QoE Estimation from MAC–Level QoS in Audio–Video Transmission with IEEE 802.11e EDCA

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***Abstract*— This paper estimates Quality of Experience (QoE), i.e., user–level QoS from MAC–level QoS for audio–video transmission over an IEEE 802.11e EDCA wireless LAN. The MAC–level QoS in this case has already been studied extensively; however, it may not provide exact information on QoE, which we can obtain by the estimation. We first examine MAC–level QoS by simulation in the case where wireless stations transmit audio and video flows to an access point (AP) in the presence of transmission errors. We then assess QoE by the method of successive categories, which is a psychometric method, and perform QoS mapping between MAC–level and user–level with multiple regression analysis. As a result, we obtain multiple regression lines which estimate QoE from MAC–level QoS. Furthermore, we evaluate the effect of content types on the QoE by using estimated values from MAC–level QoS.**

I. Introduction

With increasing demands for multimedia applications like voice over IP and streaming video, the mechanisms to support *Quality of Service (QoS)* are becoming more essential for wireless local area networks (LANs). The IEEE 802.11 Task Group E has developed an enhancement of the legacy IEEE 802.11 MAC to support QoS requirements for multimedia transmission [1]. In the IEEE 802.11e MAC, *enhanced distributed channel access (EDCA)* and *HCF controlled channel access (HCCA)* have been defined. The EDCA is a contention–based protocol based on *carrier sense multiple access with collision avoidance (CSMA/CA)* and can support relative priority services for multimedia transmission. The HCCA is a polling–based protocol and can support QoS guarantee services. In this paper, we study the audio–video transmission with the EDCA and focus on a *basic service set (BSS)* of an infrastructure wireless LAN, which includes an *access point (AP)* and stations associated with the AP.

For multimedia services over wireless LANs, we should consider QoS at each level of the protocol stack. Reference [2] identifies six levels of QoS in IP networks: *physical–level, node(link)–level, network–level, end-to-end level, application–level*, and *user–level*. In multimedia applications, user–level QoS is the most important since the final goal of multimedia services is to provide high user–level (perceptual) QoS for the end–users; this is also referred to as *Quality of Experience (QoE)* in ITU–T [3]. However, it is difficult to control QoE directly because it is perceptual. Therefore, we need to control QoS at lower–levels to achieve high QoE. This requires us to find the relation between lower–level QoS and QoE. As a first step toward this kind of study, this paper establishes a method of estimating QoE from MAC–level QoS in audio–video transmission over an IEEE 802.11e EDCA wireless LAN.

The performance of the EDCA has already been studied by many researchers [4]–[9]. In [4] and [5], the effectiveness of the *transmission opportunity (TXOP)–bursting* is evaluated. The TXOP–bursting allows a station to send multiple *MAC Protocol Data Unit (MPDU)* during a TXOP if the station succeeds in sending the first frame. Reference [6] evaluates the performance of streaming MPEG–4 video through experimental investigation in the case where the I, P, and B frames of the video stream are transmitted through different *access categories (ACs)*. A dynamic assignment scheme of the TXOP maximum duration named *DTXOP* is proposed in [7]. The *Block Acknowledgment (Block ACK)* mechanism has been examined in [8] and [9]. This mechanism improves channel efficiency by aggregating several acknowledgments into one MAC frame and can reduce the overhead due to ACK transmission.

All the papers mentioned above focus mainly on MAC–level QoS; that is, the performance of the EDCA is evaluated in terms of MAC–level QoS parameters such as throughput and MPDU delay. However, it may be difficult to grasp the QoE only by MAC–level QoS since the QoE depends on other factors including content types. In addition, data processing at upper levels can affect the QoE. For example, in continuous media transmission, media synchronization control at the application–level can improve the QoE [10].

With regard to QoS at upper levels, reference [7] evaluates application–level QoS of video transmission, using *Peak Signal–to–Noize Ratio (PSNR)* as well as MAC–level QoS. In addition, the authors have studied application–level QoS and user–level QoS (QoE) of audio–video transmission with the EDCA in [10] and [11]. Furthermore, in [12], the authors' research group has proposed a method of feasibility test for QoS control based on mapping between application–level QoS and user–level QoS with *multiple regression analysis*. However, to the best of the authors' knowledge, there is no publication that performs QoE estimation from MAC–level QoS in the IEEE 802.11e EDCA wireless LANs, though MAC–level QoS of the EDCA has been evaluated by many researchers. In addition, the effect of content types on the QoE has not been examined in [10] through [12].

