Learning-Automata-Based TDMA Protocols for Broadcast Communication Systems with Bursty Traffic

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***Abstract*—A learning-automata-based time-division multiple-access protocol for broadcast networks, which is capable of operating efficiently under bursty traffic conditions, is introduced. According to the proposed protocol, the station which grants permission to transmit at each time slot is selected by means of learning automata. The learning automata update the choice probability of each station according to the network feedback information in such a way that it asymptotically tends to be proportional to the probability that this station is ready. In this manner, the number of idle slots is minimized and the network performance is significantly improved. Furthermore, the portion of the bandwidth assigned to each station is dynamically adapted to the station's needs.**

***Index Terms*—Broadcast communication systems, bursty traffic, learning automata, time-division multiple access.**

I. INTRODUCTION

THE KEY ISSUE in broadcast networks is how to determine who gets to use the channel. A broad range of demand assignment, random access, and fixed assignment protocols have been proposed as solutions to this problem [1], [2].

Fixed assignment protocols, such as TDMA [1]–[7], RTDMA [8], and FDMA [1], assign a fixed portion of the available bandwidth to each station. In this way, collisions are avoided. Due to the absence of collisions, protocols of this family achieve a high performance when the traffic of each station is stable and *a priori* known. However, when the traffic is bursty, fixed assignment protocols are not capable of being adapted to the sharp changes of the stations' traffic. Therefore, their performance is dramatically degraded.

In this letter, a new time-division multiple-access (TDMA) protocol which is capable of operating efficiently under bursty traffic conditions is introduced. According to the proposed protocol, the station which grants permission to transmit is determined means of learning automata [9]–[12]. At each time slot, the automata take into account the network feedback information in order to update the choice probability of the selected station. The learning algorithm was designed in such a way, that the choice probability of each station asymptotically tends to be proportional to the probability that this station is ready (i.e., it has at least one packet in its queue). In this way, the number of idle slots is minimized and the network performance is significantly improved. When the traffic conditions of a station change, this leads to a change of the choice probability of this station. Therefore, the protocol is capable of being adapted to the sharp load changes of a bursty traffic environment.

The proposed learning-automata-based TDMA (LTDMA) protocol is applicable to a broad range of broadcast network architectures, including bus, star, and wireless LANs. This paper focuses on the theoretical aspects of LTDMA rather than on its application to specific network architectures. The paper is organized as follows: The proposed LTDMA protocol is presented in Section II. An analysis of the asymptotic behavior of the system which consists of the automata and the network is presented in Section III, while simulation results which indicate the superiority of the LTDMA protocol over other well-known protocols, are presented in Section IV. Finally, concluding remarks are given in Section V.

II. THE LTDMA PROTOCOL

According to the proposed LTDMA protocol, each station is provided with a learning automaton which contains the basic choice probability $P_i(t)$ of each station u_i, for $i = 1, \cdots, N$, where N is the number of stations. At each time slot t, the basic choice probabilities are normalized in the following way:

$$\Pi_i(t) = P_i(t) \Big/ \sum_{k=1}^{N} P_k(t). \tag{1}$$

The station which grants permission to transmit is selected according to the normalized probabilities Π_i, for $i = 1, \cdots, N$.

At each time slot t, the basic choice probability $P_i(t)$ of the selected station $u(t) = u_i$ is updated according to the network feedback information. If station u_i transmitted a packet during time slot t, then basic choice probability of u_i increases. Otherwise, if the selected station u_i was idle, then the basic choice probability of u_i decreases. The following probability updating scheme is used [where $L, a \in (0, 1)$]:

$$\begin{aligned} P_i(t+1) &= P_i(t) + L(1 - P_i(t)), \\ &\qquad \text{if } u(t) = u_i \text{ and } \mathrm{slot}(t) = \mathrm{success} \\ P_i(t+1) &= P_i(t) - L(P_i(t) - a), \\ &\qquad \text{if } u(t) = u_i \text{ and } \mathrm{slot}(t) = \mathrm{idle}. \end{aligned} \tag{2}$$

Since the offered traffic is bursty, when the selected station has a packet to transmit, it is probable that this station will have packets to transmit in the near future. Therefore, 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. Therefore, its choice probability is decreased.

