An Enhanced Link Layer Retransmission Scheme for IEEE 802.11

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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 losses of positive ACK frames. 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, called Dynamically Adaptive Retransmission (DAR), which uses modified 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 the proposed scheme can efficiently reduces redundant retransmission by clearly differentiating ACK frame losses from data frame losses.**

Keywords: IEEE 802.11, WLAN, positive ACK, retransmission

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. Moreover, in 802.11 the delivery of data frames followed by positive ACK confirmations is an atomic operation.

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, Request To Send (RTS) and Clear To Send (CTS) frames, are exchanged between the sender and the receiver. Other parties in the wireless neighboring regions hearing the two frames could hold their traffic for a period of time to avoid collision.

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. The positive ACK scheme is helpful in confirming the successful delivery of data frames. But 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. The proposed scheme uses modified frames containing additional information on transmission status of unacknowledged frames. The goal of our proposed scheme is to improve the efficiency of link layer retransmission by avoiding this type of redundancy.

In the following section, we will introduce some related work regarding the retransmission schemes. 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. In section VI. we will discuss the DAR scheme further. Finally conclusions will be made and future work will be proposed in Section VII..

II. RELATED WORK

Most of research has been focusing upon applying retransmission schemes to the services in various network layers, but our research is to improve the retransmission itself. Currently, two types of retransmission are applied for recovery of lost packets in wireless networks. They are the TCP layer retransmission and the link layer retransmission. 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 [6][7][9]. Balakrishnan (1995) proposed the snoop TCP scheme, a TCP-aware link layer protocol using link layer retransmission from a base station [5]. Extensions of link layer retransmission are also used in research on QoS over wireless LANs [11]. Optimizing the retransmission scheme in the link layer achieves higher transmission efficiency than that in higher layers. 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.

III. DYNAMICALLY ADAPTIVE RETRANSMISSION

A. Background Knowledge

The usage of the two-way and four-way 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.

ACK frame losses may occur in both the two-way and four-way frame exchanges, and yield redundant retransmission. 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. This research proposes an enhanced scheme, called Dynamically Adaptive Retransmission (DAR) scheme, to avoid redundant retransmissions for high transmission efficiency.

To illustrate the proposed scheme, a model based on the probability of frame losses is presented in Fig.1. 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.1. 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.

The conventional two-way frame exchange protocol is studied as follows (Fig.1). We suppose that 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:

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

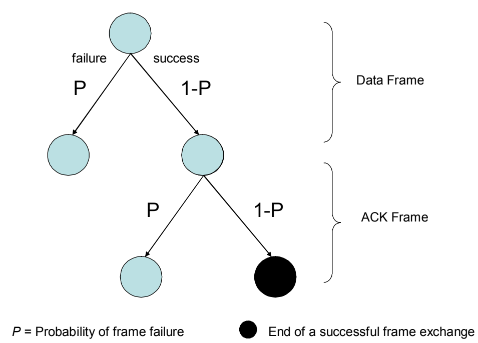

Fig.1 Scenarios of two-way frame exchange protocol.

The probability of a successful frame exchange in the 802.11 standard is represented as line 2 in Fig.2 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.2 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, represented as line 3 in Fig.2, which is closely approaching line 1 between the line 1 and line 2.

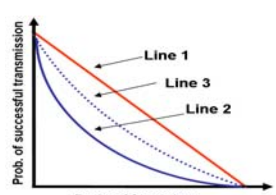

Fig.2 Probability of successful frame exchange.

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.3 and Fig.4.

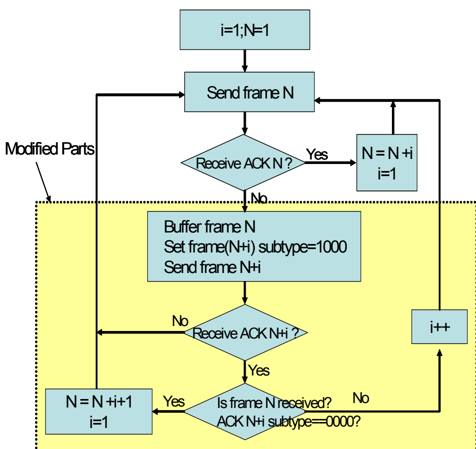

Fig.3 Improved two-way frame exchange protocol at the sender.

