

# An Efficient Retransmission Scheme for Wireless Home Networks

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**Abstract**—This paper proposes an efficient retransmission (EFR) scheme for multi-rate wireless home networks. In EFR, immediate data transmission is provided for infrastructure WLAN without major modification of IEEE 802.11 standard. Furthermore, in order to consider a more realistic wireless home networks, the EFR scheme is enhanced to accommodate the asymmetric traffic model. We propose an analytical model and a simulation model to investigate the performance of EFR and Enhanced EFR. Our study indicates that in terms of average MAC delay, average queuing delay, completion rate, average collision times and goodput, EFR and Enhanced EFR outperform standard IEEE 802.11 carrier sense multiple access/collision avoidance mechanism.

**Index Terms**—IEEE 802.11, MAC, Retransmission, Wireless Home Networks

## I. Introduction

IEEE organization has approved the 802.11 standard for wireless local area network (WLAN) in 1997. With the extensive deployment and development of WLAN and the rapid growth of wireless users, IEEE 802.11 standard has been considered for home networking between appliances. The advantages of utilizing WLANs in home environments are not only the communications without physical wires, but also the relatively high bandwidth, which make WLANs highly suited for multimedia applications. Thus interconnections of audio and video appliances such as TVs, DVD players, audio speakers through WLANs for network networking become a promising trend.

IEEE 802.11 standard supports two kinds of configurations for wireless networks. One is ad hoc WLAN where mobile stations communicate with each other without fixed wired infrastructure. The other is infrastructure WLAN (IWLAN). IWLAN provides communications among mobile stations via access points (APs). The AP also plays a role of the bridge to connect WLAN with wired networks (e.g., Internet). In IEEE 802.11, the medium access control (MAC) protocol defines a distributed coordination function (DCF) that employs carrier sense multiple access/collision avoidance (CSMA/CA) mechanism for data transmission. The mechanism is used to determine the mobile station that has authority for channel occupancy.

In IEEE 802.11 standard, a successful data transmission is recognized by ACK controls frame sent by the receiver of the data frame. If any error on the transmitted data frame occurs (i.e., ACK frame is not received by the sender), the sender would contend for channel occupancy again, and retransmit the data frame. The above procedure repeats until

the data frame is successfully transmitted, or until the maximal retry count is reached.

Based on the above discussions, the sender needs to repeatedly execute the contention procedure for data retransmission especially when the network condition is unclear (e.g., FER is high), which may result in extra bandwidth consumption and longer frame delay. Therefore, in this paper, we propose an efficient retransmission (EFR) scheme in wireless home environments to improve the system performance. By using EFR, bandwidth consumption and frame delay can be significantly reduced. Furthermore, in order to consider a more realistic wireless home networks, the EFR scheme is enhanced to accommodate the asymmetric traffic model. Both EFR and Enhanced EFR can operate on IWLAN without major modification of IEEE 802.11 standard, and their performance is superior to IEEE 802.11 standard.

The remainder of this paper is organized as follows. Section II describes EFR and Enhanced EFR. In Section III, an analytical model is proposed to investigate the performance of EFR. In Section IV, a simulation model for EFR and Enhanced EFR is presented. Based on the simulation experiments, we compare the performance of EFR and Enhanced EFR with that of IEEE 802.11 standard. Finally, conclusions are given in Section V.

## II. The Efficient Retransmission (EFR) Scheme

This section describes the proposed EFR scheme for wireless home networks. Figure 1(a) illustrates an example of standard IEEE 802.11 MAC procedure, and its message flow is shown in Figure 2(a). After waiting for the period of DCF inter-frame space (DIFS), the mobile stations that intend to transmit the data frames exercise backoff to contend for channel occupancy.

