ADAPTIVE CONTROL OF FIBER OPTIC LANS: A LEARNING-AUTOMATA-BASED APPROACH

Georgios I. Papadimitriou and Andreas S. Pomportsis
Department of Informatics,
Aristotle University, Box 888,
54006 Thessaloniki, Greece.
{gp, apombo}@csd.auth.gr

ABSTRACT

The burstiness of traffic has been a limiting factor in the performance of fiber optic LANs. A Learning-Automata-Based Protocol for WDM Star LANs, 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.

1 INTRODUCTION

The introduction of broadband services and multimedia applications has led to a dramatical increase in the bandwidth demands of Local Area Networks. WDM Passive Star Networks [1]-[5] constitute one of the most promising architectural forms for the emerging new generation of gigabit LANs.

Due to the limited speed of the stations' electronic circuits, single channel optical networks - such as FDDI, DQDB, Fasnet, Expressnet, etc - were not proved capable of supporting Gigabit data rates.

The Wavelength Division Multiplexing (WDM) technique [1],[2] solves this problem by dividing the available optical bandwidth into multiple channels of lower bandwidth which can be easily supported by the stations' electronic circuits. Both, multiplexing and demultiplexing of the multiple channels, are performed in the optical domain without the need of optical to electronic translation and vice versa. In this way, the WDM technique allows the implementation of all-optical networks which are capable of providing Gigabit data rates by using present-day optical and electronic technology.

Passive Star networks (fig.1) - which are a special category of WDM networks - use a Passive Star Coupler in order to broadcast all inputs to all outputs. There are four possible configurations of the Passive Star architectural form [1]: a) Fixed optical transmitters and fixed optical receivers b) tunable optical transmitters and tunable optical receivers c) fixed optical transmitters and tunable optical receivers and d) tunable optical transmitters and fixed optical receivers. The latter configuration is considered in this paper.

Traffic in gigabit LANs 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 [4]) suffer from low performance, since a large number of slots remain idle.

In this paper, an adaptive 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. At each time slot, the choice probabilities of the selected stations are updated 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.

The paper is organized as follows: The proposed protocol is presented in Section 2. Some implementation issues are discussed in Section 3, while simulation results are given in Section 4. Finally, concluding remarks are given in Section 5.

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2 THE LEARNING-AUTOMATA-BASED PROTOCOL (LABP)

The LABP protocol is applied to WDM Passive Star networks using tunable transmitters and fixed receivers (fig.1). Let $U = \{u_1, \ldots, u_N\}$ be the set of stations, where N is the number of stations. The set of wavelengths is defined as $\Lambda = \{\lambda_1, \ldots, \lambda_W\}$, 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.

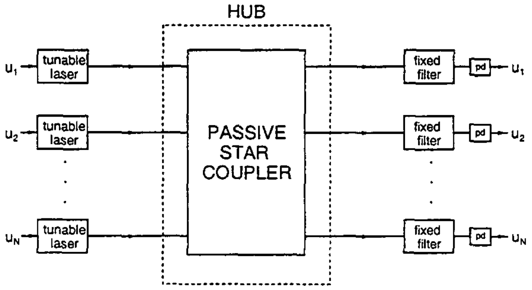

Figure 1: A WDM Passive Star Network using tunable lasers and fixed optical filters.

2.1 The Node Selection

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

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

At each time slot t, only one station (let $C_i(t)$) grants permission to transmit on each wavelength λ_i, for $i = 1, \ldots, W$. For each wavelength λ_i, the station which grants permission to transmit at time slot t, is selected according to the normalized choice probabilities $\Pi_j(t)$ ($j = 1, \ldots, N$), where:

$$\Pi_j(t) = \frac{P_{i,j}(t)}{\sum_{u_m \in U} P_{i,m}(t)}$$

Note, that each one of the W learning automata makes its choice independently, without to take into account the choices of the other automata. Therefore, it is possible that two or more automata give permission to transmit to the same station. This causes a slight performance degradation (about 1-3% in terms of throughput or packet delay), but on the other hand, it allows the parallel operation of the automata. In this way, the total processing time is reduced by a factor of W.

2.2 The Learning Algorithm

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 λ_i, at time slot t. For $i = 1, \ldots, W$, the following probability updating scheme is used (where: $L, a \in (0, 1)$ and $P_{i,j}(t) \in (a, 1)$ for all t):

if $C_i(t) = u_j$ and $slot_i(t) = busy$ then
$$P_{i,j}(t+1) = P_{i,j}(t) + L(1 - P_{i,j}(t))$$

if $C_i(t) = u_j$ and $slot_i(t) = idle$ then
$$P_{i,j}(t+1) = P_{i,j}(t) - L(P_{i,j}(t) - a)$$

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.

The role of parameter a, is to prevent the choice probabilities of the stations from taking values in the neighborhood of 0, in order to increase the adaptivity of the protocol.

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 λ_i, all the stations select the same station $C_i(t)$ which grants permission to transmit [4]. Therefore, although there is not centralized coordination between the stations, the protocol is collision-free.

The operation of a learning automaton LA_i during a time slot t, is represented by the following Pascal-like code:

```
PROCEDURE LA$_i$;
BEGIN
  $P := P_{i,C_i(t)}(t)$;
  (* Update the choice prob. of the selected station *)
  if $slot_i(t)$=idle then $\Delta P$:=$L$ * ($a$–$P$)
                      else $\Delta P$:=$L$ * (1–$P$);
  $P_{i,C_i(t)}(t) := P + \Delta P$;
  (* Update the sum of the choice probabilities *)
  $\Sigma P := \Sigma P + \Delta P$;
  (* Select a station for the next time slot *)
  $r := random * \Sigma P$;
  $sum := 0; j := 0$;
  repeat
    inc($j$);
    $sum := sum + P_{i,j}(t)$;
  until $sum > r$;
  $C_i(t+1) := j$;
END;
```

2.3 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 figure 2.

