Wireless MAC Scheme for Service Differentiation
A Distributed Protocol

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Abstract: This paper presents a fully distributed Multiple Access Control (MAC) scheme that supports service differentiation in a wireless LAN environment. In the scheme, stations use CSMA for channel access, with collisions between stations having different priorities resolved by sending beacons in a predefined manner. The scheme includes an authentication protocol for stations to join a Basic Service Set and notify their priority level. Both analytical and simulation results are presented for evaluating the performance of the MAC scheme in a two priority level scenario involving voice and data traffic. The proposed scheme has a saturation throughput of about 0.84 with 1000 byte data packets, almost independent of the number of stations. The results show that good service differentiation is achieved among different priority traffic, including support for voice traffic with Quality of Service bounds on the packet latency.

Key words: priority, quality of service, collision resolution beacon, authentication protocol

1 INTRODUCTION

Mobile multimedia communication is evolving, aided by recent developments in wireless networks and portable devices like notebook computers. Multimedia applications impose requirements on communication parameters, such as data rate, drop rate, delay and jitter. Providing the Quality of Service (QoS) required for these applications is challenging.

IEEE 802.11 [1]-[2] is the most widely used WLAN standard today, but it has drawbacks with regard to QoS. In addition to the distributed (DCF) access method, the IEEE 802.11 standard also defines a centralized (PCF) access mode for giving real-time services higher priority than non-real time services [3]-[5]. However, the centralised scheme requires the existence of

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access points with specialised functions, and moreover in [6] it is concluded that the centralised mode performs poorly. Recently, methods to implement QoS in IEEE 802.11 via service differentiation have been proposed [7]-[9].

This paper presents an alternative fully distributed Multiple Access Control (MAC) scheme that supports service differentiation in WLANs. The scheme is described in Section 2 and a throughput analysis is provided in Section 3. Simulation results are given and discussed in Section 4.

2 MAC PROCEDURE

In the MAC scheme, each station determines the number of stations in the same Basic Service Set (BSS)[2]. The station also learns the Identification numbers (ID) given when stations join the BSS. This information is used in achieving collision resolution as explained in Section 2.1.

Traffic can be prioritised to many levels. If a station wants to send Data of Priority level X (DX) data then it has to wait until the channel is idle for a time AIFSXN (Arbitration Inter Frame Space for priority X New data). If the station senses that the channel is idle for AIFSXN time then it can send data after a RTS/CTS (Request To Send / Clear To Send) exchange as in [1].

If CTS is not received, the station has to perform collision resolution. However if CTS is received but not an ACK (Acknowledgement) then the station has to try to resend the data again after an AIFSXN channel idle time.

When DX collision occurs and then the station senses an idle channel for AIFSXC (Arbitration Inter Frame Space for priority X Collision resolution) time, it sends a collision resolution beacon (CBX), of length AIFSXC. The timings obey: $AIFS(X-1)C < AIFS(X-1)N < CAIFSXC < AIFSXN$

The choice $AIFSXC < AIFSXN$ ensures that collided data has a higher priority than new data and $AIFS(X-1)N < AIFSXN$ so that new data D(X-1) has a higher priority than new data DX. Also, beacon length AIFSXC has to be greater than the RTS duration so that CBX has priority over new data that starts being sent at the same time. Collided stations send CBXs at the same time for the same duration, if they have collided data of the same priority.

2. 1 Collision Resolution

In collision resolution, a collided station sends a set of beacons to inform other collided stations that it has data to send. If the BSS has M stations and a DX collision has occurred, then after CBX, the collided station sends M-1 beacons of length NPB (No Packet Beacon) and 1 beacon of length PPB (Packet Present Beacon) in the following order: if the collided station's ID number is N $(1 \leq N \leq M)$, then the N^{th} beacon has to be a PPB. Between each beacon, there must be at least CRIFS (Collision Resolution Inter Frame Space) channel idle time. CRIFS is the maximum time for a station to switch from transmitting to receiving and back again. This is shown in Fig. 1.