The backoff time for each mobile station is uniformly set at the interval  $[0, CW]$ , where  $CW$  represents the length of the contention window. The mobile station with minimum backoff time occupies the channel. Then RTS/CTS (request-to-send/clear-to-send) four-way handshaking mechanism is utilized to reserve the coming time slots for data transmission. In the handshaking process, short inter-frame space (SIFS) is the minimum gap between two successive transmitted frames. If RTS frame is successfully transmitted to the receiver, the receiver responds with CTS frame. Otherwise, the backoff operation with the doubled  $CW$  would be re-executed. Suppose that RTS/CTS exchange is successfully performed (e.g., no collision occurs). Then the

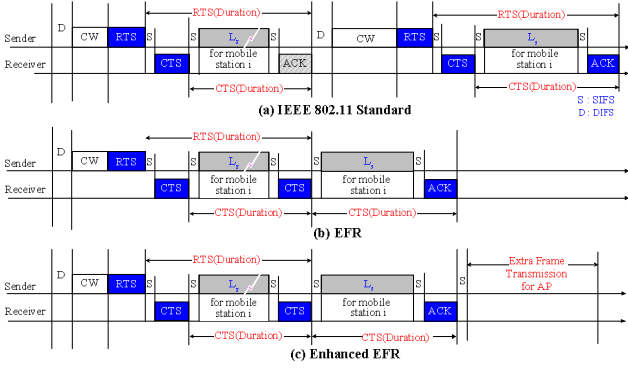


Fig. 1: The Transmission Procedure in (a) IEEE 802.11 (b) EFR (c) Enhanced EFR

data frame is delivered from the mobile station to the receiver, and the receiver sends ACK control frame to the mobile station if the data transmission is successfully exercised. If data transmission fails, the receiver does not reply ACK that the sender waits for. In this case, the contention procedure would be re-activated for data retransmission with the accordingly doubled CW.

In RTS/CTS control frames, the “Duration” field is utilized to announce how long the channel will be occupied for the coming frame transmission (including ACK frame), which is denoted as RTS (Duration) and CTS (Duration). In Figure 1(a),  $RTS(Duration) = 3SIFS + CTS + L_r + ACK$  and  $CTS(Duration) = 2SIFS + L_r + ACK$ , where  $L_r$  denotes the transmission time for the data frame at the transmission rate of  $r$  Mbps.

From the above discussions, the backoff operation in standard IEEE 802.11 MAC procedure would be activated much frequently in the environment of high FER and heavy traffic load (i.e., when the probability for data transmission failure is large), which results in extra bandwidth consumption and longer delay for data delivery. Thus an efficient retransmission (EFR) scheme is proposed in this paper to provide fast retransmission, where each data frame is given a second chance for retransmission without contention. That is, if the data frame transmission fails, the same frame will be re-transmitted in the coming time slot without exercising the backoff operation. Simultaneously, the retransmission rate is decreased to a lower level for reducing the error of data retransmission.

As shown in Figure 1(b), when the frame error occurs, the receiver informs the sender and reserves the following slots for retransmission by using the CTS control frame (see Figure 2(b) for the message flow). The CTS control frame is adopted since the frame length of CTS is the same as that of ACK. In this CTS control frame, the duration for retransmission is specified as  $2SIFS + L_s + ACK$ , where  $L_s$  represents the average interval for re-transmitting the data frame at the transmission rate  $s$  ( $s < r$ ).

In order to consider a more realistic environment, the above EFR scheme is enhanced to accommodate the asymmetric traffic model for wireless home networks where

