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Guaranteeing QoE in Audio-Video Transmission by IEEE 802.11e HCCA*

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SUMMARY This paper studies packet scheduling schemes with QoE (user-level QoS) guarantee for audio-video transmission in a wireless LAN with HCF controlled channel access (HCCA) of the IEEE 802.11e MAC protocol. We first propose the *static scheduling (SS)* scheme, which grants adjustable transmission opportunity (TXOP) duration for *constant bit rate (CBR)* traffic. The SS scheme can determine the minimum TXOP duration capable of guaranteeing high QoE; it can maximize the number of admitted flows. As the burstiness of *variable bit rate (VBR)* traffic cannot be absorbed by the SS scheme, we also propose the *multimedia priority dynamic scheduling (MPDS)* scheme, which can absorb the burstiness through allocating additional TXOP duration. We then compare the SS scheme, the MPDS scheme, and the reference scheduler (TGe scheme) in terms of application-level QoS and user-level QoS (QoE). Numerical results show that in the SS scheme, the QoE can be kept relatively higher even when the TXOP duration is reduced in the case of video with the I picture pattern; this implies that more flows can be admitted. In the case of video with the IPPPPP picture pattern, which has the VBR characteristic more remarkably, reducing the TXOP duration according to the SS scheme will deteriorate the QoS level. In this case, the MPDS scheme performs better when the number of multimedia stations is small. However, the performance of the MPDS scheme deteriorates with the increase of the number of multimedia stations, though the results are comparable to or even better than those of the SS and TGe schemes.

key words: *IEEE 802.11e HCCA, audio-video transmission, QoE, packet scheduling, application-level QoS*

1. Introduction

The IEEE 802.11 wireless local area network (WLAN) has become a major standard in wireless packet communications. From public hotspots to in-flight wireless networks, the IEEE 802.11 WLAN plays a prominent role in offering ubiquitous connectivity to the Internet. With an increasing demand for networked multimedia applications with strict delay constraint such as voice over IP (VoIP), video conferencing, and video on demand (VoD), the interest in WLANs supporting *quality of service (QoS)* has been growing rapidly. However, the IEEE 802.11 was originally designed for data transmission; it offers services on the best-effort basis. IEEE 802.11e has been introduced as an extension to the IEEE 802.11 *medium access control (MAC)* in order to provide QoS support to multimedia applications.

The IEEE 802.11e MAC defines the *hybrid coordination function (HCF)*, which has two access methods: *enhanced distributed channel access (EDCA)* and *HCF controlled channel access (HCCA)* [1]. The former is a contention-based protocol based on *carrier sense multiple access with collision avoidance (CSMA/CA)* and can support service differentiation and prioritization. The latter is a polling-based protocol and can support guaranteed media access for real-time transmission. The EDCA, which is based on distributed control, is easy to be implemented, but under heavy load conditions, QoS cannot always be met. In contrast, the centrally controlled HCCA is complex to be implemented, but it gives high assurance of QoS guarantee. In this paper, we focus on audio-video transmission with the HCCA since multimedia applications require high assurance of QoS guarantee.

The IEEE 802.11e standard has presented a reference design for an example packet scheduler for the HCCA which is referred to as the *Task Group e (TGe) scheme* as in [2]. Furthermore, the IEEE 802.11e standard allows any modification of the design of the packet scheduler. Although the HCCA can provide guaranteed medium access by granting *transmission opportunity (TXOP)* duration, only a limited number of stations will benefit from it because of the limited channel capacity available in the wireless LANs.

The packet scheduling scheme for the HCCA has already been studied by many researchers [2]–[10]. In [2], Grilo et al. propose the *scheduling scheme based on estimated transmission time-earliest due date (SETT-EDD)*. In the SETT-EDD scheme, the *hybrid coordinator (HC)* allocates the TXOP duration to stations taking into account the deadline of each packet. In [3], Ansel et al. propose a scheduling scheme called *FHCF*, where the HC allocates additional TXOP duration after it calculates the TXOP duration based on the mean data rate. Reference [4] examines a scheduling scheme where the HC polls all stations and then it performs additional polling if there are some stations that require further channel allocation. An application-aware adaptive scheduling scheme has been examined in [5]. The scheduler of the scheme adapts *service interval (SIs)*, polling order, and TXOPs depending on the traffic characteristics and instantaneous network conditions. References [6]

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and [7] propose polling schemes to reduce polling overhead by adopting variable SIs. In [8], a coordination function called *isochronous coordination function (ICF)* is proposed for efficient voice transmission with the HCCA. Admission control algorithms to support QoS requirement are studied in [6] and [9]. In [10], theoretical analysis of the HCCA is carried out.

Many researches on packet scheduling scheme of the HCCA investigate MAC-level QoS. In order to achieve high MAC-level QoS, many of them allocate longer TXOP duration than that of the TGe scheme especially for transmission of VBR traffic. However, provision of QoS guarantee to multimedia transmission should imply not only achieving high throughput and low delay but also high user satisfaction (user-level QoS), as the users are the ultimate recipients of multimedia application services.

Reference [11] identifies six levels of QoS in IP networks: *physical-level, node-level, network-level, end-to-end level, application-level*, and *user-level*. Here, the user-level QoS is the overall acceptability of an application or service, as perceived subjectively by the end-users and is the most important in multimedia transmission; this is also referred to as *Quality of Experience (QoE)* in ITU-T [12]. Although we cannot directly control QoE, it is possible to control QoS at lower levels so that QoE can be kept high.

