Available online at www.sciencedirect.com

ScienceDirect

Computer Communications 29 (2006) 2964–2974

computer communications

www.elsevier.com/locate/comcom

Efficient and fast retransmission for wireless networks

Hsueh-Wen Tseng [a], Ai-Chun Pang [a,b,*], Chin-Fu Kuo [a], Shiann-Tsong Sheu [c]

[a] *Department of Computer Science and Information Engineering, National Taiwan University, Taiwan, ROC*
[b] *Graduate Institute of Networking and Multimedia, National Taiwan University, Taiwan, ROC*
[c] *Department of Communication Engineering, National Central University, Taiwan, ROC*

Abstract

This paper proposes efficient and fast retransmission (EFR) schemes for IEEE 802.11 multi-rate wireless networks. Without major modification of IEEE 802.11 standard, EFR provides immediate data transmission for both ad hoc wireless local area networks (WLAN) and infrastructure WLAN. Also, EFR can compensate for high frame error rates resulting from existing poor rate control algorithms. We develop an analytical model and a simulation model to investigate the performance of EFR. Our study indicates that in terms of average *medium access control* delay, average queuing delay, completion rate and average collision times per transmission. EFR outperforms standard IEEE 802.11 carrier sense multiple access/collision avoidance mechanism.

Keywords: IEEE 802.11; MAC; Retransmission; Wireless networks

1. Introduction

IEEE organization has approved the 802.11 standard for wireless local area network (WLAN) in 1997. IEEE 802.11 standard supports two kinds of configurations: ad hoc WLAN and infrastructure WLAN (IWLAN). In ad hoc WLAN, mobile stations communicate with each other without fixed wired infrastructure. On the other hand, IWLAN provides communications among mobile stations via access points (APs). The AP plays the role of bridge to connect WLAN with wired networks (e.g., Internet).

IEEE 802.11 medium access control (MAC) protocol defines a distributed coordination function (DCF) that employs a carrier sense multiple access/collision avoidance (CSMA/CA) mechanism for asynchronous data transmission. The mechanism is used to determine a mobile station that has authority for channel occupancy. If the mobile station occupies the channel, a proper data rate (if WLAN supports multi-rate transmission) is selected. Intuitively, all mobile stations shall use the highest-level modulation scheme with the highest data rate all the time to achieve the maximum network throughput. However, maximum data transmission might not be obtained since the transmission rates depend on the distance as well as the number of obstructions between the transmitter and the receiver. The rate selection is mainly based on two criteria: average received signal strength indication (RSSI) and frame error rate (FER). The RSSI potentially indicates the distance between the transmitter and the receiver. The FER indicates the error probability for frame transmission.

In the first edition of IEEE 802.11 standard published in 1999 [10], the transmission rate of 1/2 Mbps was provided. Two fundamental modulation schemes, *binary phase shift keying* and *quadrature phase shift keying*, are further used to provide 1 and 2 Mbps transmission rates, respectively. For direct sequence spread spectrum (DSSS), an 11-chip Barker sequence is chosen due to its good autocorrelation property and coding gain. The DSSS with Barker code is robust against interference/noise and time delay spread condition. By replacing 11-chip Barker code with *complementary code keying* or *packet binary convolution code* scheme [1,3,4,8,13], IEEE 802.11b standard has

---

[*] Corresponding author. Tel.: +886 223625336417; fax: +886 223628167.
E-mail address: acpang@voip.csie.ntu.edu.tw (A.-C. Pang).

0140-3664/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.comcom.2006.04.014

the ability to provide four data rates 1/2/5.5/11 Mbps in 2.4–2.4835 GHz [11].

In IEEE 802.11 MAC, a successful data transmission is recognized by ACK control 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 FER is high or traffic load is heavy. This would result in extra bandwidth and power consumption (due to backoff), and longer frame delay. Therefore, in this paper, we propose two efficient and fast retransmission (EFR) schemes (i.e., EFR-o and EFR-w) in a multi-rate wireless system to improve the system performance. Under the EFR schemes, each data frame is given a secondary chance for retransmission without contention, and the retransmission rate is decreased to a lower level to resist the unstable network condition.

