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A Priority Scheme for IEEE 802.11 Wireless LAN

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ABSTRACT

This paper investigates a priority scheme for IEEE 802.11 Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) protocol in order to provide short access times for priority frames (e.g. time-deadline traffic) even whenthe overall traffic on the wireless channel is heavy. Under the compatibility constraint for the IEEE 802.11 wireless LANs, two priority systems are simulated: no priority (current IEEE 802.11 standard) for time-deadline traffics and dynamic time-deadline priority.We evaluate algorithms to improve the time-deadline traffic performance using discrete event simulation (DES).

Ⅰ. Introduction

Wireless Local Area Network (WLAN) is an emerging field of activity in computer networks. In June 1997, the IEEE approved an international interoperability standard (IEEE 802.11) for WLANs in the 2.4 GHz band [1]. All physical (PHY) layers (DSSS, FHSS, IR) support a data rate of 1 Mbps and optionally 2 Mbps. In July 1998, the IEEE approved for standardization, which describes a PHY layer providing a basic rate of 11 Mbps and a fallback rate of 5.5 Mbps. The IEEE 802.11b working group adopted complementary code keying (CCK) as the basis for the high-rate PHY layer extension. In July 1998, the IEEE decided to select orthogonal frequency-division multiplexing (OFDM)-based standard intended for the new 5 GHz band, targeting bit rates up to 54 Mbps [13]. The medium access control (MAC) layer for the higher data rates will remain the same as for the currently supported 1 and 2 Mbps rates.

The 802.11 protocol is designed with features that support multimedia applications [2,3]. The contention-free period (CFP) within superframe can handle transmission of time-deadline traffic, such as voice, image, sound, or compressed video. Also isochronous data could be handled during the contention period (CP). It guarantees that the asynchronous data and time-deadline traffics will always receive a minimum bandwidth as required. So the allocation of transmission rights between voice and data users is dynamically optimal. The frames compete freely for channel access rights and consequently their delays prior to actual transmission are unpredictable and may become large enough to render them lost. To prevent notable call set-up quality degradation the frame loss should be limited to about 1%. In every protocol cycle (superframe, 20ms), all active stations (STAs) issue a RTS (request to send) on a CSMA/CA contention basis with multiple priority and thereby compete for unique implicit polling list candidate.

The IEEE 802.11 MAC protocol should support the fairness and priority mechanisms that exist for controlling access to the shared medium.

Until now, the IEEE committee does not propose the priority scheme in the CP to support the multiple quality of service (QoS) requirements. So we propose the IEEE 802.11 compatible priority protocol which meets the time-deadline QoS requirements. Access to the WLAN must be scheduled to maintain the QoS for each virtual connection. Among them, there are many priority schemes for CSMA/CD protocols [7-12]. But they

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never consider the time-deadline concept. To support the priority traffic in CSMA/CA protocol, in our paper, asynchronous data frames will exactly follow the IEEE 802.11 standard for collision and backoff. We support the priority scheme using different binary exponential backoff (BEB) schemes for each QoS required traffic. We propose a different CSMA/CA BEB scheme with maximum threshold depending on various QoS requirements in multimedia WLAN environments. The QoS requirement in each queue is dynamically changed according to traffic type and residual time to live (RTL). DES results give good performance results for the priority scheme.

This paper is organized as follows. Section II describes the IEEE 802.11 MAC protocol. Our time-deadline priority protocol is explained in Section III. Section IV develops the simulation results and finally we conclude in section V.

II. IEEE 802.11 WLAN MAC Protocol

A. IEEE 802.11 MAC Protocol

We describe the MAC protocols that are used by the 802.11 WLAN. A compromise between the two protocol classes (contention type, CSMA/CA and controlled access type, polling) has been proposed by IEEE. Intuitively, a blend of polling with a random access should fare better than either, and this notion is the most crucial for IEEE 802.11 protocol. Even though it is the standard, certain parts may still be changed, although we expect that the basis access protocols described here will not undergo any further modification. The fundamental access methods of the 802.11 standard, the DCF (distributed coordination function), is present in all stations' within the IEEE 802.11 network. In addition to the CSMA/CA protocol there is a random backoff algorithm. This algorithm reduces the collision probability between multiple STAs accessing the medium at the point where a collision would most likely occur, just after the medium becomes free following a busy medium. The basic access scheme employed is shown in Fig. 1.

