A Safe Multiple Access-Rates Transmission (SMART) Scheme for IEEE 802.11 Wireless Networks

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***Abstract*— The IEEE 802.11 standard and enhanced amendments have defined fourteen transmission rates (1/2/5.5/6/9/11/12/18/22/24/33/36/48/54 Mb/s) for mobile stations to transmit and receive data frames. With the characteristic of modulation schemes, a higher level modulation scheme requires a higher Signal-to-Noise Ratio (SNR) and, consequently, the data rate is inversely proportional with the transmission distance. Using a higher level modulation scheme, a higher network throughput can be expected; however, the frame error probability will also become higher. Doubtlessly, it is an open issue of selecting a proper modulation scheme for a pair of mobile stations in time-varying indoor environment. This paper proposes a Safe Multiple Access-Rates Transmission (SMART) scheme for enhancing the reliability of data transmission in the IEEE 802.11 multi-rate infrastructure wireless networks. The SMART scheme provides reliable transmission by reserving a retransmission period, which immediately following the transmitted frame and is estimated from a lower transmission rate, for each transmitted frame. If any error occurs on transmitted frame, the sender will retransmit it right away by using a lower transmission rate to make sure of successful retransmission. Otherwise, the reserved period will be taken by the access point (AP), which often has the longest waiting queue and is the bottleneck in infrastructure wireless networks. The efficiency of proposed SMART scheme is evaluated by simulation. Simulation results show that the derived performance of the SMART scheme is significantly better than standard under the real environment with asymmetric traffic load.**

I. Introduction

The first edition of IEEE 802.11 standard with 1/2 Mb/s transmission rate has been published in 1999 [3]. Two fundamental modulation schemes, named as binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK), are adopted for providing 1 Mb/s and 2 Mb/s transmission rates. For the DSSS, the 11-chip Barker Sequence is chose due to its good autocorrelation property and coding gain. In other words, the DSSS with Barker code is robust against interferers/noise and time delay spread condition. By replacing 11-chip Barker code as the complementary code keying (CCK) or packet binary convolutional code (PBCC) scheme, the IEEE 802.11b standard [5] has the ability to provide four data rates 1/2/5.5/11 Mb/s in 2.400–2.4835 GHz. On the other hand, the amendment IEEE 802.11a standard [4], which using orthogonal frequency division multiplexing (OFDM) technology and operating in 5.15–5.35 GHz and 5.725–5.825 GHz, has the ability to provide eight higher data rates 6/9/12/18/24/36/48/54 Mb/s by using high-level quadrature amplitude modulation (QAM). To extend the lifetime of IEEE 802.11b, the IEEE 802.11g standard [6] is being discussed and it is designed to provide data rates 1/2/5.5/11/22/33 Mb/s using CCK, PBCC, PBCC-22 and PBCC-33 technologies or data rates 6/9/12/18/24/36/48/54 Mb/s using OFDM and CCK-OFDM technologies.

It is intuitive that all mobile stations should use the highest-level modulation scheme with the highest data rate all the time to achieve the maximum network throughput. However, the maximum data rate may not always be obtained since the data rate is inversely proportional with the transmission distance as well as the number of obstructions between the transmitter and receiver. For instance, with IEEE 802.11b specification, the maximum transmission distances between transmitter and receiver when applying 11 Mb/s, 5.5 Mb/s and 2 Mb/s are about 30m, 60m and 120m, respectively. Our previous work [7] has proposed an fuzzy-based rate switching controller for enhancing the network performance in multi-rate wireless local area networks (WLANs). The rate selection is based on three critical information: average received signal strength indication (RSSI), average medium access control (MAC) delay and frame error rate (FER). The RSSI potentially indicates how far between transmitter and receiver, the MAC delay implicitly reflects how many active mobile stations content the channel resource in WLAN and it could be further referred to estimate collision probability, and the FER is the indicator used to decide when to apply a more aggressive approach. Another method is proposed in [2], the AP needs periodically broadcast beacon frames at different transmission rate and mobile stations refer the detected beacon frames to choose the highest transmission rate for exchanging frames with AP. This simple approach can efficiently prevent from selecting a wrong modulation scheme (i.e. data rate).

