A New Protocol for Wireless LANs

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Abstract- In this paper, a TDMA-based Randomly Addressed Polling protocol (TRAP) is proposed. TRAP employs a variable-length TDMA-based contention stage with the length based on the number of active stations. Simulation results are presented that reveal the superiority of TRAP against the RAP protocol in cases of medium and high offered loads. Furthermore the implementation of TRAP is much simpler than that of CDMA-based versions of RAP, since no extra hardware is needed for the orthogonal reception of the random addresses.

Keywords: **Wireless LANs, MAC protocol, performance evaluation, TDMA.**

I. Introduction

RAP is a protocol designed to work in the harsh fading environment of a WLAN [1]-[4]. It avoids the burden of monitoring all the stations in a cell, by working only with the active stations (those having a packet to transmit) seeking uplink communication. RAP [5]-[8] employs a contention scheme using a fixed number of random numbers, known as random addresses, that are used to resolve contention among active mobile stations. The RAP protocol has been analyzed in [6]. For a small number M of active stations, compared to the number of random addresses P, the protocol performs well. RAP is inefficient when the number of stations is large. This is because a small number of available random addresses provides very little space for the contention resolution to be performed efficiently. For example, for values of M with $P \leq M$, the selection of the same random address by more than one station becomes very likely. As a result, the probability of a successful transmission is lowered, which leads to the decreased throughput and increased delay.

In this paper, we propose a mechanism that estimates the number of active stations at the beginning of each polling cycle. According to this proposal, at the beginning of each polling cycle, all active mobile stations register their intention to transmit via transmission of a short pulse. All active stations' pulses are added at the Base Station (BS), which uses the aggregate received pulse to estimate the number of active stations. Based on this estimate, the BS then schedules a TDMA-based contention stage to comprise an adequate number of slots for the active stations to successfully register their intention to transmit and then commences polling.

The remainder of this paper is organized as follows: Section II introduces TRAP, our proposal for a variable length TDMA-based Randomly Addressed Polling Protocol (TRAP) with a contention stage with the length based on the number of active stations. Section III details the simulation environment used to compare the relative performance of TRAP to that of RAP and presents simulation results that reveal TRAP's superiority in cases of medium and high loads. Finally, concluding remarks are presented in Section IV.

II. The TDMA-Based RAP (TRAP) Protocol

To combat the above-mentioned deficiency of Randomly Addressed Polling, we propose TDMA-based Randomly Addressed Polling protocol (TRAP). TRAP employs a variable-length TDMA-based contention stage with the length based on the number of active stations. This lifts the requirement for a fixed number of random addresses. The TDMA-based contention stage comprises a variable number of equally sized slots, with each slot corresponding to a random address. However, a mechanism for estimating the number of active stations is needed in order for the BS to select the appropriate number of slots in the TDMA contention stage. Thus, at the beginning of each polling cycle all active mobile stations register their intention to transmit via transmission of a short pulse. All active stations' pulses are added at the BS, which uses the aggregate received pulse to estimate the number of active stations. The proposed protocol works as follows:

1. *Active stations estimation*: At the beginning of each polling cycle, the BS sends an *ESTIMATE* message in order to receive active stations' pulses. After the BS estimates the number of active stations M based on the aggregate received pulse, it schedules the TDMA-based contention stage to comprise an adequate number of random addresses $P=k*M$ (where k is a positive integer) for the active stations to compete with few collisions for medium access.

2. *Contention invitation stage:* The BS announces it is ready to collect packets from the mobile stations by transmitting a

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READY message, containing the number of random addresses P to be used in this polling cycle.

3. *Contention stage:* Each active mobile station generates a random address R, ranging from 0 to P-1. Active stations transmit their random addresses at the appropriate slot of the TDMA-based contention stage. An active station that generates a random address R, $0 \leq R < P$, will transmit its random address at slot R. As in RAP, stations can generate addresses up to q times in a single contention stage and the contention stage may be repeated L times, with each active station generating a random address for each stage. Obviously, if two or more stations select the same random address, their random address transmissions collide and are not received at the BS. Thus, the random addresses received correctly at the BS are always distinct, with each number identifying a single active station.

4. *Polling stage*: Suppose that at the lth stage ($1 \leq l \leq L$) the BS received the largest number of random addresses and these are, in ascending order, R_1, R_2,..., R_n. The BS polls the mobile stations using those numbers. When the BS polls mobile stations with R_k, the station that transmitted R_k as its random address at the lth stage will transmit a data packet to the BS.