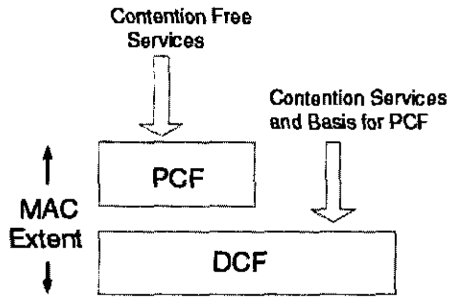

Fig. 1 MAC architecture.

The various interframe spaces (IFSs) are used to differentiate between different types of transmission. Before each transmission a STA has to wait DCF interframe space (DIFS). A complete MAC protocol data unit (MPDU), for instance, existing of a data frame and an acknowledgment (ACK) frame, is only separated by a short interframe space (SIFS). Backing off and waiting until the medium is free is not sufficient to provide reliable communications, so the CA mechanism adds a MAC-level ACK to ensure the integrity of individual frames. The algorithm uses BEB for retransmissions. To support coexisting asynchronous and time-deadline (synch.) services, the algorithm also supports different priority levels.

The protocol recognizes that the highest probability for collision immediately follows a busy period (because frames could be queued during that busy period). DCF operation uses the RTS/ clear to send (CTS) handshake signal to control traffic and the network allocation vector (NAV) embedded in each exchange to moderate access contention between STAs. Adding a backoff delay to the NAV assures that eventually every STA will be the first one to request a turn. Having acquired a channel, the point coordination function (PCF), which shall operate at the access point (AP) of the basic service set (BSS), polls each active STA in the network, using a list it maintains. During this polling period, the PCF can transmit data to a STA as well as receive it. The use of a smaller IFS implies that pointcoordinated traffic shall have priority access to the medium over STAs in overlapping BSSs operating under the DCF access method. The 802.11 MAC provides both types of access during each superframe (CFP plus CP) to allow the highest possible operating efficiency under varying network conditions. In light traffic, the DCF based CP offers quick access and low overhead. The CFP's efficiency is much less affected by heavy network traffic. But to reduce the access delay of time-deadline traffic, we need to give a priority to them.

B. Priority Protocol for IEEE DCF

The contention window (CW) parameter contains an initial value of a CW_{min} for every MPDU queued for transmission. The CW shall double using the BEB scheme at every retry until it reaches the values of a CW_{max}. The CW will remain at a value of a CW_{max} for the remaining of the retries in the IEEE standard. Recall that the IEEE uses BEB in which the backoff is doubled after every collision and reduced to the CW_{min} after every successful RTS-CTS exchange. This is done to improve the stability of the access protocol under high load conditions in the IEEE. The set of CW values is a PHY-specific CW. The assumed values for CW are: $CW_{min}=31$, $CW_{max}=255$. A CW_{min} and a CW_{max} are MAC constants that should be fixed for all MAC implementations, because they affect the access fairness between STAs. But there is no priority scheme for an access scheme to guarantee the QoS requirement of time-deadline traffics in the 802.11 protocol.

We may describe a procedure of the IEEE protocol as follow:

```
double backoff_t(proc)
   MAC_PROCESSOR_S *proc;
   double backoffTime;
       if (proc->CWsize == 0)
           proc->CWsize=CWmin;
   else {
       proc->CWsize *=BackoffFactor;
       if (proc->CWsize>CWmax) {
           proc->CWsize=CWmax;
       }
   backoff_t=proc->CWsize*unif_rv()* SlotTime;
   }
```

