A Neural Approach to Adaptive MAC Protocols for Wireless LANs

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Abstract— **An adaptive MAC protocol for distributed wireless LANs, capable of operating efficiently under bursty traffic conditions, is introduced. According to the proposed protocol, the mobile station that is granted permission to transmit is selected by means of a neural-based algorithm. The neural-based algorithm takes into account the network feedback information in order to update the choice probability of each mobile station. The proposed protocol is compared via simulation to TDMA and IEEE 802.11 and is shown to exhibit superior performance under bursty traffic conditions even when the network feedback is noisy.**

I. INTRODUCTION

There are fundamental differences between wireless [1] and wired LANs that pose difficulties in the design of Medium Access Control (MAC) protocols [2], [3], [4], [5], [6] for wireless LANs. Wireless LANs, as the name suggests, utilize wireless transmission for information exchange. The wireless medium is characterized by high bit error rates (BER), which is higher by ten times that of the wired medium. The primary reason for the increased BER is atmospheric noise, physical obstructions found in the signal's path, multipath propagation, interference from other systems and terminal mobility. Furthermore, in wireless LANs errors occur in bursts, whereas in traditional wired systems errors appear randomly. Finally, a fully connected topology between the nodes of a Wireless LAN cannot be assumed. Rather, the logical topology of a wireless LAN tends to change as users move from one position to another. As a result, wireless LANs are characterized by unreliable links between nodes resulting in bursts of errors and dynamically changing network topologies.

MAC protocols can be roughly divided into three categories: Fixed assignment (e.g. TDMA, FDMA), random access (e.g. ALOHA, CSMA/CD, CSMA/CA) and demand assignment protocols (e.g. token passing, polling). Fixed assignment protocols exhibit high performance when the traffic of each station is stable and the network topology remains unchanged. However, they fail to adapt to changes in network topologies and traffic and thus exhibit low performance when used over the wireless medium or under bursty traffic conditions. Random access protocols on the other hand, operate efficiently both without topology knowledge and under changing traffic characteristics. Nevertheless, their disadvantage is their non-deterministic behavior, a fact that causes problems in supporting QoS guarantees. Demand assignment protocols try to combine the advantages of fixed and random access protocols. However, the token-based approach is generally thought to be inefficient. This is due to the fact that in a Wireless LAN token losses are much more likely to appear due to the increased BER of the wireless medium. Furthermore, in a token passing network, the token holder needs accurate information about its neighbors and thus of the network topology. Polling, on the other hand, is a more appealing MAC option for a wireless LAN since it offers centralized supervision of the network nodes. However, constant monitoring of all nodes is required, which is not feasible in the harsh fading environment of a wireless LAN.

This paper proposes a self-adaptive neural-based MAC protocol (SANP) for distributed wireless LANs. According to the proposed protocol, the mobile station that is granted permission to transmit is selected via a neural-based algorithm, which is used to train the system in order to adapt to the network traffic pattern. The neural-like training algorithm utilizes a probability distribution vector, which contains the choice probability for each mobile station in the network. The network feedback plays the role of the system tutor. Following the reception of the feedback after a packet transmission, the neural algorithm performs a simple training procedure in order to reach the goal of "learning" the transmission probabilities of the mobile stations. It is shown that the training algorithm asymptotically assigns to each station a portion of the bandwidth proportional to its needs.

The remainder of this paper is organized as follows. In Section II, the operation of the SANP protocol is presented. Section II presents a simulation analysis of the asymptotic behavior of the system. Section IV details the simulation environment used to compare the performance of SANP to that of TDMA and IEEE 802.11 and presents simulation results that reveal SANP superiority in cases of medium and high loads in bursty-traffic networks. Finally, concluding remarks are presented in Section V.

II. THE SANP PROTOCOL

The neural-like training algorithm utilizes a probability distribution vector, which contains the choice probability Π_i for each mobile station u_i in the network. System training occurs as follows: After the network feedback, which plays the role of the system tutor, is received for the transmission at slot t, at each station u_i the basic choice probabilities are normalized in the following way:

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

Clearly, $\sum_{i=1}^{N} \Pi_i(t) = 1$, where N is the number of mobile stations. At the beginning of slot t, the normalized probabilities $\Pi_i(t)$ are used to grant permission to transmit to a mobile station.

