

# Self-Adaptive TDMA Protocols for WDM Star Networks: A Learning-Automata-Based Approach

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**Abstract**—A learning-automata-based protocol for WDM passive star networks, which is capable of operating efficiently under bursty and correlated traffic, is introduced. According to the proposed protocol, the stations which grant permission to transmit at each time slot, are selected by means of learning automata. The choice probabilities of the selected stations are updated by taking into account the network feedback information. The probability updating scheme is designed in such a way, that the number of idle slots tends to be minimized, while the bandwidth of each wavelength is allocated to the stations according to their needs.

**Index Terms**— Learning automata, learning-automata-based protocols, time-division multiple-access protocols, WDM passive star networks.

## I. INTRODUCTION

THE BANDWIDTH demands of local area networks have been growing steadily and dramatically over the last years. Wavelength-division-multiplexed (WDM) passive star networks [1]–[5] constitute one of the most promising architectural forms for the emerging new generation of gigabit LAN's.

Traffic in gigabit LAN's is highly bursty [5]. Data traffic which constitutes most of load is intrinsically bursty. As the network speed increases, the peak rate increases faster than the average, thus making traffic becoming more bursty. Furthermore, the destinations of packets transmitted by the same station are highly correlated, since most of them are fragments of large messages [6]. Under these traffic conditions, TDMA-based protocols, (e.g., RTDMA [3]) suffer from low performance, since a large number of slots remain idle. In this letter, a self-adaptive learning-automata-based protocol (LABP) for WDM passive star networks, which is capable of operating efficiently under bursty and correlated traffic, is introduced.

This letter is organized as follows. The proposed protocol is presented in Section II. Some implementation issues are discussed in Section III, while simulation results are presented in Section IV. Finally, concluding remarks are given in Section V.

## II. THE LABP PROTOCOL

The LABP protocol is applied to WDM passive star networks using tunable transmitters and fixed receivers (Fig. 1).

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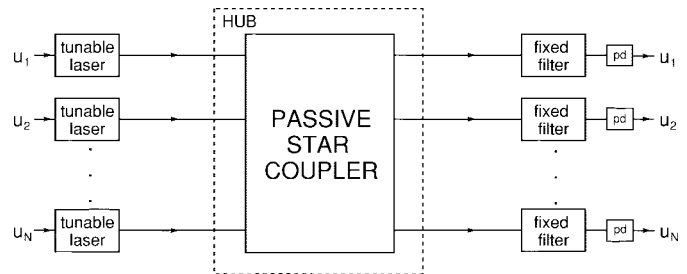


Fig. 1. A WDM Passive Star Network using tunable lasers and fixed filters.

Let  $U = \{u_1, \dots, u_N\}$  be the set of stations, where  $N$  is the number of stations. The set of wavelengths is defined as  $\Lambda = \{\lambda_1, \dots, \lambda_W\}$ , where  $W$  is the number of wavelengths. Each transmitter is provided with a tunable laser which can be tuned to each one of the  $W$  wavelengths. Optical fibers are used to connect the outputs of the lasers to the network hub. There, the optical signal is fed to a passive star coupler. Each output port of the star coupler is connected to the corresponding receiver, by means of an optical fiber. Each receiver is provided with a fixed optical filter which passes only one wavelength. Therefore, it is capable of receiving packets, which are transmitted on this wavelength. The output of the optical filter is connected to a photodetector which performs O/E translation of the incoming signal.

### A. The Node Selection

According to the LABP protocol, each station is provided with a set of  $W$  discretized learning automata [7], with each automaton  $LA_i$  corresponding to a specific wavelength  $\lambda_i$  and determining which station grants permission to transmit on this wavelength ( $i = 1, \dots, W$ ).

Each learning automaton  $LA_i$  contains a probability distribution  $P_i(t)$  over the set of stations. Thus,  $P_i(t) = \{P_{i,1}(t), \dots, P_{i,N}(t)\}$ , with  $P_{i,j}(t)$  being the basic choice probability of station  $u_j$ , for wavelength  $\lambda_i$ , at time slot  $t$ .

At each time slot  $t$ , only one station [let  $C_i(t)$ ] grants permission to transmit on each wavelength  $\lambda_i$ , for  $i = 1, \dots, W$ . The station which grants permission to transmit on wavelength  $\lambda_i$ , is selected in the following way:

- i) if  $\sum_{m=1}^N P_{i,m}(t) = 0$  then  $C_i(t)$  is selected at random.
- ii) if  $\sum_{m=1}^N P_{i,m}(t) > 0$  then  $C_i(t)$  is selected according to the normalized choice probabilities  $\Pi_{i,j}(t)$  ( $j = 1, \dots, N$ ), where:  $\Pi_{i,j}(t) = P_{i,j}(t) / \sum_{m=1}^N P_{i,m}(t)$ .