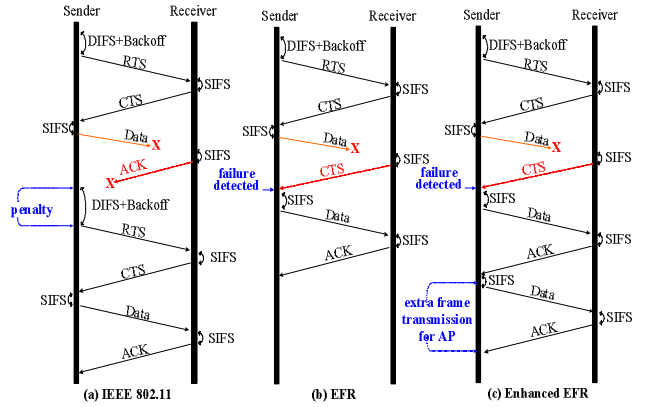


Fig. 2: The Message Flow in (a) IEEE 802.11 (b) EFR (c) Enhanced EFR

the proportion of upload traffic (i.e., from mobile stations to AP) and download traffic (i.e., from AP to mobile stations) refers to the asymmetric digital subscriber line (ADSL) network and is set to 1:8. In such wireless environment, AP becomes the bottleneck of the system, and the performance of the basic EFR scheme may slightly degrade because too many resources are utilized for mobile stations’ retransmission, which results in a significant delay for downlink transmission. Thus in Enhanced EFR, an extra data frame transmission following the mobile stations’ retransmission is reserved for AP.

As shown in Figure 1(c) (see Figure 2(c) for its message flow), upon the end of ACK frame, AP can transmit its data frame after waiting for the SIFS period. The SIFS period is used to prevent other mobile stations from occupying the channel. Furthermore, based on the MAC header of the data frame from AP, all mobile stations can recognize the receiver and the transmission duration of the data frame. Thus for the mobile stations except the receiver of the data frame, they can immediately enter in the power-save mode after retrieving this MAC information.

### III. The Analytical Model

This section proposes an analytical model to investigate the performance of EFR. The analysis is based on the model introduced by Tobagi and Kleinrock [10] for CSMA protocols. For simplicity, a frame length is normalized as a time unit (slot). Note that the performance of Enhanced EFR will be investigated through the simulation model described in the next section.

Figure 3 illustrates the state transition diagram for EFR. The diagram consists of five states: IDLE, ARRIVE, BACKOFF, ATTEMPT and RETRY. Initially, the mobile station (or STA) stays in IDLE state. When a data frame arrives, the state transits from IDLE state to ARRIVE state. In ARRIVE state, the frame arrival is queued in the buffer of the mobile station. When the frame is served by the mobile station, the mobile station selects a random backoff time to countdown. If the mobile station counts to zero and senses an

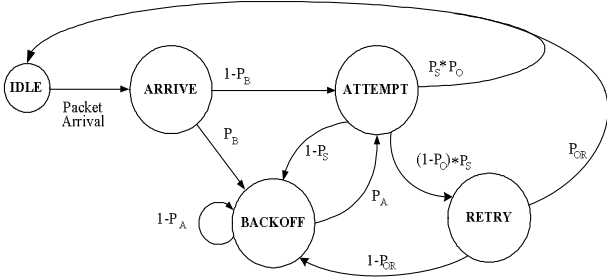


Fig. 3: The State Transition Diagram for EFR

idle channel, the state transit from ARRIVE state to ATTEMPT state. The state transition probability is  $1-P_B$ , and the average waiting time in ARRIVE state is equal to DIFS +  $W/2$ , where  $W$  is the minimum backoff window size (e.g., 32 slots). Otherwise, the mobile station enters into BACKOFF state. The state transition probability is  $P_B$ .

In ATTEMPT state, the mobile station starts to perform data transmission. Suppose that  $P_S$  and  $P_O$  represent the probabilities for successful RTS/CTS and data frame transmission, respectively. If the RTS/CTS and data frames are successfully transmitted, the state returns to IDLE with probability  $P_S * P_O$  (where  $P_O = 1 - \text{FER}$  and FER is the frame error probability for data transmission). Otherwise, if the data frame transmission fails, the state transits from ATTEMPT state to RETRY state with the probability of  $(1-P_O) * P_S$ . In RETRY state, the mobile station retransmits the data frame at a lower transmission rate. The lower data rate can resist the noise interference and reduce the FER probability for retransmission. If retransmission with a lower transmission rate fails, the state returns from RETRY state to BACKOFF state. Otherwise, the state transits from RETRY state to IDLE state with the probability  $P_{OR}$ , and the  $P_{OR}$  value equals to  $1 - (\text{FER}/3)$  [9].