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When the choice probability of a station converges to 0, then this station is not selected for a long period. During this period, it is probable that the station transits from idle to busy state. However, since the station does not grant permission to transmit, the automata are not capable of "sensing" the transition. 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 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 all the stations select the same station which grants permission to transmit. Therefore, although there is not centralized coordination between the stations, the protocol is collision-free. Coordination between the stations by using the same seed and a common network feedback information is feasible. Other protocols following this approach are the random URN [13] and the random TDMA [8].

III. ANALYSIS

Theorem 1: If the learning algorithm (2) is used and d_i is the probability that station u_i is ready, then for any station u_i

$$\lim_{t\to\infty, L\to 0, a\to 0} P_i(t) = d_i.$$

Proof: The proof is based on the methodology used in [11]. It is proved that

$$\lim_{t\to\infty, L\to 0, a\to 0} E[P_i(t)] = d_i \text{ and } \mathrm{var}[P_i(t)] = O(L).$$

Theorem 1 follows in a straightforward manner. The complete proof can be found in [12].

According to Theorem 1, for any two stations u_i and u_j (with $d_j \neq 0$), the LTDMA asymptotically tends to satisfy the relation

$$P_i/P_j = d_i/d_j. \tag{3}$$

This relation also holds for the normalized choice probabilities Π_i and Π_j:

$$\frac{\Pi_i}{\Pi_j} = \frac{P_i \Big/ \sum_{k=1}^{N} P_k(t)}{P_j \Big/ \sum_{k=1}^{N} P_k(t)} = \frac{P_i}{P_j} = \frac{d_i}{d_j}. \tag{4}$$

Thus, each station tends to take a fraction of the available bandwidth, proportional to the probability that this station is ready.

IV. SIMULATION RESULTS

In the following, the proposed LTDMA protocol is compared to protocols TDMA, RTDMA, and URN [13]. TDMA and RTDMA are representative TDMA protocols, while URN is a limited contention protocol [1]. In the simulation of URN, the round-robin window mechanism is used for determining which stations grant permission to transmit at each time slot. As it is shown in [13], this scheme is more effective than the random URN scheme.

The protocols which are under comparison were simulated to be applied to two networks (N_1 and N_2) under bursty traffic conditions. The bursty traffic was modeled in a way similar to the ones presented in [14] and [15]. Each source-node can be in one of two states S_0 and S_1. When a source-node is in state S_0 then it has no packet arrivals. When a source-node is in state S_1 then, at each time slot, it has a packet arrival with probability Z. Given a station is in state S_0 at time slot t, the probability that this station will transit to state S_1 at the next time slot is P_{01}. The transition probability from state S_1 to state S_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 $P_{01} = R/(B(NZ - R))$. Each station is provided with a FIFO queue which stores the arriving packets while they are waiting for transmission. The queue length is assumed to be equal to Q packets. A packet arriving while the queue is full, is assumed lost.

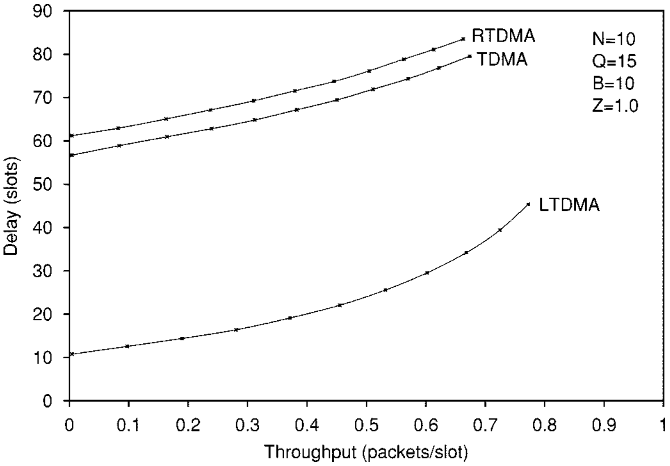

Fig. 1. The delay versus throughput characteristics of LTDMA, TDMA, and RTDMA when applied to network N_1.

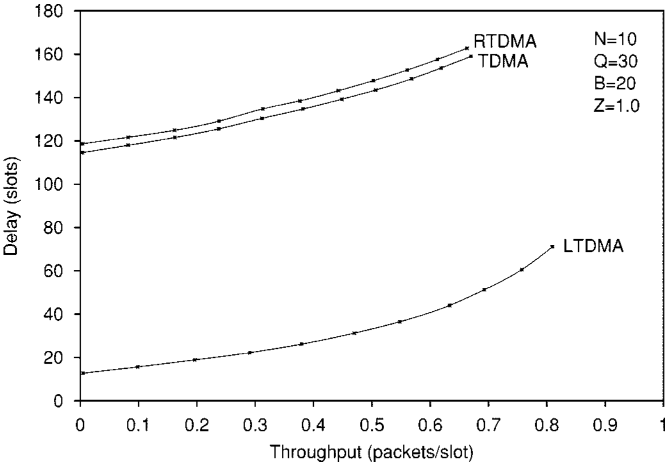

Fig. 2. The delay versus throughput characteristics of LTDMA, TDMA, and RTDMA when applied to network N_2.