5. If the BS successfully receives a packet from a mobile station, it sends a positive acknowledgment (ACK) before polling the next mobile station. If a mobile station receives an ACK, it assumes correct delivery of its packet, otherwise, it waits for the current polling cycle to complete and retries during the next cycle.

Under the assumption that all random address transmissions reach the BS, TRAP is collision-free among data packets. This is because the transmission of the same random address by two or more stations occurs in the same time slot. Thus, these stations' control packets collide, their address is not polled and consequently their data packets do not collide. This is an advantage of TRAP against the RAP protocol. Due to the CDMA nature of random address transmission in RAP, when the BS polls a random address that was selected by more than one mobile, the corresponding mobiles' packets will collide. This fact helps preserve bandwidth, since data packets are usually much larger than control packets and it has found use in other WLAN MAC protocols as well, such as IEEE 802.11 and MACAW [9].

However, the obvious advantage of TRAP is in terms of salability. Since the number of random addresses can now vary according to the number of active stations, TRAP will not degrade in cases of a large number of active stations. Simulation results that are presented in the next section reveal that the heuristic estimator $P=k*M$ for the number of random addresses is sufficient, since the performance of TRAP at medium and high loads is significantly better than that of RAP. Furthermore, the implementation of TRAP is much simpler than that of CDMA-based versions of RAP, since no extra hardware is needed for the orthogonal reception of the random addresses.

III. Performance Evaluation

A. *Simulation Environment*

In order to compare the performance of TRAP against RAP, we used an event-driven simulator coded in C. The simulator models N mobile stations, the BS and the wireless links as separate entities. Each mobile station uses a buffer to store the arriving packets. The buffer length is assumed to be equal to Q packets. Any packets arriving to find the buffer full, are dropped. Regarding the aggregate network offered load, the simulator models packet arrivals at the mobile stations with packet inter-arrival times being exponentially distributed. The arrival rate is the same among all mobile stations.

As far as modeling of the wireless environment is concerned, the condition of the wireless link between any two stations was modeled using a finite state machine with two states. Such structures can efficiently approximate the bursty-error behavior of a wireless channel [10] and are widely used in WLANs modeling [3, 4]. The model comprises two states, G and B. State G denotes that the wireless link is in a relatively "clean" condition and is characterized by a small BER, which is given by the parameter *GOOD_BER*. State B denotes that the wireless link is in a condition characterized by increased BER, which is given by the parameter *BAD_BER*.

We assume that the background noise is the same for all stations and thus the principle of reciprocity stands for the condition of any wireless link. Therefore, for any two stations A and C, the BER of the link from A to C and the BER of the link from C to A are the same. The time spent by a link in states G and B are exponentially distributed, but with different average values, given by the parameters *TIME_GOOD* and *TIME_BAD*, respectively. The status of a link probabilistically changes between the two states. When a link is in state G and its status is about to change, the link transits to stage B. When a link is in state B and its status is about to change, the link transits to stage G. By changing the model's parameter values, the protocols can be simulated for a variety of physical environments.

In the process of delivering our simulation results, we made the following assumptions:

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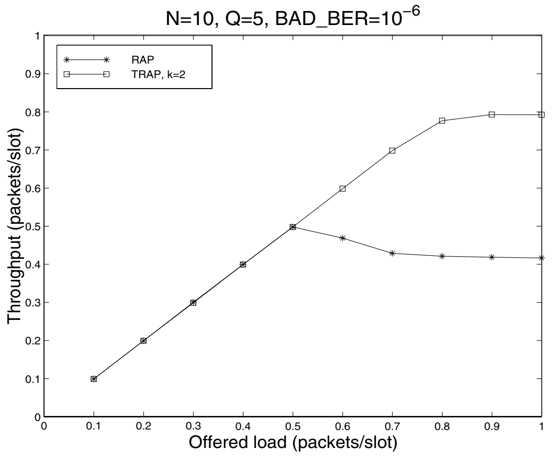

Fig. 1. The Throughput versus Offered load characteristics of RAP and TRAP when applied to network N_1.

