# Adaptive MAC Protocols for Broadcast Networks With Bursty Traffic

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***Abstract*—An adaptive medium access control 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 taking into account the network feedback information. In this way, 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*—Adaptive protocols, broadcast communication networks, bursty traffic, medium access control (MAC).**

## I. Introduction

CHANNEL allocation is the key problem in multiaccess networks. A broad range of demand assignment, random access, and fixed-assignment medium access control (MAC) protocols have been proposed as solutions to this problem [1], [2].

Fixed-assignment protocols, such as time-division multiple access (TDMA) [1]–[7], random time-division multiple access (RTDMA) [8], and frequency-division multiple access (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 TDMA protocol which is capable of operating efficiently under bursty traffic conditions is introduced. According to the proposed protocol, the stations of the network are divided into two groups: active or idle. This categorization is based on the network feedback information. The active stations are granted permission to transmit more frequently than the idle ones. In this way, the number of idle slots is minimized and the network performance is significantly improved. The categorization of the stations into active or idle ones is dynamically updated at each time slot according to the network feedback information. Therefore, the protocol is capable of being adapted to the sharp load changes of a bursty traffic environment.

The proposed adaptive time-division multiple-access (ATDMA) protocol is applicable to a broad range of broadcast network architectures, including bus, star, and wireless LANs. This letter focuses on the general principles of operation of the ATDMA rather than on its application to specific network architectures.

The paper is organized as follows. The proposed ATDMA protocol is presented in Section II. Simulation results, which indicate the superiority of the ATDMA protocol over other well-known protocols, are presented in Section III. Finally, concluding remarks are given in Section IV.

## II. ATDMA Protocol

Let $U = \{u_1, \ldots, u_N\}$ be the set of stations, where $N$ is the number of stations. The stations communicate via a slotted broadcast channel. There is no frame structure. Each slot is examined individually.

Each station is provided with a waiting queue of length $Q$, where the arriving packets are buffered before being transmitted. The traffic which is offered to the stations is assumed to be bursty. Thus, each station can be in one of two states: active or idle. When a station is active, it has one packet arrival at each time slot. On the other hand, when a station is idle, it has no packet arrivals. Each station operates independently from the others and has no knowledge of their states. According to the proposed ATDMA protocol, each station is based on the network feedback information in order to estimate which stations are active.

Each station maintains a set of stations $A$ which are estimated to be active. The stations in set $A$ are granted permission to transmit in a round-robin fashion. The key points of the protocol are summarized below.

1) Set $A$ must be determined in such a way that it contains those stations which are probably active. Set $A$ consists of the stations which transmitted a packet during the last time they were granted permission to transmit. Since the offered traffic is bursty, when a station which is granted permission to transmit is active, it is probable that this station will remain active in the near future. Therefore, this station is included in set $A$. On the other hand, when a station which is granted permission to transmit has no packets to transmit, no transmission takes place and the slot remains idle. Due to the bursty nature of the traffic, it is probable that this station will remain idle in the near future. Therefore, this station is not included in set $A$.
2) Consider a noiseless channel. At each time slot, the channel can be in one of two states: idle or busy. Each station is sensing the channel status at each time slot. The channel status is used as network feedback information by the ATDMA protocol, and it is based on this feedback information that the set of active stations $A$ is constructed. In order to avoid collisions, set $A$ must be common for all the stations, so that all the stations arrive

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at the same conclusions on which station grants permission to transmit. All the stations use the same protocol and—due to the broadcast nature of the network—the feedback information is common for all the stations. Therefore, all the stations select the same station which is granted permission to transmit. Therefore, although there is not centralized coordination between the stations, the protocol is collision-free.

However, when the channel is noisy, it is possible that the feedback is not common for all stations. In this case, set $A$ is not common for all stations and consequently, collisions may occur. At each time slot, the channel can be in one of the following three states: successful transmission, idle, or collision. When applied to a noisy channel, the ATDMA protocol must be capable of operating efficiently in the presence of collisions.