Regarding QoE of audio-video transmission with the HCCA, we can find no researches in [2]–[10]. As a first step toward this type of study, we focus mainly on assessment of QoE; we also try to control QoE through achieving high application-level QoS. In this paper, we propose the *static scheduling (SS)* scheme and the *multimedia priority dynamic scheduling (MPDS)* scheme, which are designed for *constant bit rate (CBR)* traffic and *variable bit rate (VBR)* traffic, respectively. The SS scheme is suitable for CBR traffic as it allocates fixed TXOP duration within an SI. Furthermore, the TXOP duration derived according to the SS scheme can be shorter than that of the TGe scheme; thus, the SS scheme increases the number of stations granted with TXOP.

In some cases where multimedia applications like videoconferencing produce *variable bit rate (VBR)* traffic, the SS scheme alone might not be able to keep its QoS at high level. The VBR traffic might generate data at higher rates than usual; it requires additional TXOP duration. Therefore, on the basis of our SS scheme, we also propose the *multimedia priority dynamic scheduling (MPDS)* scheme, which allocates additional TXOP duration only when the remaining channel capacity is available.

In this paper, we first explain the TGe, SS, and MPDS schemes. Here, the SS and the MPDS schemes are designed to guarantee the QoE in multimedia transmission with the HCCA.

We examine the effect of the number of multimedia stations and TXOP duration of the SS and MPDS schemes on application-level QoS through simulation. We also evaluate the QoE of the two schemes by a subjective experiment. We evaluate the application-level QoS and QoE by utilizing MPEG1 video and encode it into two types of picture pattern; I and IPPPPP, each of which has three different bit rates. The former represents the CBR traffic while the latter represents the VBR traffic. In the assessment of the SS scheme for CBR traffic, we examine the minimum TXOP duration under the condition that the application-level QoS and QoE are kept high. We aim to maximize the number of stations which can be admitted in a *basic service area (BSA)*. For VBR traffic, we show the improvement of the application-level QoS and QoE brought by the MPDS scheme. We evaluate the effect of the number of multimedia stations on the QoS because the QoS for the MPDS scheme depends on the remaining channel capacity for the additional TXOP duration.

In the QoE assessment, we consider a video stream and the corresponding audio stream together since cross-modal influences between audio and video affects the overall perceptual quality [11], [13]. Since QoE is directly related to human perception, we utilize a psychometric method referred to as the *method of successive categories* [13].

The rest of the paper is organized as follows. Section 2 explains the TGe scheme, and it proposes the SS and the MPDS schemes. Section 3 specifies simulation conditions. Section 4 gives numerical results of application-level QoS. Section 5 investigates QoE. Finally, Sect. 6 concludes this paper.

2. HCCA Scheduling Schemes

In this section, we introduce the three schemes of packet scheduling for HCCA: the TGe, SS, and MPDS. We consider *multimedia stations* and *data stations* in a *basic service set (BSS)*. A multimedia station transmits a pair of audio and video flows to the *access point (AP)*. A data station transmits a single flow of random data to the AP to interfere with the transmission of the multimedia traffic.

The HCCA provides polled access to the wireless medium. It is controlled by the HC, which is usually collocated with 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 a superframe, which starts with a beacon frame. Basically, the CFP and CP are used for the HCCA and EDCA, respectively. In the HCCA, however, the HC can start to poll stations even during the CP as well as the CFP. 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 HCCA, a station polled by the HC can deliver a burst of data frames within the duration of a TXOP. According to the reference scheduler in [1], 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 mac service*

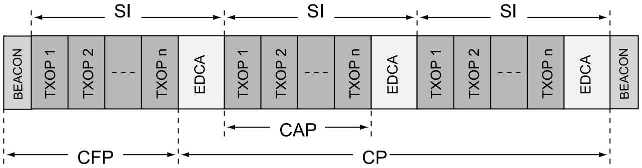

Fig. 1 IEEE 802.11e HCCA channel access.

data unit (MSDU) size (L) in octets, and *maximum service interval (MSI)* in microseconds.

2.1 TGe Scheme

The TGe scheme is presented in the IEEE 802.11e standard [1]. The TXOP duration for a station is calculated on the basis of the TSPEC information received from the station. For simplifying the description of the TGe scheme, let us focus on flow i where ρ_i is the mean data rate in bits per second, L_i is the nominal MSDU size in bits, and R_i is the minimum physical transmission rate of flow i in bits per second. Note that the TXOP duration for a multimedia station is the sum of TXOP duration for the audio flow and that for the video flow.

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

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

where *SI* is the duration of the service interval in seconds. This interval must be shorter than the minimum value of all MSI's for admitted flows and must be a submultiple of the beacon interval. In Eq. (1), 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

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

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. The superscript T means the TGe scheme.

Owing to the limitation of the capacity during an SI, the number of stations to 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 capacity of the medium exists or not by the following equation:

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

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.

The TGe scheme uses the mean data rate to compute the TXOP duration. This implies that the TGe scheduler allocates fixed TXOP duration in every SI; therefore this scheme is suitable for CBR traffic.

2.2 SS Scheme

In order to determine the minimum TXOP duration required to keep the QoS high, we propose the SS scheme which suitable for CBR traffic.

Similar to the TGe scheme, the SS scheme also statically allocates the duration of TXOP to each station. However, unlike the TGe scheme, the TXOP duration in the SS scheme is calculated on the basis of the product of the mean data rate and a parameter α; therefore, in the SS scheme, the HC can allocate longer or shorter TXOP duration by setting the value of α accordingly. The TXOP duration for flow i is calculated as $TXOP_i^S = \alpha\ TXOP_i^T$ where the value of α smaller than 1 gives shorter TXOP duration than that in the TGe scheme, while the value of α larger than 1 gives longer TXOP duration. When $\alpha = 1$, the SS scheme is equal to the TGe scheme. By setting the α value smaller than 1, we can study whether allocating TXOP duration less than that of the TGe scheme can degrade the QoS level. In the SS scheme, the HC can perform admission control utilizing an equation obtained by replacing $TXOP^T$ with $TXOP^S$ in Eq. (3).