In this paper, we first evaluate MAC–level QoS of the EDCA by simulation. We examine it in the case where audio and video streams are transferred from wireless stations to the AP with the TXOP–bursting and the Block ACK mechanism in the presence of transmission errors. We investigate the MAC–level QoS for various values of the distance between the AP and wireless stations. In our study, an increase of the distance means a larger value of *bit error rate (BER)*. We use six contents to examine the effect of content types on the QoS.

We then assess QoE on the basis of subjective experimental results and perform QoS parameters mapping between MAC–level and user–level with multiple regression analysis. Since QoE is directly related to human perception, we utilize a psychometric method referred to as the *method of successive categories* [13]. As a result, we obtain *multiple regression lines* to estimate the QoE parameter from MAC–level QoS parameters. Furthermore, we evaluate the effects of the bit error rate, the number of multimedia stations, and the content types on the QoE by using the estimated values.

The rest of the paper is organized as follows. Section II specifies simulation conditions used for the assessment of MAC–level QoS. Section III gives numerical results of the

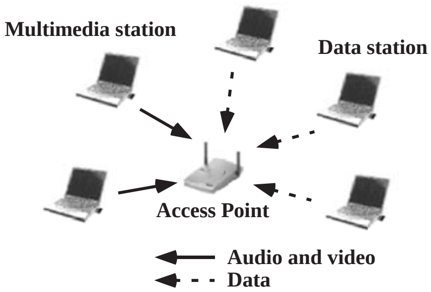

Fig. 1. System Configuration

MAC–level QoS by simulation. Section IV assesses the QoE by a subjective experiment and calculates multiple regression lines by carrying out QoS mapping between MAC–level and user–level. This section also evaluates the QoE by using estimated values. Finally, Section V gives a conclusion of this paper.

II. Simulation Conditions

This paper evaluates the MAC–level QoS by simulation with *ns2 (network simulator version 2)* [14]. In this section, we show simulation conditions used for the assessment.

Figure 1 illustrates the system configuration used in the simulation. We focus on a single BSS which consists of an AP, multimedia stations, and data stations. The number of multimedia stations and that of data stations are denoted by M and M_D, respectively. All multimedia and data stations are located at the same distance (say R) from the AP.

In the simulation, we assume that a pair of audio (voice) and video streams is transferred from each multimedia station to the AP in the uplink direction. The audio and video are transmitted as two separate transport streams by using UDP/IP. Table I shows the specifications of the audio and video in the simulation. We use an audio flow of ITU-T G.711 μ-law and an H.264 video flow. An audio MU consists of 1000 audio samples and is transferred as one UDP datagram [1]. A video MU is defined as a video frame, and we assume that a video frame is divided into 15 slices and one video slice is transferred as one UDP datagram. The header size of a UDP datagram and an IP datagram are 8 bytes and 20 bytes, respectively. We also assume that a video MU is not output at the recipient unless all MPDUs of the MU are received correctly.

We use six contents in the simulation: *Music Video*, *News*, *Sport1*, *Sport2*, *Animation*, and *Movie*. Note that *Music Video* and *News* are audio–dominant, while *Sport1* and *Sport2* are video–dominant. Both audio and video are important for *Animation* and *Movie*. Outlines of the six contents are as follows.

- *Music video*: Scenes of a female singer singing with dancing.
- *News*: A newscaster and a commentator are talking to each other.
- *Sport1*: Scenes of figure skating by a female skater with background music and a commentator's voice.
- *Sport2*: Scenes of a tennis game by two female players. The audio includes only strokes.

[1]An MU stands for a "media unit", which indicates the information unit that is delivered from a source station to a destination station at the application–level.

TABLE I
Specifications of audio and video

	Audio	Video
coding scheme	G.711 μ–law	H.264
image size [pixel]	–	320 × 240
picture pattern	–	I
average MU rate [MU/s]	8	20
average inter-MU time [ms]	125	50
average bit rate [kb/s]	64	600
measurement time [s]	15	15

TABLE II
Parameters of the EDCA

media	AC	$AIFS$[μs]	CW_{min}	CW_{max}
audio	3	50	7	15
video	2	50	15	31
data	1	70	31	1023

- *Animation*: Scenes of a man speaking to a robot, and many cars are passing behind them.
- *Movie*: Scenes of a boy moving around rapidly with background music.

