LETTER

A Novel Piggyback Selection Scheme in IEEE 802.11e HCCA

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SUMMARY A control frame can be piggybacked onto a data frame to increase channel efficiency in wireless communication. However, if the control frame including global control information is piggybacked, the delay of the data frame from a access point will be increased even though there is only one station with low physical transmission rate. It is similar to the anomaly phenomenon in a network which supports multi-rate transmission. In this letter, we define this phenomenon as "the piggyback problem at low physical transmission rate" and evaluate the effect of this problem with respect to physical transmission rate and normalized traffic load. Then, we propose a delay-based piggyback scheme. Simulations show that the proposed scheme reduces average frame transmission delay and improves channel utilization about 24% and 25%, respectively.

key words: *WLAN, HCCA, piggyback*

1. Introduction

In IEEE 802.11 wireless local area network (WLAN), a station (STA) selects the most appropriate transmission rate according to the wireless channel condition in order to maximize its throughput [1]–[3]. However, the throughput of STAs transmitting at higher data rate is dramatically degraded to the same level as that of STAs transmitting at lower data rate. As the STA which has low transmission rate uses the medium for a longer time to transmit its packet, it penalizes other STAs that use higher transmission rate. This is well known anomaly phenomenon in WLAN [4].

The similar phenomenon occurs when the piggyback scheme is used in IEEE 802.11e hybrid coordination function (HCF) controlled channel access (HCCA) [5]. HCCA is designed to guarantee QoS to delay sensitive services using the channel reservation [6]. If a QoS station (QSTA) wants to transmit data frames using HCCA, it requests a transmission opportunity from a QoS access point (QAP). Then, the QAP sends a CF-Poll frame to reserve the transmission opportunity for the QSTA. Other QSTAs need to know the channel reservation time to avoid channel collision. It is the network allocation vector (NAV) rules of HCF. Therefore, the CF-Poll frame should be listened to all QSTAs to set their NAV value to protect expected subsequent frames. The CF-Poll frame can be piggybacked onto the data frame to increase channel efficiency. However, if any QSTA uses low physical transmission rate due to successive retransmissions or channel noise, QAP should decrease the transmission rate of the data frame including the CF-Poll frame to the lowest physical transmission rate among allowable transmission rates. Therefore, the transmission time for the CF-Poll which is piggybacked onto the data frame is increased. This can cause the decrease of channel efficiency and the increase of frame transmission delay for other traffic streams (TSs). In this letter, we define this problem as "CF-Poll piggyback problem at low physical transmission rate" and evaluate the effect of this problem according to service traffic load and the physical transmission rate of a QSTA. Finally, we propose a transmission delay-based piggyback scheme which adaptively selects the use of the piggyback scheme according to physical transmission rate.

2. Transmission Delay-Based Piggyback Scheme

To design a transmission delay-based piggyback scheme, we assume the following conditions.

- Each QSTA using HCCA has just one TS and always generates MAC service data units (MSDUs) according to the mean data rate during service interval (SI).
- Service packets for TS arrive in a queue for HCCA from the upper layer when SI is started.
- The characteristic of TS for HCCA has a constant bit rate (CBR).

To consider the multiple data rates, let γ_i be a set of allowable physical transmission rates for i^{th} QSTA, then

$$\gamma_i = \left\{R_1, R_2, R_3, \cdots, R_j, \cdots, R_M\right\}, 1 \le j \le M, \tag{1}$$

where R_j means the jth physical transmission rate of QSTA and M is the number of allowable transmission rates. If QSTA supports IEEE 802.11a/g, R_M is 54 Mbps. A CF-Poll frame is used to grant a transmission opportunity to a QSTA. All QoS stations need to know the allocated transmission opportunity to avoid the channel collision. Therefore, the CF-Poll frame should be transmitted through the minimum of all maximum transmission rates for all QSTAs as follows.

$$R_{CF-Poll} = \min_{1 \le i \le k} \{\max(\gamma_i)\}, \tag{2}$$

where k means the number of QSTAs in a QoS basic service set (QBSS). ith QSTA generates the number of MSDUs that arrived at the mean data rate as follows

$$N_i = \left\lceil \frac{SI \times \rho_i}{L_i} \right\rceil, \tag{3}$$

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R_CF-Poll = R_M;
      For i = 1 to k
            If (max (R_j) <= R_CF-Poll
                  R_CF-Poll = R_j;
            end If
      end For
Delta = (1/R_CF-Poll- 1/R_j)L_(MSDU,1)
        -L_CF-Poll/R_CF-Poll;
If Delta >= 0
      Piggyback is disabled;
Else
      Piggyback is enabled;
end
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where ρ_i and L_i means the mean data rate and the nominal MSDU size for the TS of ith QSTA, respectively. When a CF-Poll frame is piggybacked onto the data frame, the maximum delay to transmit the data frame in the QSTA is