2.3 MPDS Scheme

The MPDS scheme is proposed to handle traffic with VBR characteristics because the SS scheme alone cannot absorb the burstiness of this traffic.

In the MPDS scheme, 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 product of the mean data rate and α. That is, priority is given to audio-video transmission over data transmission.

Let us describe the algorithm of the MPDS scheme. First, as usual, the HC computes the basic TXOP duration of flow i, which is denoted by $basicTXOP_i^M$, on the basis of TSPEC information sent by the station. The calculation is performed in the same way as that in the SS scheme.

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. The HC uses the *traffic identifier (TID)* of the QoS Control field in the MAC header to distinguish the flow types in the queue.

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

$$addTXOP_i^M = \frac{queue_i \times L_i}{R_i} \tag{4}$$

where $queue_i$ is the number of packets in the (audio or video) queue of flow i. Then, the HC adds the additional TXOP duration to the basic TXOP:

$$TXOP_i^M = basicTXOP_i^M + addTXOP_i^M \tag{5}$$

Note that there is no additional TXOP for data stations, which obtain the basic TXOP duration only.

If the sum of the TXOP duration for multimedia and data stations is smaller than the duration of an SI, the TXOP duration for multimedia stations can be increased proportionally so as to use up the remaining time. Otherwise, the HC reduces the TXOP duration of each station proportionally until the sum of all TXOP duration is equal to or lower than the SI. If the reduced TXOP duration for a multimedia station is lower than the *basic TXOP* duration, the HC allocates *basic TXOP* duration to the station. In contrast to the SS scheme, where the TXOP duration can be reduced to accommodate additional stations, the MPDS scheme takes an advantage of available bandwidth to accommodate VBR traffic when the number of stations is small.

In the MPDS scheme, admission control can be carried out with an equation obtained by replacing $TXOP^T$ with $basicTXOP^M$ in Eq. (3).

From the explanation above, the SS scheme is easy to be implemented, but it cannot handle the burstiness of VBR traffic. Therefore, the SS scheme is suitable for CBR traffic and can maximize the number of admitted stations by reducing the TXOP duration of each station. In contrast, the MPDS scheme is more complex to implement, but it performs well for VBR traffic transmission during low traffic condition as additional TXOP can be allocated to multimedia stations.

3. Experimental Methodology

In this paper, the application-level QoS is assessed by simulation with ns-2 (network simulator version 2) [14]. Then, the QoE (user-level QoS) is assessed by subjective experiment where we actually output the audio and video flows according to the output time-stamps obtained from the simulation. In this section, we first present the simulation conditions used for the application-level QoS assessment. We then elaborate on the methods of subjective experiment.

3.1 Simulation Conditions

Figure 2 illustrates the system configuration used in the simulation. We focus on a single *basic service set (BSS)* which includes an AP, four data stations, and a various number of multimedia stations. We assume the IEEE 802.11b physical layer based on direct sequence spread spectrum (DSSS) with a channel data rate of 11 Mb/s [15]. In the simulation, we assume error-free packet transmission, and three types of traffic are considered: audio, video, and random data. Each multimedia station sends a pair of audio and video flows to the HC as two separate transport streams using UDP/IP. Each data station generates UDP datagrams of 1472 bytes each in its payload at exponentially distributed intervals and sends them to the HC. We also assume that the average load per data station is 1 Mb/s.

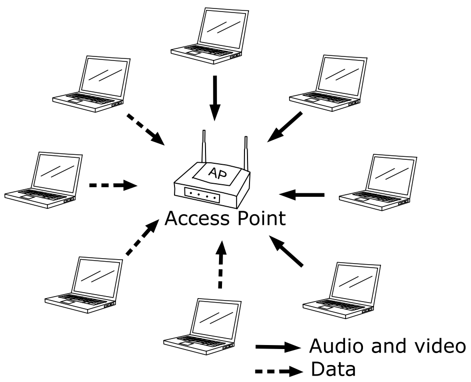

Fig. 2 System configuration.

Table 1 Specifications of audio and video.

	Audio	Video
coding scheme	G.711 μ–law	MPEG1
image size [pixel]	–	320 × 240
picture pattern	–	I
	–	IPPPPP
average MU rate [MU/s]	8	20
average inter-MU time [ms]	125	50
average bit rate [kb/s]	64	600
		800
		1000
measurement time [s]	20	20

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 [11] 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, which corresponds to a single UDP datagram.

Three types of the contents are used in the simulation: *Music video*, *Sport*, and *Movie*. The *Music video* shows scenes of a Japanese female singer dancing with background dancers. For *Sport*, scenes of an F1 race with a commentator's voice have been chosen. The *Movie* is a Japanese film with scenes of a woman having discussion with her friends. Here, we have encoded each video flow into two picture patterns of I and IPPPPP, each at three bit rates of 600 kb/s, 800 kb/s, and 1000 kb/s. Here, the video with picture pattern of I represents the CBR traffic while the video with picture pattern of IPPPPP represents the VBR traffic in our research. The difference in quality among these video flows is hardly noticeable. Note that we use only one type of video flow in each simulation.

In the simulation, we set the beacon interval to 500 ms. For the TSPEC parameters, we set the MSI's 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. We assume that each source buffer at the MAC layer in a station or an AP can accommodate a maximum of 50 *MAC protocol data unit (MPDUs)* for each flow and that a newly generated MPDU is discarded unless enough space to accommodate it is available.