The data stations generate fixed–size UDP datagrams of 1472 bytes each in its payload at exponentially distributed intervals and send them to the AP. The average load per data station is 1000 kbps.

Table II shows parameter values of the EDCA used in the simulation. These are default parameter values specified in the IEEE 802.11b standard for the *direct sequence spread spectrum (DSSS)* with a channel data rate of 11 Mb/s [15].

In the simulation we utilize the free space model of ns2 as the propagation model [16]. In ns2, the signal strength of an MPDU can be calculated by the propagation model and distance between the transmitter and receiver. In calculating SNR, we assume the receiver noise strength based on Orinoco 802.11b Card [16].We also use an empirical curve of BER versus SNR provided by Intersil wireless LAN chipset [17].

We make the following assumptions in the simulation. When a station generates one or more MPDUs, it first transmits a *Request To Send (RTS)* frame to the AP. If the station cannot receive a *Clear To Send (CTS)* frame, it goes into backoff and contends for the medium again. If the station succeeds in exchanging the RTS/CTS frames of access category AC, it obtains a TXOP and retains the medium for an interval of $TXOP_{Limit}[AC]$. During a TXOP, the station can send more than one MPDU utilizing the immediate Block ACK mechanism. The maximum number of MPDUs transferred as one block is four. If the station fails to send an MPDU because of transmission error, it retransmits the MPDU. The maximum allowable number of retransmissions of a MPDU is four. Each source buffer at the MAC layer in a station can accommodate a maximum of 300 MPDUs; a newly generated MPDU is discarded if its buffer does not have space to accommodate the MPDU. In addition, a multimedia station drops a voice or video MPDU if it cannot finish to send the MPDU within 160 ms from the generation time.

The duration of each simulation run was taken to be 15 sec. We calculated the 95-percent confidence intervals of the simulation results. However, we do not show them in the following figures because the interval is smaller than the size of the corresponding simulation symbol.

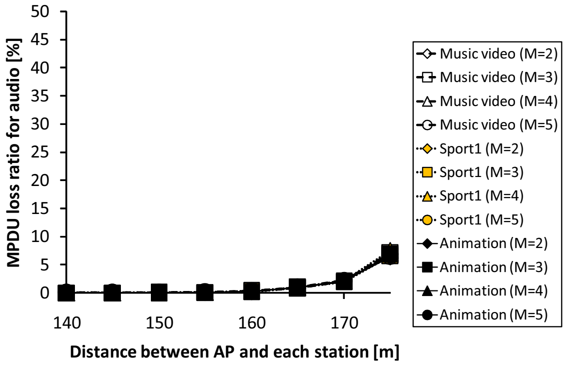

Fig. 2. MPDU loss ratio for audio versus distance between AP and each station.

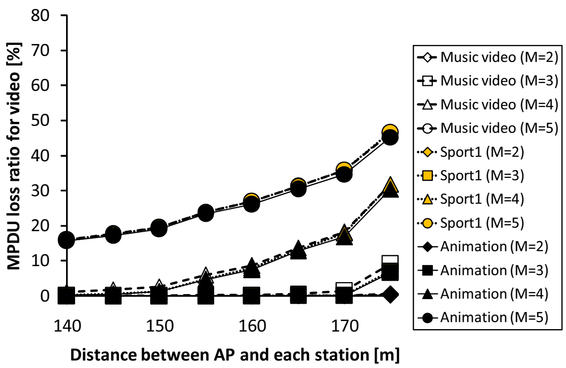

Fig. 3. MPDU loss ratio for video versus distance between AP and each station.