Ⅲ. Proposed Time-deadline Approach for the IEEE Backoff Scheme

Multimedia traffic contains both time-deadline and jitter-tolerant types. Time-deadline traffic can not accept long set-up time but can not be queued while jitter-tolerant traffic is bursty and can not require fast transfer. We may apply a priority scheme in two areas: shorter random backoff time for time-deadline traffic and shorter IFS (IEEE 802.11 already adopted this). If the waiting time exceeds a threshold, called the RTL, we just discard requested call when transmission capacity is not available. In order to improve performance for certain situations such as time-deadline traffic, low RTL, and congested STAs, we propose a variation of the BEB which can apply any traffic situations. If a collision occurs, both the asynchronous and time-deadline request are backed off. This is achieved by assigning a maximum threshold to the number of backoff retransmissions for each QoS required traffic. When a number of collisions of a particular time-deadline frame exceeds this maximum threshold, the backoff counter is reset to zero, and CW is reset to the CW_{min} and the process continues. But whenever RTL of the frame is zero, we just discard the frame. There are two approaches in priority assignments for each frame in each STA: earliest-deadline-first (EDF) and oldest-customer-first (OCF) discipline [4,5,6]. Even though a practical disadvantage of these two schemes is the expensive processing and sorting necessary at each queue, we can simply use RTL information for the priority assignment. Whenever each RTL of time-deadline traffic is less than the threshold (QoS), the CW_{max} size is reduced; so probabilistically priority is given. The proposed priority algorithm is easy and flexible to implement. There was an approach for priority using the different timer (IFS) [12]. But this had the compatibility problem. A simplified transition diagram of the transmission control of the 802.11 MAC protocol is shown in Fig. 2.

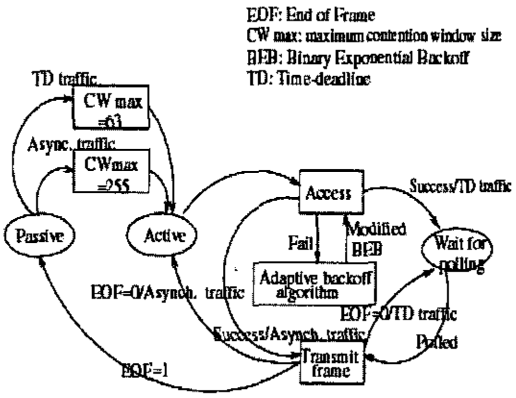

Fig. 2 State transition diagram for the STA.

Fig. 3 shows the proposed backoff scheme. We modify the basic structure of the backoff algorithm to fairly allocate bandwidth.

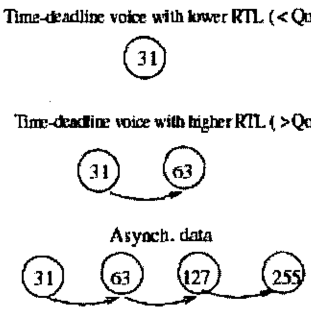

Fig. 3 State transition diagram for the proposed backoff scheme.

An additional adjustment to the backoff computation can improve the efficiency of the protocol. We may classify priority level to 2 levels (time-deadline and async. traffic). In this case, the maximum threshold for time-deadline traffics is about 2 attempts (the CW_{max} is 63) and the maximum threshold for asynchronous data traffic is about 4 attempts (the CW_{max} is 255). A priority level is assigned according to RTL value of time-deadline traffic. Each priority traffic has its own priority level and then follow the normal IEEE BEB scheme until the maximum attempts of each level. Eventually higher priority traffic can access quickly; also our protocol supports fairness to each station with the same priority level traffics. But there is no free lunch. Adding delay of asynchronous is imposed by the longer backoff time.

