# Delay-based Piggyback Scheme in Multi-Rate Supported Network

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## Abstract

IEEE 802.11e has two different access mechanisms to differentiate the channel access opportunity and uses a control frame piggyback mechanism to increase the channel efficiency. However, the piggyback mechanism may cause the decrease of the channel efficiency and the increase of the frame transmission delay in the distributed access network if the station has the low transmission rate and the control frame presents the global control information such as the channel reservation time. In this paper, we modeled HCCA mechanism using OPNET. And, we propose the delay-based piggyback scheme which decides to use the piggyback for a control frame based on the delay efficiency.

## 1. Introduction

IEEE 802.11 WLAN is being accepted widely and rapidly for many different environments [1]. WLAN supports 54Mbps using OFDM in IEEE 802.11a/g and provides eight different transmission rates ranging from 6 to 54Mbps [2]. The higher data rates are achieved by adopting more efficient modulation scheme and coding technique. Therefore, each station (STA) has to select the most appropriate transmission rate according to the wireless channel condition in order to maximize its throughput.

An auto rate fallback (ARF) and a receiver based auto rate (RBAR) are the link adaptation technique to select the appropriate transmission rate in IEEE 802.11 [3], [4]. In ARF [3], a STA selects the lowest transmission rate after two consecutive retransmission and increase the transmission rate after ten successive successful transmissions. RBAR uses the channel feedback strategy [4]. The receiving STA estimates the channel quality and communicates it to the transmitting STA on a per-packet basis during the RTS/CTS handshake. However, the throughput of STAs transmitting at a higher data rate dramatically degrades below the same level as that of STAs transmitting at a lower data rate. As a STA which has low transmission rate uses the medium for a long time to transmit a packet, it penalizes other STAs that use the higher transmission rate. It is anomaly phenomenon in IEEE 802.11 WLAN [5]. And several papers are published to solve this problem [6], [7].

The similar phenomenon occurs when the piggyback scheme is used in HCF controlled channel access (HCCA). HCCA is standardized to support the reservation based QoS for the delay sensitive services such as VoIP, multimedia streaming service. IEEE 802.11e specification provides many types of QoS data frames and their associated usage rules to increase the channel [8]. For example, a CF-Poll frame is used to grant a channel bandwidth to a QoS station (QSTA) and is piggybacked in a data frame to increase the channel efficiency. It may, however, not only increase the complexity but also decrease the channel efficiency.

All QSTAs in QoS basic service set (QBSS) inherently obey the network allocation vector (NAV) rules of hybrid coordination function (HCF) to avoid the channel collision. Since each frame transmitted by the hybrid coordinator (HC) or by QSTAs contains its transmission time, all QSTAs in QBSS set their NAV value to protect expected subsequent frames. Therefore, a CF-Poll frame or a QoS-Data frame, which piggybacks a CF-Poll frame, should be transmitted through a minimum transmission rate among the allowable transmission rates of all QSTAs. If any QSTA uses low physical transmissions rate due to the consequent retransmission or the channel noise, QAP must decrease the transmission rate of the data frame including the CF-Poll frame, until it equals the QSTA’s transmission rate. Therefore, a transmission time for the CF-Poll, which is piggybacked in a data frame is increased. This can cause the decrease of the channel efficiency and the increase of the frame transmission delay for other traffic streams (TSs). In this paper, we define this as “CF-Poll piggyback problem at low physical transmission rate” and evaluate the effect of this problem. We also proposed the delay-based piggyback scheme to optimize the usage rule of the piggyback scheme.

The remainder of the paper is organized as follows. In Section II, we give an overview of the parameterized QoS scheme in IEEE 802.11e. Our implemented HCCA model using OPNET is described in Section III and the piggyback problem is described in section IV. Section V describes the proposed delay-based piggyback scheme. The simulation model and the simulation results are presented in Section VI and Section VII. Finally, we will conclude our paper.

## 2. IEEE 802.11e HCCA Overview

In IEEE 802.11e, HCCA supports the parameterized QoS using the polling access method. In order to be included in the polling list of HC, a QSTA must issue a QoS reservation by means of sending special QoS management action frames which are traffic specification (TSPEC). HC administrates admission of TS of a QSTA using admission control unit (ACU) and schedules the TS of a QSTA.

### Resource Management Unit

The resource management unit is consists of two components: the reference packet scheduler, ACU. The reference packet scheduler uses the mandatory set of TSPEC parameters to generate a schedule. The schedule for an admitted stream is calculated in two steps. First step is the calculation of service interval (SI) using (1).

$$SI = \frac{T}{\left\lceil T / \min_{0 \le i \le n} \{SI_i\} \right\rceil} \tag{1}$$

Where $T$ means the beacon interval, $SI_i$ means the service interval for $i^{th}$ traffic stream. $n$ means the number of QSTAs in a service set. Second step is the calculation of a transmission opportunity (TXOP) duration for the given $SI$. To calculate the TXOP, the scheduler calculates (2) for the number of MSDUs ($N_i$) that arrive at the mean data rate during $SI$.