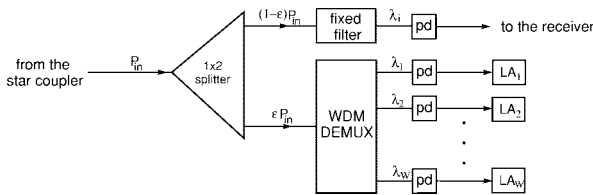


Fig. 2. The feedback mechanism of LABP.

**B. The Probability Updating Scheme**

At each time slot  $t$ , the basic choice probabilities of the selected stations are updated according to the network feedback information. If  $C_i(t) = u_j$  and station  $u_j$  transmitted a packet during time slot  $t$ , then the basic choice probability  $P_{i,j}(t)$  is increased. Otherwise, if the selected station  $u_j$  was idle, then the basic choice probability  $P_{i,j}(t)$  is decreased. Let  $slot_i(t) \in \{busy, idle\}$  be the state of wavelength  $\lambda_i$ , at time slot  $t$ . If  $C_i(t) = u_j$ , then the following probability updating scheme is used for each wavelength  $\lambda_i$  (where  $k$  is an integer parameter):

$$P_{i,j}(t+1) = P_{i,j}(t) + \frac{1}{k},$$

if  $slot_i(t) = busy$  and  $P_{i,j}(t) < 1$

$$P_{i,j}(t+1) = P_{i,j}(t) - \frac{1}{k},$$

if  $slot_i(t) = idle$  and  $P_{i,j}(t) > 0$ .

Initially,  $P_{i,j}(t) = 1/k, \forall i, j$ . Therefore, according to the above probability updating scheme, the basic choice probabilities take values from a finite set. Thus,  $P_{i,j}(t) \in \{0, 1/k, 2/k, \dots, 1\}$ .

The offered traffic is assumed to be bursty and the destinations of packets transmitted by the same station are assumed to be correlated. Therefore, when the selected station has a packet to transmit, it is probable that this station will have packets to transmit on the specific wavelength in the near future. So, its choice probability is increased. On the other hand, when the selected station is idle, it is probable that this station will remain idle in the near future. So, its choice probability is decreased.

All the stations use the same learning algorithm and—due to the broadcast nature of the network—the network feedback information is common for all the stations. Consequently, all the automata always contain the same choice probabilities. Furthermore, since the same random number generator and the same seed is used by all the stations, it follows that for each wavelength  $\lambda_i$ , all the stations select the same station  $C_i(t)$  which grants permission to transmit [3]. Therefore, although there is not centralized coordination between the stations, the protocol is collision-free.

**C. The Feedback Mechanism**

In order to implement the above learning algorithm, each station must be informed of the state of each wavelength (busy or idle), at each time slot. In order to be provided with this feedback information, each station uses the simple feedback mechanism which is presented in Fig. 2.

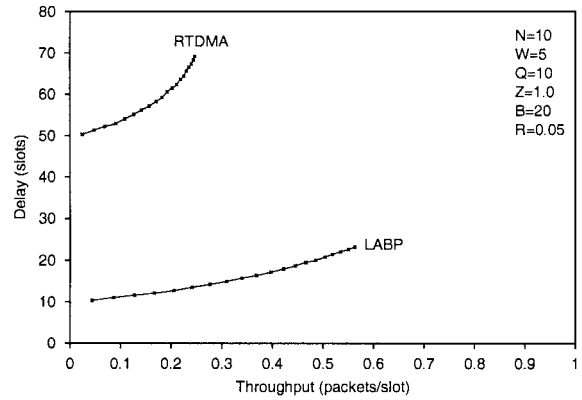


Fig. 3. The throughput versus load characteristics of protocols LABP and RTDMA when applied to network  $N_1$ .

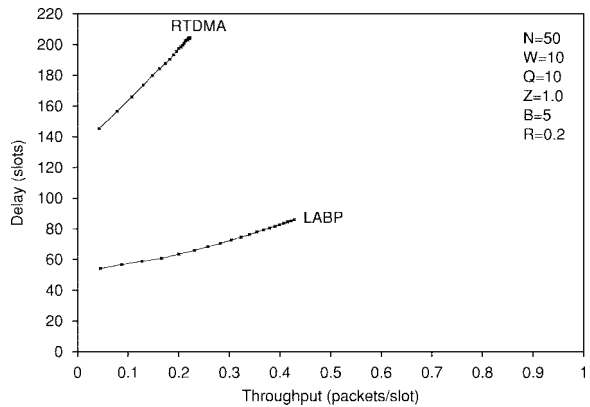


Fig. 4. The delay versus throughput characteristics of protocols LABP and RTDMA when applied to network  $N_2$ .

A small fraction  $\epsilon$  of the incoming signal is fed to a WDM demultiplexer, which separates the different wavelengths. The output ports of the demultiplexer are fed to an array of photodetectors which detect whether the corresponding wavelength is idle or a packet transmission is taking place.

