

Enhancing Limit MAC Performance for IEEE 802.11 Wireless LANs

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Abstract— To provide the best effort and real-time traffic services in IEEE 802.11 wireless LANs, the DCF (Distributed Coordination Function) and PCF (Point Coordination Function) protocols were proposed for the basic MAC (Medium Access Control) protocols and the enhanced MAC protocols such as EDCA (Enhanced Distributed Channel Access) and HCCA (Hybrid Coordination Function Controlled Channel Access) protocols for the differentiated QoS (Quality of Service) traffic services have been developed based on the DCF and PCF protocols. Unlike the PCF protocol and the enhanced MAC protocols based on the PCF protocol, as the number of nodes contending for the access to WM (Wireless Medium) increases, the MAC throughput of the DCF protocol and the enhanced MAC protocols based on the DCF protocol degrades exponentially and converges to zero. To deal with the problem of the performance degradation of the DCF protocol, we propose the simple however efficient modification of the DCF protocol by which each node in a backoff stage attempts to transmit its data frame with probability $1/n$ PIFS a (PCF Inter-Frame Space) period after the detection of idle channel state without performing the backoff procedure when n nodes exist in a IEEE 802.11 wireless LAN and are associated with the AP (Access Point) of the wireless LAN.

Keywords— IEEE 802.11 Wireless LAN, MAC, DCF, Performance, Throughput

I. INTRODUCTION

Since the fundamental IEEE 802.11 standard for the basic MAC protocols of the DCF (Distributed Coordination Function) and PCF (Point Coordination Function) protocols were released to realize IEEE 802.11 wireless LAN systems in 1997, the new PHY transmission technologies for increasing the PHY data rates from 1 or 2 Mbps to more than 1 Gbps have been developed and the enhanced MAC protocols such as EDCA (Enhanced Distributed Channel Access) and HCCA (Hybrid Coordination Function Controlled Channel Access) protocols based on the DCF and PCF protocols have been developed to provide the relative and absolute QoS (Quality of Service) differentiation[1-7]. Unlike the PCF protocol for the real-time traffic service, the DCF protocol for the best effort traffic service has the disadvantage of exponentially degraded MAC performance as the number of nodes participating in the DCF backoff procedure increases. Therefore, considering the cases where ubiquitous wireless sensor devices and RFID

(Radio Identification) devices are connected to IEEE 802.11 wireless LANs and transmit the various kinds of data such as room temperature and patients' biological status data via IEEE 802.11 wireless LANs, the research is needed to solve the problem of the performance degradation of the DCF protocol.

Assuming the Poisson arrival process of data frames to each node, it was proved that the MAC throughput of the protocols employing BEB (Binary Exponential Backoff) converges to zero as the number of nodes participating in the backoff algorithm increases[8]. To solve the problem of the performance degradation of the backoff algorithm, the techniques for optimizing the parameters of the size of contention window and the number of backoff stages have been researched[9, 10]. However, because the relationship between the MAC performance and the parameters of the size of contention window and the number of backoff stages is complicated in realistic traffic environment and the parameters of the size of contention window and the number of backoff stages converge to infinite numbers as the number of nodes participating in the backoff algorithm increases, it is difficult to develop an efficient optimization technique of the parameters.

In this paper, To deal with the problem of the MAC performance degradation of the DCF protocol, we propose the simple however efficient modification of the DCF protocol by which each node in a DCF backoff stage i attempts to transmit its data frame with probability $1/n$ a PIFS (PCF Inter-Frame Space) period after the detection of idle channel state without performing the backoff procedure when n nodes exist in a IEEE 802.11 wireless LAN and are associated with the AP (Access Point) of the wireless LAN. $1/n$ is the optimal channel access probability that maximizes the MAC performance of the modified DCF protocol in IEEE 802.11 wireless LANs loaded with heavy traffic. By the proposed modification of the DCF protocol, the nodes in backoff stage i the transmissions of which have been possibly delayed due to the repeated transmission collisions or failures can skip the backoff procedure and expedite the transmission procedure. We want to maximize the MAC performance of wireless LANs by optimally selecting backoff stage i in which the expedited transmission procedure is activated.