In ATTEMPT state, if the collision of RTS/CTS transmission occurs, the state transits from ATTEMPT state to BACKOFF state with the probability of  $1-P_S$ . Note that due to short length of RTS/CTS frames, the frame error probability for RTS/CTS can be ignored. The derivation of  $P_S$  is described as follows. We assume that the arrival process of frames at a mobile station form the Poisson distribution with the arrival rate of  $\lambda$  [4][6][10]. The probability  $P_S(\Delta t)$  that the RTS/CTS frame is successfully transmitted is given by

$$P_S(\Delta t) = e^{-\Lambda \Delta t} \quad (1)$$

where  $\Lambda$  is the total (i.e., uplink and downlink) frame arrival rate in the system. For the number  $N$  of mobile stations, we have  $\Lambda = \lambda_a + N\lambda_s$ , where  $\lambda_a$  and  $\lambda_s$  are the frame arrival rates of AP and a mobile station, respectively. We assume that  $N\lambda_s/\lambda_a = K$  and  $0 < K < 1$ . In the analytical model,  $K$  is set to 80%.

When residing in BACKOFF state, the mobile station

selects a random backoff time according to the backoff rule. If the minimum backoff time is selected, the state for the mobile station transits from BACKOFF state to ATTEMPT state after the end of backoff countdown. The state transition probability is  $P_A$ . Otherwise, the mobile station suspends the backoff countdown and waits for next contention with the probability of  $1-P_A$ .

In EFR, the renewal interval is defined as the time between successive renewal points. Each renewal point represents the end of successful transmission (i.e., when the sender receives the ACK control frame). A renewal interval consists of the idle and busy periods. In the idle period, the transmission medium remains idle due to backoff, DIFS interval, or no frame arrival. In the busy period, the medium is used to perform data/control frame transmission/retransmission. Based on the above discussions, the transition probability  $P_B$  from ARRIVE state to BACKOFF state is expressed as

$$P_B = \frac{B}{I+B} \quad (2)$$

where  $I$  and  $B$  are, respectively, the average lengths of idle and busy periods in each renewal interval. The average length  $I$  of the idle period is derived as

$$I = 1/\Lambda + \text{DIFS} + W/2 \quad (3)$$

In the remainder of this section, the derivations for EFR scheme will be respectively elaborated in subsections.

The average length  $B$  of the busy period for EFR is derived as follows. Let  $T_{RS}$ ,  $T_S$  and  $T_C$  respectively be the average times for the intervals of retransmission, four-way handshaking and RTS/CTS transmission. From Figure 1(b), we have

$$T_{RS} = \tau + 2\text{SIFS} + L_s + \text{ACK} \quad (4)$$

$$T_S = \text{RTS} + 3\tau + 3\text{SIFS} + \text{CTS} + L_r + \text{ACK} \quad (5)$$

$$T_C = \text{RTS} + 2\tau + \text{SIFS} + \text{CTS} \quad (6)$$

where  $\tau$  is the propagation delay for control frame transmission. The propagation delay  $\tau$  is omitted for the data frame since the transmission time for the data frame is extremely large compared to  $\tau$ .

