

# An Enhanced IEEE 802.11 Retransmission Scheme

Hao-Li Wang, Jinghao Miao, J. Morris Chang

Dept. of Electrical and Computer Engineering

Iowa State University

haoli, jhmiao, morris@iastate.edu

**Abstract** – In the IEEE 802.11 WLAN standard, a positive acknowledgement informs the sender of successful arrivals of data frames. However unacknowledged frames could result from either unsuccessful delivery of data frames or positive ACK frame losses. Therefore the sender will simply retransmit the unacknowledged data frame, which may cause redundant retransmission in case of positive ACK frame losses. In this paper we propose an enhanced retransmission scheme that we call Dynamically Adaptive Retransmission (DAR), which uses modified RTS and CTS frames containing additional information on transmission status of unacknowledged frames. Based on that information, the sender is able to dynamically determine whether to retransmit or not. Experiments and analysis show that our proposed scheme efficiently decreases redundant retransmission by clearly differentiating the reasons for frame loss.

**Keywords:** IEEE 802.11, WLAN, positive ACK, retransmission, Dynamically Adaptive Retransmission (DAR)

## I INTRODUCTION

Wireless local area networks (WLANs) are gaining wider and wider popularity in various fields. As a standard for WLAN, 802.11 was initiated by IEEE in 1997 to provide simple and robust features for wireless connections [1].

Unlike the Ethernet 802.3 standard which uses CSMA/CD in manipulating link layer frames, instead, the IEEE 802.11 standard uses CSMA/CA to avoid transmission collision, and uses positive acknowledgements to inform the sender of successful delivery of data frames. To address the hidden node problem in wireless networks, the IEEE 802.11 standard has two special control frames, Request To Send (RTS) and Clear To Send (CTS) frames. When the sender fails to receive the ACK frame from the receiver upon expiration of the timer, which is deemed an unsuccessful delivery in the current 802.11 standard, the sender simply retransmits the data frame. But limitations exist. Though the positive ACK scheme is helpful in confirming the successful delivery of data frames, in case of the ACK frame loss after a successful data frame delivery the sender is unable to differentiate it from unsuccessful data delivery and will

simply invoke the retransmission scheme. Thus the receiver will get redundant retransmitted frames, which degrades the transmission efficiency. Hence, the goal of our proposed scheme is to improve the efficiency of link layer retransmission by avoiding this type of redundancy.

Currently, two types of retransmission are applied for recovery of lost packets in lossy networks. They are the retransmission mechanisms existing in both the TCP layer and the link layer. TCP retransmission is a part of TCP congestion control mechanisms. When three duplicate ACKs are received (Fast Retransmit), or timeout occurs (Slow Start), the sender retransmits the corresponding TCP packet. On the other hand, retransmission in the link layer happens when the timer to receive an ACK expires. Compared with TCP retransmission, link layer retransmission adapts quickly to link characteristics due to shorter timeout periods. Moreover, since the length of a frame is much shorter than that of a TCP packet, retransmission in the link layer costs less than that in TCP. In the last five years many researchers have been focusing on improving TCP retransmissions to solve wireless TCP problems [5][6][7]. Balakrishnan (1995) proposed the snoop TCP scheme, a TCP-aware link layer protocol using link layer retransmission from a base station [4]. Extensions of link layer retransmission are also used in research on QoS over wireless LANs [8]. To optimize the retransmission scheme in the link layer to achieve high transmission efficiency in higher layers is an important issue. However, no research has been done on link layer retransmission to improve the efficiency of the basic frame exchange protocol. In this paper we proposed an enhanced link layer retransmission scheme based on the 802.11 standard to make transmission more effective.

In the following section, we will discuss some preliminaries regarding the current IEEE 802.11 standard. In section III our Dynamically Adaptive Retransmission (DAR) scheme will be introduced in detail. Some theoretical analysis will be done in section

IV. After that experiments that were carried out will be explained. Finally conclusions will be made and future work will be proposed in Section Fig.12.