The paper is organized as follows. In the next section, we propose the efficient modification of the DCF and by the

theoretical analysis, we derive the formula for the limit MAC throughput of the modified DCF protocol and prove that the MAC throughput of the modified DCF protocol converges to non-zero values. In Section 3, we present numerical examples to show the MAC performance improvement by the proposed modification of the DCF protocol. Finally, we conclude in Section 4.

II. PROPOSED MODIFICATION OF DCF PROTOCOL AND LIMIT MAC PERFORMANCE ANALYSIS

Before each node is connected to IEEE 802.11 wireless LANs, the authentication and association processes between each node and the AP should be performed. Therefore, the AP knows the number n of nodes connected to itself. For the proposed modification of the DCF protocol, the information fields of the number n of nodes connected to the AP and backoff stage i in which the expedited transmission procedure is activated should be added to the beacon frames, which are broadcast in CP (Contention Period) on a regular basis. Receiving the beacon frames from the AP, each node knows the updated number n of nodes that contend for the access to WM (Wireless Medium) and backoff stage i in which the expedited transmission procedure is activated.

When a node reaches to backoff stage i after possibly the repeated transmission collisions or failures, it generates a random number in $[0, 1]$. If the generated random number is smaller than $1/n$, the node can attempt to transmit its data frame a PIFS period after the detection of idle channel state without performing the backoff procedure. The other nodes than the nodes in backoff stage i that generated the random numbers smaller than $1/n$ follow the general DCF backoff procedure to transmit their data frames. The AP can optionally access to WM a SIFS (Short Inter-Frame Space) period, which is smaller than a PIFS period by a time slot, after the detection of idle channel state. Using the optional channel access, the AP can broadcast the beacon frames safely. For the transitions between backoff stages of the nodes using the expedited transmission procedure after the successful or unsuccessful expedited transmissions, the nodes follow the existing DCF backoff procedure.

Considering the traffic environment in wireless LANs, we should optimally select backoff stage i in which the expedited transmission procedure is activated. For this purpose, the AP lets the expedited transmission procedure be activated in backoff stages $0, 1, \dots, m$ each for amount of time X and monitors the MAC throughputs of the modified DCF protocol with $i = 0, 1, \dots, m$. m is the maximum backoff stage of the DCF protocol. Then, the AP selects i^* having the maximum MAC throughput and let the expedited transmission procedure be activated in backoff stage i^* for amount of $Y \gg X$. By AP's monitoring the MAC throughputs at different i values, updating i^* and letting the expedited transmission procedure be activated in backoff stage i^* , we can optimize the MAC performance of the modified DCF protocol.

Assume that n nodes continuously attempt to transmit their data frames to the AP. As n increases, the probability that each node resides in the maximum backoff stage converges to 1,

therefore, the optimal backoff stage in which the expedited transmission procedure is activated converges to the maximum backoff stage. The probability that the expedited transmission procedure in the maximum backoff stage is successful, that is, only one node in the maximum backoff stage accesses to WM without collision can be derived as follows:

$$\begin{aligned} p_s &= \lim_{n \rightarrow \infty} n \left(\frac{1}{n} \right) \left(1 - \frac{1}{n} \right)^n \\ &= \lim_{n \rightarrow \infty} \left(1 - \frac{1}{n} \right)^n \\ &= e^{-1}. \end{aligned} \quad (1)$$

From the formulae in [11], we can derive that as n increases, the probability p_r that more than one node attempt to transmit their data frame in a time slot converges to 1, therefore, the mean number $E[\Psi]$ of time slots having no node attempting to transmit the data frames converges to zero. Furthermore, T_s , which is total transmission time of ACK and data frames including a DIFS (DCF Inter-Frame Space) period and an SIFS period, is greater than T_c , which is the channel recovery time including the transmission time of data frame in case of collision. Therefore, ignoring the probability of successful data frame transmissions by the backoff procedure without the expedited transmission procedure, which converges to zero as n increases, the limit throughput S of the modified DCF protocol is lower bounded as follows:

$$\begin{aligned} S &\geq \lim_{n \rightarrow \infty} \frac{p_s P}{E[\Psi] + p_s T_s + (1 - p_s) T_c} \\ &= \lim_{n \rightarrow \infty} \frac{p_s P}{p_s T_s + (1 - p_s) T_c} \\ &\geq \lim_{n \rightarrow \infty} \frac{p_s P}{p_s T_s + (1 - p_s) T_s} \\ &= \frac{P}{e \cdot T_s} \\ &\approx \frac{0.368P}{T_s}. \end{aligned} \quad (2)$$

where P is the fixed length of payloads in data frames and T_s the sum of a data frame transmission time, an ACK frame transmission time, a DIFS period and an SIFS period.