The algorithmic description of the ATDMA protocol is presented below. In the following description, $u_{s(t)}$ denotes the station which was granted permission to transmit at time slot $t$. The channel is assumed to be noiseless. Therefore, the network feedback information at time slot $t$ is $\mathrm{slot}(t) \in \{\mathrm{busy},\ \mathrm{idle}\}$.

```
PROCEDURE ATDMA;
REPEAT
  t := t + 1;
  i := s(t);
  (* Update the set of active stations A *)
  if slot(t) = busy and u_i ∉ A(t − 1) then A(t) := A(t − 1) ∪ {u_i};
  if slot(t) = idle and u_i ∈ A(t − 1) then A(t) := A(t − 1) − {u_i};
  (* Select station s(t + 1) which grants permission to transmit *)
  if A(t) = ∅ then s(t + 1) := (i mod N) + 1
  else
  begin
    repeat
      i := (i mod N) + 1;
    until u_i ∈ A(t);
    s(t + 1) := i;
  end
FOREVER.
```

In a noisy environment (e.g., a wireless LAN environment), the network feedback information at time slot $t$ is $\mathrm{slot}(t) \in \{\mathrm{success},\ \mathrm{idle},\ \mathrm{collision}\}$. The updating of the set of active stations $A$ is implemented in the following way.

```
(* Update the set of active stations A *)
if slot(t) = success then
begin
  if u_i ∉ A(t − 1) then A(t) := A(t − 1) ∪ {u_i};
  suc := i;
end
else if slot(t) = idle and u_i ∈ A(t − 1) then
  A(t) := A(t − 1) − {u_i}
else if slot(t) = collision then A(t) = {u_suc}.
```

TABLE I
STATIONS' PERCENTAGES OF TRAFFIC

| station # | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| percentage of traffic | 5% | 10% | 5% | 5% | 40% | 1% | 2% | 20% | 3% | 9% |

## III. SIMULATION RESULTS

Two protocols for broadcast networks that take into account the burstiness of traffic are learning-automata-based TDMA (LTDMA) [9] and packet reservation multiple access (PRMA) [10].

The PRMA protocol was designed to handle primarily voice traffic in a wireless LAN environment. A base station is placed in the center of a cell. It receives packets from the wireless stations via an uplink channel and broadcasts them to the wireless stations via a downlink channel. Time slots are organized into frames, and when a wireless station successfully transmits a packet to the base station during a time slot, it reserves this slot for transmission in the next frame. Due to the presence of a base station and the use of two communication channels, protocol PRMA can not be fairly compared to the proposed ATDMA one.

Protocol LTDMA is a general purpose protocol that can be applied in a wide range of broadcast networks including copper, optical, and wireless networks. According to the LTDMA protocol, the station which grants permission to transmit at each time slot is selected by means of learning automata [11]–[14]. The learning automata update the choice probability of each station according to the network feedback information. When a station grants permission to transmit but it has no packets to transmit, its choice probability is decreased. On the other hand, if the result is a successful transmission, the choice probability of the selected station is increased. When a collision occurs, the choice probabilities of stations are reset. The probability updating scheme is 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. In this way, the number of idle slots is minimized and the network performance is improved. Furthermore, the portion of the bandwidth assigned to each station is dynamically adapted to the station's needs. LTDMA uses the same network architecture and the same network feedback information as the proposed ATDMA one. Therefore, the two protocols can be fairly compared, and a performance comparison between the two schemes would be very helpful in evaluating the proposed ATDMA protocol. In the rest of this section, the proposed ATDMA protocol is compared to LTDMA.

The protocols which are under comparison were simulated to be applied to two 10-station networks ($N_1$ and $N_2$) under asymmetric traffic conditions. The stations' traffic (as percentages of the total network traffic) are presented in Table I.

The offered traffic is assumed to be bursty. Simulation results for a mixture of Poisson and bursty traffic are also provided (network $N_2$). The bursty traffic was modeled in the same way used in [9] and [15]. Each source node can be in one of two states, $S_0$ or $S_1$. 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 it has