At each time slot t, the training procedure alters the choice probability of the selected station u_i according to the network feedback information. If station u_i,transmits a packet during slot t then its basic choice probability will increase. Otherwise, if the station were idle, its basic choice probability would decrease. Thus:

$$\begin{aligned} &P_i(t+1) = P_i(t) + L(1 - P_i(t)), \\ &\text{if } u(t) = u_i \text{ and } SLOT(t) = SUCCESS \\ &P_i(t+1) = P_i(t) - L(P_i(t) - a), \\ &\text{if } u(t) = u_i \text{ and } SLOT(t) = IDLE \end{aligned} \tag{2}$$

For all t, it holds that $L, a \in (0, 1)$ and $P_i(t) \in (a, 1)$. L governs system training speed and the selection procedure for a value of L reflects the classic speed versus accuracy problem. The lower the value of L the more accurate the estimation made by the algorithm, a fact however that comes at expense over convergence speed. The role of parameter a is to enhance the adaptivity of the protocol. This is because when the choice probability of a station approaches zero, then this station is not selected for a long period of time. During this period, it is probable that the station transits from idle to busy state. However, since the mobile station does not grant permission to transmit, the algorithm is not capable of "sensing" such transitions. Thus, the use of a non-zero value for parameter a prevents the choice probabilities of the stations from taking values in the neighborhood of zero and increases the adaptivity of the protocol.

In a noiseless environment, SANP is collision-free, as all stations use the same protocol and due to the broadcast nature of the wireless medium the network feedback is common for all stations. Therefore, the protocol is collision-free despite its distributed nature since at each slot, all stations choose the same station to be granted permission to transmit.

However, this is not true when the network feedback is not common for all stations. In these cases the choice probabilities values may be different at several stations and thus collisions may occur since it is likely that two or more stations may sometimes not grant permission to transmit to the same station. In such a situation, the wireless channel can be in one of the following three states:

- successful transmission
- collision
- idle

The simulation results that are presented in this paper assume the followings:

1) A "successful" slot is perceived by a station as "idle", slot if this station is out of range of the transmitting one.
2) A "successful" slot is perceived by a station as a "collision" slot if there are bit errors imposed by the wireless channel.
3) A "collision" slot is perceived by a station as "successful" slot due to the power capturing phenomenon.
4) A "collision" slot it perceived by a station as "idle" if this station is out of range of the transmitting ones.

In order to avoid collisions, the probability distribution vectors at the various network nodes must not greatly differ. Thus, after each transmission is performed, SANP piggybacks the K largest probabilities in the stations data packet and the rest of the probabilities, which obviously concern stations that are not likely to transmit at this time, take the value of a. It is obvious that even with this mechanisms, collisions will occur again due to the noisy wireless network feedback. However, this time the dissemination of the probability distribution vector between the network stations produces commonality among the values of the various probability vectors that correspond to those stations that are likely to transmit. This mechanism leads to a fewer collisions.

It is obvious that the selection for the value of K depends on the number of stations. If the network comprises a large number of stations N, then a selection for K with $K < N$ will limit the overhead caused by the protocol. The simulation results presented later in the paper reveal that this mechanism leads to a satisfactory performance for the protocol.

III. ASYMPTOTIC BEHAVIOR

The SANP protocol updates the choice probabilities of mobile stations according to the network feedback information. The choice probability of each mobile station converges to the probability that this station has a packet to transmit. Thus, it has a non-empty queue. The analytical proof is ommited due to lack of space. The remainder of this section discusses the choice for values of the parameters a and L and provides a simulation of the asymptotic behavior of the system.

The exact values of a and L depend on the environment where the system operates. When the environment is slowly switching or when the environmental responses have a high variance, a and L must be very close to 0 in order to guarantee a high accuracy. On the other hand, in a rapidly switching environment or when the variance of the environmental responses is low, higher values of a and L can be used, in order to increase the adaptivity of the protocol. Thus, when the burst length is high or the queue length is low, then small values of a and L must be selected. On the other hand, when the burst length is low or when the queue length is high, then a and L can be much higher.

