed tuned, receiver collisions are not an issue.

MAC protocols for optical networks are generally categorized as either pre-transmission co-ordination based or pre-allocation. In pre-allocation MAC protocols channel allocations to transmitting nodes are fixed and scheduled in advance. Conversely, pre-transmission co-ordination based protocols perform schedule computation at the beginning of each time slot. This process entails the following steps: the algorithm accepts initially the requirements of all nodes and organizes them in a transmission frame, called traffic demand matrix, $D = [d_{i,j}]$. Time is divided in timeslots. Usually, transmission is organized as frames where each frame is composed of a reservation phase followed by a data phase. The frame then stores for every node the number of timeslots required for transmission to a specific channel. Then the nodes transmit the requested data during the current frame at different moments.

A scheduling algorithm that needs to read the entire demand matrix before beginning schedule computation is referred to as offline while an online scheduling algorithm begins schedule computation just after reading the requests of the first node and then proceeds with the schedule computation and the reading of the demand matrix in parallel. Representatives of MAC protocols that allow receiver collisions is the family of Aloha [7], Slotted Aloha [7], Delayed Slotted Aloha [7], Aloha CSMA [7], Aloha / Slotted CSMA [8], DTWDMA [9], Quadro Mechanism [10], and N-DT-WDMA [11].

Background (OIS & POSA)

OIS (on-line interval-based scheduling) [12] is a typical online algorithm, which has the advantages of the algorithms that do not need the entire demand matrix but only a part of it in order to begin schedule computation. The function of the algorithm is as follows: once a set of requests by node n is known, the algorithm examines the availability of the channels for t_1 timeslots transmission that node n requires. If the available channel w is located in the time gap between timeslot t and timeslot $t + (t_1 - 1)$, then the next step is to examine any potential collisions. In other words, the algorithm checks whether in the timeslots t until $t + (t_1 - 1)$, node n can be scheduled to transmit in another channel w_1 ($w_1 \neq w$). If the registration has been accomplished, then the timeslots t to $t + (t_1 - 1)$ are bound to node n for the wth channel. Thereafter, the lists are renewed and other requests from the remaining N - n nodes are examined.
Consequently, the request table (scheduling matrix) of OIS contains for every timeslot the nodes that transmit at that moment and the equivalent transmission channel.

POSA (predictive online scheduling algorithm) [13] is a variation of OIS that adds the element of requests' prediction. The main aim of POSA is to decrease the time of the estimation of the scheduling matrix with the help of a hidden Markov chain. With this method, the algorithm succeeds in predicting the requests of the nodes for the subsequent frame based on the requests of the nodes for the previous frames. Thus, time is saved since the algorithm does not wait for the nodes to send their requests and then to construct the scheduling matrix. Having predicted the requests of the nodes, the scheduling is pipelining at the real time of the transmission of the packets. This parallel elaboration leads to an important –if not complete- decrease of the time of estimation of the scheduling.

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. The learning algorithm is implemented in three steps:

1. At the beginning of each frame f, the predictor reads the actual value of the requests from node n in channel w for the previous (f-1) and the current (f) frame. It then increases the corresponding state transition probability by one.
2. The oldest transition recorded by the predictor (V timeslots earlier) is taken into account in order to reduce the corresponding state transition probability by one.
3. The state of the predictor changes to a state that represents the actual number of slots requested by node N in channel W during data frame f.

The prediction algorithm is implemented in two steps:

1. For frame f, the algorithm determines the state with the highest transition count and gives it as a prediction for the following frame.
2. If there is more than one state with the same highest transition count, then the tie is resolved by traversing the history queue from the tail. The first instance of one of the tied transitions encountered within the history queue (i.e. the oldest transition) is the output of the specific predictor.

CS-POSA

The new proposed algorithm is called CS-POSA (check and sort-predictive online scheduling algorithm). CS-POSA operates in three phases: a learning phase during which CS-POSA learns from the workload of the network how to maintain the history queues, a switching phase during which there is a change from learning to predicting and a prediction phase during which CS-POSA predicts the requests of the nodes for the following frame. The innovation that is introduced here is the way of processing the predictions. 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.

In order to understand better the need for studying and co-estimating the individual workload in each node separately, a specific example is examined. The following traffic matrix has been constructed by nine individual predictors:

$$D=\begin{bmatrix} 1..2..2 \\ 3..3..1 \\ 5..4..3 \end{bmatrix}$$

It is clear that the predictor $p_{0,0}$ predicted one timeslot for node n_0 with channel w_0, the predictor $p_{0,1}$ predicted two timeslots for node n_0 with channel w_1, and so on.

Before CS-POSA constructs the scheduling matrix, it takes the two following steps:

STEP 1. Add each row of the traffic matrix D in a new vector S that will register the total amount of requests by each node:

$$D = \begin{bmatrix} 1..2..2 \\ 3..3..1 \\ 5..4..3 \end{bmatrix} \qquad S = \begin{bmatrix} 5 \\ 7 \\ 12 \end{bmatrix}$$

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.