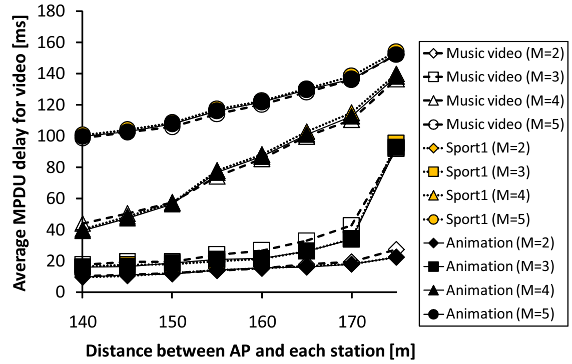

Fig. 4. Average MPDU delay for video versus distance between AP and each station.

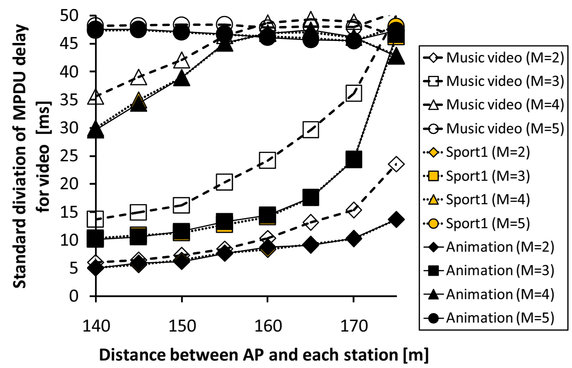

Fig. 5. Standard deviation of MPDU delay for video versus distance between AP and each station.

III. MAC–LEVEL QOS ASSESSMENT

In this section, we present simulation results of the MAC–level QoS of audio–video transmission with the EDCA. We have evaluated the MAC–level QoS for the six contents. However, in the following numerical results, we will show only *Music video*, *Sports1*, and *Animation* because of space limitations. We suppose the number of data stations M_D=3 and plot four cases of the number of multimedia stations, namely, M=2, 3, 4, and 5, for each of the three contents. We also set $TXOP_{Limit}$[1]=0 ms, $TXOP_{Limit}$[2]=6.016 ms, and $TXOP_{Limit}$[3]=3.264 ms. $TXOP_{Limit}$=0 ms means that the TXOP–bursting scheme is not used.

A. MAC–level QoS parameters

In this paper, we adopt ten MAC–level QoS parameters. First, we use the *MPDU loss ratio*. This parameter is denoted by L_a for audio and L_v for video. The MPDU loss ratio indicates the ratio of the number of MPDUs lost to the number of MPDUs generated by stations. Second, we use *throughput* for audio T_a and that for video T_v. The throughput is defined as the average number of bits delivered from a station to the AP per second. Third, we adopt the *average MPDU delay* for audio D_a and that for video D_v. The average MPDU delay means the average time from the moment an MPDU is generated at a station until the moment the MPDU is received at the AP. Finally, we treat the *variance of MPDU delay* for audio V_a and that for video V_v. We also use the *standard deviation of MPDU delay* for audio J_a and that for video J_v.

B. Simulation results

Figure 2 shows the MPDU loss ratio for audio as a function of the distance R between the AP and each station. In Figs. 3, 4, and 5, we plot the MPDU loss ratio, average MPDU delay, and standard deviation of MPDU delay for video versus R, respectively. The distances 140 m, 145 m, 150 m, 155 m, 160 m, 165 m, 170 m, and 175m correspond to BER=$1.3 * 10^{-5}$, $1.8 * 10^{-5}$, $2.4 * 10^{-5}$, $3.1 * 10^{-5}$, $4.1 * 10^{-5}$, $5.6 * 10^{-5}$, $7.0 * 10^{-5}$, and $1.0 * 10^{-4}$, respectively.

First, we discuss the audio quality of the EDCA, using Fig. 2. Figure 2 shows that the values of the MPDU loss ratio for audio become almost 0 for all the values of M to be shown when R is less than or equal to 160 m. However, this figure also indicates that MPDU loss ratio begins to increase when R exceeds 160 m. This is because multimedia stations cannot transmit audio MPDUs within the maximum allowable number of retransmissions due to channel transmission error.

We have confirmed through simulation that the average MPDU delay and standard deviation of MPDU delay for audio become slightly larger as R increases since a larger value of BER leads to an increase of retransmission traffic. However, We have also confirmed that the average MPDU delay and standard deviation of MPDU delay for audio are less than 40 ms even if R=175 m and M=5. Audio transmission is given higher priority than video and data transmission. Therefore, audio quality is kept relatively high on heavy traffic conditions.