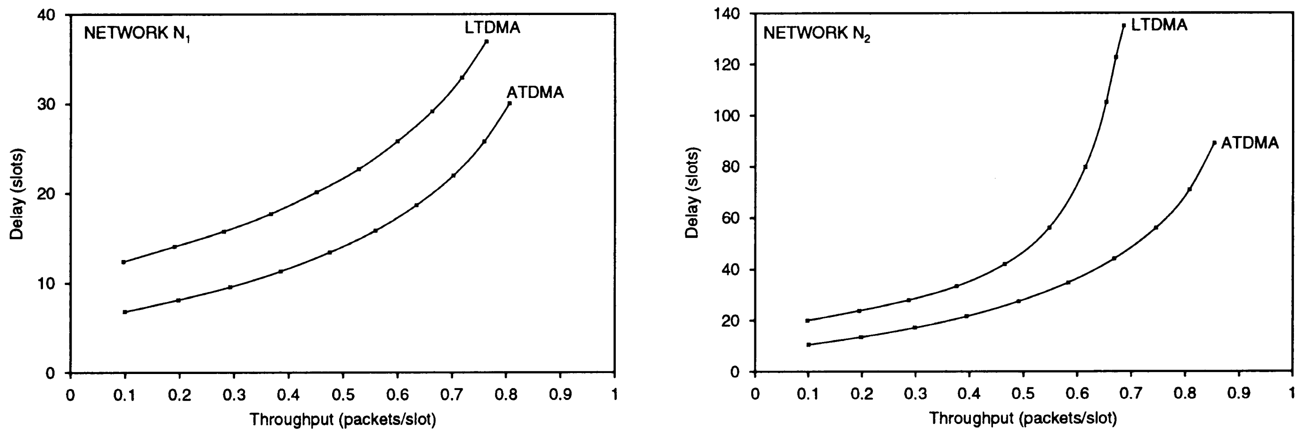


Fig. 1. Delay versus throughput characteristics of ATDMA and LTDMA when applied to networks $N_1$ and $N_2$.

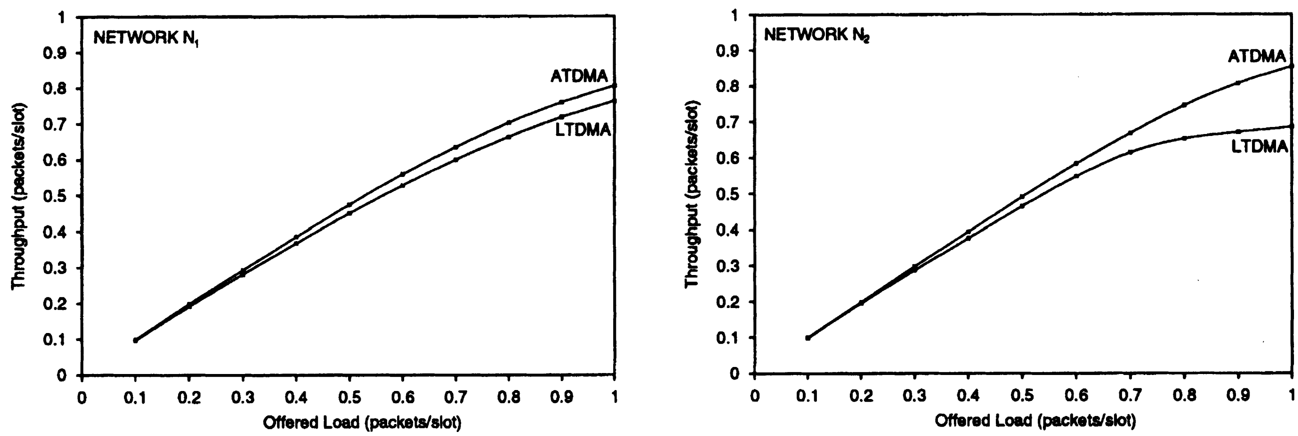


Fig. 2. Throughput versus offered load characteristics of ATDMA and LTDMA when applied to networks $N_1$ and $N_2$.

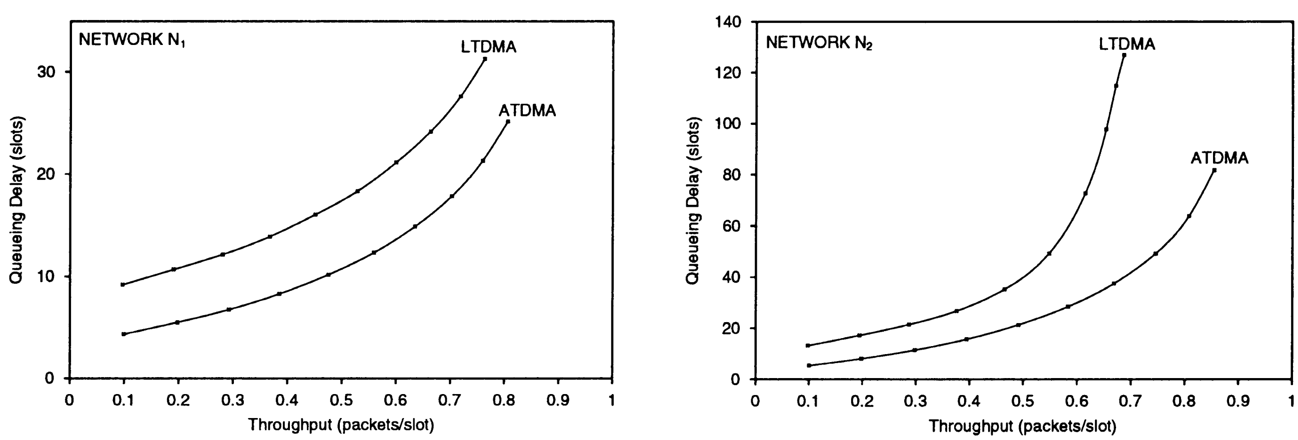


Fig. 3. Queuing delay versus throughput characteristics of ATDMA and LTDMA when applied to networks $N_1$ and $N_2$.

exactly one packet arrival at each time slot. 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 $P_{01} = R/(B(N-R))$.