$$N_i = \left\lceil \frac{SI \times \rho_i}{L_i} \right\rceil \tag{2}$$

where $\rho_i$ means the mean data rate, $L_i$ is the nominal MSDU size for $i^{th}$ traffic stream. Then, the scheduler calculates the TXOP duration time ($TXOP_i$) for an $i^{th}$ traffic stream using $N_i$ as follows:

$$TXOP_i = \max\left( \frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O \right) \tag{3}$$

where $R_i$ is the physical transmission rate, $M$ means the maximum allowable size of MSDU, and $O$ means overheads in time units which is composed to inter frame space (IFS), QoS-ACK frame transmission time. ACU is used to determine whether or not admits new TS according to TSPEC which is delivered from a QSTA. When new TS requests an admission, ACU is done in three steps. First, ACU calculates the number of MSDUs that arrived at the mean data rate during $SI$ using (2). Second, ACU calculates the TXOP duration that needs to be allocated for new TS using (3). Finally, ACU determines that new TS can be admitted when the following inequality is satisfied:

$$\frac{TXOP_{k+1}}{SI} + \sum_{i=1}^{k} \frac{TXOP_i}{SI} \le \frac{T - T_{CP}}{T} \tag{4}$$

where $k$ is the number of existing traffic streams and $k+1$ is used as index for the newly arriving traffic stream. $T_{CP}$ means the time for contention period which is used for EDCA traffic.

### HCCA

The polling access method of HCCA is similar to this of point coordination function (PCF), but HCCA has two major differences from PCF. Most important is that the HCF frame exchange sequences may be used among QSTAs during both contention free period (CFP) and contention period (CP). Another significant difference is that HC grants a QSTA a polled TXOP with duration specified in a CF-Poll frame. In order to support the parameterized QoS in the HCCA, a QSTA shall negotiate with the HC using TSPEC as shown in Figure 1, which describes characteristics of traffic streams, such as data rate, packet size, delay, and service interval. Numbers mean the number of bytes in Figure 1. The HC has higher medium access priority than QSTAs. The HC gains control of the channel after sensing that the channel is idle for the PCF inter frame space (PIFS) period. After grabbing the channel, the HC polls a QSTA on its polling list. Upon receiving a poll, the polled QSTA either responds with a QoS-Null frame, if it has no data to send, or responds with a QoS-Data+QoS-ACK frame, if it has data to send.

| | | | | |
|---|---|---|---|---|
| Elements ID (1) | Length (1) | TS info (2) | Nominal size MSDU (2) | Maximum MSDU size (2) |
| Minimum Service Interval (4) | Maximum Service Interval (4) | Inactivity Interval (4) | Minimum Data Rate (4) | Mean Data Rate (4) |
| Maximum Burst Size (4) | Minimum PHY Rate (4) | Peak Data Rate (4) | Delay Bound (4) | Surplus Bandwidth Allowed (4) |

Figure 1: Traffic Specification elements format

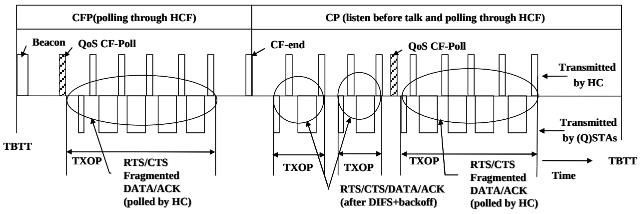

Figure 2: The procedure to transmit the service traffic in HCCA

The polled QSTA may perform several packet exchange sequences during specified TXOP. At the end of the TXOP, the HC either sends a QoS-Poll to the next station on its polling list after a PIFS interval, or releases the channel if there is no more station to poll. Figure 2 presents the procedure to transmit the service traffic in a HCCA. In this way, the HC can utilize the higher channel access priority. It coordinates QSTAs to provide limited-duration controlled access phase (CAP) for contention-free transfer of QoS data through the use of the HCCA TXOPs. As shown in Figure 2, CAP is a time period when the HC maintains control of the medium.

## 3. An OPNET HCCA Model

We used OPNET to develop a simulation model for HCCA. Our implemented model supports the polling mechanism, TSPEC negotiation mechanism and the control-frame piggyback mechanism. We also implement a simple resource allocation unit and an admission control unit according to the specification [8] and use the configuration and system parameters shown in Table 1. Figure 3 is the reference network model of our implemented model. The client-server model is assumed.

As shown in Figure 4, a source model has two roles: one is the service flow generation and the other is the frame transmission delay measurement. If the source model wants to send any packet, it generates the flow generation request statistic and the traffic characteristic table which is based on the traffic specification elements. When HCCA_buffer model receives the statistic interrupt from the source, it gathers the traffic information from the traffic characteristic table and sends a TSPEC_negotiation packet to a QAP. QAP calculates the required channel allocation time using (3) and determines whether or not admits traffic stream according to required channel allocation time using (4). Then, it sends an admission state packet to the QSTA which has sent the TSPEC_negotiation packet. If HCCA_buffer model receives the admission state packet, it sends the admission state packet to the source. When the negotiation procedure is completed, the source generates the data packets based on the traffic characteristic table and sends them to the HCCA_buffer model.

| HCCA parameter | Values |
|---|---|
| Transmission rate (Mbps) | 6, 9, 12, 18, 24, 36, 48, 54 |
| Simulation time | 5 minutes |
| Frequency band | 2.402 GHz |
| Multiplexing | OFDM |
| Beacon interval | 0.5 sec |
| Supported Application | Voice and Video |
| Processing Delay | 0 msec |