The number of stations N, the queue size Q, the mean burst length B and the packet arrival probability Z of each active station, were taken to be as follows: 1) network N_1: $N = 10$, $Q = 15$, $B = 10$, $Z = 1.0$ and 2) network N_2: $N = 10$, $Q = 30$, $B = 20$, $Z = 1.0$

The delay versus throughput characteristics of protocols LTDMA, TDMA, and RTDMA when applied to networks N_1 and N_2 are appeared at Figs. 1 and 2, correspondingly. From the above graphs, it becomes clear that, LTDMA achieves a higher throughput-delay performance than protocols TDMA and RTDMA, when operating under bursty traffic conditions. The superiority of LTDMA over TDMA and RTDMA is due to its

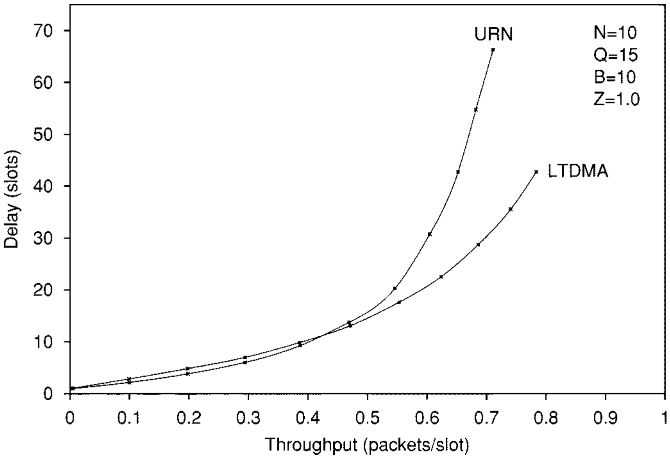

Fig. 3. The delay versus throughput characteristics of LTDMA and URN when applied to network N_1.

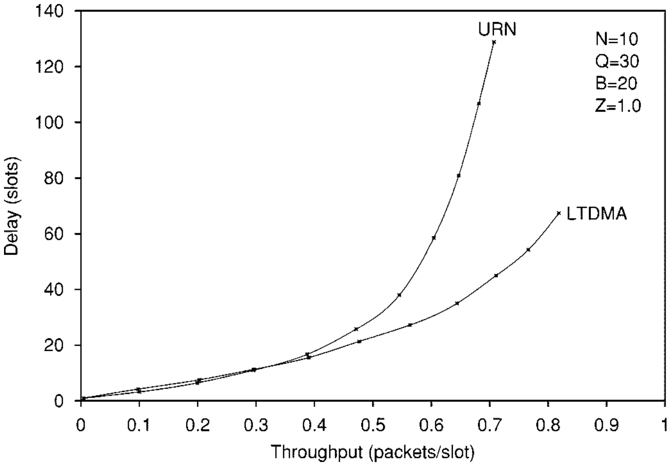

Fig. 4. The delay versus throughput characteristics of LTDMA and URN when applied to network N_2.

capability of using the network feedback information, instead of blindly selecting the station which grants permission to transmit.

URN is based on the knowledge of the number of ready stations, in order to decide how many stations will grant permission to transmit. Since the basic LTDMA protocol does not require any knowledge of the number of ready stations, it was slightly modified, in order to be fairly compared to URN. When there are more than one ready stations, then the LTDMA protocol operates as described above. When there is only one ready station, then all the stations grant permission to transmit. The delay versus throughput characteristics of the modified LTDMA protocol and URN when applied to networks N_1 and N_2 are appeared at Figs. 3 and 4, correspondingly. Under light load conditions, both protocols achieve a similar performance since both of them degenerate to slotted ALOHA. Under medium or high load conditions, LTDMA achieves a superior performance than URN. The superiority of LTDMA is due to the following reason:

URN determines how many stations grant permission to transmit, but makes no effort to determine which stations should be selected. Therefore, these stations are selected in a round-robin fashion. Under medium or heavy load conditions only one station grants permission to transmit, thus the network throughput is: $T_{\mathrm{URN}} = (1/N)\sum_{i=1}^{N} d_i$.