In the two-way frame exchange protocol, as shown in Fig.3, 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.

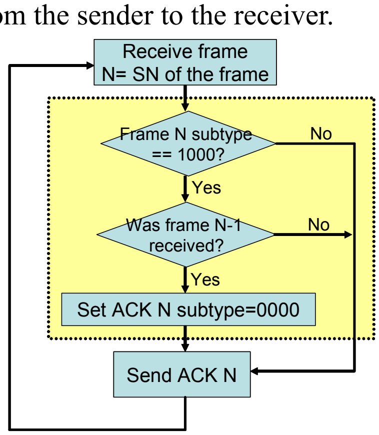

Fig.4 Improved two-way frame exchange protocol at the receiver.

As shown in Fig.4, 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

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.5.

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

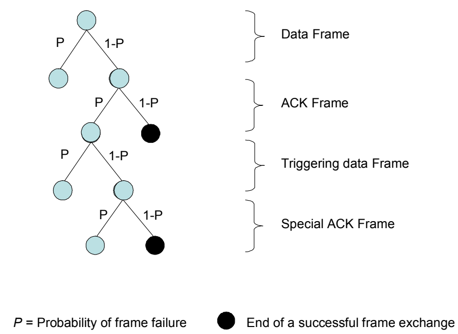

Fig.5 Scenarios of the improved two-way frame exchange protocol.

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.6 and Fig.7.

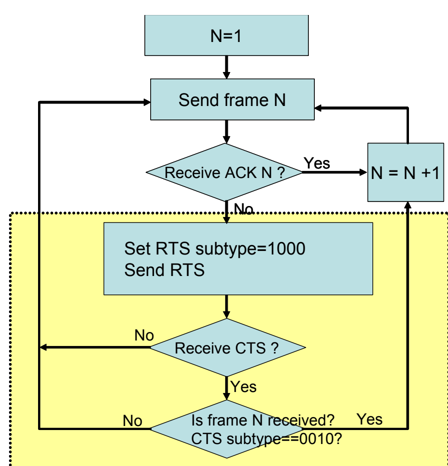

Fig.6 Improved four-way frame exchange protocol at the sender.

In the improved four-way frame exchange protocol, as shown in Fig.6, 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.

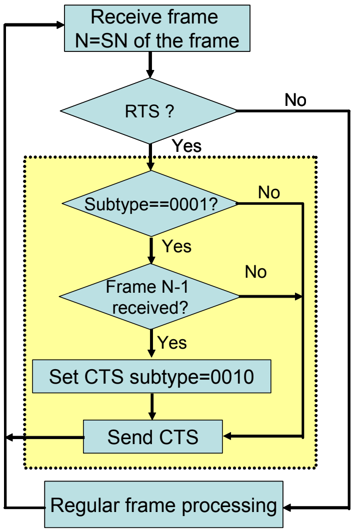

Fig.7 Improved four-way frame exchange protocol at the receiver.

As shown in Fig.7, the sender knows that the previous data frame did not arrive at the receiver upon receipt of a regular CTS frame. 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.

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.8 show the scenarios of DAR.

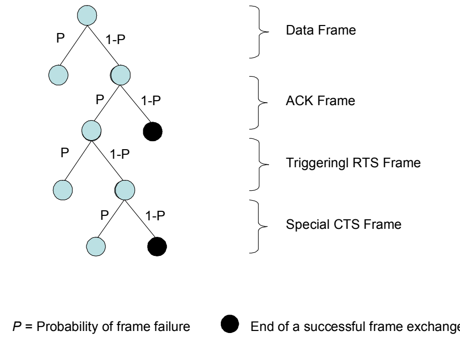

Fig.8 Scenarios of the improved four-way frame exchange protocol.