Then from (2), (4), (5) and (6), the average length  $B$  of the busy period is derived as follows.

$$\begin{aligned} B &= (1-P_S) T_C + P_S P_O T_S + P_S (1-P_O) P_{OR} (T_{RS} + T_S) \\ &= (1-e^{-\Lambda \tau}) \times (\text{RTS} + 2\tau + \text{SIFS} + \text{CTS}) + e^{-\Lambda \tau} \times P_O \times (\text{RTS} + \\ &3\tau + 3\text{SIFS} + \text{CTS} + L_r + \text{ACK}) + e^{-\Lambda \tau} \times (1-P_O) \times P_{OR} \times [(\tau + 2 \\ &\text{SIFS} + L_s + \text{ACK}) + (\text{RTS} + 3\tau + 3\text{SIFS} + \text{CTS} + L_r + \text{ACK})] \end{aligned} \quad (7)$$

Let  $D$  be the average MAC delay of a frame arrival for EFR. That is,  $D$  is the interval between the time that the mobile station serves the frame and the time that the frame is successfully transmitted. Thus we have

$$D = P_B \times \left(\frac{B}{2} + D_B\right) + (1 - P_B) \times \left(\text{DIFS} + \frac{W}{2} + D_A\right) \quad (8)$$

where  $D_A$  and  $D_B$  are the average waiting times in ATTEMPT and BACKOFF states, respectively. From Figure 3,  $D_A$  is given by

$$D_A = (1 - P_S) \times (T_C + D_B) + P_S \times \{P_O \times T_S + [(1 - P_O) \times P_{OR}] \times T_{RS}\} \quad (9)$$

Similarly,  $D_B$  is derived as

$$D_B = P_A \times (\text{DIFS} + T_B + D_A) + (1 - P_A) \times (\text{RTS} + \text{SIFS} + D_B) \quad (10)$$

where  $T_B$  is the mean backoff time for a frame transmission and from [8], we have

$$T_B = \sum_{i=0}^4 [P_S(\tau) \times (1 - P_S(\tau))^i 2^{i-1} W] + 1 - P_S(\tau)^5 2^4 W \quad (11)$$

Furthermore,  $P_A$  can be derived as

$$P_A = e^{-\Lambda(\text{DIFS} + T_B)} \quad (12)$$

From (10),  $D_B$  is re-written as

$$D_B = \text{DIFS} + T_B + D_A + \frac{(1 - P_A)}{P_A} \times (\text{RTS} + \text{SIFS}) \quad (13)$$

Then from (8), the average MAC delay  $D$  is re-written as

$$D = T_S + \frac{1}{P_S} \times \text{DIFS} + \frac{(1 - P_S)}{P_S} \times T_C + (P_O P_{OR}) \times \frac{(1 - P_B)}{2} \times W + \frac{P_B + (1 - P_B)(1 - P_S)}{P_S} \times T_B + \left\{ \frac{P_B}{2} + \frac{(1 - P_A)[P_B + (1 - P_B)(1 - P_S)]}{P_S P_A} \right\} \times (\text{RTS} + \text{SIFS}) \quad (14)$$

Based on (14), let  $T$  be the average queuing delay for a frame arrival in EFR. From Little's formulas [7], we have

$$T = \frac{D}{1 - \lambda D} \quad (15)$$

The above analytical model for EFR can be extended to accommodate Enhanced EFR. Due to page limit, we will not re-iterate the derivations for Enhanced EFR scheme. Our analytical model has been validated against the simulation

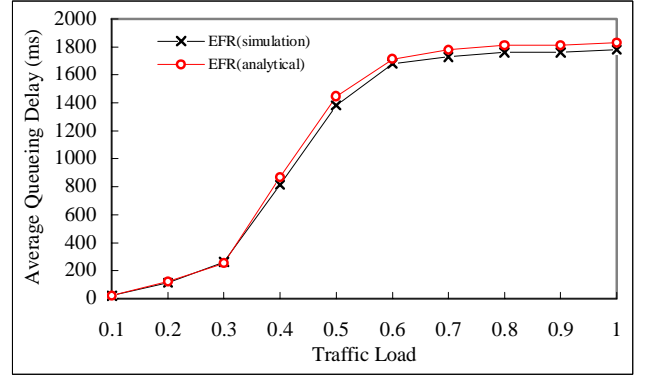


Fig. 4: Comparison of the Analytical and Simulation Results

experiments. The simulation model will be presented in the following section. Figure 4 shows the average queuing delay obtained from analysis and simulation for EFR, where the average length for a data frame is assumed to be 1500 bytes and FER=30%. This figure indicates that the analytical and simulation results are consistent.

