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An unequal error protection mechanism for video streaming over IEEE 802.11e WLANs

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ABSTRACT

A Cross-Layer Mapping Unequal Error Protection (CLM-UEP) mechanism is proposed for video streaming over IEEE 802.11e wireless networks. In the proposed approach, the transmitted video frames are assigned a different number of redundant packets in accordance with their video coding significance. An adaptive cross-layer mapping algorithm is then applied in the Media Access Control (MAC) layer to map the video and redundant packets to appropriate Access Category (AC) queues based on their coding significance and the network load. The numerical results show that the UEP mechanism provides an effective protection against wireless transmission losses. Moreover, the CLM algorithm maximizes the utilization efficiency of the AC queues and minimizes network congestion. As a result, a significant improvement is obtained in both the Playable Frame Ratio (PFR) and the peak signal-to-noise ratio of the transmitted video.

1. Introduction

Wireless network technology has advanced rapidly in recent years and is now widely regarded as the method of choice for surfing the Internet, receiving and sending e-mails, listening to music, watching video streams, and so on using notebooks, mobile phones or other handheld devices. However, IEEE 802.11, which is one of the most widely used wireless network technologies in the world, provides only limited Quality of Service (QoS) support. Accordingly, the IEEE 802.11e standard [1] has been proposed with an improved ability to support differentiated services by means of multiple MAC layer queues with different access priorities.

Due to the effects of channel fading, scattering and interference, the packet loss rate in wireless channels is higher than that in wired networks. Thus, for applications such as video streaming, the perceived quality of the received content is significantly reduced [2–7]. Accordingly, the literature contains many proposals for mitigating the effects of packet losses in wireless networks. For example, in the Automatic Retransmission reQuest (ARQ) scheme [8,9], the sender retransmits the frames/packets at regular intervals until it receives an acknowledgment message from the receiver or has performed a pre-specified number of retransmissions. However, ARQ results in a large transmission delay, and is therefore unsuitable for delay-sensitive applications such as video streaming. In the Forward Error Correction (FEC) scheme [10–14], additional packets are injected into the network together with the source packets such that the receiver can correct errors once they are detected without the need for retransmissions. However, FEC does not provide a priority protection service. In other words, all of the frames/packets transmitted by the sender are assigned the same level of protection, irrespective of their coding significance.

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In video coding formats such as MPEG-4 and H.264, the video frames are assigned differing levels of importance in accordance with the coding dependency between them. For example, intra-frames are regarded as being more important than inter-frames. Several researchers have exploited this fact to improve upon the limitations of the traditional FEC method by developing Unequal Error Protection (UEP) mechanisms to support loss recovery utilizing different redundancy rates. For example, Shih and Tsai [15] proposed a slice-based UEP mechanism which provides UEP at the Macroblock (MB) level. However, slice-based UEP mechanisms are unsuitable for applications such as real-time video streaming since the processing time required to distinguish the significance of each MB in each frame leads to an unacceptable delivery delay. In [16,17], Ha et al. proposed a layer-based UEP scheme in which a greater degree of protection is provided to the base layer. While the results showed that the scheme yields a significant improvement in the perceived quality of the received video, it is applicable only to scalable video streaming applications. Wu et al. [18] proposed a frame-based UEP mechanism designed to provide the optimal degree of redundancy for each video frame. However, the effects of network congestion were not considered.

Accordingly, this paper proposes a Cross-Layer Mapping with Unequal Error Protection (CLM-UEP) mechanism to improve the quality of video streaming over IEEE 802.11e wireless networks. In the proposed approach, a UEP controller is applied at the application layer to assign a different level of protection to frames of different types in accordance with the current packet loss rate. A CLM algorithm is then applied at the MAC layer to allocate the coded video packets to an appropriate AC queue. Notably, the CLM algorithm provides an adaptive mapping function. That is, when a higher priority queue is almost full, the CLM algorithm directs incoming packets to a lower priority queue in order to avoid congestion losses.