Table 1: System Parameters

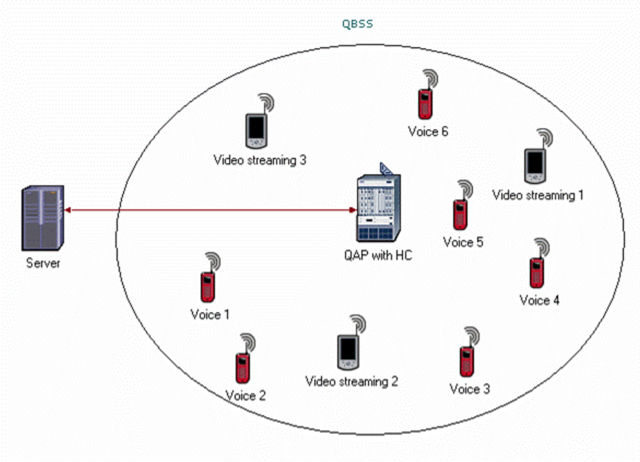

Figure 3: Reference network model

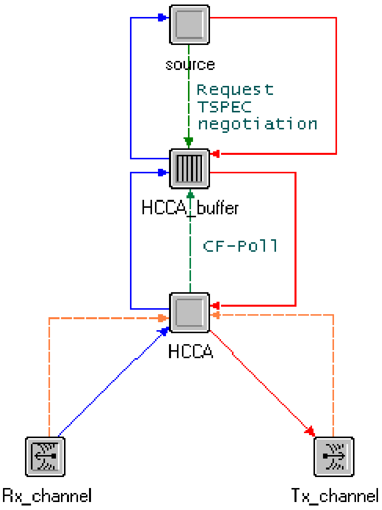

Figure 4: QSTA node model

When HCCA_buffer model receives the data packet from the source model, it inserts them to a queue. When HCCA_buffer receives the polling packet from the QAP, it calculates the number of packet to send during the polling time and extracts the data packets from the queue to transmit. Whenever HCCA receives a packet from the channel, it performs two different actions: First, the data packet recognition is executed to decide whether the received packet belongs to QSTA. If the ID of the received packet is the same as QSTA’s ID, HCCA delivers this packet to the upper layer.

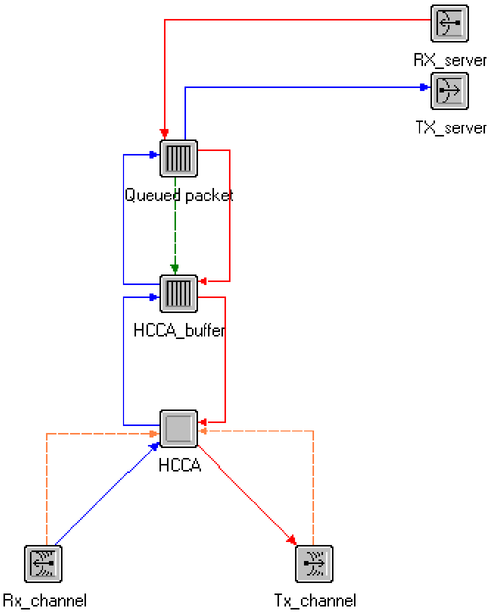

Figure 5: QAP node model

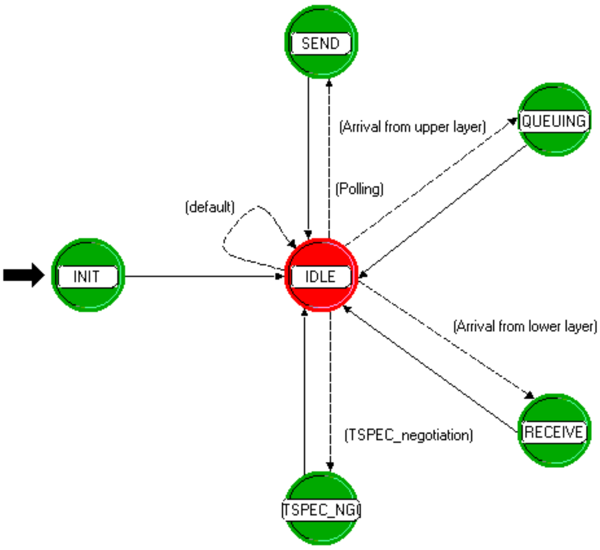

Figure 6: HCCA_buffer process model

The second is the polling packet recognition. If either the received packet is the CF-Poll packet or the piggyback option in the header is enabled, HCCA checks the CF-Poll’s ID. If CF-Poll’s ID equals to the QSTA's ID, it notifies the upper layer to transmit the queued packet. The actions of each state are as follows:

**INIT state**: In this state, the state variables used in the entire process are initialized.

**IDLE state**: The machine enters an IDLE state and waits for an incoming event. First, when any event is happen, this state interprets the event type in the exit. If the event type is the