Each station is provided with a first-in, first-out queue which stores the arriving packets while they are waiting for transmission. The capacity of the waiting queue is assumed to be equal to $Q$ packets. A packet arriving while the queue is full is assumed lost.

The environment in which both protocols are applied is assumed to be noisy. Thus, the network feedback information can be corrupted, due to the presence of noise. When a time slot contains a successful transmission, a station can sense it as a "collision" with probability $P_{\mathrm{sc}}$ or as "idle" with probability $P_{\mathrm{si}}$. A slot containing a collision can be sensed as "idle" with probability $P_{\mathrm{ci}}$ or as a "success" with probability $P_{\mathrm{cs}}$. Finally, an idle slot can be sensed as "collision" with probability $P_{\mathrm{ic}}$ or as a

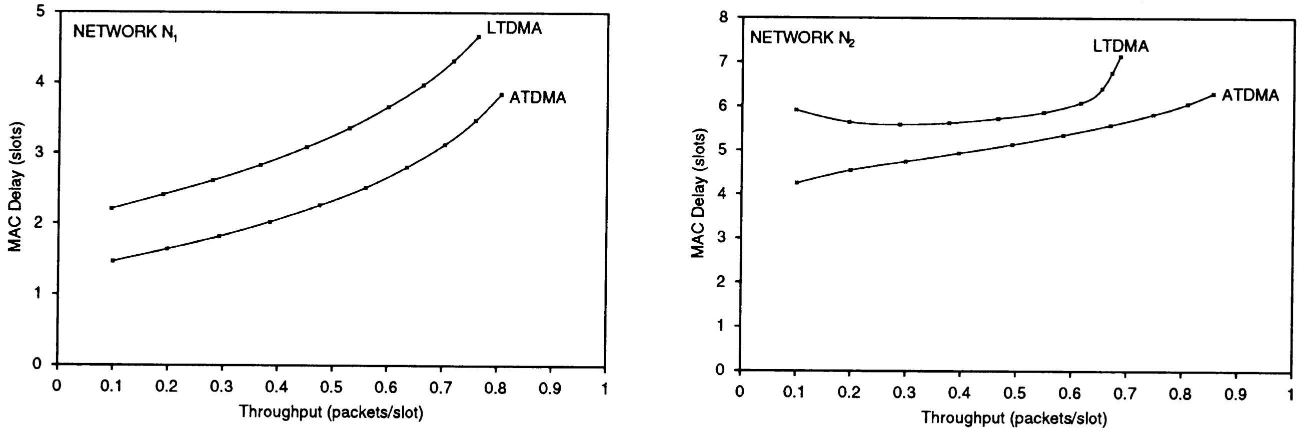


Fig. 4. MAC delay versus throughput characteristics of ATDMA and LTDMA when applied to networks $N_1$ and $N_2$.

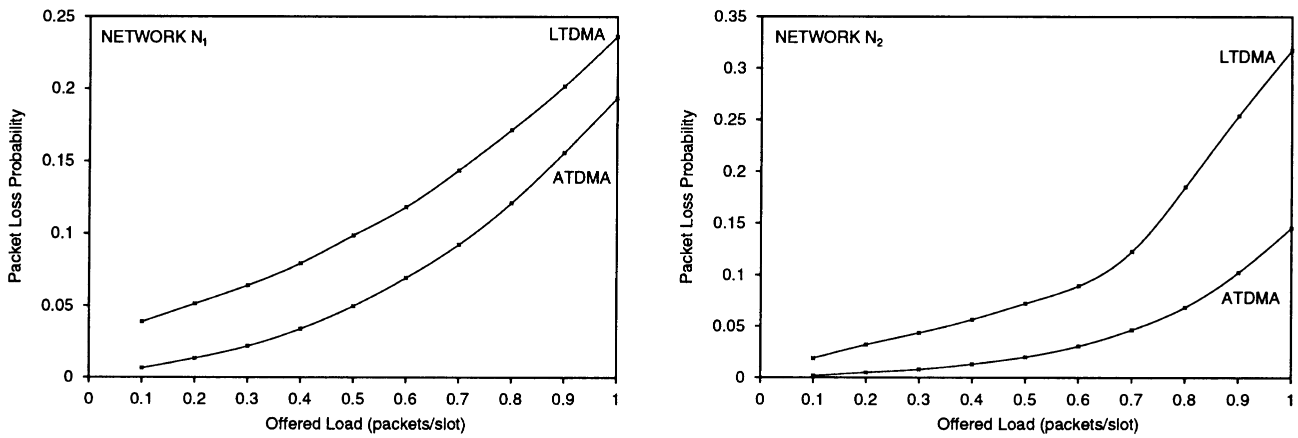


Fig. 5. Packet loss probability versus offered load characteristics of ATDMA and LTDMA when applied to networks $N_1$ and $N_2$.