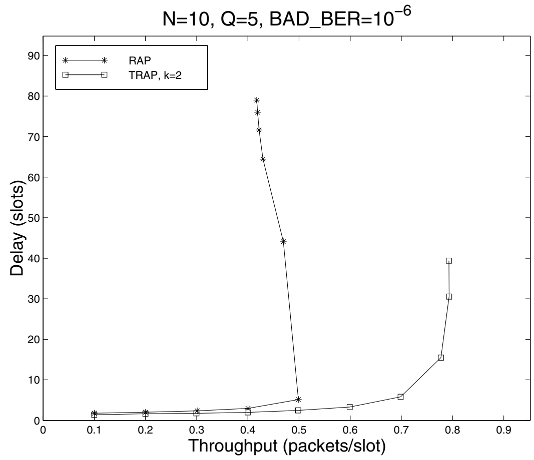

Fig. 2. The Delay versus Throughput characteristics of RAP and TRAP when applied to network N_1.

1. We did not include the effect of adding a physical layer preamble in our simulations.

2. No error correction is used and did not account for the possibility of packet capturing. Whenever two packets collide, they are assumed lost.

3. No data traffic is exchanged between the BS and the mobiles. Upon polled, a mobile station can initiate a data packet transmission with any other mobile as its destination. These assumptions limit the role of the BS to be only the means of executing the polling algorithms. They were made to measure the performance increase of TRAP over RAP due to the proposed contention stage. Furthermore, the ability for a mobile station to transmit to any other mobile station within its cell is clearly a more realistic assumption, especially in the absence of backbone traffic to/from the WLAN.

We employed the broadly used throughput versus offered load and delay versus throughput characteristics as performance metrics to compare the protocols. The number of mobile stations N under the coverage of the BS, the buffer size Q and the parameter BAD_BER were taken as follows:

1. Network N_1: N=10, Q=5, *BAD_BER*=10^{-6}
2. Network N_2: N=10, Q=5, *BAD_BER*=10^{-3}
3. Network N_3: N=50, Q=5, *BAD_BER*=10^{-6}
4. Network N_4: N=50, Q=5, *BAD_BER*=10^{-3}

All other parameters remain constant for all simulation results and are shown below:

- *GOOD_BER*=10^{-10}.
- *TIME_GOOD*=30 sec.
- *TIME_BAD*=10 sec.
- *L*=2.
- *k*=2.
- *P*=5.
- *RETRY_LIMIT*=3. This variable sets the maximum number of retransmission attempts per packet. If the number of retransmissions of a packet exceeds this value (either due to collisions or channel errors) the packet is dropped.
- At the MAC layer, the size of all control packets for the protocols is set to 160 bits, the size of data packets is set to 6400 bits and the overhead for the orthogonal CDMA reception of the random addresses in RAP is set to five times the size of the poll packet, as in [6]. The wireless medium bit rate was set to 1 Mbps. The propagation delay between any two stations was set to 0.05 msec.

B. Simulation results

The throughput versus offered load characteristics of the compared protocols when applied to networks N_1, N_2, N_3 and N_4 are shown in Figures 1, 3, 5 and 7, respectively, while the delay versus throughput characteristics when applied to networks N_1, N_2, N_3 and N_4 are shown in Figures 2, 4, 6 and 8, respectively. In these graphs, the term "slot" corresponds to the transmission time of a data packet. From the Figures, it is obvious that TRAP is superior to that of RAP in cases of medium and high-load conditions. This superiority is due to the ability of TRAP to dynamically adjust the number of available random addresses according to the number of active mobile stations.

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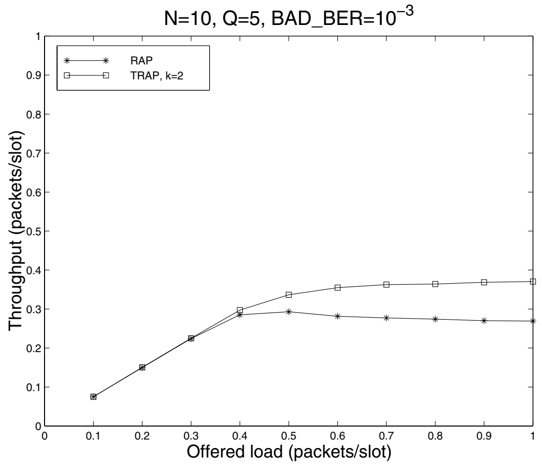

Fig. 3. The Throughput versus Offered load characteristics of RAP and TRAP when applied to network N_2.