In this paper, as application-level QoS parameters for audio-video traffic, we adopt the *average MU delay*, *MU loss ratio*, 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 MU loss ratio is the ratio of the number of MUs not output at the receiver to the number of MUs generated by the source station. 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 of a video MU means the output time of the corresponding audio MU plus the difference between the timestamps of the two MUs.

3.2 Methods for Subjective Experiment

The QoE assessment performed in our study is done according to part of the methodology recommended in [16] and [17]. The subjective assessment was conducted by 30 students; their ages were 20 s. In each simulation, we have six samples by changing the value of α. The number of samples each assessor assessed is 216, since for each value of α we used two packet scheduling schemes, two picture patterns, three video contents, and three bit rates. We fix the number of multimedia stations to 4. Note that we use only the SS and the MPDS schemes in the assessment because the results for the TGe scheme is equivalent to the result of the SS scheme when the value of α is equal to 1.00. For the assessment, we use 17-inch liquid crystal displays (LCD), and the distance between the assessors and the display is about 50–70 cm. The assessors listen to the audio output using a headphone. The assessors were asked to classify the test samples into a certain number of categories each assigned an integer. Here, we use five categories of *impairment* of the *rating-scale method*: "imperceptible" assigned integer 5, "perceptible, but not annoying" 4, "slightly annoying" 3, "annoying" 2, and "very annoying" 1.

4. Application-Level QoS Assessment

In this section, we show simulation results of application-level QoS assessment of audio-video transmission with the TGe, the SS, and the MPDS schemes.

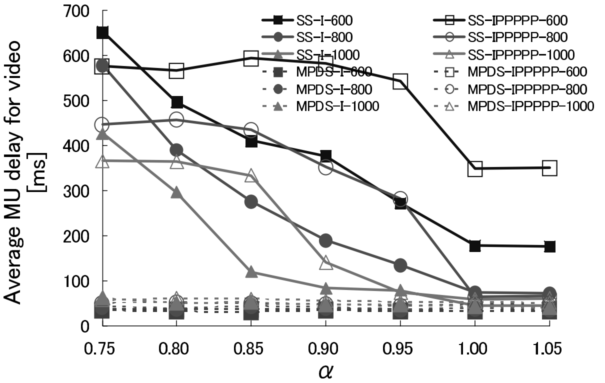

Fig. 3 Average MU delay for video. (Music video)

First, we compare the three schemes by changing the value of α used in the calculation of TXOP duration for video flows. We study whether allocating TXOP duration in the SS scheme less than that of the TGe scheme can degrade the QoS. From this simulation, we can find the minimum TXOP duration needed by the video flow to keep its QoS high. We also evaluate the performance of the MPDS scheme.

Second, we compare the TGe scheme and the MPDS scheme by changing the number of multimedia stations. This is because we should examine how much improvement the MPDS can give in the QoS of audio and video flows by means of the allocation of additional TXOP. Note that the MPDS uses the remaining channel capacity to allocate additional TXOP and that as the number of multimedia stations increases, the remaining channel capacity becomes smaller.

4.1 The Effect of Static TXOP Duration for Video

Here, we compare the three schemes by changing the value of α used in the calculation of TXOP duration for video flows. Note that in the SS scheme α less than 1.00 derives shorter TXOP duration than that of the TGe scheme. We study whether allocating TXOP duration (*basic TXOP* duration in the case of the MPDS scheme) less than that of the TGe scheme can degrade the application-level QoS. We also look into the effects of the video picture pattern, bit rate, and content type on the QoS. This is because different video specifications produce different bit rate distributions and also require different TXOP duration. In the following simulation results, we set the number of multimedia stations to 4.

Figures 3 through 11 show simulation results of application-level QoS assessment of audio-video transmission with the TGe, the SS, and the MPDS schemes. In this figure, notation "SS-I-600," for instance, refers to the result for the SS scheme in the case of the I picture pattern at the bit rate of 600 kb/s. Each figure consists of simulation results of the two schemes for all combinations of the picture patterns and bit rates. We use the video with the I and IPPPPP

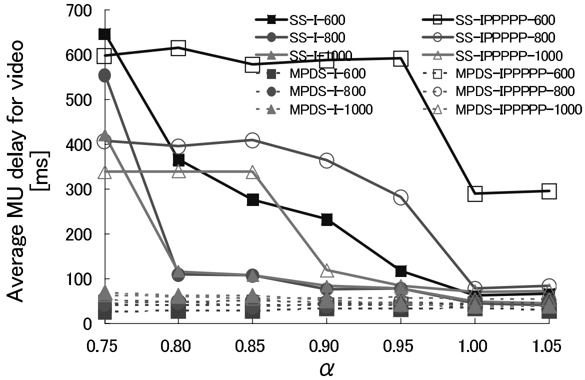

Fig. 4 Average MU delay for video. (Sport)

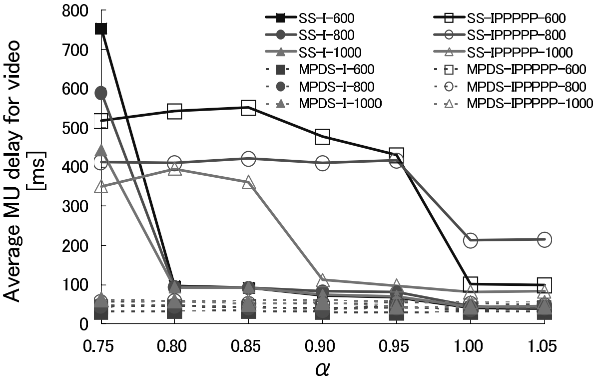

Fig. 5 Average MU delay for video. (Movie)