## II PRELIMINARIES

In the IEEE 802.11 standard [1], three types of frames are defined. They are management, control and data frames. The format of an 802.11 MAC frame is represented in Fig.1.

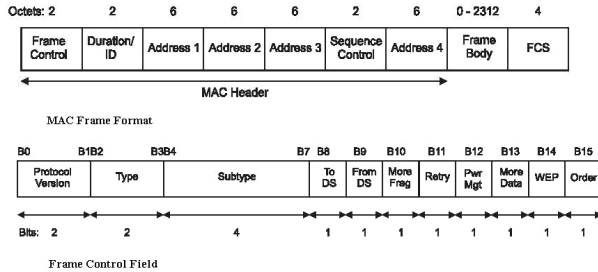


Fig.1 MAC frame format and control field.

The type and subtype values in the frame control field of a frame determine the type of the frame. There are some reserved values in the field, not defined in the current standard. We have defined four new frames using some of the reserved subtype values (shown in Table 1). Their functions will be explained in the following section. Other fields in the new frames will be filled according to the current IEEE 802.11 standard.

Table 1 New frame types and subtypes

Frame	Type	Subtype
Data	10	1000
ACK	01	0000
RTS	01	0001
CTS	01	0010

## III DYNAMICALLY ADAPTIVE RETRANSMISSION

### A. Background Knowledge

Two types of frame exchange protocols, two-way and four-way frame exchange protocols, are used in the IEEE 802.11 standard. The two-way frame exchange protocol includes a pair consisting of a data frame from the sender to the receiver and a corresponding positive ACK frame from the receiver to the sender confirming a successful data frame delivery. Lack of reception of an expected ACK frame indicates to the sender that an error has occurred in the frame exchange. On the other hand, the four-way frame exchange protocol aims at

eliminating the hidden node problem by claiming the occupancy of wireless mediums before real transmission. Two types of small control frames RTS and CTS are exchanged between the sender and the receiver so that other parties in the wireless neighboring regions hearing the two frames could hold their traffic for a period of time to avoid collision.

The usage of the two types of frame exchange protocols are specifically defined in the IEEE 802.11 standard. A variable, called  $RTSThreshold$  as defined in the MIB (Message Information Base) of 802.11 standard, determines which type of frame exchange is used. When the frame size is less than the value of  $RTSThreshold$ , the two-way frame exchange will be utilized. Otherwise, the four-way frame exchange will take effect. However, redundant retransmission occurs in both cases. That means the receiver may have received the data frame correctly, and the error may only have occurred in the reception of the ACK frame. To the sender of the frame exchange, this condition is indistinguishable from that in which an error occurs in the initial data frame. The sender may then simply retransmit the unacknowledged frame, which is redundant to the receiver. Therefore we will propose an enhanced scheme, called Dynamically Adaptive Retransmission (DAR) scheme, to avoid redundant retransmissions for high transmission efficiency.

To facilitate understanding of our scheme, we use a simple model to demonstrate scenarios for the retransmission enhancement. As shown in Fig.2, each node represents a transmission state and each directed edge represents a state transition. A value is assigned to show the probability of the transition on each edge. The initial state is at the top in Fig.2. If the directed edge goes southeast, it stands for a successful frame delivery. If the directed edge goes southwest, it indicates a frame delivery failure.

Before we introduce our enhanced scheme, the conventional two-way frame exchange protocol is studied as follows (Fig.2). To simplify our analysis, we suppose the probability of frame errors is a fixed value  $P$ , regardless of the frame type. Let  $F(e)$  be the probability of an event  $e$ . We have the following:

$$\begin{aligned}
 &F(\text{Successful frame exchange}) \\
 &= F(\text{Successful data frame delivery}) * F(\text{Successful ACK frame delivery}) \\
 &= (1 - P) \times (1 - P) \\
 &= (1 - P)^2
 \end{aligned}$$

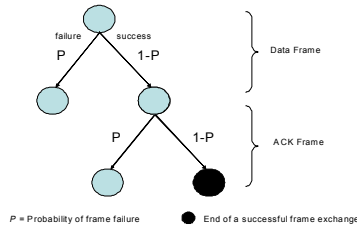


Fig.2 Scenarios of two-way frame exchange protocol.

