A Packet Scheduling Scheme for Audio-Video Transmission with IEEE 802.11e HCCA and its Application-Level QoS Assessment

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Abstract

This paper proposes a new scheduling scheme for audio-video transmission with HCCA of the IEEE 802.11e MAC protocol. In the proposed scheduling scheme, the hybrid coordinator (HC) first calculates transmission opportunity (TXOP) duration in a service interval (SI) for each wireless station on the basis of its mean data rate; it then adds additional TXOP for each wireless station which had audio or video packets in its source buffers at the end of the previous TXOP. By simulation, we compare application-level QoS of the reference scheduler in the IEEE 802.11e draft standard and the proposed scheme. Numerical results show that the proposed scheduling scheme outperforms the reference scheduling scheme in video quality and inter-stream media synchronization quality under low traffic conditions.

1. Introduction

The IEEE 802.11 wireless LAN has become a major standard for wireless communication and has been widely used. The IEEE 802.11 MAC protocol includes two access methods: *distributed coordination function (DCF)* and *point coordination function (PCF)* [1]. The DCF is based on *carrier sense multiple access with collision avoidance (CSMA/CA)*, while the PCF is a kind of polling controlled by an *access point (AP)*. These access methods are mainly designed for data transmission and cannot guarantee *quality of service (QoS)*.

The widespread use of multimedia applications over wireless LANs has raised the needs of QoS support in the IEEE 802.11 standard. Therefore, to meet this requirement, the IEEE 802.11 Task Group E (TGe) has introduced an enhancement of the IEEE 802.11 MAC: the *hybrid coordination function (HCF)*. HCF consists of two access methods: *enhanced distributed channel access (EDCA)* and *HCF controlled channel access (HCCA)*. The former enhances the DCF by classifying traffic into a set of priority which has its own medium access parameters. The latter improves the PCF by supporting guaranteed medium access for traffic flows based on their QoS requirements.

In the IEEE 802.11e draft standard, a reference design for an example scheduler has been presented [1]. In this paper, the scheduling scheme is referred to as the *TGe scheme* as in [2]. In the TGe scheme, however, it is inefficient to deliver *variable bit rate (VBR)* traffic since *transmission opportunity (TXOP)* duration for each station in a *service interval (SI)* is calculated on the basis of the mean data rate.

The performance of the HCCA has already been studied by several researchers. In [2], Grilo *et al.* propose a scheduling scheme called estimated transmission times-earliest due date (SETT-EDD). The SETT-EDD allocates TXOP to wireless stations, considering the deadline of each packet as well as the mean data rate. In [3], Ramos *et al.* propose a scheduling scheme where the scheduler polls each station to allocate fixed TXOP duration and then it can perform additional polling if the stations require further allocation. Admission control algorithms to support QoS requirement in the IEEE 802.11e wireless LANs are studied in [4] and [5].

The papers mentioned above mainly focus on MAC-level QoS, which are evaluated in terms of delay, delay jitter, frame loss, and throughput at the MAC layer. However, in multimedia applications, an audio-video flow has strict temporal structure that should be preserved. Therefore, application-level QoS should be examined to evaluate the degree of preservation of the audio-video temporal structure.

This paper proposes a new scheduling scheme for efficient transmission of audio-video traffic in a wireless LAN with the HCCA of the IEEE 802.11e MAC protocol. It focuses on a basic service set (BSS) of an infrastructure wireless LAN. In the scheme, the scheduler first calculates the TXOP duration in an SI for each station on the basis of the mean data rate; it then allocates the remaining duration of the SI to each station which had audio or video packets in its source buffers at the end of the previous TXOP. The *hybrid coordinator (HC)* uses the traffic identifier (TID) of the QoS Control field in the MAC header to distinguish the flow type in the queue. In order to demonstrate the effectiveness of the proposed scheme, this paper compares application-level

QoS of the TGe scheme and the proposed scheme through simulation.