$$\begin{aligned}\delta_{pb} &= 2N_i \times t_{PLCP} + (2N_i - 1)\, t_{SIFS} \\ &\quad + \frac{N_i \cdot L_{ACK}}{R_j} + \frac{L_{MSDU,1}}{R_{CF\_Poll}} + \sum_{l=2}^{N_i-1} \frac{L_{MSDU,l}}{R_j},\end{aligned} \tag{4}$$

where t_{PLCP} is the transmission time of a physical layer convergence protocol (PLCP) preamble and a PLCP header. t_{SIFS} is the short inter-frame space (SIFS) duration time and L_{ACK} is the ACK frame size. $L_{MSDU,l}$ means the lth MSDU size. When the CF-Poll frame is not piggybacked onto the data frame, the maximum delay to transmit the data frame in a QSTA is

$$\begin{aligned}\delta_{npb} &= 2N_i \times t_{PLCP} + (2N_i - 1)\, t_{SIFS} \\ &\quad + \frac{N_i \cdot L_{ACK}}{R_j} + \frac{L_{CF\_Poll}}{R_{CF\_Poll}} + \sum_{l=1}^{N_i-1} \frac{L_{MSDU,l}}{R_j},\end{aligned} \tag{5}$$

where L_{CF_Poll} is the CF-Poll frame size. We define a delay efficiency as the maximum delay difference between the piggyback scheme and non piggyback scheme as follows:

$$\begin{aligned}\Delta &= \delta_{pb} - \delta_{npb} \\ &= \left(\frac{1}{R_{CF\_Poll}} - \frac{1}{R_j}\right) L_{MSDU,1} - \frac{L_{CF\_Poll}}{R_{CF\_Poll}}.\end{aligned} \tag{6}$$

The total size of the MSDU is not changed even though the piggyback scheme is enabled because the granted time is informed by TXOP limit field in QoS control field when the CF-Poll frame is piggybacked. The pseudo code about the proposed scheme is as follows: First, a QAP selects the appropriate data rate to transmit a CF-Poll frame. Then, it calculates the delay efficiency using Eq. (6). The piggyback scheme is disabled when the delay efficiency is a positive value which means that the transmission time of the data frame with the CF-Poll frame is longer than that of the normal data frame and the CF-Poll frame. If it is negative, the piggyback scheme is enabled.

Table 1 Simulation parameters.

Parameter	Value
PIFS (μsec)	25
SIFS (μsec)	16
PLCP preamble and PLCP header (μsec)	20

Table 2 Traffic model parameters.

Service type	Video streaming	Voice
Frame size (bytes)	17,280	160
Frame inter-arrival time (msec)	100	20
Activity	CBR	Exponential dist.
Service interval (msec)	100	20

3. Simulation Models

To evaluate the effect of piggyback problem at low physical transmission rate and the performance of the proposed piggyback scheme, we performed the simulation using OPNET. We set up the network model which consists of one QAP, one server and the varied number of QSTAs from 35(voice service users are 30, video streaming service users are 5, and total traffic load is 18.98%) to 115(voice service users are 110, video streaming service users are 5, and traffic load is 27.3%). We fixed the physical transmission rate of all QSTAs to 54 Mbps except for one QSTA which uses the voice service. The allowable physical transmission rate are 6, 9, 12, 18, 24, 36, 48, and 54 Mbps since we consider IEEE 802.11g. Table 1 describes the simulation parameters [6]. For the voice traffic model, we assume that the voice codec is the pulse code modulation (PCM) and the voice activity factor is 0.65. The video streaming traffic is generated with CBR at 10 frames per second. The frame size is 17280 bytes (128 × 120 pixels). Therefore, the data rate of video streaming traffic is 1.35 Mbps. Table 2 describes parameters used in the service traffics model. The voice service frame can be transmitted in one MSDU, while the video streaming service frame is fragmented into 8 MSDUs in the MAC protocol layer since the maximum allowable MSDU size is 2324 bytes in IEEE 802.11e.

4. Performance Evaluation

We evaluated the effect of the piggyback problem in terms of average frame transmission delay and channel utilization. We varied the physical transmission rate for one voice user and normalized traffic load in a QBSS. In Fig. 1, the horizontal axis means the physical transmission rate of the QSTA which uses a voice service and the vertical axis is the average transmission delay of a QSTA which supports the video streaming. The lowest average frame transmission delay is 9.6 msec when the CF-Poll frame is piggybacked and the physical transmission rate is 54 Mbps. However, it increases as physical transmission rate decreases. Finally, it reaches to 15.2 msec when the physical transmission rate

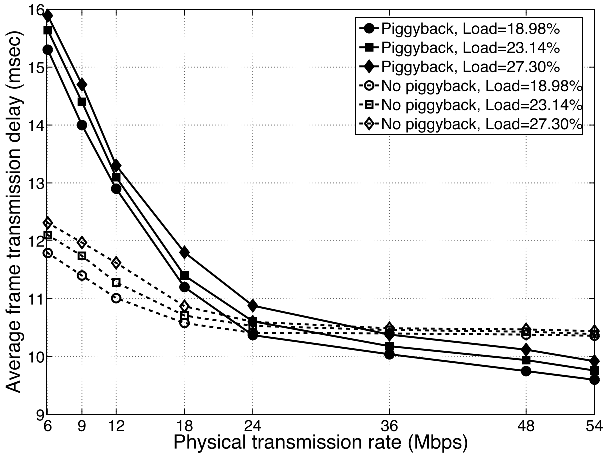

Fig. 1 Average frame transmission delay of a QSTA to support the video streaming service.