We next discuss the video quality, referring to Figs. 3 through 5. These figures show that a larger value of R

leads to lower video quality. In addition, we can observe in Figs. 3 through 5 that the video quality is highly affected by the number of multimedia stations M. In particular, the MPDU loss ratio becomes more than 15 % and the average MPDU delay becomes more than 100 ms if M=5. When M=5, the wireless channel is saturated owing to excessive contention. Therefore, many video MPDUs are dropped at the source stations because of the maximum allowable number of retransmissions and the delay limit. Figure 3 also indicates that the MPDU loss ratio for video at M=4 begins to increase if R exceeds 150 m.

It should be noted that in Figs. 2 through 5, the MAC–level QoS is almost the same for the three contents except the standard deviation of MPDU delay for video of *Music video*. Figure 5 indicates that the standard deviation of *Music video* is slightly larger than that of *Sport1* and *Animation*. This is because the variance of video MPDU length is larger in the case of *Music video*.

IV. QoE estimation

In this section, we first calculate the QoE parameters for audio–video transmission with the EDCA on the basis of subjective experimental results; we utilize a psychometric method referred to as the method of successive categories. We then perform QoS mapping between MAC–level and user–level with multiple regression analysis and obtain multiple regression lines to estimate the QoE parameter from the MAC–level QoS parameters. Furthermore, we assess the QoE by using the estimate values.

A. QoE measurement by a subjective experiment

The subjective experiment was conducted as follows. We first made test samples for subjective assessment by actually outputting the audio and video MUs with the output timing obtained from the simulation for the six contents. In the assessment, we use a PC with headphones and a 17 inch–LCD display. The number of assessors is 30, and their ages were 20s. We used five categories of *impairment* of the *rating–scale method*; that is, each assessors was shown the test samples and was asked to classify each sample into the following five categories with their scores: “imperceptible” assigned score 5, “perceptible, but not annoying” 4, “slightly annoying” 3, “annoying” 2, and “very annoying” 1.

As the QoE parameter, we utilize the *psychological scale* instead of the *mean opinion score (MOS)*, which is often used in subjective assessment. It should be noted that the MOS is an *ordinal scale*; the integers (namely, scores) assigned to the categories only have a greater-than-less-than relation between them. On the other hand, the psychological scale is an *interval scale*; an interval between the scale values means a distance between amounts of the sensory attribute measured [13].

From the scores obtained by the rating–scale method, we calculated the interval scale as the QoE parameter by the *law of categorical judgment* as in [13]. For the comparison of the interval scale, we applied the law of categorical judgment to the measurement results of the six contents by the rating–scale method all together. To verify the obtained interval scale, we performed Mosteller’s test. As a result of the Mosteller’s test, by removing some values, we were not able to reject the hypothesis that the obtained interval scale fits the observed data at a significance level of 0.01; therefore, we use the interval scale as the psychological scale. We selected the minimum value of the psychological scale as the origin. Thus, we obtained the lower boundary of each category as 3.955 for category 5, 2.831 for category 4, 1.909 for category 3, and 0.653 for category 2.

TABLE III

PRINCIPAL COMPONENT LOADING

	First principal component	Second principal component	Third principal component
L_a	0.464	-0.877	0.064
T_a	-0.351	0.924	-0.104
D_a	0.994	0.039	0.035
V_a	0.981	0.031	-0.173
J_a	0.991	0.100	0.027
L_v	0.942	0.021	-0.332
T_v	-0.944	-0.017	0.325
D_v	0.989	0.107	0.027
V_v	0.909	0.238	0.326
J_v	0.897	0.229	0.376

TABLE IV

CLASSIFICATION OF MAC–LEVEL QOS PARAMETERS

group A	group B	group C
L_a, T_a	D_a, V_a, J_a, D_v	L_v, T_v, V_v, J_v

B. QoE estimation from MAC–level QoS

Next, we perform QoS mapping between MAC–level and user–level with multiple regression analysis as in [13]. In the analysis, we consider that the MAC–level QoS parameters are the *predictor variables* and the QoE parameter is the *criterion variable*.