It is proved that according to SANP, that for any two mobile stations k_i and k_j (with $d_j \neq 0$), the protocol asymptotically tends to satisfy the relation:

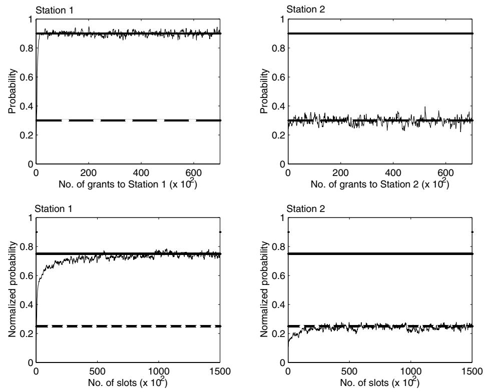

Fig. 1. Convergence of basic and normalized choice probabilities for stations 1, and 2.

$$\frac{P_i}{P_j} = \frac{d_i}{d_j} \tag{3}$$

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

$$\frac{\Pi_i}{\Pi_j} = \frac{\frac{P_i}{\sum_{k=1}^{N} P_k}}{\frac{P_j}{\sum_{k=1}^{N} P_k}} = \frac{P_i}{P_j} = \frac{d_i}{d_j} \tag{4}$$

In order to obtain a better understanding of the claim of the above two Equations, we performed a simulation study for an SANP WLAN of 10 mobile stations, from which only stations 1 and 2 are active, with $d_1 = 0.9$ and $d_2 = 0.3$. The result of this experiment, which can be seen in Figure 1, shows that the estimates of the basic choice probabilities P_1 and P_2 converge to 0.9 and 0.3, respectively. The same stands for the normalize choice probabilities Π_1 and Π_2 which converge to 3/4 and $\frac{1}{4}$ respectively. Thus, the claim of Equations (3) and (4) indeed stands.

IV. PERFORMANCE EVALUATION

A. Simulation Environment

Using simulation, we compared SANP against TDMA and the Distributed Coordination Function (DCF) of IEEE 802.11. The bursty traffic was modeled in the following way: We define "time slot" as the time duration required for a data packet to be transmitted. Each source node can be in one of two states, S_0 and S_1. When the source is in state S_0, then it has no packet arrivals. When it is in state S_1 then, at each time slot, the station 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: $P_{01} = \frac{R}{B(NZ-R)}$ and $P_{10} = \frac{1}{B}$. Each station uses a Q-sized buffer to store arriving packets. Packets that arrive and find the buffer full, are dropped.

In our simulation model, 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 behavior of a wireless channel [8], [9] and are widely used in simulations. The model comprises two states and four parameters:

- State G: This denotes that the wireless link is in a relatively "clean" condition and is characterized by a small BER, which is given by the parameter G_BER.
- State B: This denotes that the wireless link is in a condition characterized by increased BER, which is given by the parameter B_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 B, the BER of the link from A to B and the BER of the link from B to A are the same. The time periods spent by a link in states G and B are exponentially distributed, but with different average values, given by the parameters TG and TB. The status of a link probabilistically changes between the two states. When a link has spent its time in state G, the link transits to state B. When a link has spent its time in state B, the link transits to state G.

We employed the broadly used a) throughput versus offered load and b) delay versus throughput performance metrics relationships in order to compare the three protocols. We simulated the protocols for the following two different network configurations:

1) Network N_1: N=20, Q=15, B=10, Z=1.
2) Network N_2: N=5, Q=3, B=1000, Z=0.9.

In these simulations, the following parameter values remain constant: G_BER=10^{-10}, B_BER=10^{-4}, TG= 30 sec, TB=10 sec, $K = 2$, R_LIM=1 and $P_c = 0.1$, $P_i = 0.1$. R_LIM sets the maximum number of retransmission attempts per packet. P_c is the probability that when two or more data packets collide, one of them is successfully decoded at the destination station due to the power capture phenomenon. P_i is the probability that each transmission does not get through to a certain station, thus this station perceives the slot as idle. Finally, the DATA packet size is set to 1000 bits. The wireless medium bit rate was set to 1 Mbps and the propagation delay between any two stations was set to 0.0005 msec corresponding to inter-station distances of 150 meters.

B. Simulation results

The throughput versus offered load characteristics of the compared protocols when applied to networks N_1 and N_2 are shown in Figures 2 and 4, respectively, while the delay versus throughput characteristics when applied to networks N_1 and N_2 are shown in Figures 3 and 5, respectively. The main conclusions that can be drawn from the Figures are:

- SANP enjoys a large performance superiority over TDMA in all cases. This is due to the fact that SANP "learns" the environment, whereas the behaviour of TDMA is not adaptive.