3) Frame Formats

Currently in the IEEE 802.11 standard [1], four frames (RTS, CTS, data and ACK) are used in a frame exchange process. Their formats are represented in Fig.9. The type and subtype values in the frame control field of a frame determine the type of the frame. In these fields there are some reserved values, not defined in the current standard. Four special frames required in support of DAR use the reserved values (shown as an example in Table 1) to convey additional information on the transmission status.

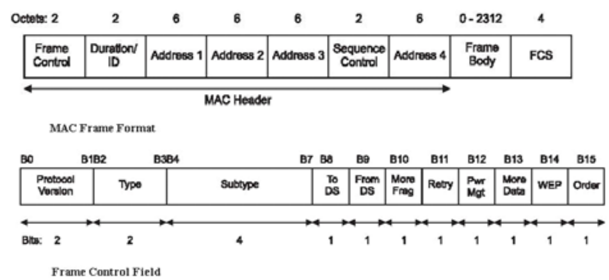

Fig.9 MAC frame format and control field.

Table 1 New frame types and subtypes

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

4) 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).

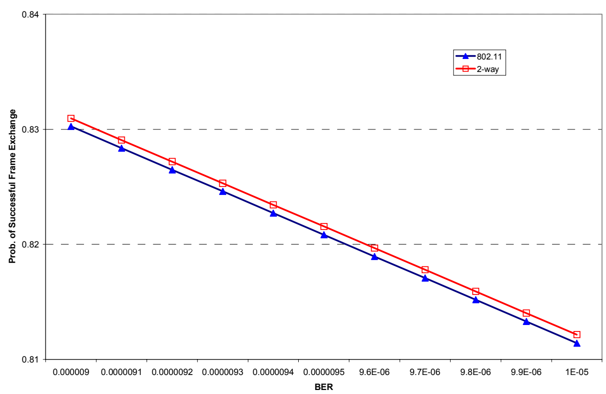

Fig.10 Performance improvement in the DAR scheme.

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 fellows.

$$Diff. = \frac{(\text{\# of successfully delivered data frames with lost ACKs})}{(\text{\# of failed frames})}$$

$$= \frac{[(1-p)\times len_d]\times[p\times len_a]\times[(1-p)\times len_d]\times[(1-p)\times len_a]}{[(1-p)\times len_d]\times[p\times len_a]}$$

$$= [(1-p)\times len_d]\times[(1-p)\times len_a]$$

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.

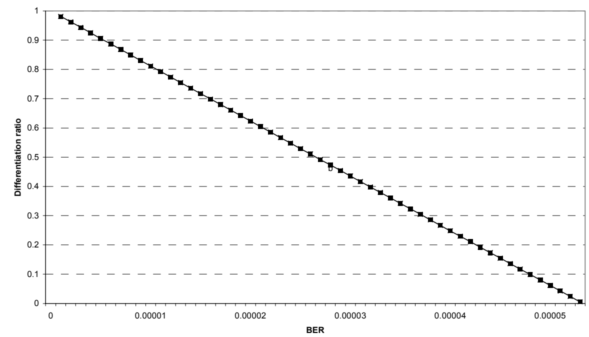

Fig.11 Differentiation ratio in the improved two-way frame exchange protocol.

V. EXPERIMENTS

A. *Experimental Methodologies*

We developed a simulator in C 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 [13].

Table 2 Parameters in the experiments

Frame	Size (Byte)	Transfer Time (μs)
Data	500 (4-way) 300 (2-way)	4292 2575
ACK	14	120
RTS	20	144
CTS	14	120
RTSThreshold	400	

Table 3 Parameters in the experiments (cont'd)

Interframe space	Duration (μs)
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. To demonstrate the benefit of DAR scheme we calculated the time savings using the BER loss rate as shown in Fig.13. The improved four-way frame exchange protocol saves more time expenditures on RTS and CTS frames in addition to data frames.