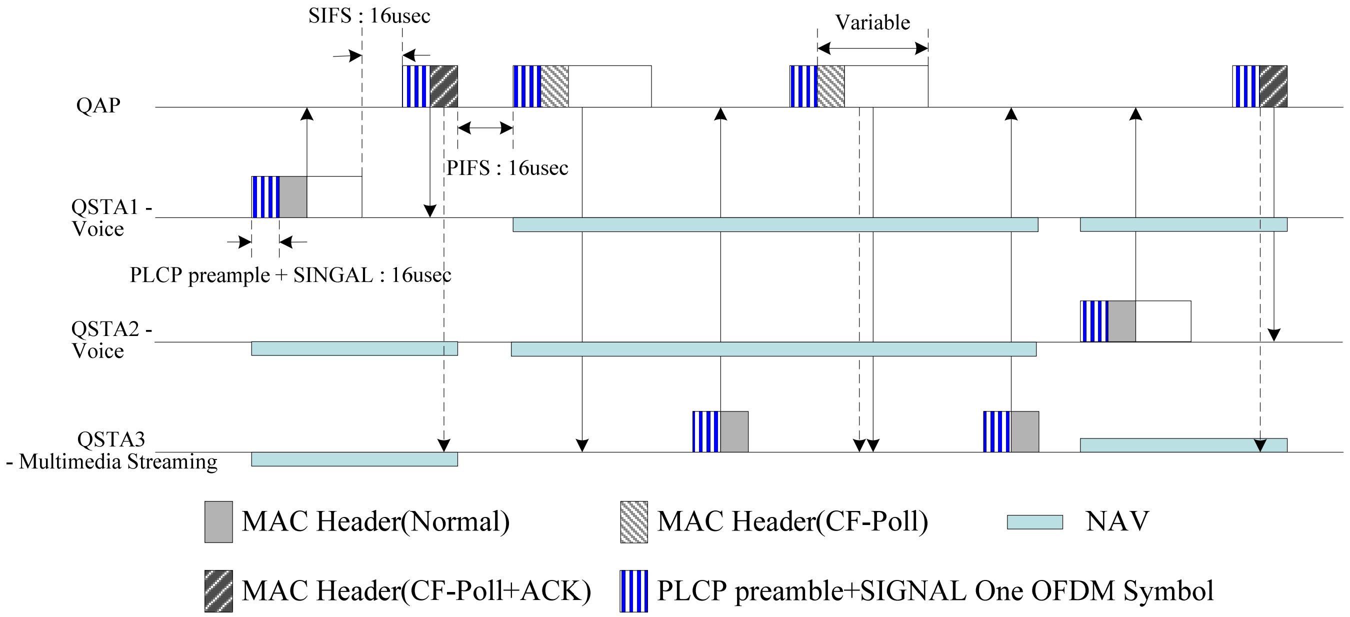

Figure 7: The MAC frame transmission procedure when the CF-Poll frame is piggybacked in a data frame using HCCA

statistic event and the statistic event is sent from the upper layer in QSTA or the TSPEC_negotiation packet is arrived from the lower layer in QAP, TSPEC_negotiation event is triggered and transit to TSPEC_NGO state. Else, polling condition is satisfied when the statistic event is sent from the lower layer in QSTA or when the clock tick event based on the self-interrupt is occurred in QAP. If the event type is the stream event, this state transit to QUEUING state or RECEIVE state according to the direction of the stream event.

**TSPEC_NGO state**: When the statistic event from the upper layer, this state gather the traffic information from the traffic characteristic table at the source. Then, it generates the TSPEC_negotiation packet according to the traffic characteristic table and sends to QAP. In QAP, it calculates the TXOP time and the polling timer to adjust CF-Poll sending rate. It also determines whether or not admits the requested traffic stream.

**SEND state**: When a statistic event from the lower layer is occurred, it gathers the TXOP information from the HCCA model and transmit the packets to the lower layer during to the allocated time.

**QUEUING state**: When a data packet from the upper layer, the state machine transits this state to queues the data packet.

**RECEIVE state**: When a data packet from the lower layer, the state machine transits this state to send the packet to the upper layer.

## 4. Case Study: Piggyback Problem

All STAs inherently obey the NAV rules of the HCF because each frame transmitted under HCF by the HC or by a QSTA contains a duration value chosen to cause STAs in QBSS to set their NAVs to protect the expected subsequent frames. Therefore, CF-Poll packet and QoS data packet which is piggybacked CF-Poll shall be sent through the minimum data rate of the allowable data rate for all QSTAs. The CF-Poll is able to piggyback on a QoS data frame which is sent from a QAP to a QSTA to increase the channel efficiency. Figure 7 illustrates the example which the CF-Poll piggybacks in a QoS data frame. The dotted line means that the frame must be listened by all QSTAs. The solid line means that the frame is listened by the target QSTA. First, QAP allocates QSTA1 the grant to grab the channel. QSTA1 sends the QoS data frame. And then, The QAP sends the QSTA3 on its polling list the CF-Poll when QSTA1 finishes packet exchange sequences during its TXOP duration. The CF-Poll is piggybacked in QoS-ACK frame. Thus, all QSTAs in QBSS must listen to the CF-Poll which is piggybacked in QoS-ACK frame and set their NAVs. However, it may decrease the channel efficiency when any QSTA associated in QBSS uses the low physical transmission rate due to the deep channel fading. The CF-Poll piggyback also increases the delay for all QSTA and the packet loss. For example, in Figure 7, the last frame sent from QAP to QSTA3 must be listened by all QSTAs since the CF-Poll is piggybacked in the last frame to provide the grant to grab the channel. Therefore, the transmission time may be increased according to the minimum physical transmission rate of the allowable data rate for all QSTAs.
It seems to the abnormally phenomenon in IEEE 802.11 legacy system. In this paper, we define this problem to the piggyback problem. In this paper, we evaluate the piggyback problem according to the service traffic load and the physical transmission rate of a QSTA which uses low physical transmission rate due to the consecutive retransmission or the channel noise and propose the delay-based piggyback algorithm using delay difference.