#### IV. The Simulation Model and Numerical Examples

In our performance study, we focus on wireless home environments where according to IEEE 802.11b specification, the maximum transmission distances between senders and receivers by applying the 11-Mbps data rate is about 30m (see Figure 5). In general, wireless home networks have many noise sources (i.e. Microwave, Bluetooth and HomeRF), and frame transmission is prone to erroneous. Thus in this simulation model, the FER value is assumed to be 30%.

Our simulation model follows the IEEE 802.11b-1999 using DCF at the MAC layer with the long physical layer convergence protocol (PLCP) data unit (PPDU) format [3]. The input parameters are referred to the standard and listed in Table 1. We assume that the arrival process of frames at a mobile station and AP forms the Poisson distribution with the arrival rates  $\lambda_s$  and  $\lambda_a$ , respectively [1][2][5]. The  $\lambda_s$  and  $\lambda_a$  values are the same as those in the previous analytical model. We also assume that the length of data frames is exponentially distributed with a mean of  $1/\mu$  time slots. Without loss of generality, several assumptions are made to reduce the complexity of the simulation model and described as follows.

- All mobile stations support 5.5 and 11 Mbps rates for data frame transmission.
- All control frames are sent at 2 Mbps transmission rate.
- AP is static and located at the center of simulated area.
- All mobile stations support power-save mode.
- Each mobile station maintains a FIFO waiting buffer of 64 frames, and the mean frame length is assumed to be 1500 bytes.

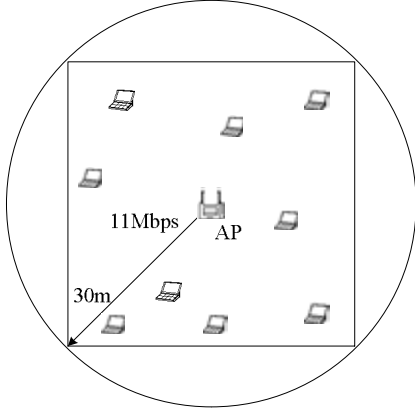


Fig. 5: The Simulation Scenario

Table 1: System Parameters used in the Simulation Model

Parameters	Values
Transmission rate of data frame	5.5, 11 Mbps
Transmission rate of control frame	2 Mbps
Slot time	20 $\mu$ s
SIFS period	10 $\mu$ s
DIFS period	50 $\mu$ s
RTS frame period (length)	80 $\mu$ s (160 bits)
CTS frame period (length)	56 $\mu$ s (112 bits)
ACK frame period (length)	56 $\mu$ s (112 bits)
Size of $CW_{min}$	31 slots
Size of $CW_{max}$	1023 slots
Number of mobile stations	9
Average data frame size	1500 bytes

To observe the mobility impacts, the random way point model [10] in a rectangular field is considered. In the simulation experiments, we simulate a scenario of 9 mobile stations actively in a square area, and their initial locations are randomly assigned within this square area. Each mobile station randomly chooses a direction and keeps moving towards the direction until the boundary of the rectangular field is reached. When the boundary is reached, the mobile

station re-selects a direction, and moves toward the direction as described above. The moving speed of the mobile station is randomly selected from 0 to 1 meter/second. Each simulation run lasts 300 seconds ( $\approx 15 \times 10^6$  time slots) and each simulation result is obtained from averaging the results of 10000 independent simulations.