We may describe a procedure of the time-deadline protocol as follow:

```
double backoff_t (proc, frame, RTL)
    MAC_PROCESSOR_S    *proc;
    MAC_PACKET_S    *frame;
    double          RTL;

   if (frame->type ==ASYNC_DATA)
        if (proc->CWsize == 0)
            proc->CWsize = CWmin;
        else {
            proc->CWsize *= BackoffFactor;
            if (proc->CWsize >CWmax) {
                proc->CWsize =CWmax;
            }
        }
    else
        if (proc->CWsize == 0)
            proc->CWsize = CWmin;
        else{
           proc->CWsize *= BackoffFactor;
           if (RTL<QoS){
              if(proc->CWsize<32)
                  proc->CWsize=CWmin;
              if(proc->CWsize<64)
                  proc->CWsize=CWmin;
              if(proc->CWsize<128)
                proc->CWsize=CWmin;
              if(proc->CWsize<256)
                proc->CWsize=CWmin;
           }
           else{
              if(proc->CWsize<32)
                proc->CWsize=CWmin;
              if(proc->CWsize<64)
```

```
            proc->CWsize=CWmin*2;
        if(proc->CWsize<128)
            proc->CWsize=CWmin;
        if(proc->CWsize<256)
            proc->CWsize=CWmin;
    }
}
backoff_t=proc->CWsize*unif_rv() * SlotTime;
```

Ⅳ. Simulation Results

We simulate the 10 STAs in a single BSS using direct sequence PHY layer under imperfect channel. Assume that all STAs have associated with AP. We assume that the QoS threshold in Fig. 3 is 0.01sec. The IEEE configuration consisted of 11 nodes, all of which used an identical BEB scheme. Consequently, the channel access is fair among the STAs. In the proposed configuration, 10 of the 11 nodes were allowed to use the proposed backoff scheme, while the remaining 1 node still used the BEB. In simulation, we use the Poisson arrival process, and the DCF and the PCF coexist in a manner that permits both to operate concurrently within the same BSS. When a point coordinator (PC) is operating in a BSS, the two access methods alternate, with a CFP followed by a CP.

The performance of the priority access control mechanism is compared to the regular BEB access scheme which is provided by the IEEE 802.11. Our results easily apply to a multiple priority scheme as well. This model is reasonably flexible in its use. It can simulate the behavior of each STA, and provide information relative to the overall performance of 802.11 systems. For example, the effects of different backoff algorithms, frame sizes and arrival distribution, propagation delay, and IFS values can be evaluated by using the simulation model. The results indicated that the delay time of these STAs was significantly reduced at a nominal cost of slightly increasing the average delay of the low-priority STAs. If each STA is allowed to maintain a flexible backoff scheme depending on the time-deadline limit, a priority frame system could be easily realized. We summarize our assumption as Table I.

In Fig. 4, we present the mean delay of time-deadline traffic according to asynchronous traffic loads. We can see the improvement in the mean delay of time-deadline traffic.

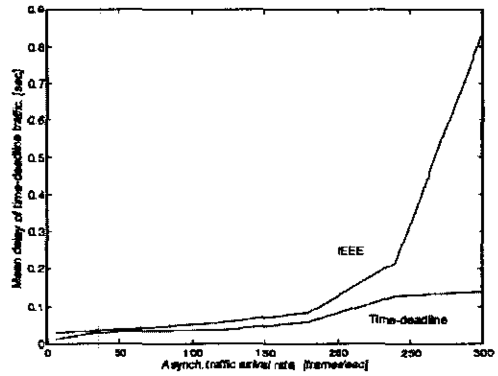

Fig. 4 Mean delay of time-deadline traffic vs. asynch traffic load (time-deadline traffic load= 80 frames/sec).

In Fig. 5, it shows that the system capacity can reach only 38% of the available bandwidth, and that the average delay of time-deadline traffic is quite long when the traffic load is beyond 35%. An improvement of the average delay in the proposed priority scheme can be observed, and the system capacity is only slightly increased. Since the introduction of the 802.11, little effort has been made to modify the backoff scheme so as to reduce the frame's access delay.

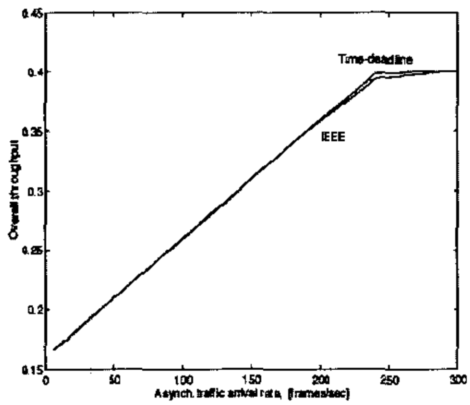

Fig. 5 Overall throughput vs. asynch. traffic load (time-deadline traffic load=80 frames/sec).