The rest of the paper is organized as follows. Section 2 introduces the TGe scheduling scheme and the proposed scheme. Section 3 specifies simulation conditions, and Section 4 describes simulation results to compare the two kinds of scheduling schemes. Finally, Section 5 concludes this paper.

2. Scheduling Schemes

In this section, we will explain the two kinds of scheduling schemes for HCCA: TGe and the proposed schemes.

2.1. HCCA

Like the PCF, the HCCA provides polled access to the wireless medium. It is controlled by the HC, which is usually located at the AP. In a wireless LAN, the *contention free period (CFP)* and *contention period (CP)* alternate periodically over time, and a combination of CFP and CP forms one superframe that starts with a beacon frame. The PCF can be used for accessing the wireless medium during the CFP only. However, in the HCCA, the HC can start to poll stations at any time. Figure 1 shows an example of the IEEE 802.11e superframe where the HC grants TXOPs in both CFP and CP. In this figure, the *controlled access period (CAP)* means the duration used for the HCCA in the CP.

In this paper we assume that all channel capacity is used for the CFP for simplifying the discussion. In the PCF, a station polled by the *point coordinator (PC)* is allowed to deliver only one *MAC service data unit (MSDU)*. On the other hand, in the HCCA, a station polled by the HC can deliver a burst of data frames within the duration of a TXOP. The duration of the TXOP is computed by the HC on the basis of *traffic specification (TSPEC)*. Main parameters of the TSPEC are the *mean data rate* (ρ) in units of bits per second, *nominal MSDU size (L)* in octets, and *maximum service interval (MSI)* in microseconds. In order for a station to be included in the polling list of the HC, it must issue its TSPEC to HC via a QoS management action frame.

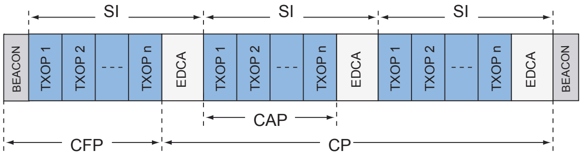

Figure 1. IEEE 802.11e HCCA Channel Access

2.2. TGe Scheme

The TGe scheme is presented in the IEEE 802.11e draft standard [6]. For simplifying the description of the TGe scheme, let us focus on flow i where ρ_i is the mean data rate, L_i is the nominal MSDU size, and R_i is the minimum physical transmission rate of flow i. In the TGe scheme, the HC first calculates the number of MSDUs of flow *i* that arrives at the mean data rate during an SI as

$$N_i = \lceil \frac{SI \times \rho_i}{L_i} \rceil \tag{1}$$

where *SI* is the duration of the service interval. This interval must be shorter than the minimum value of all MSIs for admitted flows and must be a submultiple of the beacon interval. In Eq. (1), we use the ceiling function. The ceiling function of x is defined as the smallest integer greater than or equal to x.

Then, the TXOP duration for flow *i* is computed as

$$TXOP_i = max(\frac{N_i \times L_i}{R_i} + O, \frac{M}{R_i} + O) \tag{2}$$

where M is the maximum size of an MSDU, and *O* is the overhead in time units due to the physical header, MAC header, *inter-frame space (IFS)*, acknowledgment frames, and poll frames.

Owing to the limitation of the capacity during an SI, the number of stations which TXOP can be allocated is limited. Therefore, the TGe scheduler implements admission control to ensure that all admitted flows have adequate TXOPs for their QoS. Admission control decides which flow should be admitted and which flow should be dropped from the polling list. When flow *k+1* issues a QoS reservation, the HC will first check whether the available medium exists or not by the following equation:

$$\frac{TXOP_{k+1}}{SI} + \sum_{i=1}^{k} \frac{TXOP_i}{SI} \leq \frac{T - T_{CP}}{T} \tag{3}$$

where T is the beacon interval, and T_{CP} is the time for the EDCA. If Eq. (3) is satisfied, the HC admits flow *k+1* into its polling list and allocates TXOP to the flow.