Figure 6 shows the effects of traffic load on completion rate for EFR, Enhanced EFR and IEEE 802.11 standard, where completion rate is defined as the number of successful transmitted frames over the total number of transmitted frames. This figure shows an intuitive result that for all schemes under investigation, the completion rate decreases as the traffic load increases. The decreasing rate is sharper for

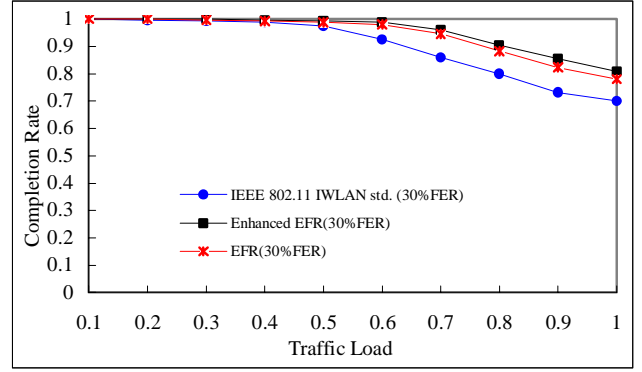


Fig. 6: Effects of Traffic Load on Completion Rate

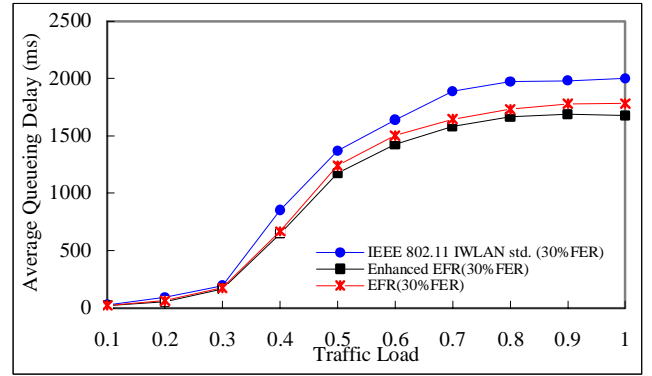


Fig. 7: Effects of Traffic Load on Average Queuing Delay

the heavy traffic load than that for the light one. Furthermore, for the heavy traffic load, IEEE 802.11 is more sensitive to the traffic load than EFR and Enhanced EFR. The reason is that in IEEE 802.11, the contention for channel occupancy under the heavy traffic load becomes severe, which significantly results in completion rate degradation.

Figure 7 shows the average queuing delay obtained from EFR, Enhanced EFR and IEEE 802.11 standard. This figure intuitively shows that for all schemes under investigation, the average queuing delay increases as traffic load increases. This figure also indicates that when the traffic load is light (e.g., less than 0.3), the curves for all schemes are insensitive to traffic load and their values are below 200ms. On the other hand, in the heavy traffic load, the

average queuing delay significantly increases as the traffic load increases. Furthermore, EFR and Enhanced EFR have similar performance and outperform IEEE 802.11 standard. Figure 8 shows the average MAC delay obtained from EFR, Enhanced EFR and IEEE 802.11 standard. This figure indicates the same result as that of Figure 7. That is, the performance of EFR and Enhanced EFR is similar and their average MAC delay is less than that of IEEE 802.11 standard.

Figure 9 shows the effects of traffic load on the average number  $N_c$  of collisions occurred for each data frame prior to being successfully transmitted based on EFR, Enhanced EFR