## 5. Proposed Delay-based Piggyback Scheme

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

1) Each QSTAs using HCCA has just one TS and always generates MAC service data units (MSDUs) according to the mean data rate during SI.

2) Service packets for TS are arrived at queue for HCCA from the upper layer when SI is started.
3) The characteristic of TS for HCCA has a constant bit rate (CBR).

To consider the multiple data rate, Let $\gamma_i$ is the set of the allowable physical transmission rate for $i^{th}$ traffic stream

$$\gamma_i = \left\{R_1, R_2, R_3, \cdots, R_j\right\}, 1 \le j \le M, \qquad (5)$$

where $R_j$ means index for allowable physical transmission rate in $i^{th}$ traffic stream and $R_M$ means the maximum physical transmission. If QSTAs support IEEE 802.11a/g, $R_M$ is 54Mbps. The physical transmission rate to send the CF-Poll frame is

$$R_{CF-Poll} = \min_{1 \le i \le k}\left\{\max_{\gamma_i}\left(R_j\right)\right\}, \qquad (6)$$

where $k$ means the number of QSTAs in QBSS. When the CF-Poll frame is piggybacked in a data frame, the maximum delay to transmit the queued packet in one QSTA is

$$\delta_{pb} = 2N_i \times t_{PLCP} + \left(2N_i - 1\right)t_{SIFS} + \frac{N_i \cdot L_{ACK}}{R_j} + \frac{L_{MSDU,1}}{R_{CF-Poll}} + \sum_{l=2}^{N_i-1}\frac{L_{MSDU,l}}{R_i}, \qquad (7)$$

where $t_{PLCP}$ is the physical layer convergence protocol (PLCP) preamble time plus PLCP header time, respectively. And $t_{SIFS}$ is the short IFS (SIFS) duration time and $L_{ACK}$ is ACK frame size. $L_{MSDU,l}$ means the $l^{th}$ MSDU size. When the CF-Poll frame is not piggybacked in a data frame, the maximum delay to transmit the queued packet in one QSTA is

$$\delta_{npb} = 2N_i \times t_{PLCP} + \left(2N_i - 1\right)t_{SIFS} + \frac{N_i \cdot L_{ACK}}{R_i} + \frac{L_{CF-Poll}}{R_{CF-Poll}} + \sum_{l=1}^{N_i-1}\frac{L_{MSDU,l}}{R_i} \qquad (8)$$

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

$$\Delta = \delta_{pb} - \delta_{npb} = \left(\frac{1}{R_j} - \frac{1}{R_{CF-Poll}}\right)L_{MSDU,1} - \frac{L_{CF-Poll}}{R_{CF-Poll}} \qquad (9)$$

The pseudo code about the proposed scheme is as follows:

```
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
```

First, the QAP selects the appropriate data rate to transmit the CF-Poll frame. Then, it calculates the delay efficiency using Eq. (9). If the delay efficiency has the positive value which means that the transmission time of the piggyback CF-Poll frame is longer than that of the non piggyback CF-Poll, the CF-poll piggyback is disabled. On the contrary, the CF-Poll piggyback is enabled.

| Parameter | Value |
|---|---|
| UDP/IP Header (bytes) | 28 |
| PIFS (usec) | 25 |
| SIFS (usec) | 16 |
| PLCP Preamble (usec) | 16(OFDM), 144(FHSS) |
| PLCP Header (usec) | 4 (OFDM), 48(FHSS) |
| Maximum Transmission Rate | 54 |

Table 2: Simulation Parameters

| Service type | Video | Voice |
|---|---|---|
| Frame size(bytes) | 17280 | 160 |
| Frame inter-arrival time (msec) | 100 | 20 |
| Activity | CBR | Exponential dist. (0.65:0.35) |
| Direction | Unidirectional | Bidirectional |
| Service interval (msec) | 100 | 20 |

Table 3: Service Traffic Model Parameters

## 6. Simulation Model

To evaluate the effect of the piggyback problem at the low physical transmission rate and the performance of the delay-based piggyback scheme, we performed the simulation using our implemented model. 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, a total traffic load is 18.98%) to 115(voice service users are 110, video streaming service users are 5, traffic load is 27.3%) as Figure 3. We fixed the physical transmission rate of all QSTAs to 54Mbps except for one QSTA which uses the voice service. The QAP and QSTAs support HCCA and TSPEC negotiation and OFDM. Therefore, allowable physical transmission rates are 6, 9, 12, 18, 24, 36, 48, and 54 Mbps. Table 2 describes the simulation parameters [8] and Table 3 describes the parameters used in the service traffics model. We consider the voice and the video streaming for service traffic models. For the voice traffic model, we assume that a voice codec is the pulse code modulation (PCM) and the voice activity factor is 0.65. The video streaming traffic is generated by the CBR type with 10 frames per second. The frame size is 17280 bytes (128X120 pixels). Therefore, the data rate of the video streaming traffic is 1.35 Mbps. The voice service frame can be transmitted in one MSDU, while the video streaming service frame is fragmented into 8 MSDUs in MAC protocol layer since the maximum allowable MSDU size is 2324 bytes.