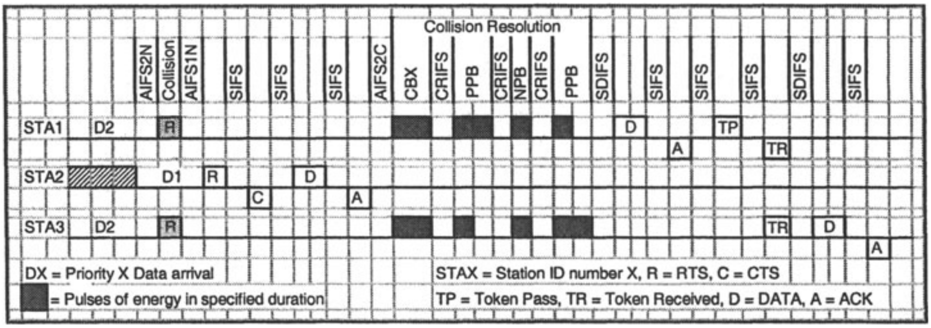

Figure 1. Collision Resolution for a BSS that has 3 stations

After the K^{th} NPB the station senses the channel for beacons. If a beacon is present, this means the station with ID K has sent a PPB announcing it has DX data to send. In this way collided stations learn which stations have DX data to send, and this data is then sent in the order of the stations' priority.

Each station (STA) involved in collision resolution sets a counter to the number of stations that have transmitted PPB beacons prior to it. For example, in Fig. 1, after collision resolution STA1 sets its counter to 1 and STA3 sets its counter to 2. At the end of collision resolution, a token is generated at the station that has the counter value 1, giving it the right to transmit its data. Then the token is sent to the other STAs involved in the collision. A different token is used for different collisions, so each time a collision occurs a new token is created. Stations decrement the counter after sensing an idle channel for a time SDIFS (Scheduled Data Inter Frame Space). If a station does not receive the token when its counter reaches 0, it assumes that the token is lost and will try to send the data again after the channel is idle for a time AIFSXN.

When collision resolution is over, the station with the lowest ID number that has data to send will start to send the data after the channel is idle for a time SDIFS. SDIFS has to be greater than SIFS but less than AIFS1C so that newly arriving data will not collide with scheduled data. When the station completes the data transfer it sends a TP (Token Pass) message to the station that has the next lowest ID number, from which it must receive a TR (Token Received) message. If a TR is not received and a timeout (specified channel idle time) occurs then the station sends a TP to the next STA in line. The timeout duration has to be greater than SIFS (Short Inter frame Space) but less than SDIFS so that the stations' counters will not decrement.

Furthermore, if timeout has not occurred but a TR is not received correctly then the TP has to be sent to the next station in line as before. After reception of the TP, the receiving station has to send a TR to the sender of the TP. After sending the TR, if the next channel idle time is less than SDIFS then the station has to assume that the token has been lost.

2.2 New Stations and ID Numbers

New STAs use a similar method to the IEEE 802.11 DCF protocol to access the channel. The new STA senses the channel before initiating a packet transmission. If the channel is idle for a time greater than an Authentication Initiation Inter Frame Space (AIIFS), then the new STA broadcasts the authentication initiation frame (AIF). (AIIFS must be greater than the largest AIFSXN to avoid overloading the BSS with new stations). Otherwise, transmission is deferred and a backoff process is entered.

The new STA accesses the channel when its backoff timer expires. An Authentication Confirmation Frame (ACF) is used to notify it that the frame it sent has been received. If an ACF is not received before the channel is again idle for an AIIFS time, the new STA reenters the backoff process.

The STAs in the BSS must respond when they receive an AIF from a new STA. If the authentication is successful, an ACF must be sent to the new STA after SIFS channel idle time but if unsuccessful, an authentication rejection frame must be sent. Each of these frames must be acknowledged by the new STA .

If an acknowledgement frame is not received from the new STA and timeout occurs then the STAs in the BSS enter collision resolution after the channel has been idle for AIFSAC (Arbitration Inter Frame Space for Authentication Collision Resolution) as shown in Fig.2. AIFSAC must be less than AIIFS and greater than the largest AIFSXN.

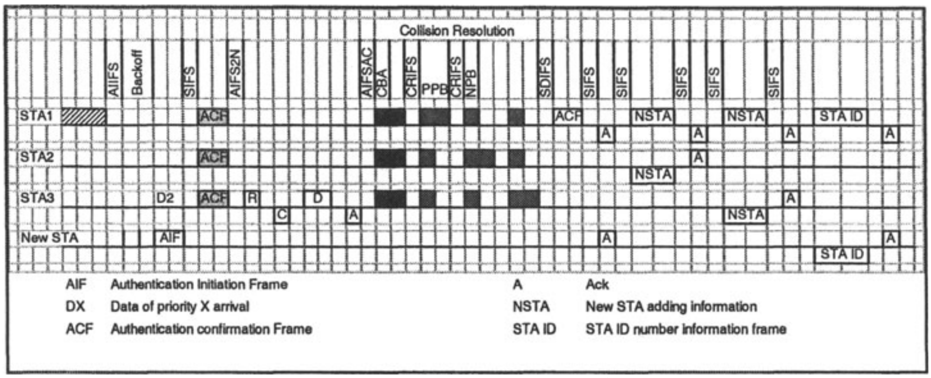

Figure 2. Addition of new STA into the BSS

The STA with the token after collision resolution sends an authentication response frame to the new STA. If authentication fails, the process ends when the acknowledgement frame is received from the new STA.