**III. IMPLEMENTATION ISSUES**

The feedback information is provided at the beginning of each time slot. Therefore, the computational time of the learning automata is overlapped by the packet transmission time. However, an exceedingly long computational time could cause time gaps between the packets, resulting to a performance degradation. Therefore, it is important for the implementation of LABP, to keep the computational time of the learning automata below the slot duration.

**A. A Fast Implementation of the Learning Automaton**

During a time slot  $t$ , the learning automaton has to update the probability distribution  $P_i(t)$  and then, to select a station according to the new probability distribution. A fast algorithm which implements these operations is presented below.

The following algorithm is based on keeping a variable size array  $A$  which consists of “probability cells” with each cell representing a probability mass equal to  $1/k$ . Each cell owns to a specific station. The choice probability of each

station is proportional to the number of cells it has in array  $A$ . Therefore, to select a station according to the present probability distribution it suffices to select one of the cells at random (with uniform distribution). The owner of the selected cell grants permission to transmit. When the choice probability of the selected station has to be increased, then a clone of the selected cell is inserted into array  $A$ . On the other hand, when the choice probability of the selected station has to be decreased, then the selected cell is removed from array  $A$ . This procedure is presented below:

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Procedure LAi;
repeat
  t := t + 1;    j := Ci(t);
  (*Update the choice probability of the selected station*)
  if (sloti(t) = busy) and (number_of_cells[j] < k) then
    begin
      inc(usize);    A[usize] := j;
      inc(number_of_cells[j])
    end
  else if (sloti(t) = idle) and (number_of_cells[j] > 0)
    then
      begin
        A[index] := A[usize];    dec(usize);
        dec(number_of_cells[j])
      end;
  (*Select a station for the next time slot*)
  if usize > 0 then
    begin
      index := [random * usize];
      Ci(t + 1) := A[index]
    end
  else Ci(t + 1) := [random * N]
forever;

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### B. A Case Study

Assume, for example, that a Pentium/166MHz microprocessor is used for the implementation of the  $W$  learning automata. If the above algorithm is implemented in assembly language, then a Pentium microprocessor takes 110 clock cycles to execute it. Due to the spatial and temporal locality of reference, all the variables of the learning algorithm are always stored in the internal cache of the microprocessor. Therefore, there are no wait states, and consequently,  $0.663 \times W \mu\text{s}$  are required for the execution of the algorithm. If each station has a bit rate of 2 Gb/s, and the packet length is equal to 4 kbytes [4], then the slot duration is 16  $\mu\text{s}$ . Thus, even when a relatively slow microprocessor is used for the implementation of the learning algorithm, the network is capable of supporting up to 24 wavelengths and an overall network capacity of 48 Gb/s.

## IV. SIMULATION RESULTS

In the following, the proposed LABP protocol is compared to RTDMA [3]. The protocols which are under comparison were simulated to be applied to two different networks ( $N_1$ ,  $N_2$ ) under bursty and correlated traffic. The bursty traffic was modeled in a way similar to the ones presented in [8] and

[9]. Each node can be in one of two states  $X_0$  and  $X_1$ . When a node is in state  $X_0$  then it has no packet arrivals. When a node is in state  $X_1$  then at each time slot it has a packet arrival with probability  $Z$ . Given a station is in state  $X_0$  at time slot  $t$ , the probability that this station will transit to state  $X_1$  at the next time slot is  $P_{01}$ . The transition probability from state  $X_1$  to state  $X_0$  is  $P_{10}$ . It can be shown that, when the network load is  $L$  packets/slot and the mean burst length is  $B$  slots, then,  $P_{10} = 1/B$  and  $P_{01} = L/B(NZ - L)$ . The correlated arrivals were modeled in the following way [2]: With probability  $R$ , the destination of a newly arriving packet is selected at random among all the stations. With probability  $(1-R)$ , a newly arriving packet has the same destination with the previous packet. The number of users  $N$ , the number of wavelengths  $W$ , the queue size  $Q$  and the traffic parameters  $B$ ,  $Z$ , and  $R$ , were taken to be as follows: a) Network  $N_1$ :  $N = 10$ ,  $W = 5$ ,  $Q = 10$ ,  $B = 20$ ,  $Z = 1.0$ ,  $R = 0.05$ , b) Network  $N_2$ :  $N = 50$ ,  $W = 10$ ,  $Q = 10$ ,  $B = 5$ ,  $Z = 1.0$ ,  $R = 0.2$ .

The delay versus throughput characteristics of the compared protocols, when applied to networks  $N_1$  and  $N_2$ , appear at Figs. 3 and 4, correspondingly. From the above graphs, it becomes clear that, LABP achieves a significantly higher throughput-delay performance than protocol RTDMA, when operating under bursty and correlated traffic.

## V. CONCLUSION

This letter has presented a new self-adaptive time division multiple access protocol for WDM Star Networks. According to the proposed LABP protocol, the station which grants permission to transmit on each wavelength is selected by means of learning automata, which are capable of being adapted to the varying traffic conditions.

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