The probability of a successful frame exchange in the 802.11 standard is represented as line 2 in Fig.3 where the X axis is probability of frame loss and the Y axis is the probability of a successful frame exchange. Line 1 in Fig.3 is an ideal target which means the probability of a successful frame exchange = 1 - (the probability of the frame loss). And our objective in proposing an enhanced scheme is to find a curve closely approaching line 1 between the two lines, represented as line 3 in Fig.3.

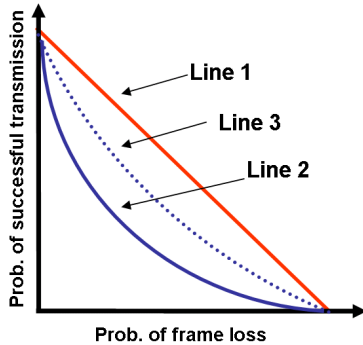


Fig.3 Probability of successful frame exchange.

In the following part of this section, the proposed Dynamically Adaptive Retransmission (DAR) scheme is described in detail.

### B. Dynamically Adaptive Retransmission (DAR) Scheme

In order to avoid retransmission redundancy, the sender needs additional information to determine whether a retransmission is necessary. The two-way and four-way frame exchange protocols may be different in conveying the retransmission information because different frame types may be involved in the two protocols. Hence the DAR scheme consists of two parts of improvements and will be explained respectively in the following of this section.

### 1) Improved Two-Way Frame Exchange Protocol

The improved two-way frame exchange protocol for both the sender and the receiver are illustrated in Fig.4 and Fig.5.

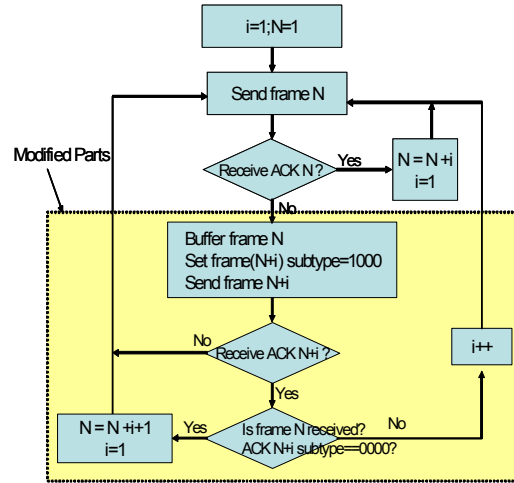


Fig.4 Improved two-way frame exchange protocol at the sender.

In the two-way frame exchange protocol, after the sender sends a data frame, call it frame  $N$ , it buffers the frame in case it does not receive the corresponding ACK frame. The sender then sends the next data frame with subtype = 1000, called a triggering data frame, which triggers an inquiry from the sender to the receiver. The receiver will respond to the triggering data frame with a special ACK frame whose subtype is 0000 when the previous data has been successfully received. Otherwise a regular ACK frame will be sent back to the sender so that the sender is able to determine the previous data frame was lost and retransmission is necessary.

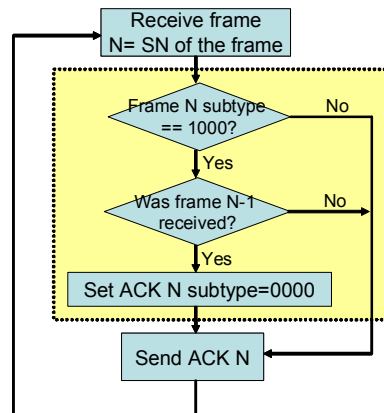
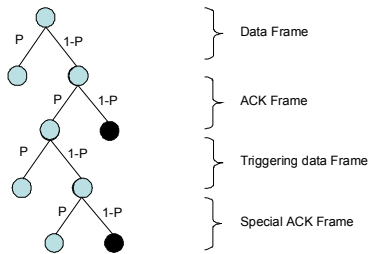


Fig.5 Improved two-way frame exchange protocol at the receiver.