After successful authentication of the new STA, the STA holding the token has to inform all other STAs in the BSS that a new STA is being added to the BSS. This information includes new STA ID number and new STA address. This process is shown in the Fig. 2.

If the new station adding information could not be sent to any of the stations in the BSS, then the station sending this information has to try again after AISFAC channel idle time. Any station that does not respond again is removed from the BSS by broadcasting a removal information frame.

Each station keeps a list, including addresses and ID numbers, of stations in the BSS. When a packet is received the receiving station checks whether the sender's address is in the list. If not, the receiver informs the sender that it is no longer a member of the BSS and so has to try to join the BSS again.

3 SATURATION THROUGHPUT

The saturation throughput is defined as the throughput achieved by the system when all stations in the BSS have non-empty transmission queues. To calculate it, assume the saturation condition is reached in the system so that every station in the BSS has the same priority data ready for sending. This situation is shown in the Fig. 3 where the BSS has 3 stations and every station always has data of priority 1 to send.

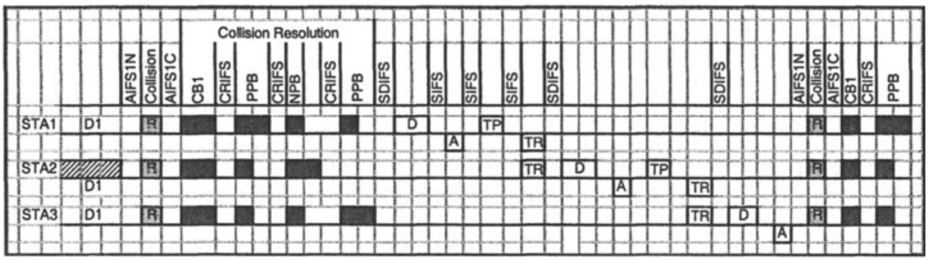

Figure 3. Saturation condition of the system

In the Figure, the same situation is repeated during the next period. The period duration for a BSS that has M stations and has priority 1 data is given by:

$$Period = AIFS1N + RTS + AIFS1C + CB1 + M \times CRIFS + M \times PPB + (M-1)(SDIFS + ACK + D + TP + TR + 3 \times SIFS) + (SDIFS + ACK + D + SIFS)$$

Then the *Saturation Throughput* = *M(D-h)/period*, where
h = No. of Header bits / channel rate in seconds.

4 SIMULATION RESULTS AND DISCUSSION

To evaluate the performance of the MAC protocol, simulation results are obtained using MATLAB. The parameters used are summarised in Table. 1. These values are based on the IEEE 802.11 wireless LAN standard. All the packets include MAC and PHY headers.

Table 1. Parameters used in the Simulation

Data packet payload	8000 bits	MAC header	272 bits	PHY header	128 bits
ACK	112 bits + PHY header	Slot Time	20 ms	CB1	70 ms
RTS	180 bits + PHY header	SIFS	10 ms	AIFS2C	110 ms
CTS	112 bits + PHY header	CRIFS	30 ms	AIFS2N	130 ms
TP	112 bits + PHY header	SDIFS	50 ms	CB2	110 ms
TR	112 bits + PHY header	AIFS1C	70 ms	PPB	30 ms
Channel Bit rate	2 Mbps	AIFS1N	90 ms	NPB	10 ms

4.1 Average voice packet delay

Two types of voice traffic, Continuous Bit Rate (CBR) and ON-OFF, are simulated. In the ON-OFF case, the on and off periods average 300 ms and are exponentially distributed. With CBR, and during the on periods of ON-OFF traffic, stations generate 160 byte packets at 32 kb/s. Thus the inter-packet time is 40 ms and the voice frame duration (with headers) is 840 μs.

The results obtained are shown in Fig. 4. The average delay shown is the average duration between voice packet generation at the station and the receipt of the packet's ACK. This Figure shows that, as expected, CBR traffic experiences more delay than ON-OFF traffic. This is because with CBR more voice packets are generated in a given time interval.