2.3. Proposed Scheme

The TGe scheduling algorithm uses the mean data rate to compute the TXOP duration. Therefore, the TGe scheduler allocates a fixed TXOP duration in every SI, and this scheme is suitable for *constant bit rate (CBR)* traffic. However, if stations generate VBR traffic, it cannot use the available HCCA time resource effectively under low traffic conditions.

In this paper, we propose a new scheduling algorithm where the HC scheduler allocates additional TXOP duration to stations for transmission of only audio and video packets after it calculates the TXOP duration based on the mean data rate. That is, priority is given to audio-video flows. When the required TXOP duration is smaller than the available resource, the TXOP duration for audio and video flows is increased until all HCCA remaining time is fully occupied. However, when the sum of TXOP requested from all stations exceeds the duration of an SI, the HC changes its scheduling algorithm to that of the TGe scheduler. We also consider an admission control mechanism similar to the TGe scheme; so no further flows joining the polling list will be admitted if channel capacity is insufficient to allocate TXOP to a new flow.

Let us describe the algorithm of the proposed scheme. First, as usual, the HC computes the TXOP duration of the *i*-th flow on the basis of TSPEC information sent by a station. This calculation is performed in the same way as the TGe scheme as follows:

$$TXOP_i = max(\frac{\lceil \frac{SI \times \rho_i}{L_i} \rceil \times L_i}{R_i} + O, \frac{M}{R_i} + O) \qquad (4)$$

where ρ_i is the mean data rate, and L_i is the mean MSDU size.

Secondly, the HC uses the QoS control field of the IEEE 802.11e MAC header to record the queue length of the audio buffer and that of the video buffer of the station at the end of the TXOP. This queue length means the number of packets which could not be transmitted during the current SI because of the insufficient TXOP duration. This case usually happens when VBR traffic is transmitted. Note that the scheduler records the queue length only for audio and video traffic because these kinds of traffic require strict QoS guarantee. In this scheme, the queue length for data traffic is not estimated.

After obtaining the queue length record during the previous SI and then computing the basic TXOP duration as shown in Eq. (4), the HC computes the additional TXOP duration required for transmission of packets left in the queue as follows:

$$addTXOP_i = \frac{queue_i \times L_i}{R_i} \qquad (5)$$

where $queue_i$ is the queue length of flow *i*. Then, the HC adds the additional TXOP duration to the TXOP duration obtained from Eq. (4):

$$TXOP_i \leftarrow TXOP_i + addTXOP_i \qquad (6)$$

If the sum of all TXOP duration for all stations given by Eq. (6) is smaller than the duration of an SI, the TXOP duration for audio and that for video will be increased to fulfill the remaining time. Otherwise, the HC allocates TXOP duration according to Eq. (4) only.

3. Simulation Conditions

In this paper, the effect of the packet scheduling schemes on application-level QoS is evaluated by simulation with ns-2 (network simulator version 2) [7].

Figure 2 illustrates the system configuration used in the simulation. We focus on a single BSS, which includes an AP, four data stations, and a various number of multimedia stations, which transmit audio-video flows. We assume the IEEE 802.11b physical layer based on direct sequence spread spectrum (DSSS) with a channel data rate of 11 Mb/s [8]. In the simulation, three types of traffic are considered: audio, video, and UDP datagram. The multimedia stations send a pair of audio and video flows to the HC as two separate flows using UDP/IP. The data stations generate UDP datagrams of 1472 bytes in its payload at exponentially distributed intervals and send them to the HC. We assume that the average load per data station is 1 Mb/s.

Table 1 summarizes media specifications of audio-video flows used in the simulation. We use an audio flow of ITU-T G.711 μ-law and an MPEG1 video flow. An MU stands for a“ media unit ”, which indicates the information unit for media synchronization [9] at the application layer. A video MU is defined as a video frame and is transferred as one or more UDP datagrams. An audio MU consists of 1000 audio samples.