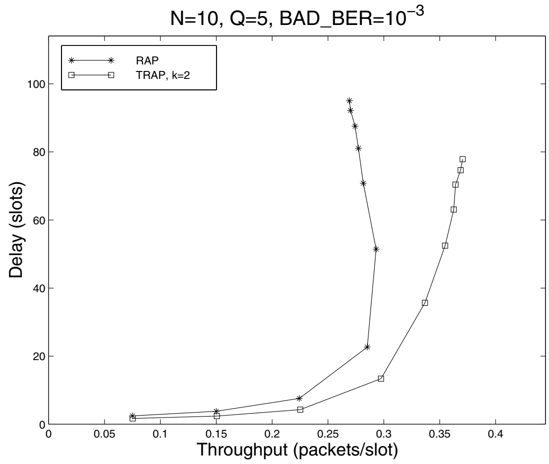

Fig. 4. The Delay versus Throughput characteristics of RAP and TRAP when applied to network N_2.

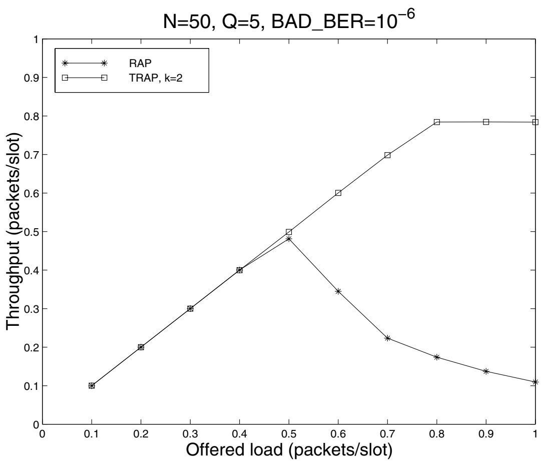

Fig. 5. The Throughput versus Offered load characteristics of RAP and TRAP when applied to network N_3.

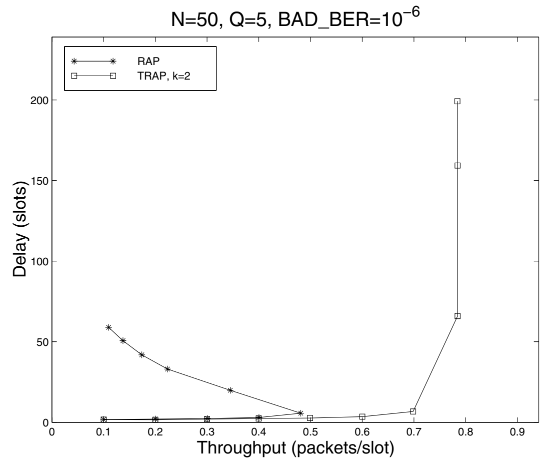

Fig. 6. The Delay versus Throughput characteristics of RAP and TRAP when applied to network N_3.

From the Figures, we observe that for a WLAN of N=10 mobile stations:

1. Under relatively "clean" wireless links (*BAD_BER*=10^{-6}), TRAP reaches a throughput gain over RAP, ranging from about 26 % at medium loads (0.6 packets/slot) to about 90 % at high loads (1 packet/slot) (Fig. 1).

2. Under error-prone wireless links (*BAD_BER*=10^{-3}), TRAP reaches a throughput gain over RAP, ranging from about 26 % at medium loads (0.6 packets/slot) to about 37 % at high loads (1 packet/slot) (Fig. 3).

This superiority at high loads becomes clearer when the number of stations is high (N=50). In that case:

1. Under relatively "clean" wireless links (*BAD_BER*=10^{-6}), TRAP reaches a throughput gain over RAP, ranging from about 73 % at medium loads (0.6 packets/slot) to about 600 % at high loads (1 packet/slot) (Fig. 5).

2. Under error-prone wireless links (*BAD_BER*=10^{-3}), TRAP reaches a throughput gain over RAP, ranging from about 100 % at medium loads (0.6 packets/slot) to about 250 % at high loads (1 packet/slot) (Fig. 7).

Finally, we observe that the achieved superiority of TRAP at medium and high loads comes at no expense over the performance at low loads, since both the throughput versus offered load and delay versus throughput characteristics of both the protocols are practically the same for network loads ranging from 0 to 0.5 packets/slot.