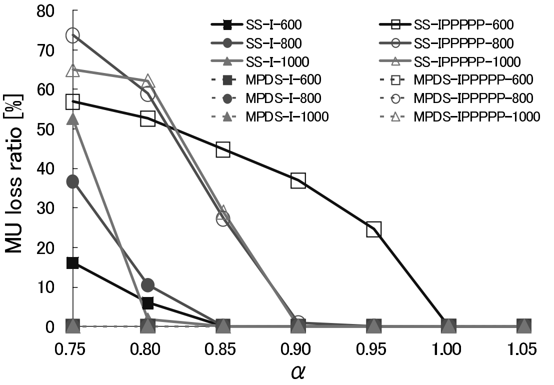

Fig. 6 The MU loss ratio for video. (Music video)

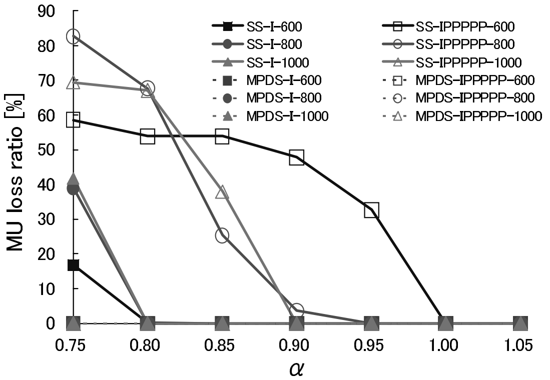

Fig. 7 The MU loss ratio for video. (Sport)

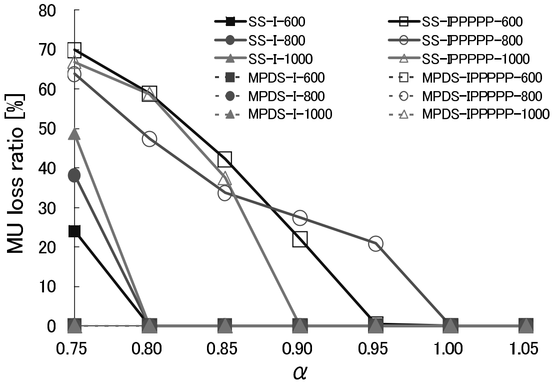

Fig. 8 The MU loss ratio for video. (Movie)

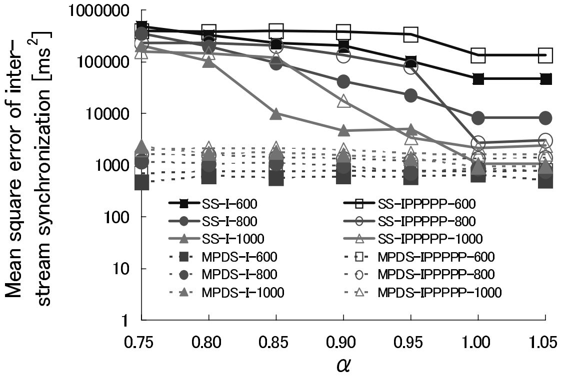

Fig. 9 Mean square error of inter-stream synchronization versus static TXOP duration for video. (Music video)

picture patterns to imitate CBR traffic and VBR traffic, respectively. The value of α used in the simulations is set to one ranging from 0.75 to 1.05. Note that the results for the TGe scheme are equivalent to those of the SS scheme with $\alpha = 1.00$.

In the case of audio flows, we set the value of α to 1.00 for the calculation of the TXOP duration. For this reason, the simulation results of the audio flows do not show significant difference between all the three schemes. Therefore, we do not show the simulation results for the audio flows in this paper.

4.1.1 The SS Scheme for CBR Traffic

First, we discuss the performance of the SS scheme in the case of CBR traffic, namely, the I picture pattern.

Figures 3 through 5 show the average MU delay for *Music video, Sport* and *Movie*, respectively. From these figures, we can observe that the average video MU delay deteriorates with the decrement of the α. For video content of *Movie*, however, it remains lower even if the α is reduced to 0.80.

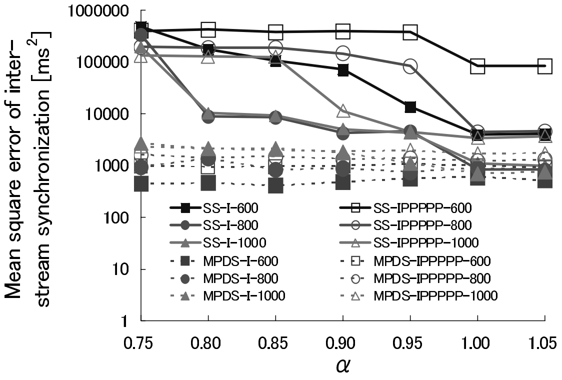

Fig. 10 Mean square error of inter-stream synchronization versus static TXOP duration for video. (Sport)

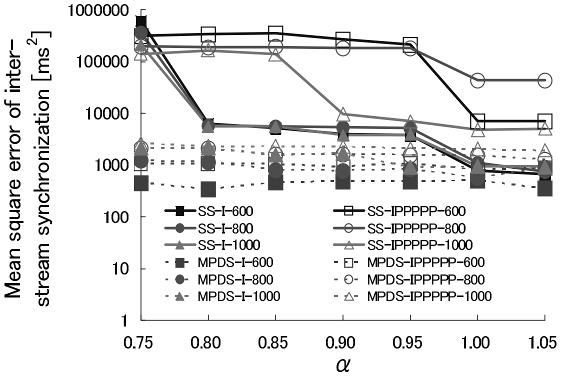

Fig. 11 Mean square error of inter-stream synchronization versus static TXOP duration for video. (Movie)

Similar results can also be seen in Figs. 6 through 11, which indicates the MU loss ratio and mean square error of inter-stream synchronization for video, respectively. For video with the I picture pattern, the MU loss ratio starts to increase only when the α is set to below 0.80. This is because even if the TXOP duration for video flows is reduced, the video MUs are stored temporarily at the source buffer before being sent in the next SI. This shows that the SS scheme keeps the application-level QoS at high level for CBR traffic by using shorter TXOP duration than that of the TGe scheme.