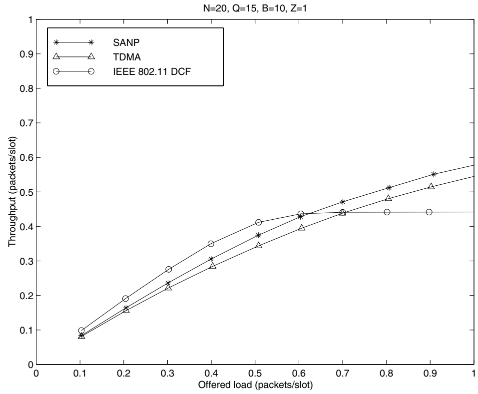

Fig. 2. Throughput versus Offered load characteristics of SANP, TDMA and IEEE 802.11 DCF when applied to network N_1.

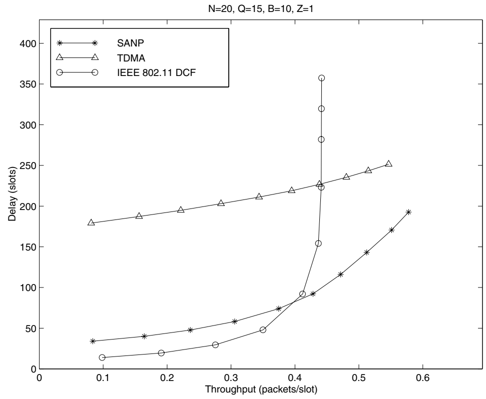

Fig. 4. Delay versus Throughput characteristics of SANP, TDMA and IEEE 802.11 DCF when applied to network N_1.

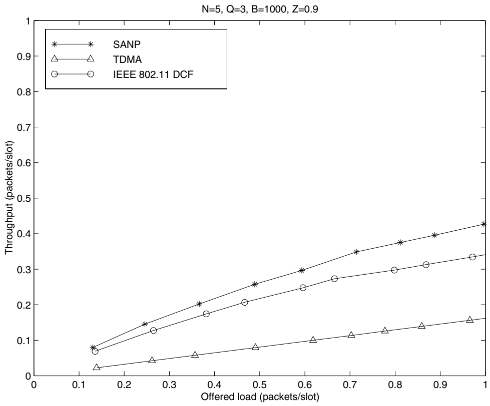

Fig. 3. Throughput versus Offered load characteristics of SANP, TDMA and IEEE 802.11 DCF when applied to network N_2.

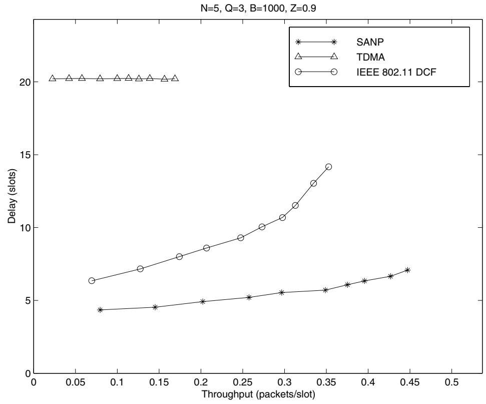

Fig. 5. Delay versus Throughput characteristics of SANP, TDMA and IEEE 802.11 DCF when applied to network N_2.

- For small values of the mean burst length B (Network N_1) and for small and medium network loads, SANP exhibits a similar throughput with that of the DCF of IEEE 802.11. For high loads (approaching 1 packets/slot) SANP exhibits a higher throughput than that of the DCF of IEEE 802.11. This is due to the fact that the throughput of the DCF of IEEE 802.11 remains the same for high loads (around 1 packets/slot) due to the increasing number of RTS collisions in IEEE 802.11 at high loads.
- For networks characterized by heavy bursty traffic (Network N_2), SANP exhibits a performance superior to that of IEEE 802.11 both in terms of load versus throughput and throughput versus delay. This is due to the fact that in the case of heavy bursty traffic (very large B), SANP manages to make the correct decision about which station to be granted permission to transmit almost all of the times. This is due to the facts that:
  1) In a heavy-bursty network, a single station dominates network packet arrivals (equivalently it is active) for relatively large time periods. Thus, the system is infrequently burdened with the cost of finding the active station.
  2) Each data packet transmission in SANP has an overhead of one control packet (ACK), while IEEE 802.11 has a three-control packet overhead (RTS-CTS-ACK) per data packet transmission.

V. CONCLUSION

This paper proposes SANP, a self-adaptive neural-based MAC protocol for distributed wireless LANs. SANP is a fully distributed, self-adaptive MAC protocol that achieves a high performance, even when the offered traffic is bursty and the network feedback is noisy. It is very simple to implement. The only extra requirement over TDMA is the existence at of a processor at each station, which implements the neural algorithm.

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