On the other hand, LTDMA is based on the network feedback information in order to give permission to transmit to stations that are most likely to be ready. In this case, the network throughput is: $T_{\mathrm{LTDMA}} = \sum_{i=1}^{N} \Pi_i d_i$. As stations with higher probability of being ready d_i are selected with higher probability Π_i, it follows that: $T_{\mathrm{LTDMA}} > T_{\mathrm{URN}}$.

V. CONCLUSION

This letter has presented a new TDMA protocol. According the proposed LTDMA protocol, the station which grants permission to transmit at each time slot is selected by means of learning automata, which are capable of being adapted to the sharp changes of the stations' traffic. Therefore, the new protocol is capable of achieving a low delay and a high throughput in the dynamic bursty traffic environment.

The main characteristics of the LTDMA protocol are summarized below.

1) It achieves a high performance, even when the offered traffic is bursty.
2) The protocol is self-adaptive. Theorem 1, indicates that each station tends to take a fraction of the available bandwidth proportional to its needs.
3) No centralized control of the stations is required, since the protocol is fully distributed.

REFERENCES

[1] A. S. Tanenbaum, *Computer Networks*. Englewood Cliffs, NJ: Prentice-Hall, 1996.
[2] W. Stallings, *Local and Metropolitan Area Networks*. Englewood Cliffs, NJ: Prentice-Hall, 1997.
[3] I. Rubin and J. Baker, "Media access control for high-speed local area and metropolitan area networks," *Proc. IEEE*, vol. 78, pp. 168–203, Jan. 1990.
[4] J. M. Capone and I. Stavrakakis, "Delivering QoS requirements to traffic with diverse delay tolerances in a TDMA environment," *IEEE/ACM Trans. Networking*, vol. 7, pp. 75–87, Feb. 1999.
[5] G. Anastasi, D. Grillo, and L. Lenzini, "An access protocol for speech/data/video integration in TDMA-based advanced mobile systems," *IEEE J. Select. Areas Commun.*, vol. 15, pp. 1498–1509, Oct. 1997.
[6] W. W. Chu and A. G. Konheim, "On the analysis and modeling of a class of computer communication systems," *IEEE Trans. Commun.*, vol. 20, pp. 645–660, 1972.
[7] I. Rubin, "Access control disciplines for multiaccess communications channels: Reservation and TDMA schemes," *IEEE Trans. Inform. Theory*, vol. 25, pp. 516–526, 1979.
[8] A. Ganz and Z. Koren, "Performance and design evaluation of WDM stars," *J. Lightwave Technol.*, vol. 11, pp. 358–366, Feb. 1993.
[9] K. Najim and A. S. Poznyak, *Learning Automata: Theory and Applications*. New York, NY: Pergamon , 1994.
[10] G. I. Papadimitriou and D. G. Maritsas, "Learning automata-based receiver conflict avoidance algorithms for WDM broadcast-and-select star networks," *IEEE/ACM Trans. Networking*, vol. 4, pp. 407–412, June 1996.
[11] ——, "WDM passive star networks: A learning automata based architecture," *Computer Communications*, vol. 19, no. 6–7, pp. 580–589, June 1996.
[12] G. I. Papadimitriou and A. S. Pomportsis, "Analysis of a learning-automata-based time division multiple access protocol," Dep. Informatics, Aristotle Univ., Thessaloniki, Greece, Tech. Rep..
[13] L. Kleinrock and Y. Yemini, "An optimal adaptive scheme for multiple access broadcast communication," in *Proc. IEEE ICC'78*, Toronto, Canada, pp. 7.2.1–7.2.5.
[14] S. L. Danielsen, C. Joergensen, B. Mikkelsen, and K. E. Stubkjaer, "Analysis of a WDM packet switch with improved performance under bursty traffic conditions due to tuneable wavelength converters," *J. Lightwave Technol.*, vol. 16, pp. 729–735, May 1998.
[15] M. W. McKinnon, G. N. Rouskas, and H. G. Perros, "Performance analysis of a photonic single-hop ATM switch architecture with tunable transmitters and fixed frequency receivers," *Perform. Eval.*, vol. 33, no. 5, pp. 113–136, June 1998.