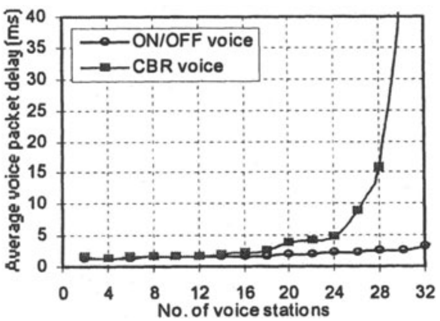

Figure 4. Average delay of voice packets

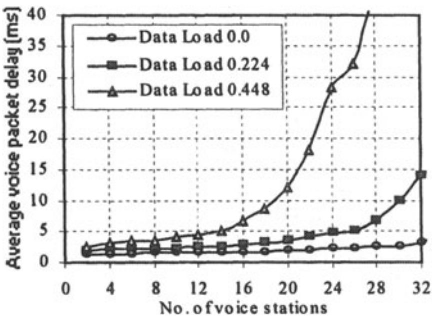

Figure 5 Both voice and data traffic

4.2 Performance of voice with data traffic present

In this simulation every station generates ON-OFF priority 1 voice traffic. In addition, stations also generate lower priority 2 data traffic at a Poisson rate λ / M packets/s. M is the number of stations in the BSS. During each simulation the data load $\rho_D = \lambda b_{data} / r_C$ of the channel is kept constant. Here b_{data} is the number of bits in the data packet (including headers) and r_C is the channel bit rate. The data frame length is 4.1 ms. Simulations are run for 3 different data loads and the average voice delay is shown in Fig. 5.

The Figure shows that the average voice packet delay increases with an increase in the data load. Thus, for example, if the maximum tolerable delay of a voice packet is 10 ms, then 19 voice stations can be supported with a data load of 0.448, and more than 32 voice stations with no data load.

4.3 Saturation Throughput

In the simulation, saturation is achieved by generating packets faster than the channel can serve so that all stations have non-empty transmission queues. Results for different data packet lengths are shown in Fig. 6. It is seen that the saturation throughput is not very dependent on the number of stations in the BSS but depends on the data packet length. The simulation results agree closely with the analytical result obtained in Section 3.

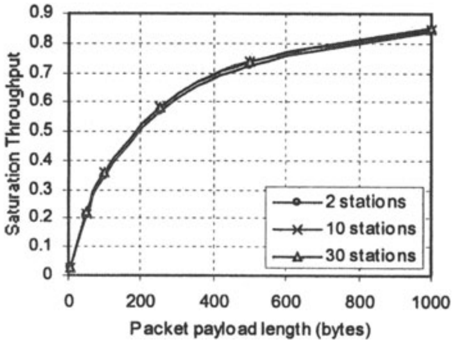

Figure 6. Saturation throughput

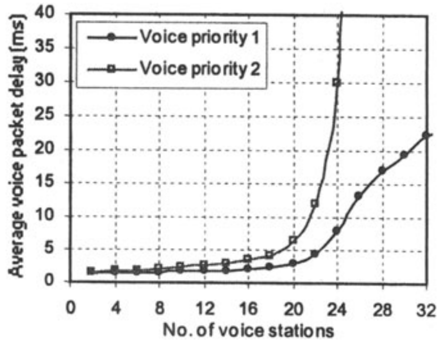

Figure 7. Two voice priorities

4.4 Service Differentiation

In this simulation every station in the BSS generates two streams of voice traffic, one with priority 1 and another with priority 2. In each case, voice traffic is of the ON-OFF type. The results obtained are shown in Fig. 7. It is seen that priority 2-voice stream experiences more delay than does the priority 1 stream. This confirms that service differentiation is achieved among traffic of different priorities.

5 CONCLUSIONS

A distributed multiple access control scheme was proposed that was shown to provide service differentiation in wireless LAN environment. The MAC scheme presented can support any desired number of priority levels. A new approach is used to resolve the collisions between stations. With this new approach a saturation throughput of about 0.84 is obtained with packet data load length of 1000 bytes and this does not depend very much on the number of stations in the network.

A simulation study was also presented to assess the impact of data traffic on the voice traffic. It was shown that for a wireless LAN operating at 2 Mbps with ON/OFF voice using coding rate of 32 kbps can support 19 voice stations with simultaneous data utilization of 0.448 with a maximum accepted voice packet delay of 10ms. Furthermore, this increases to 30 voice stations when data utilization is decreased to 0.224.

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