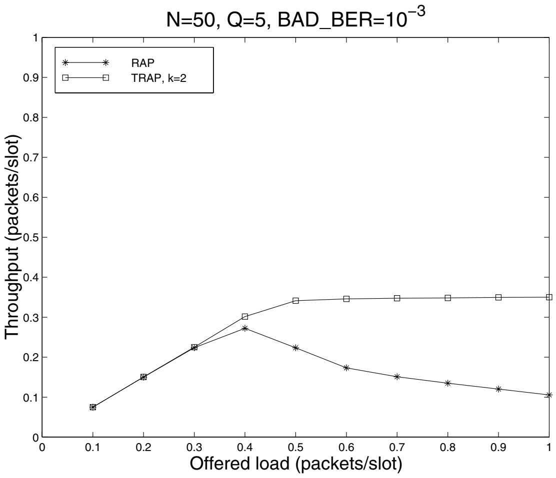

Fig. 7. The Throughput versus Offered load characteristics of RAP and TRAP when applied to network N_4.

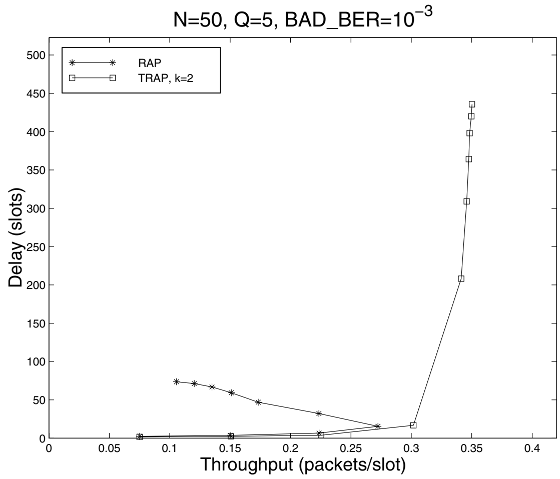

Fig. 8. The Delay versus Throughput characteristics of RAP and TRAP when applied to network N_4.

IV. CONCLUSION

The fixed number of available random addresses of RAP leads to decreased performance in case of many active stations. This paper introduced a TDMA-based Randomly Addressed Polling protocol (TRAP). TRAP employs a variable-length TDMA-based contention stage with the length based on the number of active stations. TRAP lifts the requirement of RAP for a fixed number of random addresses and is thus scalable to a large number of stations. Simulation results were presented that reveal the superiority of TRAP against the RAP protocol under medium and high loads. Furthermore, the implementation of TRAP is much more simple than that of CDMA-based versions of RAP, since no extra hardware is needed for the orthogonal reception of the random addresses.

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REFERENCES

[1] W. Stallings, "Data and computer communications, sixth Edition", Prentice Hall, NJ, 2000.
[2] J. Geier, "Wireless LANs, Implementing interoperable networks", Macmillan Network Architecture and Development Series, 1999.
[3] B. P. Bhattacharya, A. Krishna, S. Tripathi, "Enhancing throughput over wireless LANs using channel state dependent packet scheduling", *Proceedings of IEEE INFOCOM'96,* 1996, pp. 1133-1140.
[4] P. Bhagwat, P. Bhattacharya, A. Krishna and K. Tripathi, "Using channel state dependent packet scheduling to improve TCP throughput over wireless LANs", *ACM/Baltzer Wireless Networks*, 1997, pp. 91-102.
[5] K. C. Chen, "Medium Access Control of Wireless LANs for mobile computing", *IEEE Network*, September/ October 1994, pp. 50-63.
[6] K. C. Chen, C. H. Lee, "RAP-A Novel Medium Access Control protocol for wireless data networks", Proceedings of IEEE GLOBECOM, TX, USA, 1993, pp. 1713-1717.
[7] K. C. Chen, C. H. Lee, "Group Wireless Addressed Polling for multicell wireless data networks", *Proceedings of IEEE ICC'94*, New Orleans, LA, USA, 1994, pp. 913-917.
[8] J. W. Dai, "The stability of Randomly Addressed Polling protocol", *IEICE Transactions on Communications,* October 1997, pp. 1502-1508.
[9] V. Bharghavan, "MACAW, A MAC protocol for wireless LANs", *ACMSIG-COMM'94*, London, UK, 1994, pp. 212-225.
[10]E. Gilbert, "Capacity of a burst noise channel", *Bell System Technology Journal*, vol. 39, September 1960, pp. 1253-1265.