STEP 2. Grade 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':

$$S' = \begin{bmatrix} 12 \\ 7 \\ 5 \end{bmatrix}$$

This denotes that the requests of node n_2 will be first examined, then those of node n_1 and finally those of node n_0.

It is imperative that the complexity of the scheduling algorithm in an optical network is kept low so as the operating speed is maximized. In POSA, the time complexity of the overall predictor is given by: $O\left(\frac{(K+1+V)(NW)}{P}\right)$

where $P = \frac{NW}{p}$ is the number of processors that simultaneously perform schedule computation and p is a constant.

CS-POSA does not add to the complexity of the individual predictors but the overall complexity of the algorithm by the sorting process. Considering that the complexity of the shifting process is O(NlogN) and co-estimating the fact that the algorithm works with P different processors at the level of NW, then the extra complexity of the CS-POSA is: $O(\frac{\log N}{W})$

Simulation results

This section presents the performance analysis results. Two algorithms, POSA and CS-POSA, have been studied and analyzed in the context of utilization, throughput, throughput-delay, throughput-delay jitter, throughput-load, and delay jitter-load, 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. 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. Its duration was 10000 frames from which the 1000 belong to the learning phase of the algorithms. A random number generator was used to provide values to the traffic matrix. The values range between 0 and K and in order the goal of scalability to be achieved, the value of K is not constant in the following experiments but each time it is equal to: $K = \left\lfloor \frac{NW}{5} \right\rfloor$

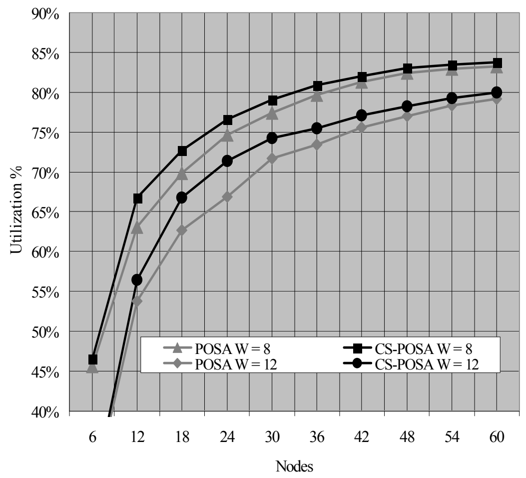

Fig.2. Channel Utilization

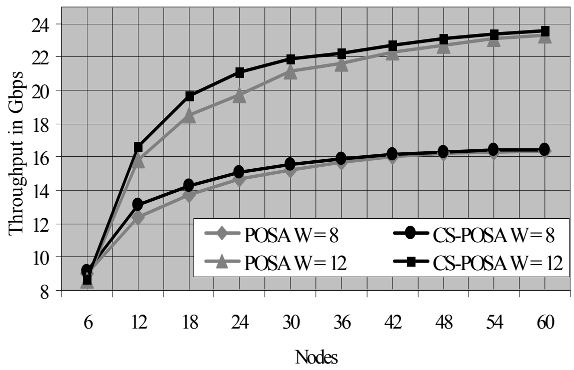

Fig.3. Network Throughput

The results from the comparison between POSA and CS-POSA, in terms of channel utilization are shown in Figure 2 and in terms of network throughput are shown

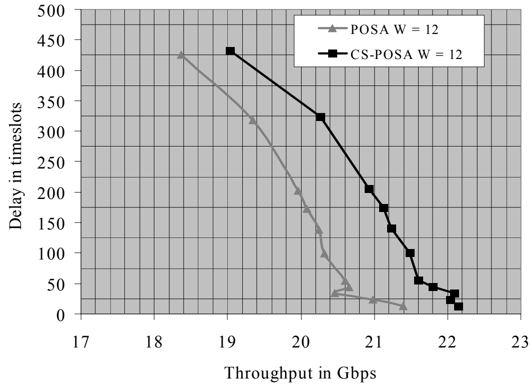

Fig.4. Throughput vs. Delay

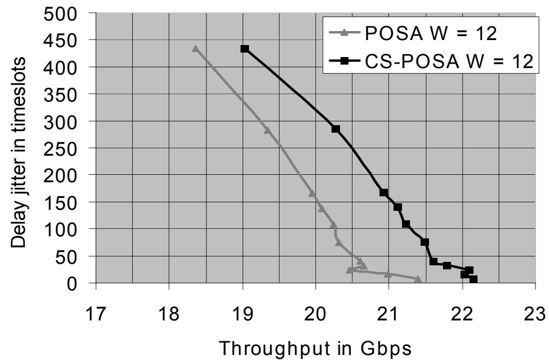

Fig.5. Throughput vs. Delay jitter

in Figure 3. It is obvious that CS-POSA remains constantly better than POSA for each number of nodes, either for 8 or for 12 channels. The results from the comparison between the two algorithms in terms of throughput vs. delay and in terms of throughput vs. delay jitter are presented in the Figure 4 and Figure 5 respectively.