In the simulation, we set the beacon interval to 500 ms. For the TSPEC parameters, we set the MSI for all flows to 50 ms, and the nominal MSDU size for audio, that for video, and that for data are set to 1000 bytes, 1500 bytes, and 1500 bytes, respectively.

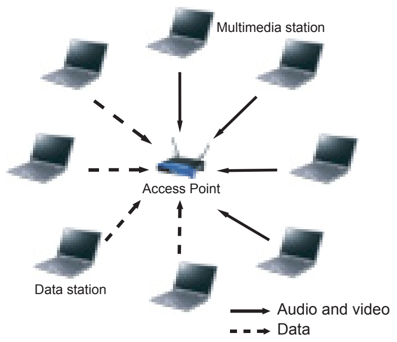

Figure 2. System Configuration

Table 1. Specifications of Audio and Video

	Audio	Video
coding scheme	G.711 μ–law	MPEG1
image size [pixel]	–	320 × 240
picture pattern	–	IPPPPP
average MU size [byte]	1000	5000
average MU rate [MU/s]	8	20
average inter-MU time [ms]	125	50
average bit rate [kb/s]	64	800
measurement time [s]	20	20

4. Numerical Results

In this section, we show simulation results of application-level QoS assessment of audio-video transmission with the HCCA, using the two kinds of scheduling schemes: the TGe and the proposed schemes.

4.1. Application-level QoS Parameters

In this paper, as application-level QoS parameters for audio-video traffic, we adopt the *average MU delay*, *coefficient of variation of output interval*, and *mean square error of inter-stream synchronization*.

The average MU delay is the average time from the moment an MU is generated at the source station until the moment the MU is output at the receiver. The coefficient of variation of output interval is defined as the ratio of the standard deviation of the MU output interval of a flow to its average. This QoS parameter represents the smoothness of the output flow. The mean square error of inter-stream synchronization is an indicator of " lip-sync " and is the average square of the difference between the output time of each video MU and its derived output time obtained from the output time of the corresponding audio MU. The derived output time means the output time of the corresponding audio MU plus the difference between the timestamps of the two MUs.

For the load data, we use *throughput* of the UDP datagram. The throughput is the average number of bits of UDP datagrams per second received by the HC.

4.2. Evaluation

Figures 3 through 8 show measured application-level QoS parameters obtained through simulations as the function of the number of multimedia stations. We compare the proposed scheme with the TGe scheme.

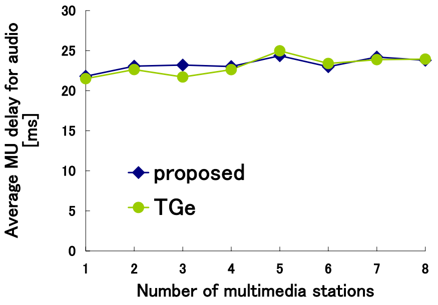

Figure 3. Average MU delay for audio

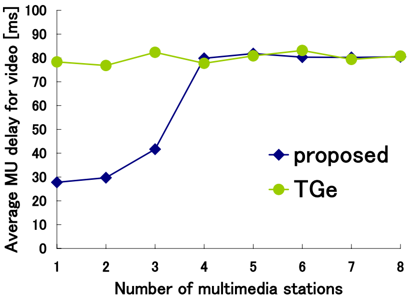

Figure 4. Average MU delay for video

Figures 3 and 4 indicate the average MU delay of audio and that of video, respectively. Figure 3 shows that for the two schemes, the average MU delay for audio is less than 25 ms. Our observation in the simulations showed that the queue length of audio flow is always zero at the end of a TXOP. This means that even if the proposed scheme allocates additional TXOP to the audio flow, there is no audio data to send; thus, no improvement of audio QoS is obtained compare to the TGe scheme. On the other hand, from Fig. 4, we can observe that the proposed scheme outperforms the TGe schemes with respect to video delay when the number of multimedia stations is smaller than four. If the number of multimedia stations increases beyond four, the average MU delay for video in the proposed scheme becomes almost constant and is almost equal to that for the TGe scheme.