These figures also indicate that the video flows with lower bit rates are more affected by the value of α than the ones with higher bit rates. This is because the ceiling function used in Eq. (1) gives more extra TXOP duration for a high bit rate than for a low bit rate.

4.1.2 The SS Scheme for VBR Traffic

We then discuss the SS scheme in the case of VBR traffic, namely, the IPPPPP picture pattern.

In this case, the average MU delay, MU loss ratio and mean square error of inter-stream synchronization degrade drastically when the value of α is reduced. Especially, the MU loss ratio increases drastically when α is smaller than 0.90.

Moreover, the MU loss ratios for lower bit rates are higher than the ones for higher bit rates in the case of the IPPPPP picture pattern when the value of α is large. However, the results turn oppositely for *Music video* and *Sport* when the value of α becomes less than 0.85. This is due to lack of transmission time for the video with higher bit rates compared to the video with lower bit rates when the value of α is too small.

From these results, we see that the SS scheme is not efficient to be used with the VBR traffic.

4.1.3 The MPDS Scheme

From the simulation results of the SS scheme, we have noticed that this scheme is inefficient and cannot keep high QoS for VBR traffic. For this type of traffic, we propose the MPDS scheme. Figures 3 through 5 show that the average MU delay for video is kept low regardless the value of α. We can see in these figures that no MU loss is observed and that the mean square error of inter-stream synchronization is kept almost constant below the threshold value (6400 ms^2) for high-quality lip sync [11] regardless of the value of the static video TXOP duration. This is because the MPDS scheme utilizes available remaining channel capacity for additional TXOP duration allocation so that it can absorb the burstiness of VBR traffic even when the *basic TXOP* duration is reduced. However, when the number of multimedia stations increases and no more remaining channel capacity is available, the MPDS scheme is comparable to the SS scheme.

In Figs. 3 through 5, we have not shown the average MU delay for video when $\alpha < 0.75$ or $\alpha > 1.05$. The average MU delay for the MPDS scheme is kept low even if $\alpha < 0.75$ or $\alpha > 1.05$. This is because enough TXOP duration is allocated to each multimedia station, though the basic TXOP duration increases and the additional TXOP duration decreases as α becomes bigger. In the case of video flows with average bit rate of 800 kb/s, for example, when $\alpha > 2.30$, not all four multimedia stations can be admitted in the MPDS scheme.

4.2 The Effect of the Number of Multimedia Stations

Let us evaluate the effect of the number of multimedia stations on application-level QoS. In this simulation, we compare two scheduling schemes: the TGe and the MPDS schemes. In the MPDS scheme, we set $\alpha = 1.00$; in this case the *basic TXOP* duration in the MPDS scheme is equal to the TXOP duration in the TGe scheme. Note that the results for the TGe scheme are the same as those for the SS scheme when α is equal to 1.00.

Figure 12 through 14 show the average video MU delay as a function of the number of multimedia stations for the three contents. These figures show that the MPDS scheme outperforms the TGe scheme if the number of multimedia stations is small. Especially, the difference in the average video MU delay between the two scheduling schemes

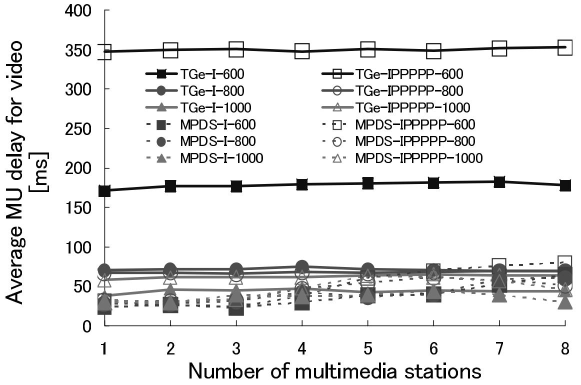

Fig. 12 Average MU delay for video versus the number of multimedia stations. (Music video)

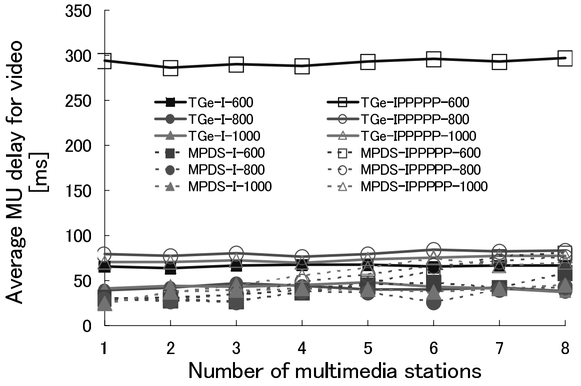

Fig. 13 Average MU delay for video versus the number of multimedia stations. (Sport)

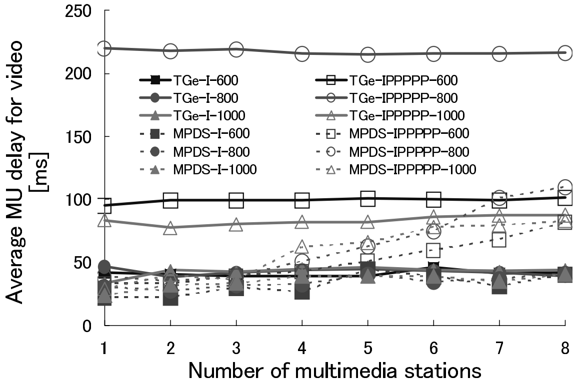

Fig. 14 Average MU delay for video versus the number of multimedia stations. (Movie)

becomes larger as the number of multimedia stations decreases. This is because when the number of multimedia stations becomes smaller, the remaining time for the additional TXOP in the MPDS scheme increases.