In the IEEE 802.11 MAC protocol, a successful data transmission is recognized by the Acknowledgement (ACK) frame from recipient. If any error occurs on transmitted data frame, the sender will hold the data frame and retransmit it at the same transmission rate if possible for obtaining higher throughput. This procedure is repeated until this frame is being retransmitted successfully at the same transmission rate or at a lower transmission rate, or the maximal retry count is reached. However, such scheme wastes an amount of bandwidth since the extra time period needed for resolving contentions/collisions for each retransmission. Therefore, in this paper, we propose a Safe Multiple Access-Rates Transmission (SMART) scheme to provide a reliable transmission and to keep the network throughput as higher as possible. The basic concept of SMART scheme is to reserve an extended period, which is calculated from a lower transmission rate, for each transmitted frame. If any error occurs on the transmitted frame, the sender will immediately retransmit it in the pre-reserved period but using a lower transmission rate to make sure of successful retransmission. On the other hand, if the ACK frame has been received successfully at the first time transmission, the reserved period will be used by the access point (AP), which often has the longest waiting queue and is the bottleneck in infrastructure wireless networks. Based on this scheme, more than one frames could be served for each transmission opportunity and the channel utilization and network throughput would become higher.

The remainder of this paper is organized as follows. In Section II, we introduce the details of SMART scheme. In Section III, we will describe the simulation models and then compare the simulation results derived from SMART scheme and the IEEE 802.11 standard. Finally, some conclusions are given in Section IV.

II. The Safe Multiple Access-Rates Transmission (SMART) Scheme

This section will depict and discuss the proposed SMART scheme for an infrastructure WLAN. The IEEE 802.11 MAC protocol includes a distributed coordination function (DCF) that employs the carrier sense multiple access/collision avoidance (CSMA/CA) as the basic channel access/contention protocol for asynchronous data transmissions. In DCF, mobile stations can use the optional RTS/CTS (Request-to-Send/Clear-to-Send) four-way handshaking mechanism to make a reservation for their packets. The RTS/CTS handshaking reserves the channel to get rid of the hidden terminal problem, to reduce the bandwidth wastage, and to provide virtual carrier sense for saving battery power. The most important information carried on RTS and CTS control frames is the *duration*, which is used to announce how long the channel will be occupied for the successful transmission (including the ACK frame of course). Other stations receiving such control frames will obey this information and cease their transmissions. So, if we simply extend the duration of a transmitted frame, the extra time period could be used for retransmission or the other purpose. This is the basic concept of providing safe and reliable transmissions in SMART scheme.

Before introducing the SMART scheme, we first introduce some useful notations. Let $\mathrm{T}^{r}_{\mathrm{type}}$ denote the transmission time (excluding PHY overhead) of a "type" MAC frame at transmission rate r Mb/s (for example, $\mathrm{T}^{2}_{\mathrm{RTS}}$ refers to the length of a RTS frame transmitted at 2 Mb/s, $\mathrm{T}^{11}_{\mathrm{Data}}$ refers to the length of a data frame transmitted at 11Mb/s) and $\mathrm{PHY}^{2}_{\mathrm{hdr}}$ denote the necessary overhead of PHY layer. Recall all control frames and PHY layer overheads are transmitted at 2 Mb/s. We let $\mathrm{RTS} = \mathrm{PHY}^{2}_{\mathrm{hdr}} + \mathrm{T}^{2}_{\mathrm{RTS}}$, $\mathrm{CTS} = \mathrm{PHY}^{2}_{\mathrm{hdr}} + \mathrm{T}^{2}_{\mathrm{CTS}}$ and $\mathrm{ACK} = \mathrm{PHY}^{2}_{\mathrm{hdr}} + \mathrm{T}^{2}_{\mathrm{ACK}}$ be the exact transmitting lengths of control frames in PHY layer. Since the length of a data frame