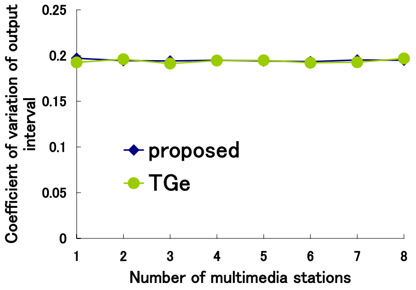

Figure 5. Coefficient of variation of output interval for audio

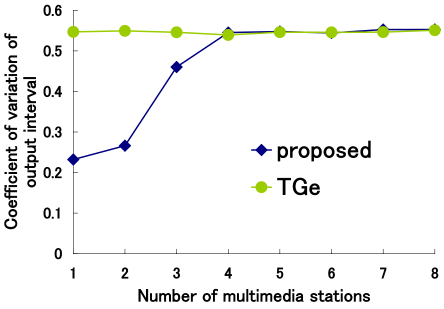

Figure 6. Coefficient of variation of output interval for video

The coefficient of variation of output interval for audio and that for video are depicted in Figs. 5 and 6, respectively. Figure 5 shows no significant difference between the two schemes. From Fig. 6, we can find that when the number of multimedia stations is small, the proposed scheme outperforms the TGe scheme. The reason for the results is as follows. In the TGe scheduler, the TXOP duration is calculated on the basis of the mean data rate. On the other hand, in the proposed scheme, additional TXOP duration can also be allocated to audio and video transmission if the duration of an SI is longer than the sum of TXOP duration for all stations based on the mean data rate.

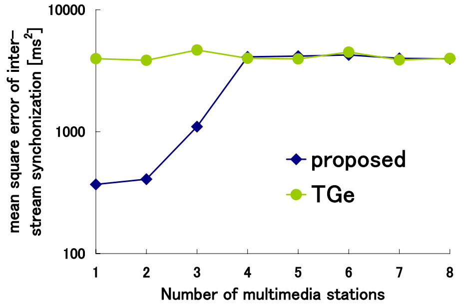

Figure 7. Mean square error of inter-stream synchronization

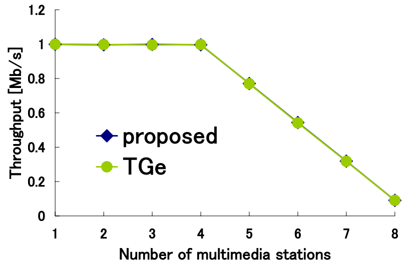

Figure 8. Throughput for data stations

Figure 7 illustrates the mean square error of inter-stream synchronization versus the number of multimedia stations. We can observe from this figure that the mean square error of inter-stream synchronization exhibits similar characteristics to the average MU delay for video.

Finally, the throughput for four data stations versus the number of multimedia stations is depicted in Fig. 8. This figure shows that the average throughput decrease when the number of multimedia stations is more than four. This is because the channel capacity available to data traffic becomes insufficient if the number of multimedia stations is more than four.

5. Conclusions

In this paper, we proposed a new scheduling scheme for audio-video transmission with HCCA and compared the application-level QoS of our proposed scheme and the TGe scheme. From the simulation results, we can conclude that in the video quality and inter-stream media synchronization quality, our proposed scheme outperforms the TGe scheme when the number of multimedia stations is small.

In [10], we also compare the performance of the proposed scheme with the TGe scheme and FHCF scheme [11]. The results show that our proposed scheme outperforms the TGe and FHCF scheme when the number of stations is small.

Our future work includes investigation of user-level QoS for multimedia transmission with the HCCA of the IEEE 802.11e. We also plan to investigate the effect of TSPEC parameter values and admission control on application-level QoS of audio-video transmission.

Acknowledgment

This work was supported by the Grant-In-Aid for Scientific Research of Japan Society for the Promotion of Science under Grant 17360179.

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