A small fraction ϵ 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.

Note, that no full reception of the incoming signals is performed in the feedback mechanism. Only a detection of the presence or the absence of optical signal at each wavelength is required. Therefore, the splitting ratio ϵ [2] can be very small. Consequently, the power of the incoming signal is practically unaffected by the presence of the feedback mechanism.

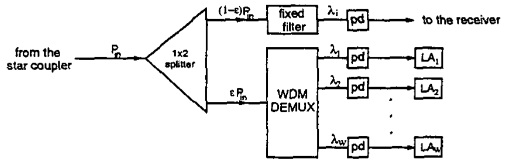

Figure 2: The feedback mechanism of LABP.

3 IMPLEMENTATION ISSUES

The feedback information is provided at the beginning of each time slot. Therefore, the computational time 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 algorithm below the slot duration.

Assume, for example, that a 75MHz Pentium microprocessor is used for the implementation of the learning algorithm. All the instructions of the algorithm presented in section 2.2 are executed only once, except of the repeat-until loop which is executed at most N times. If the algorithm is implemented in assembly language, then a Pentium processor takes 12 clock cycles for executing the loop and 95 clock cycles for the rest program. 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 Pentium microprocessor. Therefore, there are no wait states, and consequently, $(12N + 95)$ clock cycles or equivalently, $((12N + 95)/75)$ μsec are required for the execution of the algorithm. If each station has a bit rate of 2 Gbps, and the packet length is equal to 4 kbytes, then the slot duration is 16 μsec. Therefore, we have: $(12N + 95/75) \leq 16$ and consequently, $N \leq 92$. Thus, even when a relatively slow microprocessor is used for the implementation of the leaning algorithm, the network is capable of supporting up to 92 stations, with each of them operating at 2 Gbps.

4 SIMULATION RESULTS

In the following, the proposed LABP protocol is compared to RTDMA [4]. 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 modelled in a way similar to the ones presented in [8] and [9]. Each node can be in

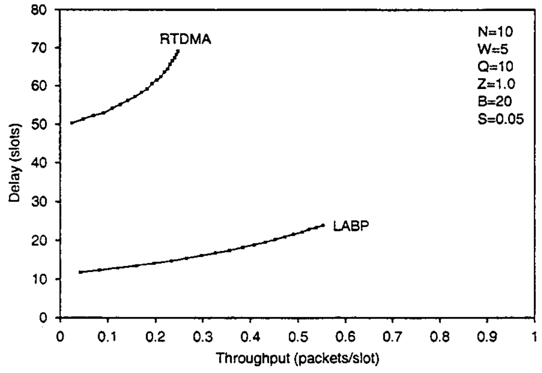

Figure 3: The Throughput versus Load characteristics of protocols LABP and RTDMA when applied to network N_1.

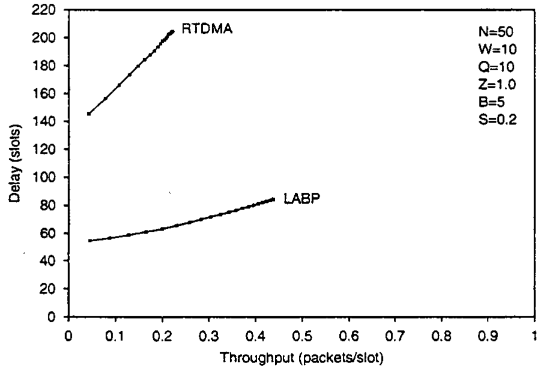

Figure 4: The Delay versus Throughput characteristics of protocols LABP and RTDMA when applied to network N_2.

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 load offered to the network is R packets/slot and the mean burst length is B slots, then the transition probabilities are: $P_{10} = 1/B$ and $P_{01} = \frac{R}{B(NZ-R)}$. The correlated arrivals were modelled in the following way [3]: With probability S, the destination of a newly arriving packet is selected at random among all the stations. With probability $(1 - S)$, 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 S, were taken to be as follows: a) Network $N_1 : N = 10, W = 5, Q = 10, B = 20, Z = 1.0, S = 0.05$, b) Network $N_2 : N = 50, W = 10, Q = 10, B = 5, Z = 1.0, S = 0.2$.

We have used the delay versus throughput characteristic as a performance metric in order to compare the two protocols. The delay versus throughput characteristics of the compared protocols when they are applied to networks N_1 and N_2 appear at figures 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.

5 CONCLUSION

This paper has presented a new self-adaptive time division multiple access protocol for WDM Star Networks. According 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.

The main characteristics of the LABP protocol are summarized below:

a) It achieves a high throughput-delay performance, even when the offered traffic is bursty and correlated.

b) The protocol is self-adaptive. Each station tends to take a fraction of the available bandwidth proportional to its needs. Furthermore, when a station goes down for a long period, its choice probability converges to a and consequently, the available bandwidth is shared between the other stations.

c) No centralized control of the stations is required, since the protocol is fully distributed.

d) It is fault-tolerant, since its operation is not affected from a possible node failure.

e) No significant increase of the implementation cost is introduced. The only additional hardware - in relation to RTDMA - is the feedback mechanism.

The use of learning automata offers a new highly promising approach to the design of self-adaptive multiaccess protocols for WDM Star Networks. We are currently working on this direction.

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