Note that the MPDS scheme is efficient only when extra bandwidth is available. The MPDS scheme can absorb burstiness of VBR traffic by allocating additional TXOP; thus, it reduces the MU output delay. The performance of the MPDS scheme deteriorates with the increase of the number of multimedia stations where the results become comparable to or better than that of the TGe scheme. When extra bandwidth is not available, the MPDS scheme works just as the SS and TGe scheme.

Meanwhile, in the case of the TGe scheme, the average video MU delay is not affected by the number of multimedia stations as the HC allocates constant TXOP duration. Note that under the simulation conditions, at most 8 multimedia stations can be admitted in the TGe and the MPDS schemes when the admission control is carried out. If the number of multimedia stations is more than eight, only the first eight stations will be admitted, while the admission requests of the rest of the multimedia stations will be rejected because there is no enough bandwidth available.

It should be noted that we assume in our simulation that all channel capacity is used for the CFP. Under a mixture of the HCCA and EDCA traffic, the admitted number of multimedia stations will be decreased because the channel capacity for the HCCA becomes smaller.

Furthermore, we have confirmed through simulation that the MPDS scheme can also improve the mean square error of inter-stream synchronization compare to the TGe scheme.

5. QoE Assessment

In this section, we first assess QoE (i.e., user-level QoS) of the TGe, the SS, and the MPDS schemes by a subjective experiment. From the assessment of the application-level QoS, we found that the video quality of the SS scheme deteriorates when the α value for the video flow is reduced. However, through application-level QoS only, it is hard to make a conclusion that the QoE is good or not. This is because the results of the MU delay, the MU loss ratio and the mean square error of inter-stream synchronization each produce different degree of QoS degradation. Therefore, we examine the effect of the α value of the SS and MPDS schemes on QoE. In the QoE assessment, we utilize the method of successive categories as in [13].

We will then present a method for determining an appropriate value of α.

5.1 Psychological Scale

In this paper, the results obtained from the rating-scale method are calculated into the *interval scale* with the *law of categorical judgment* [18]. As the QoE parameter, we utilize the interval scale instead of the *mean opinion score (MOS)*, which is often used in subjective assessment. Basically, the MOS value is obtained by averaging the subjective scores under an implicit assumption that the difference in integer between any two successive categories means the same magnitude of the assessor's sensation to a sensory attribute of a sample; assessor's sensation between category 5 and category 4, for example, has the same magnitude as that between category 3 and category 2. However, this is not necessarily the case. Thus, the MOS is an *ordinal scale*; the

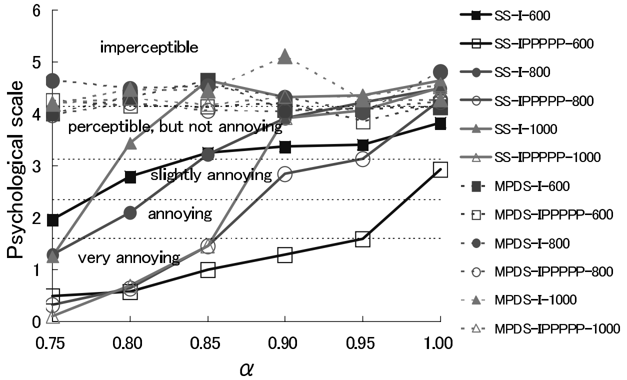

Fig. 15 Psychological scale. (Music video)

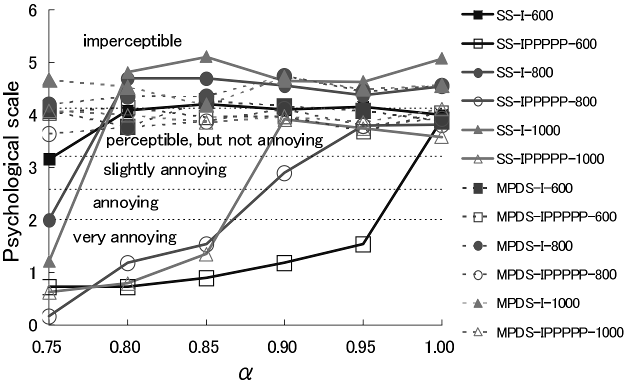

Fig. 16 Psychological scale. (Sport)

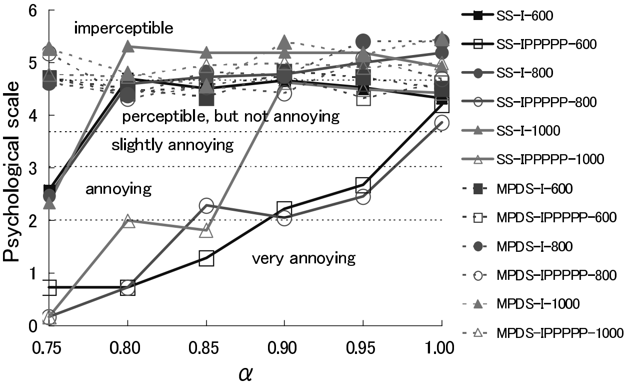

Fig. 17 Psychological scale. (Movie)

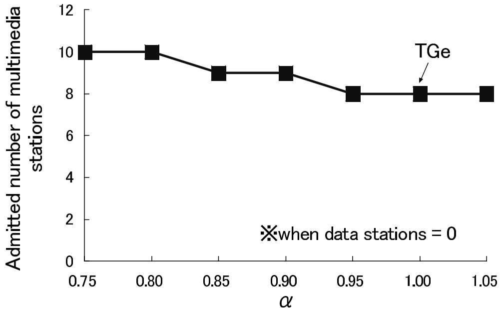

Fig. 18 Admitted number of multimedia stations versus α.

integers assigned to the categories only have a greater-than-less-than relation between them. In contrast, in the interval scale, an interval between the scale values means a distance between amounts of the sensory attribute measured [13].