## 7. Performance Evaluation

We evaluate the effect of the piggyback problem in terms of the average frame transmission delay according to the physical transmission rate and the normalized traffic load. In Figure 8 and Figure 9, the horizontal axis means the physical transmission

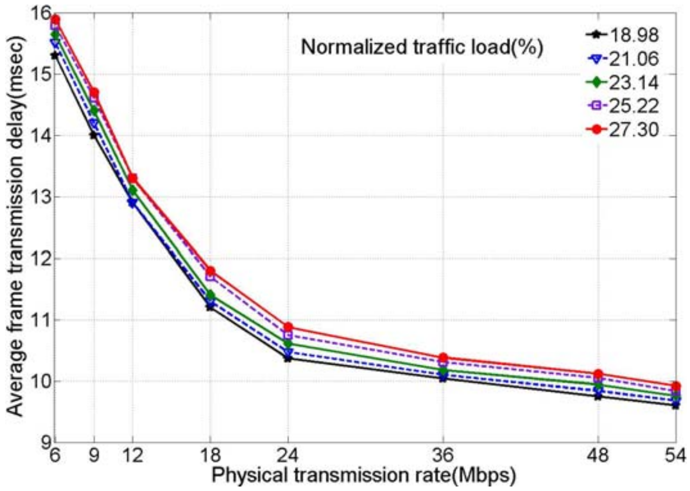

Figure 8: The average frame transmission delay of a QSTA to support the video streaming service when the CF-Poll frame is piggybacked in a data frame.

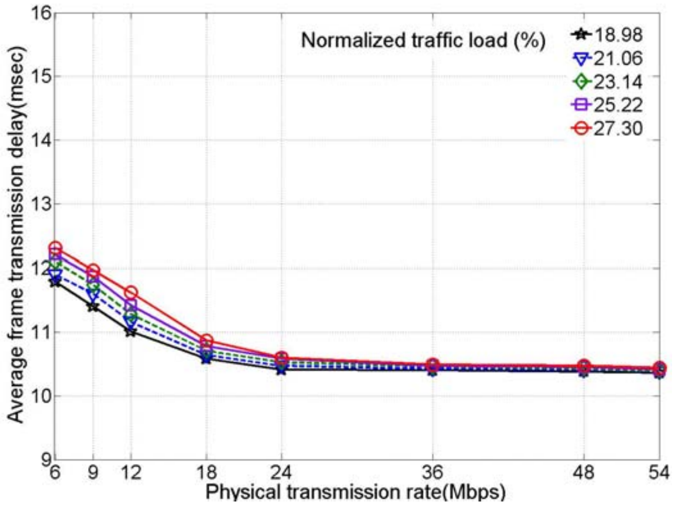

Figure 9: The average frame transmission delay of a QSTA to support the video streaming service when the CF-Poll frame is not piggybacked in a data frame

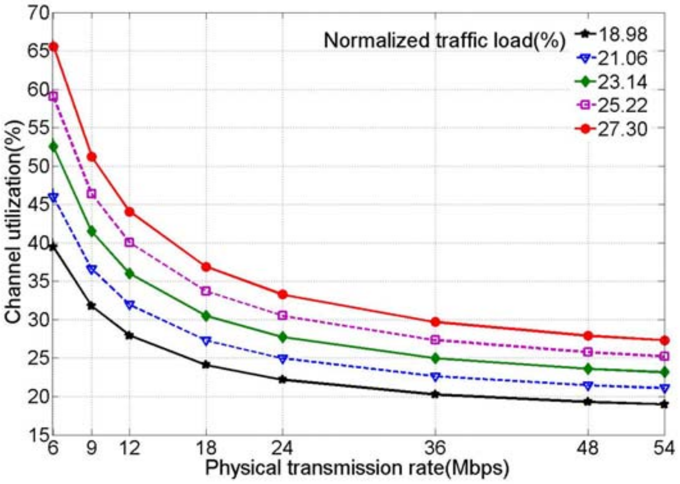

Figure 10: The channel utilization of the total service traffic when the CF-Poll frame is piggybacked in a data frame