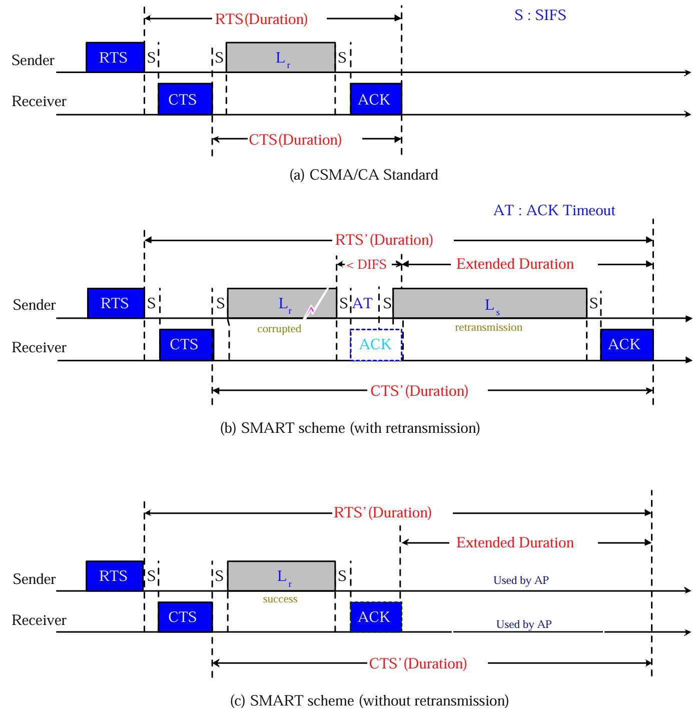

Fig. 1. Duration Estimation in CSMA/CA standard and SMART scheme. (a) CSMA/CA Standard. (b) SMART scheme (with retransmission). (c) SMART scheme (without retransmission).

is depending on the transmission rate, we let L_r denote the length of transmitting a data frame at data rate r Mb/s. We have $\mathrm{L}_r = \mathrm{PHY}^{2}_{\mathrm{hdr}} + \mathrm{T}^{r}_{\mathrm{Data}}$.

If a mobile station has data frame to send, it first determines the proper transmission rate, say r, and then calculates the transmitting period $\mathrm{L_r}$ of this frame. If the frame length (including MAC header) is M bits, we have $\mathrm{L}_r = \mathrm{PHY}^{2}_{\mathrm{hdr}} + M/r$. We note that, given a frame length, the derived L_r is not linearly inverse proportional with data rate r due to the fixed PHY overhead $\mathrm{PHY}^{2}_{\mathrm{hdr}}$. In standard, the duration value carried in RTS frame, denoted as RTS(Duration) will be 3SIFS+CTS+L_r+ACK and the duration value carried in CTS frame, denoted as CTS(Duration), will be 2SIFS+L_r+ACK (see Fig. 1(a)).

As mentioned before, an aggressive rate selection algorithm will increase both the network throughput and the frame error probability. For the sake of channel utilization, it is worthy applying an aggressive rate selection algorithm. In order to increase the transmission reliability, SMART scheme particularly gives a second chance for each transmitted frame. This is done by enlavging the regular duration value carried in RTS/CTS control frames and the extended period is measured by a lower transmission rate if any. As shown in Fig. 1(b), the duration carried in RTS frame, denoted as RTS′(Duration) will become 5SIFS+CTS+AT+L_r+L_s+ACK, where AT is the ACK timeout and s denote the same or a lower transmission rate than r. If the transmission rate s is the lowest one, we set $r = s$. We also emphasize that the new RTS′(Duration) is shorter than RTS(Duration)+SIFS+L_s+SIFS+ACK and the difference between RTS′(Duration) and RTS(Duration) is ACK-AT. The reason is that when ACK timeout occurs, the sender will retransmit the data frame after delaying an extra SIFS, which is needed for switching between receiving mode and transmitting mode, instead of whole ACK frame period. Moreover, to prevent from other stations unintentionally disturb retransmission, the gap between the original frame and the retransmitted frame should be less than DIFS, which is the minimal gap between two successive frame transmissions defined in CSMA/CA protocol. In standard, the SIFS is smaller than DIFS. Therefore, the following constrain must be satisfied:

$$\mathrm{AT} < \mathrm{DIFS} - 2 \times \mathrm{SIFS}. \quad (1)$$

Considering IEEE 802.11b DSSS PHY for example, the DIFS and SIFS are 50μs and 10μs respectively, and the AT must be less than 30μs. In this paper, we set AT as 20μs.