To verify the obtained interval scale, we have performed Mosteller's test [18]. From the Mosteller's test, after removing some values, we cannot reject the hypothesis that the obtained interval scale fits the observed data at a significance level of 0.05. Thus, we refer to the interval scale as the *psychological scale* [13].

Figures 15 through 17 depict the psychological scale for *Music video, Sport*, and *Movie*, respectively. In these figures, the number of multimedia stations is set to 4. We have selected the minimum value of the psychological scale as the origin. Note that, in the interval scale, we can select an arbitrary origin and any unit of scale. In these figures, each of the four horizontal dotted lines indicates the lower boundary of a category.

From these figures we find that in the case of the I picture pattern, the psychological scale for the SS scheme decreases if the value of α is set lower than 0.85 for *Music video* and 0.80 for the *Sport* and *Movie*. We can say that in the cases of the SS scheme for the three contents, about 85% of the TXOP duration in the TGe scheme is enough to obtain approximately the highest QoE, especially when we use the contents with a CBR characteristic. However, the QoE for the IPPPPP picture pattern degrades more rapidly with the decrement of the α value. This means that the SS scheme performs well only for transmission of video with the I picture pattern. Moreover, the video flows with lower bit rates are more affected by the value of α than the ones with higher bit rates.

We also find that the MPDS scheme keeps the QoE high for the three contents on any conditions. This is due to the allocation of additional TXOP duration performed by the MPDS scheme. This shows that the MPDS scheme is suitable for transmission of video with the IPPPPP picture pattern. As the number of multimedia stations is set to 4, extra bandwidth is always available. This is why the QoE of the MPDS scheme performs well. If the number of multimedia stations increases, QoE for the MPDS scheme degrades as the available extra bandwidth decreases; even in this case, the MPDS scheme is comparable to the SS scheme.

Figure 18 shows the admitted number of multimedia stations in the SS scheme as a function of α, which is equivalent to the static TXOP duration for video. From Fig. 18, we observe that when the α value is set to 0.80, the maximum number of multimedia stations that can be accommodated by the HC with the admission control is 10, while at most 8 multimedia stations can be admitted in the TGe scheme. As seen from the results of QoE, the TXOP duration obtained when α is equal to 0.80 achieves relatively high QoE especially in the case of video with the I picture pattern.

Thus, we can say that the SS scheme can support a larger number of multimedia stations as a BSS than the TGe scheme under the condition that the QoE is kept high for video with the I picture pattern.

5.2 Determining an Appropriate Value of α

So far, we have discussed the cases of given values of α. In order to take advantage of reducing the TXOP duration while keeping the QoE high, we need a method for determining an appropriate value of α.

In the case of CBR traffic, we found that the SS scheme can guarantee high QoE with shorter TXOP duration than that of the TGe scheme. To determine an appropriate value of α, one method we can easily consider is eliminating the ceiling function used in the calculation of the TXOP duration. This method derives an α value of 0.83. From our QoE assessment, we found that the TXOP duration for $\alpha = 0.83$ achieves high QoE for Sport and Movie in the case of the I picture pattern. For Music video, the QoE is not highly degraded.

Meanwhile, in the case of VBR traffic, we recommend $\alpha = 1.00$ in the MPDS scheme. In most cases of our QoE assessment, the QoE of the IPPPPP picture pattern for the MPDS scheme is equivalent to or better than that of the TGe scheme. Furthermore, QoE for the MPDS scheme depends on the number of multimedia stations. We have found in Fig. 12 through 14 that the application-level QoS for $\alpha = 1.00$ in the MPDS scheme is also equivalent to or better than that for the TGe scheme even if the number of multimedia stations is eight. However, the QoE for the MPDS scheme can be improved for α greater than 1.00. The finding of the optimum value of α to keep the QoE high should be for further study.

6. Conclusions

In this paper, we have proposed the SS and MPDS schemes and compared them with the TGe scheme in terms of application-level QoS and user-level QoS (QoE). Three types of content were used in the simulation: *Music video*, *Sport*, and *Movie*. They have been encoded in two types of picture pattern: I and IPPPPP, each at three different bit rates. We studied the effect of the picture patterns, bit rates, and content types on QoS. We also examined the effect of TXOP duration on the QoS.

In the SS scheme, we have learned that the QoE for video with the I picture pattern is kept high even when the TXOP duration for video flow is reduced. This shows that it is possible to guarantee QoE with less bandwidth; so more flows can be admitted and served with QoS guarantee. However, the QoS level for the video with the IPPPPP picture pattern deteriorates with the decrease of the value of α. This shows that the SS scheme is not suitable for the VBR traffic transmission.

The MPDS scheme outperforms the SS and TGe schemes when the number of stations is small. This shows that the MPDS scheme is suitable for transmission of video with the IPPPPP picture pattern. However, even if the performance of the MPDS scheme deteriorates with the increase of the number of stations, the results are comparable to or better than that of the SS and TGe schemes.

Our future work includes finding of the optimum reduction ratio of the TXOP duration. In addition, we have a plan to devise an adaptive scheduling scheme where the HC determines the TXOP duration by measuring application-level QoS parameters which highly affect QoE.

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