Before we apply the multiple regression analysis, we carry out the *principal component analysis* to decrease the number of predictor variables [13]. As a result of the principal component analysis, we adopted the first three principal components since the cumulative contribution rate for the first three principal components becomes 99.262 %. Table III shows the principal component loading of each principal component. From this Table, we find that the ten MAC–level QoS parameters can be classified into three groups as shown in Table IV.

We then performed multiple regression analysis of all combinations of the predictor variables under the condition that one predictor variable is selected from each group. The predictor variables of the adopted combination were statistically tested whether they make significant contributions to the multiple regression line. As a result, we removed the predictor variables in group C since those variables do not make any significant contributions and again performed multiple regression analysis. Finally, we found combinations of the MAC–level QoS parameters which make the highest contribution rate adjusted for degrees of freedom.

The obtained multiple regression lines for *Music video*, *News*, *Sport1*, *Sport2*, *Animation*, and *Movie* are as follows:

$$\hat{S}_{Music} = 3.727 - 0.295 \times L_a - 0.013 \times D_v \quad (R^{*2} = 0.935) \tag{1}$$

$$\hat{S}_{News} = 3.758 - 0.243 \times L_a - 0.011 \times D_v \quad (R^{*2} = 0.921) \tag{2}$$

$$\hat{S}_{Sport1} = 3.877 - 0.137 \times L_a - 0.021 \times D_v \quad (R^{*2} = 0.920) \tag{3}$$

$$\hat{S}_{Sport2} = 4.101 - 0.076 \times L_a - 0.022 \times D_v \quad (R^{*2} = 0.953) \tag{4}$$

$$\hat{S}_{Animation} = 3.746 - 0.228 \times L_a - 0.012 \times D_v \quad (R^{*2} = 0.878) \tag{5}$$

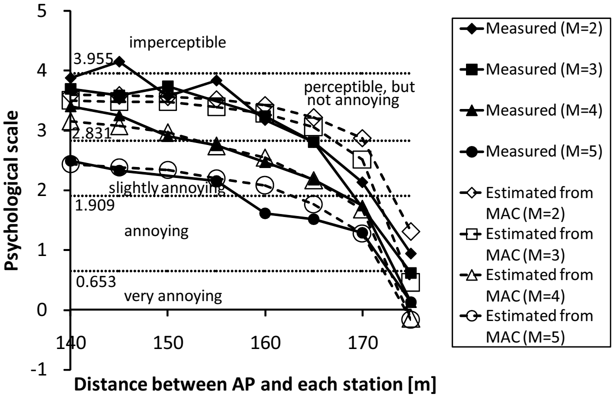

Fig. 6. The psychological scale versus the distance (Music video).

$$\hat{S}_{Movie} = 3.977 - 0.140 \times L_a - 0.018 \times D_v \quad (R^{*2} = 0.933) \tag{6}$$

In the above equations, $\hat{S}$ represents the estimate of the psychological scale and its subscript means content type, while R^{*2} denotes the contribution rate adjusted for degrees of freedom. From these equations, we can calculate the estimated values of the psychological scale from the MAC–level QoS parameters.

We notice from the above equations that the values of the regression coefficient of L_a in Eqs. (1) and (2) are larger than those in the other equations. This makes us confirm that *Music video* and *News* are more sensitive to the audio quality than the other types of contents. On the other hand, we also see that the values of the regression coefficient of D_v in Eqs. (3) and (4) are larger than those in the other equations since *Sport1* and *Sport2* are video–dominant.

C. Numerical results

We then examine the psychological scale of audio–video transmission with the EDCA. Figures 6, 7, and 8 show the estimated values of the psychological scale along with the measured ones as a function of R for *Music Video*, *Sport1*, and *Animation*, respectively. In these figures, we selected the minimum measured value of the psychological scale as the origin of the ordinate, and each of four horizontal dotted lines indicates the boundary of a category. In Figs. 6 through 8, we show the results of the four values of M for each of *Measured* and *Estimated from MAC*. *Measured* means the values of the psychological scale calculated from the subjective experimental results. On the other hand, *Estimated from MAC* represents the estimated values of the psychological scale from the MAC–level QoS parameters.

We now discuss the estimated values of the psychological scale using Figs. 6 through 8. From these figures, we find that the psychological scale becomes smaller as the distance increases. This implies that the QoE deteriorates as BER becomes larger.