It is obvious that there is a constant difference between the algorithms in the context of throughput as the time delay and the delay jitter is increased, since for each value of the workload, CS-POSA precedes POSA without a significant time delay. The

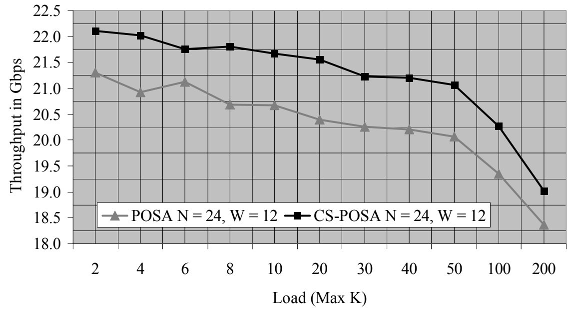

Fig.6. Throughput vs. Load

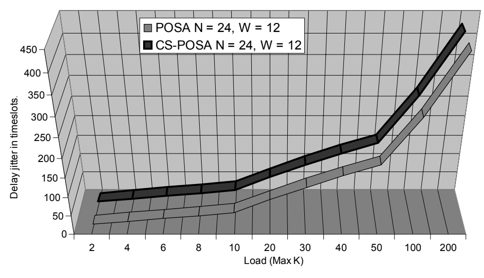

Fig.7. Delay jitter vs. Load

results concerning throughput and load from the comparison of the two algorithms are shown in the Figure 6. The number of the nodes is 24, while the available channels are 12. The results from the comparison of the two algorithms in terms of delay jitter vs. load are shown in Figure 7. The number of the nodes is 24, while the available channels are 12. The two algorithms do not differ greatly, since for each value of the workload, CS-POSA precedes POSA without a significant delay-jitter.

Conclusions

This paper presented an improved protocol for WDM Broadcast-and-Select networks, with passive star coupler architecture. The protocol is collision-free and pretransmission coordination-based. It improves not only the schedule utilization and the throughput of the network, but also the mean time delay in relation to the throughput. So, it is a reliable solution in the context of network throughput, without extra time burden or extra hardware implementation.

References

[1] G. I. Papadimitriou, Ch. Papazoglou, and A. S. Pompotrsis, “Optical Switching : Switch Fabrics, Techniques, and Architectures”, IEEE/OSA Journal of Lightwave Technology, vol. 21, no. 2, 2003, pp. 384-405.

[2] C.A. Brackett, “Dense wavelength division multiplexing network: Principles and applications”, IEEE J. Selected Areas Commun., vol. 8, 1990, pp. 948-964.

[3] T. E. Stern, and K. Bala, Multiwavelength Optical Networks, Addison-Wesley, 1999.

[4] P. Green, “Progress in optical networking, IEEE Communications magazine”, vol. 39, no. 1, 2001, pp. 54-61.

[5] M. Tsukada, and A. J. Keating, “Broadcast and Select Switching System Based on Optical Time-Division Multiplexing (OTDM) Technology”, IEICE Trans. Commun., vol. E82-B, no. 2, 1999, pp. 335-343.

[6] G. I. Papadimitriou, A. N. Miliou, and A. S. Pomportsis, OCON: “An optically controlled optical network”, Computer Communications vol. 22, 1998, pp. 811-824.

[7] I. MI. Habbab, M. Kavehrad and C. W. Sundberg, “Protocols for very high-speed optical fibre local area networks using a passive star topology”, IEEE/OSA Journal of Lightwave Technology, vol. LT-5, no. 12, 1987, pp. 1782-1794.

[8] H. Shi and M. Kavehrad, “Aloha/slotted-CSMA protocol for a very high-speed optical fibre local area network using passive star topology”, in Proceedings IEEE INFOCOM`91, Bal Harbour, Florida, USA, vol. 3, 1991, pp. 1510-1515.

[9] M. S. Chen, N. R. Dono and R. Ramaswami, “A media-access protocol for packet-switched wavelength-division metropolitan area networks”, IEEE Journal on Selected Areas in Communications, vol. 8, no. 6., 1990, pp. 1048-1057.

[10] I. Chlamtac and A. Fumagalli, “QUADRO-Star : High performance optical WDM star networks”, in Proceedings IEEE Globecom`91, Phoenix, Arizona, USA, 1991, vol. 42, pp. 2582-2590.

[11] P. A. Humblet, R. Ramaswami and K. N. Sivarajan, “An efficient communication protocol for high-speed packet switched multichannel networks”, IEEE Journal on Selected Areas in Communications, vol. 11, no. 4, 1993, pp. 568-578.

[12] K. M. Sivalingam, J. Wang, J. Wu and M. Mishra, “An interval-based scheduling algorithm for optical WDM star networks”, Photonic Network Communications, vol. 4, no. 1, 2002, pp. 73-87.

[13] E. Johnson, M. Mishra, and K. M. Sivalingam, “Scheduling in optical WDM networks using hidden Markov chain based traffic prediction, Photonic Network Communications”, vol. 3, no. 3, 2001, pp. 271-286.