"success" with probability $P_{\mathrm{is}}$. It is not possible that an idle slot is sensed as a successful transmission. Therefore, $P_{\mathrm{is}}$ is taken to be equal to 0 for all simulated networks.

Networks $N_1$ and $N_2$ consist of 10 stations. Their parameters were taken to be as follows.

1) Network $N_1$: All the stations are assumed to have bursty traffic. Three stations are assumed to have a burst size $B = 5$, four stations have a burst size $B = 10$, and three stations have a burst size $B = 15$. The queue capacity was taken to be $Q = 15$. Probabilities $P_{\mathrm{sc}}$, $P_{\mathrm{si}}$, $P_{\mathrm{ci}}$, $P_{\mathrm{cs}}$, and $P_{\mathrm{ic}}$ are taken to be equal to $10^{-3}$.
2) Network $N_2$: Five stations are assumed to have Poisson traffic and five stations have bursty traffic with a burst length $B = 50$. The queue capacity is $Q = 50$. Probabilities $P_{\mathrm{sc}}$, $P_{\mathrm{si}}$, $P_{\mathrm{ci}}$, $P_{\mathrm{cs}}$, and $P_{\mathrm{ic}}$ are taken to be equal to $10^{-2}$.

We have used five performance metrics in order to evaluate protocols ATDMA and LTDMA.

1) Delay versus throughput characteristic (Fig. 1).
2) Throughput versus offered load characteristic (Fig. 2).
3) Queuing delay versus throughput characteristic (Fig. 3). Queuing delay is defined as the time between the arrival of a packet at the waiting queue and the instant that this packet becomes the head-of-line in the waiting queue.
4) MAC delay versus throughput characteristic (Fig. 4). MAC delay is defined as the time required for a head-of-line packet in the waiting queue to gain access to the medium.
5) Packet loss probability versus offered load characteristic (Fig. 5).

From the above graphs, it becomes clear that ATDMA achieves a higher performance than LTDMA. The performance advantage of ATDMA over LTDMA becomes higher when both protocols operate in a highly noisy environment or when the burst length is high. The superiority of the proposed ATDMA protocol is due the following two reasons.

1) Protocol ATDMA is a deterministic one. Once a station is characterized as active, it is guaranteed that it will be granted permission to transmit within the next few slots. On the other hand, the stochastic nature of LTDMA does not provide such a guarantee. An active station can wait for an arbitrary number of slots before it is granted permission to transmit.
2) Protocol ATDMA reacts more rapidly to the transition of a station from idle to active state, by adding this station in the set of active stations $A$. On the other hand, protocol LTDMA reacts more slowly, because the learning automata take some time to converge.

Overall, although the two protocols use the same network feedback information, the proposed ATDMA protocol makes a more efficient use of this feedback information.

In [9] it is shown that LTDMA achieves a significantly higher performance than protocols TDMA, RTDMA, and Urn [16]. Since the proposed ATDMA protocol clearly outperforms LTDMA, it becomes clear that it also outperforms protocols TDMA, RTDMA, and Urn.

## IV. Conclusion

This letter has presented a new MAC protocol for broadcast networks. According to the proposed ATDMA protocol, the station which grants permission to transmit at each time slot is selected from the set of active stations. At each time slot, the set of active stations is updated according to the network feedback information. Therefore, the proposed ATDMA protocol is capable of being adapted to the sharp changes in 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 ATDMA protocol are summarized below.

1) It achieves a high performance, even when the offered traffic is bursty.
2) The protocol is self-adaptive. The available bandwidth is shared between active stations. In this way, the number of idle slots is minimized, and consequently, the network performance is significantly improved.
3) No centralized control of the stations is required, since the protocol is fully distributed.
4) It is fault tolerant, since its operation is not affected from a possible node failure.
5) No significant increase of the implementation cost is introduced. The only additional hardware, in relation to TDMA or RTDMA, is a processor which implements the adaptive MAC algorithm.

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