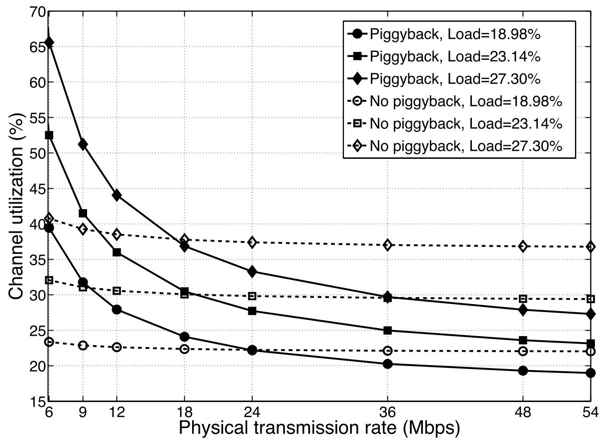

Fig. 2 Channel utilization of the total service traffic.

of the QSTA is 6 Mbps. Comparing average frame transmission delay with and without the piggyback scheme, it can be seen that the piggyback scheme has the bad influence on frame transmission delay when there is at least one QSTA with low physical transmission rate in a QBSS. For example, if the piggyback scheme is used, the average frame transmission delay of the video streaming data is 15.2 msec when the transmission rate of any QSTA is 6 Mbps and traffic load is about 19%. However, it is about 11.8 msec when the piggyback scheme is not used. Therefore, if any QSTA has low physical transmission rate, it influences the average frame transmission delay for other QSTAs. However, average frame transmission delay is little bit increased as traffic load increases. We found that the piggyback problem is one of major effects of frame transmission delay in HCCA. We also evaluated channel utilization with and without the piggyback scheme in Fig. 2. The channel utilization means the proportion of total frame transmission time to the superframe length. If the piggyback scheme is enabled, all QSTAs use channel resource about 65% when only one QSTA has 6 Mbps and other QSTAs have 54 Mbps. However, the allocated channel resources with the same traffic load is reduced to 40% if the piggyback scheme is disabled. Therefore, we can save channel resource about 25% without any other system or network changes except the piggyback option whenever any QSTA has low physical transmission rate. If the usage rule of piggyback scheme is well determined, we can get more channel efficiency and reduce frame transmission time. Figure 3 presents the average frame transmission delay and the channel utilization when the proposed scheme is used with the same traffic load in Fig. 1 and Fig. 2. We also found that the proposed scheme improved the delay performance and the channel utilization about 24% and 25%, respectively. Furthermore, the QoS of application services will increase due to the reduced delay variation of service traffics for all QSTAs.

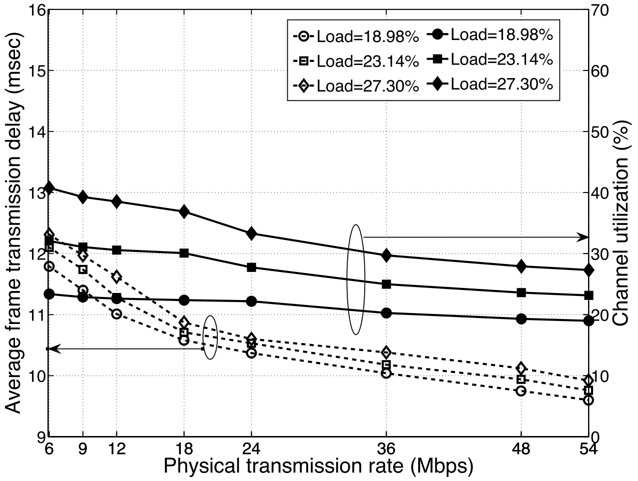

Fig. 3 Average frame transmission delay and channel utilization for the proposed delay-based piggyback algorithm.

5. Conclusion

In a multi-rate supported network, the piggyback of control frame degrades network performance with respect to transmission delay and channel utilization when any station has low physical transmission rate. We defined this problem as a piggyback problem at low physical transmission rate. To solve this problem, we calculated the delay efficiency of piggyback scheme and proposed the transmission delay-based piggyback scheme. In the simulation results, we found that the piggyback problem was one of major effects of frame transmission delay and channel efficiency in HCCA. The proposed scheme shows superior performance in terms of delay performance and channel efficiency.

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