From (2), we can see that the proposed modification of the DCF protocol resolves the problem that the MAC throughput of the DCF protocol converges to zero as n increases.

III. SIMULATION RESULTS

We assume that $n = 10, 50, 100, 150, 200, \dots, 750$ nodes exist in an IEEE 802.11a wireless LAN and each node continuously attempts to transmit its data frame with payloads of 2,000 bits to the AP. It is assumed that the hidden node

problem does not exist, therefore, the transmissions of RTS (Request to Send) and CTS (Clear to Send) frames are not needed. The transmission failures only occur due to the collisions between transmissions. The values of parameters used for simulations are presented in Table 1.

TABLE 1. SIMULATION PARAMETERS

Parameters	Values
Data Trans. Rate	54 Mbps
ACK Trans. Rate	24 Mbps
SIFS	16 μ s
PIFS	25 μ s
DIFS	34 μ s
Time Slot	9 μ s
Backoff Max. Stage	7
PHY Header Trans. Length	24 μ s
X	1 minute
Y	500 ms

In Figure 1, the MAC throughputs of the existing DCF protocol and the modified DCF protocol for each n are compared. For each throughput result, we initially let more than 3,000 data frames arrive to each transmission buffer and simulation continues until all the data frames in the transmission buffer of each node are successfully transmitted and the observed MAC throughput does not change within 0.1 %. The lower bound of MAC throughput of the modified DCF protocol, which is derived in Section 2, is also presented in Figure 1. In Figure 2, the optimal backoff stage i^* in which the expedited transmission procedure is activated is presented.

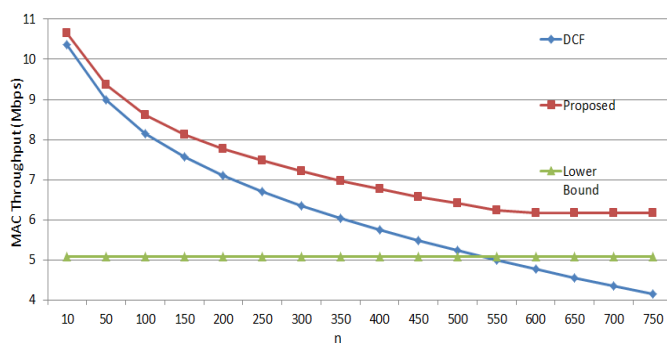


Figure 1. MAC throughput results of DCF and Modified DCF

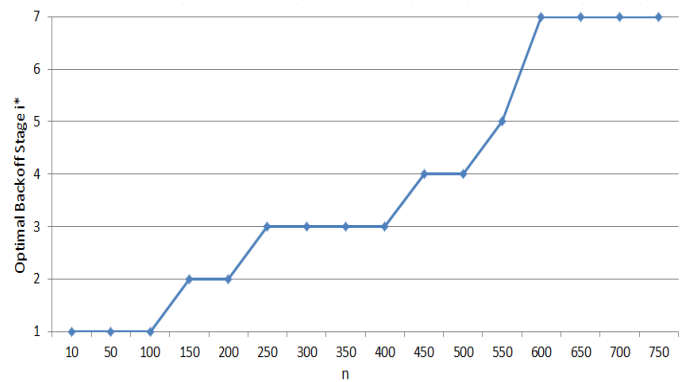


Figure 2. Optimal backoff stage of modified DCF

As we can see from Figure 1, as n increases, the throughputs of the DCF and modified DCF protocols decrease, however, the decreasing rate of MAC throughput is diminished by the proposed modification of the DCF protocol. As n increases, the relative improvement of MAC performance by the modified DCF protocol over the DCF protocol becomes greater. From Figure 2, we can see that as n increases, the optimal backoff stage in which the expedited transmission procedure is activated becomes higher because as n increases, the probability that each node resides in higher backoff stages becomes larger.

IV. CONCLUSIONS

In this paper, we proposed the efficient modification of the DCF protocol to deal with the problem of MAC performance degradation of the DCF protocol. Simulation results show that the proposed modified DCF protocol significantly enhances the MAC performance.

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