It is obvious that the triggering data frame and the special ACK frame with additional transmission information are helpful in determining whether a

retransmission is necessary. Clearly the probability of a successful frame exchange improves as shown in Fig.6.

$$\begin{aligned}
 F(\text{A successful frame exchange}) &= (1-P)^2 + (1-P) \times P \times (1-P)^2 \\
 &= (1-P)^2 + P(1-P)^3 > (1-P)^2
 \end{aligned}$$



$P$  = Probability of frame failure    ● End of a successful frame exchange

Fig.6 Scenarios of the improved two-way frame exchange protocol.

### 2) Improved Four-Way Frame Exchange Protocol

Different from the improved two-way frame exchange protocol, we use the existing RTS/CTS frame exchange to piggyback the transmission information to the sender in the improved four-way frame exchange protocol as shown in Fig.7 and Fig.8.

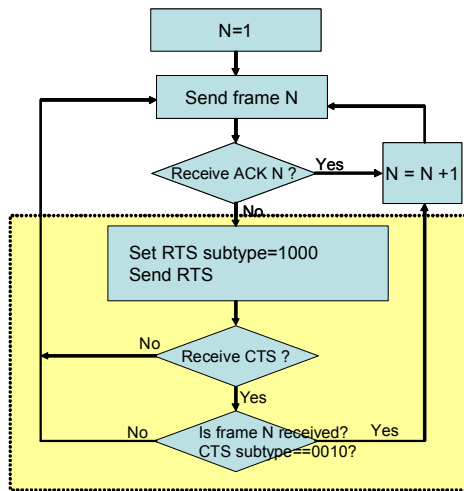


Fig.7 Improved four-way frame exchange protocol at the sender.

In the improved four-way frame exchange protocol, the frame exchange initiator sends a special RTS frame whose subtype is 0001, called a triggering RTS if it is unable to receive a positive ACK frame before the next transmission. Retransmission is not invoked immediately at this time. Upon receipt of a regular CTS frame, the sender knows that the previous data frame did not arrive at the receiver. Retransmission becomes necessary in this case.

Otherwise, the sender just ignores the case of a lost ACK frame if it receives a special CTS frame whose subtype is 0010. If the last data frame is followed by an ACK loss, the sender will still initiate a triggering RTS inquiring whether the last data frame has been successfully delivered. In this RTS frame the duration field will be filled in accordance with the expected special CTS only.

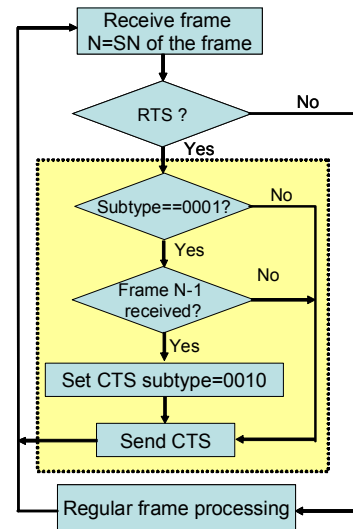
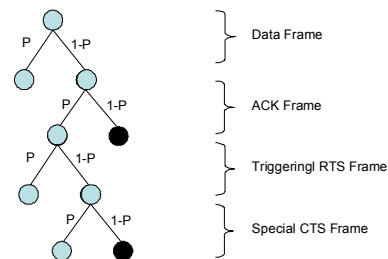


Fig.8 Improved four-way frame exchange protocol at the receiver.