We next examine the effect of content types on the QoE. We notice in Figs. 6 through 8 that in the case of M=5, the estimated values of the psychological scale for *Sport1* become lower than those for *Music video* and *Animation* if $R < 175$ m. Fig. 3 shows that MPDU loss ratio for video at M=5 becomes more than 15 %. Therefore, the psychological scale for *Sport1* deteriorates more drastically than that for *Music video* and *Animation* since *Sport1* is more sensitive to the video quality than the others. In the case of M=5 and R=175 m, the QoE for all the three contents becomes very low. This is because the audio quality as well as video quality deteriorates. In Fig. 2, we find that MPDU loss ratio for audio becomes about 6 % when R=175 m. We also notice in Figs. 6 through 8 that the estimated value of the psychological scale at M=2 and R=175 m for *Music video* becomes lower than that for *Animation* and *Sport1*. *Music video* is audio–dominant. Therefore, the QoE for *Music video* deteriorates more drastically than that for the other contents if MPDU loss ratio for audio increases. It should be noted in Fig. 3 that in the case of M=2, video MPDU loss does not occur.

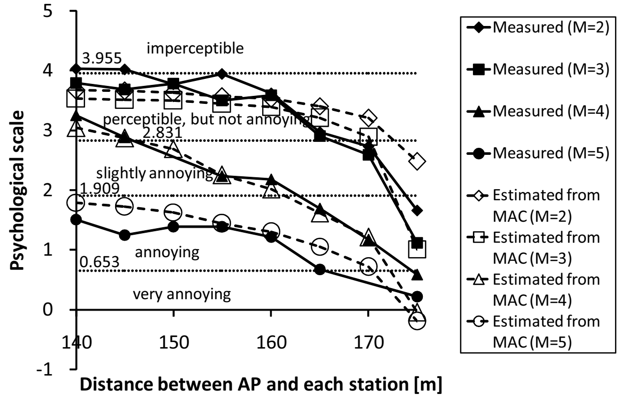

Fig. 7. The psychological scale versus the distance (Sport1).

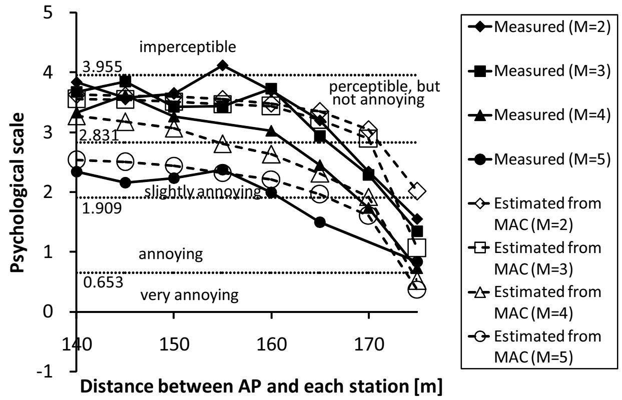

Fig. 8. The psychological scale versus the distance (Animation).

Now, we examine the effect of the $TXOP_{Limit}$[2] on the psychological scale. Figures 9 and 10 reveal the psychological scale versus the $TXOP_{Limit}$[2] in the case of *Music video* and *Sport1*, respectively. We calculated the psychological scale as a function of $TXOP_{Limit}$[2] after we obtained multiple regression lines by the method of QoS mapping described in the previous subsection. These figures show four cases: (M, R) = (2, 150), (4, 150), (2, 170), and (4, 170), for each of the *Measured* and *Estimated from the MAC*. We set $TXOP_{Limit}$[1]=0 ms and $TXOP_{Limit}$[3]=3.264 ms, and show seven values of $TXOP_{Limit}$[2]: 0 ms, 3.008 ms, 4.080 ms, 6.016 ms, 8.160 ms, 12.032 ms, and 16.352 ms.