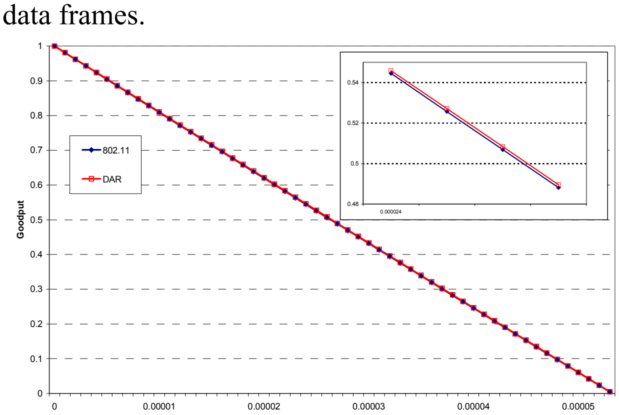

Fig.12 Goodput in the improved four-way vs. 802.11 with respect to BER.

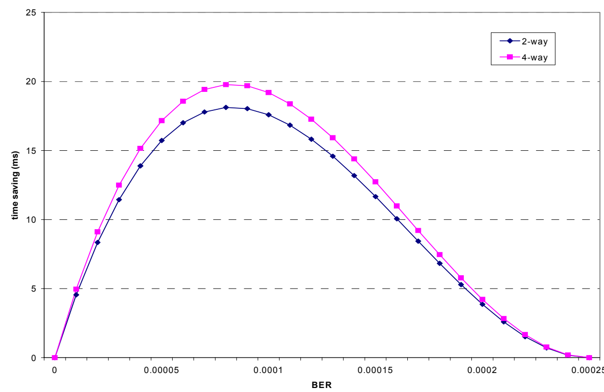

Fig.13 Time savings in the DAR scheme.

VI. FURTHER DISCUSSION

As mentioned in section III., to recover from the frame loss, a data buffer is needed at the sender for the unacknowledged frame. It is obvious that more buffers may handle more complex cases such as consecutive ACK or CTS losses. However, it might be impractical to allocate a huge amount of buffer for each transmission due to limitations on memory resources. Moreover, the probability of the above event can be low. Experiments to explore the amount of buffer needed for each transmission therefore are necessary.

Theoretically the number of buffers determines the number of consecutive response losses that can be handled, because the unacknowledged data frames can be buffered before the sender receives either affirmative or negative confirmation from the receiver.

Fig.14 shows the probability of consecutive response losses in various BER situations. The X axis represents the number of consecutive response losses including ACK and CTS frame losses. The Y axis represents the probability of these occurrences. Three lines have been drawn based on three different bit error rates, 0.001, 0.01 and 0.1. It can be seen that the more consecutive lost responses considered, the lower the probability. The lower the bit error rate, the more quickly the possibility degrades. Considering practical situations where the BER is low, it is unnecessary to cope with more than two consecutively lost responses as proposed in our DAR scheme.

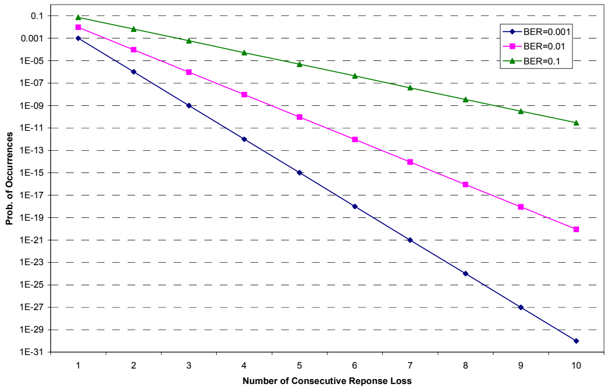

Fig.14 Probability of consecutive response losses in various BERs.

VII. CONCLUSIONS

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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