If the first transmission is failed, the mobile station will retransmit frame by using a lower transmission rate if possible. Note that if the previous transmission rate is the lowest one, the sender will keep this rate to retransmit data frame. If the first transmission is success, the extended duration definitely make the bandwidth to be wasted. Therefore, if this period could be smartly used by the others, especially the one who has the most heavy traffic load, network throughput can be kept as higher as possible. In our scheme, the extra time period is always taken by the AP as shown in Fig. 1(c). During this period, the AP may transmit a number of data frames and they could be with different destinations, different frame lengths and different transmission rates. We also note that the last transmission might cross the duration boundary and, still, it will not be disturbed due to the carrier-sense feature of CSMA/CA protocol.

TABLE I

SYSTEM PARAMETERS IN SIMULATIONS

Parameter	Normal Value
Transmission rate	2, 5.5, 11 Mb/s
Slot time	20 μs
SIFS	10 μs
DIFS	50 μs
RTS frame length	160 bits (80 μs)
CTS frame length	112 bits (56 μs)
ACK frame length	112 bits (56 μs)
ACK Timout	20 μs
Preamble and PLCP header	192 bits (192 μs)
MAC header	34 octets
CWmin	31 slots
CWmax	1023 slots
Average frame length	200 slot times

III. SIMULATION MODEL AND RESULTS

A. Simulation Model

The simulation model follows the IEEE Standard 802.11b-1999 using Direct Sequence Spread Spectrum (DSSS) at the physical layer with the long Physical Layer Convergence Protocol (PLCP) protocol data unit (PPDU) format and the DCF at the MAC layer. Most of the parameters are referred from the standard and are listed in Table I. Poisson distribution was used to determine the number of arrival MAC service data units (MSDU) per unit time and the lengths of the MSDUs were decided by the exponential distribution function. Several assumptions are also made to reduce the complexity of the simulation model:

1) All mobile stations support 2, 5.5, 11 Mb/s transmission rates.
2) All control frames are sent at 2 Mb/s.
3) The propagation delay is neglected.
4) All mobile stations are active (not in power-saving mode).
5) The AP is static and is located at the center of simulated area.

Every mobile station communicates with AP and relies on AP to forward data frames or download outside data. To observe the mobility impacts, the *random waypoint* model [1] in a rectangular field is considered. In our simulations, we simulated a scenario of 10 mobile stations active in a square area of 140m $\times$ 140m and the initial location of them are randomly assigned within the area. Each mobile station is free to move anywhere within this square area and the moving speed is randomly selected from 0 m/s to 1 m/s.

Each mobile station has one transceiver and its transmission ranges are 100m (2 Mb/s), 50m (5.5 Mb/s) and 30m (11 Mb/s), respectively. We assume every mobile node always selects the proper transmission rate according to the distance between AP and itself. The packet arrival rate of each mobile station follows the Poisson distribution with a mean λ, and the packet length is an exponential distribution with a mean of L time slots. Each mobile station maintains a FIFO *waiting buffer* of 64 packets. The mean packet length is set to be 1 KBytes (i.e. 200 time slots at 2 Mb/s transmission rate, excluding PHY and MAC header). The network load consists of uplink (from mobile stations to AP) and downlink (from AP to mobile staions) traffic. According to the realistic environment, we assume an asynchronous upload/download traffic model in all simulations. The proportion of upload traffic to download traffic is 1:8 which is cited from the pervasive 64 Kbps/512 Kbps asymmetric digital subscriber line (ADSL) network. The upload traffic is equally shared by all active mobile stations. Meanwhile, we also consider the frame error rate (FER) as 8% (which is the least acceptable quality in WLAN) to simulate the interference of wireless communications. Each simulation run lasts 1000 seconds ($\approx 5 \times 10^7$ time slots) and each simulation result is obtained from averaging the results of 10 independent simulation runs.