We here discuss the effect of $TXOP_{Limit}$[2] on the estimated values of the psychological scale. In the case of M=2, Figs. 9 and 10 represent that the estimated values of the psychological scale for both R=150 m and 170 m keep approximately the maximum if $TXOP_{Limit}$[2] is greater than or equal to 3.008 ms. This means that 3.008 ms is enough

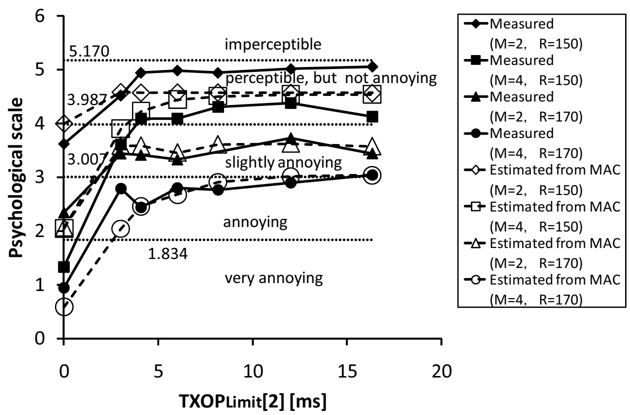

Fig. 9. The psychological scale versus $TXOP_{Limit}[2]$ (Music video).

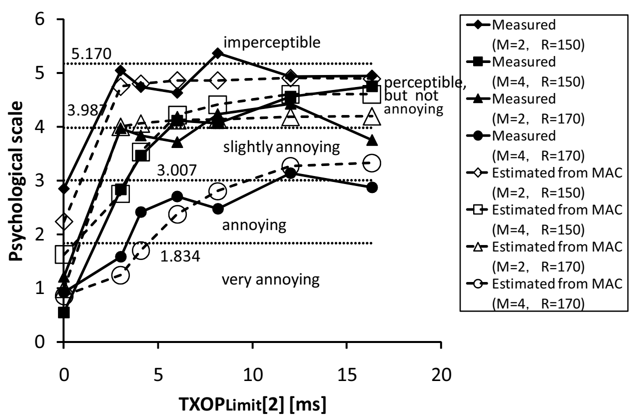

Fig. 10. The psychological scale versus $TXOP_{Limit}[2]$ (Sport1).

duration of $TXOP_{Limit}[2]$ to achieve high QoE. On the other hand, we see in Figs. 9 and 10 that the psychological scale for the two contents at M=4 takes small values if the value of $TXOP_{Limit}[2]$ is too small. Therefore, we should select enough duration of $TXOP_{Limit}[2]$ to achieve high QoE. We can obtain from these figures that in the case of M=4 and R=150 m, the minimum value of $TXOP_{Limit}[2]$ which makes the estimated QoE "perceptible but not annoying" is 4.080 ms for *Music video* and 6.016 ms for *Sport1*. This result indicates that *Sport1* needs longer duration of $TXOP_{Limit}[2]$ than *Music video* to achieve high QoE since the effect of video degradation on the QoE for the former is larger than that for the latter. We also observe in Fig. 9 that the psychological scale for *Music video* is approximately the same if $TXOP_{Limit}[2]$ is greater than or equal to 8.160 ms when M=4 and R=170 m. On the other hand, Fig. 10 shows that in the case of *Sport1*, the value of the psychological scale for M=4 and R=170 m becomes smaller if $TXOP_{Limit}[2]$ decreases below 12.032 ms.

These results mean that an appropriate value of $TXOP_{limit}[2]$ depends on content types as well as the number of multimedia stations and the bit error rate.

V. Conclusions

This paper performed QoE estimation from MAC–level QoS for audio–video transmission over an IEEE 802.11e EDCA wireless LAN. We first examined MAC–level QoS by simulation. In the assessment, we assumed that wireless stations transmit audio and video flows to an AP in the presence of transmission errors. We then carried out QoS mapping between MAC–level and user–level with multiple regression analysis and obtained multiple regression lines to estimate QoE from MAC–level QoS. Furthermore, we examined the QoE by using the estimate values of the psychological scale. Numerical results indicated that the values of the psychological scale can be different depending on content types. Therefore, to achieve high QoE we should select the value of $TXOP_{Limit}[2]$, considering content types.

In this paper, we estimated the QoE parameter from the MAC–level QoS parameters. However, the MAC–level QoS parameters cannot reflect processing of received media at higher layer such as buffering control of MU's, which affects QoE. Therefore, our future work includes QoE estimation from application–level QoS parameters. In the case of application–level QoS parameters, media synchronization quality of received audio–video stream can be taken into consideration, for instance. We should also perform QoE estimation for other video coding rates and physical data rates.

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