It can be seen that the sender does not need to buffer frames in this scheme because it will be capable of determining which frame to send before real transmission. Note that the 802.11 MAC layer semantics are not violated in this scheme because the frame exchange process is not intercepted and the frame exchange sequence remains the same, which means it is still atomic. Fig.9 show the scenarios of DAR.



$P$  = Probability of frame failure    ● End of a successful frame exchange

Fig.9 Scenarios of the improved four-way frame exchange protocol.

### 3) Benefits of DAR

It is worthy to note that the DAR scheme does not require new frame formats, but uses the reserved

values of the subtype filed in the 802.11 standard. No extra cost on the bandwidth will be wasted because the DAR scheme does not utilize additional frames in the frame exchange. Informative bits in the specially defined frames in the DAR scheme convey the transmission condition with which the transmission initiator can wisely determine whether to retransmit or not. Thus great benefits will be achieved when redundant retransmissions can be avoided.

#### IV THEORETICAL ANALYSIS

To demonstrate the benefits of DAR, Fig.10 shows the performance improvement (represented as the probability of successful frame exchange on the Y axis) with respect to bit error rate (represented as BER on the X axis).

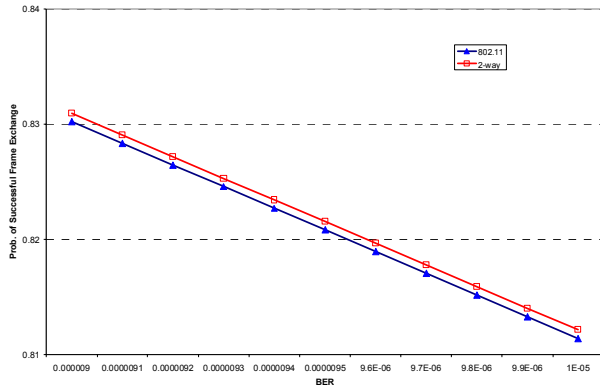


Fig.10 Performance improvement in the DAR scheme.

Obviously the probability of successful frame exchange in the enhanced scheme is higher than that in the current IEEE 802.11 standard. Performance will be improved as a result.

An important concept in the analysis is the differentiation ratio, defined to measure the performance of DAR. We define the differentiation ratio as the ratio of successfully delivered frames with lost ACKs that can be differentiated by the sender using the enhanced scheme over all failed frames detected by the conventional retransmission scheme. It is obvious that the differentiation ratio in the conventional 802.11 frame exchange protocol is always 0. An example of the differentiation ratio in the improved two-way frame exchange protocol is shown as follows.

$$\begin{aligned}
 \text{Diff.} &= \frac{(\# \text{ of successfully delivered data frames with lost ACKs})}{(\# \text{ of failed frames})} \\
 &= \frac{[(1-p) \times len_d] \times [p \times len_a] \times [(1-p) \times len_d] \times [(1-p) \times len_a]}{[(1-p) \times len_d] \times [p \times len_a]} \\
 &= [(1-p) \times len_d] \times [(1-p) \times len_a]
 \end{aligned}$$

where  $p$  represents BER, and  $len_d$  and  $len_a$  represent the lengths of the data and ACK frames. Fig.11 shows the differentiation ratio in the improved two-way frame exchange protocol with respect to BER. When the bit error rate is relatively low, the differentiation ratio is high, which means many failure cases can be differentiated by the improved protocol as ACK loss cases without invoking retransmission. This gives a desirable result.

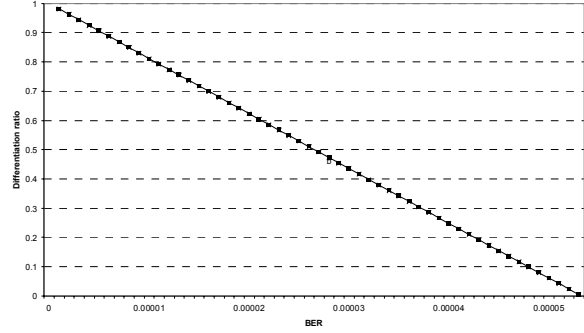


Fig.11 Differentiation ratio in the improved two-way frame exchange protocol.