By using EFR-o, bandwidth/power consumption and frame delay can be significantly reduced. However, the performance of EFR-o may degrade under the following situations: (1) occurrence of hidden nodes, (2) activation of power-save mode. Thus EFR-w is developed to provide instant retransmission even when the above situations exist. Both EFR-o and EFR-w can operate on IWLAN and ad hoc WLAN without major modification of IEEE 802.11 standard. Without loss of generality, we will use IWLAN as an example to illustrate how EFR-o and EFR-w work in the next sections.

The remainder of this paper is organized as follows. Section 2 describes EFR schemes. In Section 3, an analytical model is proposed to investigate the performance of EFR-o and EFR-w. In Section 4, a simulation model for EFR schemes is presented. Based on the simulation experiments, we compare the performance of EFR schemes with that of IEEE 802.11 standard. Finally, conclusions are given in Section 5.

2. The efficient and fast retransmission (EFR) schemes

This section describes our proposed EFR-o and EFR-w for wireless networks. Fig. 1(a) illustrates an example of standard IEEE 802.11 MAC procedure. 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 chosen in the interval [0,CW], where CW represents the length of the contention window. The mobile station with minimum backoff time occupies the channel. Then request-to-send/clear-to-send (RTS/CTS) four-way handshaking is utilized to reserve the coming time slots for data transmission. In the handshaking process, a minimum gap between two successive transmitted frames is reserved, and defined as short inter-frame space (SIFS). If RTS is successfully transmitted to the receiver, the receiver responds with CTS. Otherwise, the backoff operation with a doubled CW would be re-executed. Suppose that RTS/CTS handshaking is successfully performed (i.e., no collision occurs). Then the data frame is delivered from the sender to the receiver, and the receiver sends ACK to the sender if 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 an 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 Fig. 1(a), $\text{RTS\_Duration} = 3\text{SIFS} + \text{CTS} + \text{L}_r + \text{ACK}$ and $\text{CTS\_Duration} = 2\text{SIFS} + \text{L}_r + \text{ACK}$, where L_r denotes data transmission time with transmission rate of r Mbps.

From the above discussions, the backoff operation in standard IEEE 802.11 MAC procedure would be activated frequently in the environment of high FER and heavy traffic load, which results in extra bandwidth/power consumption and longer delay for data delivery. Thus EFR-o and EFR-w schemes are proposed to provide efficient and fast retransmission. In EFR-o, each data frame is given a secondary 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 probability. As shown in Fig. 1(b), when the frame error occurs, the receiver informs the sender of transmission failure by using a CTS control frame. 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 and reserved, where $\text{CTS\_Duration} = 2\text{SIFS} + \text{L}_s + \text{ACK}$. Then the sender retransmits the data frame with the transmission rate s (where $s \leqslant r$) after the SIFS period. The s value for retransmission is set to a one-level lower rate than r. For example, in IEEE 802.11b, three different transmission rates, i.e., 11, 5.5 and 2 Mbps (note that 1 Mbps-rate is used to transmit physical-layer headers), are provided. If $r = 5.5$ Mbps, then $s = 2$ Mbps.

The proposed EFR-o scheme indeed provides efficient and fast retransmission. However, under the occurrence of hidden nodes and activation of power-save mode (i.e., situations (1) and (2) described in Section 1), the performance improvement of EFR-o may degrade. We use Fig. 2(a) as an example to illustrate the effect of the hidden-node problem and the power-save mode on EFR-o in IWLAN.

Assume that *mobile station* (STA) *A* and STA *B* cannot sense each other, i.e., STA *A* is the hidden node of STA *B*. As shown in Fig. 2(a), STA *A* occupies the channel for