TABLE1. Input parameters for simulations.

Attribute	Value	Attribute	Value
Network configuration	Infrastructure	DIFS	30000 nsec
Number of STAs	10	CWmin	31
Traffic model	Poisson	CWmax	255
Bit error rate	1.0E-4	Slot time	1.0 usec
Propagation delay	100 nsec	Time out interval for CTS	126 usec
Channel capacity	2.048 Mbps	Time out interval ACK	63 usec
RTS	192 bit	Buffer size	180
CTS	144 bit	Frag. threshold	4096 bit
ACK	144 bit	RTS threshold	1024 bit
MAC header size	304 bit	Max. retry	100
Preamble size	192 bit	superferame period	20E-3 sec
Max data size	4096 bit	Poll size	192 bit
SIFS	20000 bit	Poll ACK	40 bit
PIFS	25000 nsec	Poll response time out	256E-6 sec

In Figs. 6 and 7, we also see the improvement of mean delay and overall throughput of time-deadline traffic according to the time-deadline traffic arrival rate. The proposed scheme may experience more frame discards due to time-deadline.

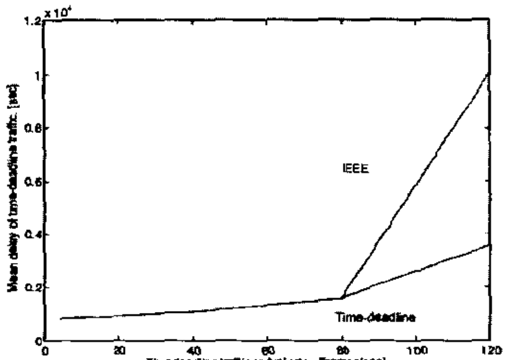

Fig. 6 Mean delay of time-deadline traffic vs. time-deadline traffic arrival rate (asynch. traffic load=120 frames/sec).

The results further suggest that, by varying each STA's backoff algorithm, a priority frame system can easily be supported, or frames with time-deadline can be handled, provided that this type of traffic does not constitute the majority of the frames in the system. Frames with a smaller time-deadline can backed off to relatively smaller CW. If all frames have the same time-deadline limit, this scheme may not work like normal BEB scheme, but if all have the same smaller deadline limit, this scheme is like the threshold backoff scheme. Without the RTL, the efficiency of the proposed backoff scheme for handling collisions is suspect under heavy loads.

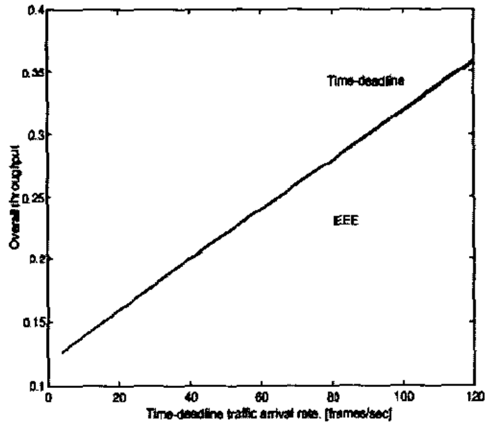

Fig. 7 Overall throughput vs. time-deadline traffic arrival rate (asynch. traffic load=120 frames/sec).

V. Conclusion

This paper investigated a priority scheme for the IEEE 802.11 CSMA/CA protocol in order to provide short access times for priority frames. Under the compatibility constraint for the IEEE 802.11, we compared the two priority systems: no priority and dynamic time-deadline priority. We could see an improvement in mean delay and throughput using DES. For time-deadline traffic, we can guarantee the QoS requirement, end-to-end (or access) delay using RTL values with slight degradation of asynch. traffic performance. Our scheme can be directly applied to any real-time wireless contention based access system.

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