#### V EXPERIMENTS

##### A. Experimental Methodologies

We developed a simulator in C and performed several simulations to determine the performance and efficiency of the proposed DAR scheme. The MAC layer basically follows the IEEE 802.11 standard [1]. The DAR protocol is implemented as a set of modifications to the frame exchange protocol in the MAC layer. Our experimental testbed consists of two mobile hosts, which are interconnected using a shared-medium wireless LAN with a raw signaling bandwidth of 2 Mbps. This is because we attempt to ensure that losses are due only to wireless errors, not congestion. This also allows us to focus on the effectiveness of the mechanisms for handling such losses. The simple testbed topology represents typical scenarios for wireless links and mobile hosts, such as cellular wireless networks. In addition, our experiments focus on MAC frame exchange between the mobile hosts.

In order to measure the performance of the protocols under controlled conditions, we generate errors on the lossy link using a uniformly distributed bit-error model. Each run in the experiment consists of a 10 MByte transfer from the sender to the receiver across the wireless link. We chose this rather long transfer size in order to limit the impact of transient behavior. During each run, we measure the

goodput as normalized between 0 and 1. The other parameters in the simulation models, listed in the Table 2 and 3, are referenced from [9].

**Table 2 Parameters in the experiments**

Frame	Size (Byte)	Transfer Time ( $\mu s$ )
Data	500 (4-way) 300 (2-way)	4292
ACK	14	120
RTS	20	144
CTS	14	120
RTSThreshold	400	

**Table 3 Parameters in the experiments (cont'd)**

Interframe space	Duration ( $\mu s$ )
SIFS	10
DIFS	110
ACK timeout	120

We use *goodput* to measure the performance of both DAR and the 802.11 standard. The concept of goodput of the link layer is taken from TCP and defined as the bandwidth delivered to the receiver through the link excluding duplicate frames. Thus, the goodput  $G_l$  of a link  $l$  during a time interval  $t$  corresponds to the number of bytes  $B$  of link  $l$  forwarded to the upper layer during the interval  $t$  [5].

### B. Experiment Results

Fig.12 shows the goodputs in 802.11 vs. the improved four-way frame exchange protocol with respect to BER. DAR achieves higher goodput than the 802.11 standard. The improved four-way frame exchange protocol saves more time expenditures on RTS and CTS frames in addition to data frames.

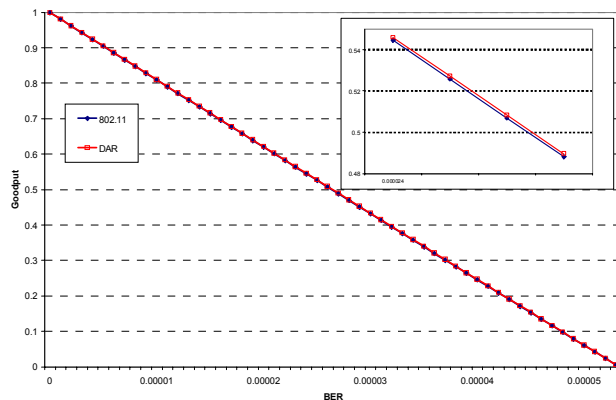


Fig.12 Goodput in the improved four-way vs. 802.11 with respect to BER

## VI CONCLUSIONS AND FUTURE WORK

The current IEEE 802.11 standard confuses the sender when a positive ACK is lost during its way back. The sender will take it as an unsuccessful delivery and simply retransmit the data frame. An enhanced DAR scheme is introduced in our paper, proposing a new feedback scheme, in which the CTS frames carry additional information concerning the previous data delivery without violating the 802.11 MAC layer semantics. Our method proves to be efficient in handling such error conditions as stated in the paper. Experiments and analysis show that the DAR scheme efficiently decreases redundant retransmission by clearly differentiating ACK frame losses.

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