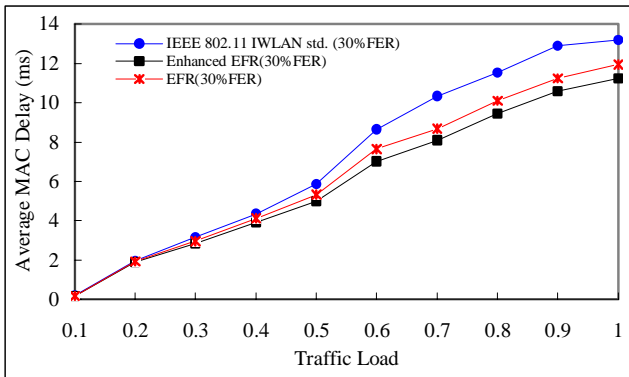


Fig. 8: Effects of Traffic Load on Average MAC Delay

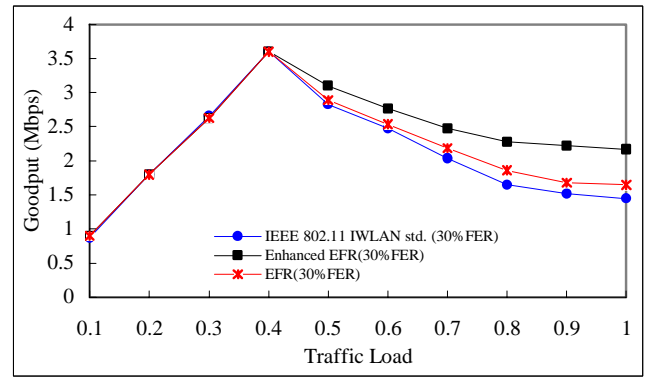


Fig. 10: Effects of Traffic Load on Goodput

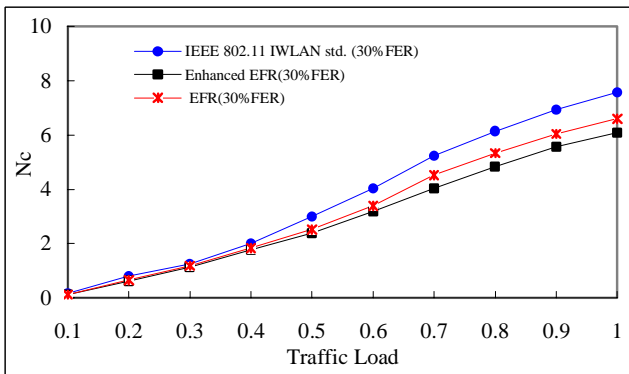


Fig. 9: Effects of Traffic Load on Number of Collisions for Each Data Frame

and IEEE 802.11 standard. A trivial result is observed that for all schemes under investigation,  $N_c$  increases as the traffic load increases. From Figure 9, we observe that performance of EFR and Enhanced EFR is similar and significantly outperforms IEEE 802.11 standard. A large  $N_c$  value implies that mobile stations may try to send data frames many times before the frames are successfully transmitted, which results in more power consumption of mobile stations. Therefore by using EFR and Enhanced EFR, the usage duration of mobile stations is significantly lengthened.

Finally, Figure 10 shows the effects of the traffic load on goodput for EFR, Enhanced EFR and IEEE 802.11 standard. This figure indicates an intuitive result that goodput for all schemes increases and then decreases as the traffic load increases. Furthermore, we find that EFR and Enhanced EFR achieve higher goodput than IEEE 802.11 especially when the traffic load is heavy. The high goodput for EFR and Enhanced EFR mainly results from the extra opportunity for data retransmission. In other words, by using EFR and Enhanced EFR, the contention overhead is reduced and therefore the goodput improves.

## V. Conclusions

This paper presented an efficient retransmission (EFR) scheme to provide immediate data retransmission for multi-rate wireless home networks. By using EFR, bandwidth consumption and frame delay can be significantly reduced. Furthermore, in order to consider a more realistic wireless

home networks, the EFR scheme was enhanced to accommodate the asymmetric traffic model. Both EFR and Enhanced EFR can operate on IWLAN without major modification of IEEE 802.11 standard. We proposed an analytical model and a simulation model to investigate the performance of EFR and Enhanced EFR. The analytical model has been validated against the simulation experiments. Our study indicated that EFR and Enhanced EFR significantly outperform standard IEEE 802.11 CSMA/CA mechanism.

## Acknowledgment

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