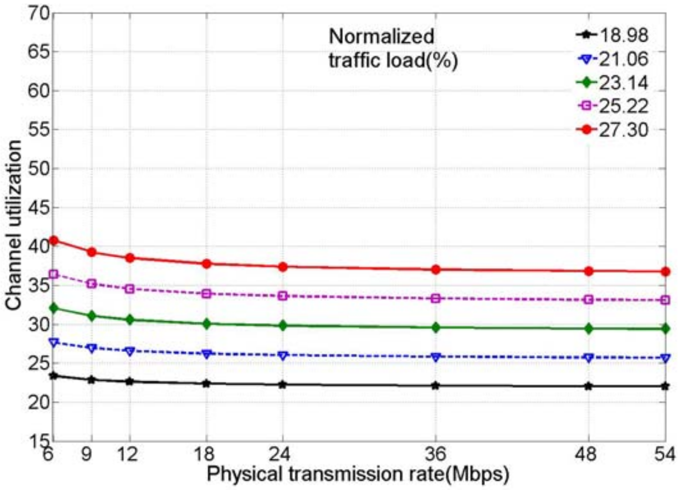

Figure 11: The channel utilization of the total service traffic when the CF-Poll frame is not piggybacked in a data frame

rate of QSTA which uses the voice service and the vertical axis is the average transmission delay of QSTA which supports the video streaming. In Figure 8, the lowest average frame transmission delay is 9.6 msec when the CF-Poll frame is piggybacked. However, it increases as the physical transmission rate decreases. Finally, it is reached to 15.2 msec when the physical transmission rate of a QSTA is 6 Mbps. To compare the average frame transmission delay with and without the piggyback scheme, we use to same simulation environment except the CF-Poll piggyback option in Figure 9. It can be seen that CF-Poll piggyback has a bad influence on the frame transmission delay when there is at least one QSTA with low physical transmission rate. For example, if piggyback is used, the average frame transmission delay of the video streaming data is 15.2 msec when the data rate of any QSTA is 6 Mbps and the traffic load is about 19% in Figure 8. However, the average frame transmission delay is about 11.8 msec when the piggyback is not used. Therefore, if any QSTA has low physical transmission rate, it influences the average frame transmission delay for all QSTAs. However, the average frame transmission delay is little bit increased as the traffic load increases. We find that the piggyback problem is one of major effects of the transmission delay in HCCA.

We also evaluate the channel utilization with and without the CF-Poll frame piggyback in Figure 10 and Figure 11, respectively. The channel utilization means the proportion of the total frame transmission time to the superframe length. If the CF-Poll frame piggyback is enabled, all QSTAs use the channel resource about 65% when only one QSTA has 6Mbps and other QSTAs have 54Mbps in Figure 10. However, the channel utilization is reduced to 40% in Figure 11 if the CF-Poll frame piggyback is disabled. Therefore, we can save the channel resource about 25% without any other system or network changes except the CF-Poll piggyback option when one QSTA has low physical transmission. If the usage rule of the CF-Poll piggyback scheme is well determined, we can get more channel efficiency and the reduced transmission time. To evaluate the

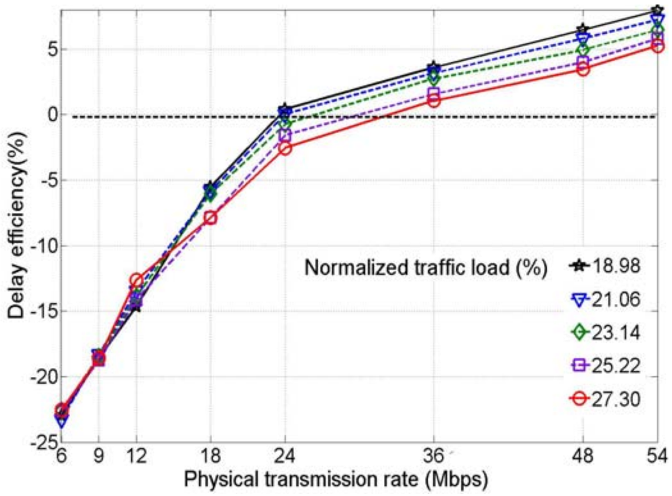

Figure 12: The delay efficiency with respect to the average frame transmission delay with and without CF-Poll frame piggyback.

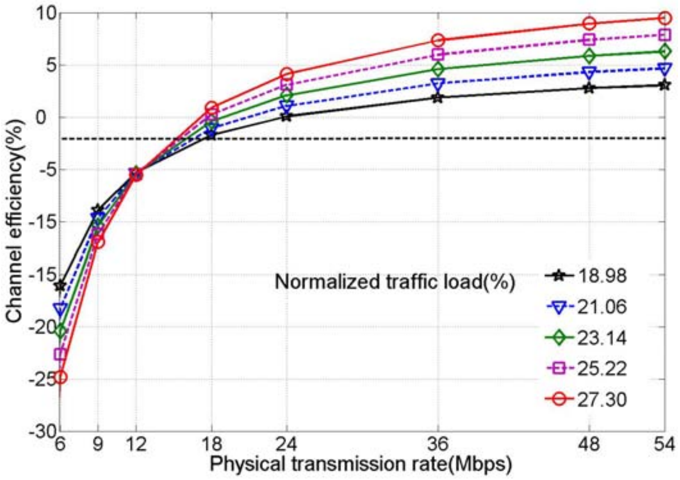

Figure 13: The channel efficiency with respect to the channel utilization with and without CF-Poll frame piggyback.

efficiency of the CF-Poll piggyback scheme with respect to the frame delay and the channel utilization, we define the delay efficiency and the channel efficiency as follows:

$$\varepsilon_{delay} = \left(\delta_{npb} - \delta_{pb}\right) / \delta_{pb}, \tag{10}$$

$$\varepsilon_{channel} = \eta_{npb} - \eta_{pb}, \tag{11}$$

where $\eta_{pb}$ and $\eta_{npb}$ means the channel utilization with and without the piggyback, respectively. We evaluate the delay efficiency versus the traffic load and the minimum physical transmission rate in Figure 12. The negative value means that the CF-Poll piggyback scheme is inefficient. In the meanwhile, the positive value means that the CF-Poll piggyback scheme is efficient. In this scenario, a cross point of the delay efficiency for the CF-Poll piggyback scheme is between 24 and 36Mbps depending on the traffic load. When the CF-Poll piggyback scheme is used, the delay efficiency is increased about 5% compared with it when CF-Poll piggyback scheme is not used.