B. Simulation Results

Fig. 2 shows the goodput derived from IEEE 802.11 and the SMART scheme with and without frame error probability. The goodput is defined as the amount of pure data payload comes from network layer have been successfully transmitted in an observation unit time. Without loss generality, the goodput is measured in Mb/s. From this figure, we can find that

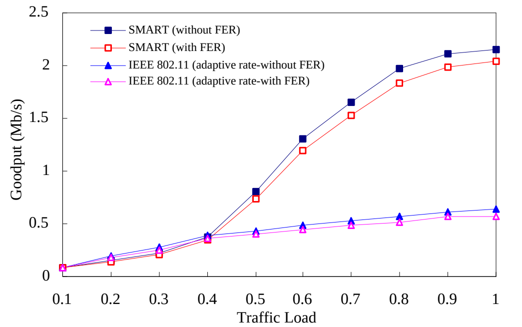

Fig. 2. Comparisons of goodput derived from IEEE 802.11 and SMART under different traffic loads and with or without FER factor.

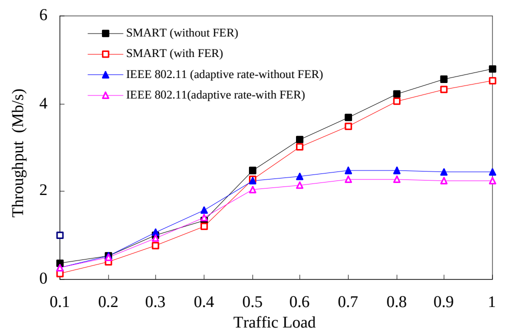

Fig. 3. Comparisons of throughput derived from IEEE 802.11 and SMART under different traffic loads and with or without FER factor.

the proposed SMART achieves a higher goodput than IEEE 802.11 CSMA/CA when traffic load is larger than 40%. The goodput of SMART scheme and standard are saturated about 2.2 Mb/s and 0.6 Mb/s respectively when the frame error ratio is set as zero. From our observations, the goodput increment is mainly contributed from AP reuses the redundant extra period. In other words, with SMART scheme, more than one frames are serviced for each contention resolving and, consequently, the overheads of contention backoff time is significantly reduced and the goodput is enhanced as expected. On the other hand, if the frame error occurs (e.g., FER=8%), a certain portion of extended periods is used by retransmission which will slightly degrade goodput. From this figure, we can see that a lower goodput is derived from either standard or SMART scheme.

For comparisons, Fig. 3 shows the throughput derived from IEEE 802.11 and the SMART scheme with and without frame error probability. The throughput is defined as the amount of data payload and overheads transmitted in an observation unit time. From Fig. 3 we can see that the derived network throughput by using SMART scheme and IEEE 802.11 protocol are still quite different. The maximal throughput of SMART with no FER condition is 4.8 Mb/s when traffic load is 100% and the IEEE 802.11 protocol achieves the maximal throughput 2.5 Mb/s when traffic load is 70%. Fig. 4 shows the average access delay derived from SMART scheme and standard. The

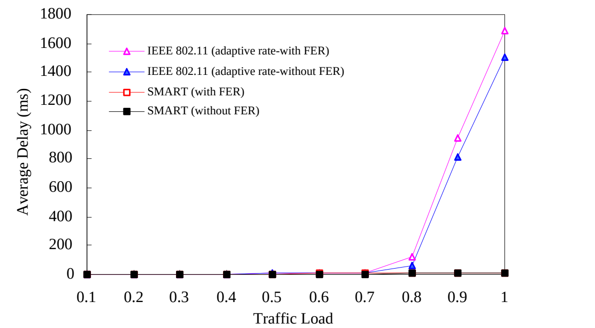

Fig. 4. Comparisons of average access delay derived from IEEE 802.11 and SMART under different traffic loads and with or without FER factor.

IEEE 802.11 protocol will suffer a longer average access delay when the traffic load is larger than 70%. The average access delay of SMART scheme is always under 14 ms.

IV. Conclusions

This paper proposed a Safe Multiple Access-Rates Transmission (SMART) scheme for enhancing the reliability of data transmission in the IEEE 802.11 multi-rate infrastructure wireless networks. The proposed scheme provides reliable transmission by reserving a retransmission period, which immediately following the transmitted frame and is estimated from a lower transmission rate, for each transmitted frame. The sender has the right to retransmit the data frame at a lower transmission rate if there is any error occurs on previous transmission. To avoid bandwidth wastage, the reserved period could be taken by the access point (AP), which often has the longest waiting queue and is the bottleneck in infrastructure wireless networks. Simulation results showed that the derived performance of the SMART scheme outperforms standard under the real environment with asymmetric traffic load.

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