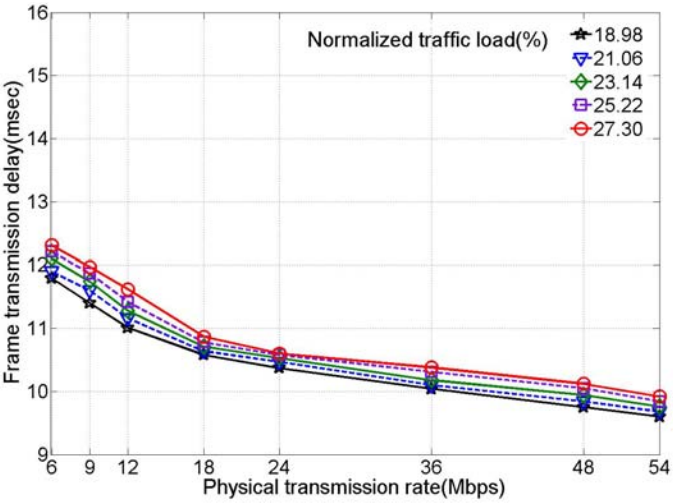

Figure 14: The average frame transmission delay for the proposed delay-based piggyback scheme

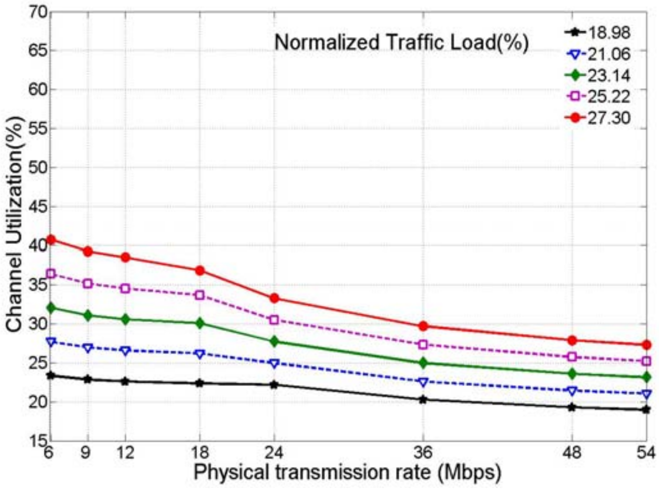

Figure 15: The average frame transmission delay for the proposed delay-based piggyback scheme

However, the delay efficiency is decreased as the physical transmission rate decreases. Finally, it is decreased about -23%. We also find the similar results in terms of the channel efficiency in Figure 13. The QSTA using the CF-Poll piggyback will consume the channel resource 25% more to send the same data packet even though there are only one QSTA with low physical transmission rate. In the meanwhile, if all QSTAs using the piggyback scheme have high transmission rate, the QSTA may save the channel resource about 10% maximally. Figure 14 and Figure 15 present the average frame transmission delay and the channel utilization when the proposed delay-based piggyback algorithm is used. In the simulation results, the proposed scheme reduces the frame transmission delay at the same traffic load in Figure 8 and Figure 9. We also show that the proposed scheme improves the delay performance and the channel efficiency about 24% and 25%, respectively. Furthermore, the QoS of the application service will increase due to the reduced delay variation of the service traffic for all QSTAs.

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## Conclusion

IEEE 802.11 WLAN is one of the most widely deployed wireless network technologies in the world, today. The QoS support which is one of the weaknesses is almost solved in IEEE 802.11e. Especially, HCCA supports the reservation based QoS for the delay sensitive service. In this paper, we implements HCCA model using OPNET. Our implemented model has the basic HCCA mechanism which consists of the polling mechanism, the TSPEC negotiation mechanism and the simple resource allocation mechanism. However, these are the mandatory mechanism to support the reservation based QoS. For the case study, we handled the CF-Poll piggyback problem at low physical transmission rate. This problem is easily happened when any station has the low transmission rate and the control frame presents the global control information in the multi-rate support network. In this paper, we evaluate the effects of this problem with respect to the average frame transmission delay and the channel utilization. We also propose the delay-based piggyback scheme to mitigate the piggyback problem. In the simulation results, we found that the piggyback decrease the channel efficiency and increase the frame transmission delay even the presence of one station with low physical transmission rate. However, the channel efficiency and the delay efficiency are increased as the physical transmission rate increases. Therefore, if the usage rule of the piggyback is well determined, we increase the channel efficiency and reduce the frame transmission delay. The proposed delay-based piggyback scheme uses the delay and channel efficiency shows the superior performance in terms of the delay performance and the channel efficiency.

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