The remainder of this paper is organized as follows. Section 2 reviews the IEEE 802.11e standard, the MPEG-4 video structure and the basic concepts of FEC and UEP. In addition, the related work is reviewed and the contributions of the present study defined. Section 3 outlines the proposed CLM-UEP mechanism and illustrates the analytical model used to evaluate the Playable Frame Ratio at the receiver end. Section 4 presents and discusses the simulation results. Finally, Section 5 provides some brief concluding remarks and indicates the intended direction of future research.

2. Related works

2.1. IEEE 802.11e EDCA

The IEEE 802.11e EDCA (Enhanced Distributed Channel Access) function defines four Access Categories (ACs), each with four key parameters, namely the Arbitration Inter-Frame Space Number (AIFSN), the minimum Contention Window size (CW_{min}), the maximum Contention Window size (CW_{max}), and the Transmission Opportunity limit ($TXOP_{limit}$). As shown in Fig. 1, the four ACs are used for different types of network traffic, namely AC_VO (voice traffic), AC_VI (video traffic), AC_BE (best effort traffic) and AC_BK (background traffic). Furthermore, as shown in Table 1, to support traffic streams with different QoS requirements, the four ACs are assigned different access priorities and different values of the four key parameters For example, the AC_VO channel has the smallest values of the AIFS, CW_{min} and CW_{max} parameters; and therefore has the greatest probability of gaining access to the wireless medium. Moreover, the higher priority ACs have a longer $TXOP_{limit}$, i.e., a bounded interval defined by the starting time and a maximum duration, during which a station is permitted to transmit multiple frames [19,20].

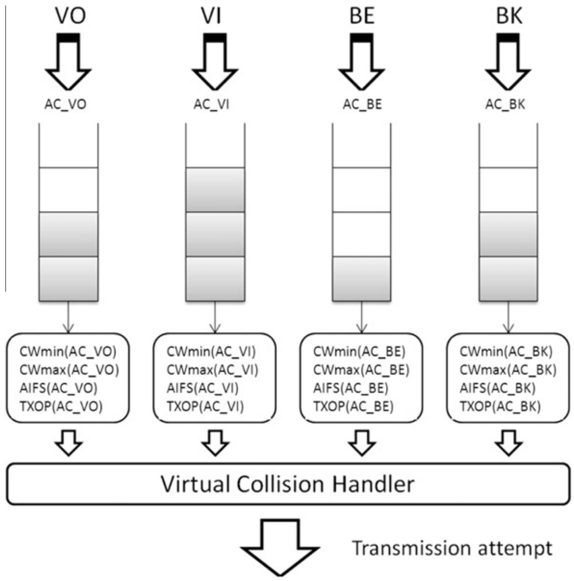

Fig. 1. Four access categories in IEEE 802.11e.

2.2. MPEG-4 overview

In MPEG-4 video coding, the encoded video stream comprises a series of consecutive Group of Picture (GOP) each of which contains a series of consecutive frames. Each GOP comprises three different types of frame, namely I-frames, P-frames and B-frames. The I-frames (intra-coded pictures), are coded independently of any of the other frames in the GOP. By contrast, the P-frames (predictive coded pictures), are coded based on information relating to the previous I- or P-frame. In other words, if the previous I- or P-frame cannot be recovered, the P frame is also undecodable. Finally, the B-frames (bi-directionally predictive coded pictures) are coded based on information relating to the previous or subsequent I- or P-frame. Thus, if the previous or subsequent I- or P-frame cannot be recovered, the B frame is also unrecoverable.

The GOP structure is annotated as G (N, M), where N is the I-to-I frame distance and M is the I-to-P frame distance. For example, the structure of the GOP shown in Fig. 2, comprising one I-frame, two P-frames and six B-frames, is annotated as G (9, 3). Due to the coding dependency of MPEG-4, packet losses within an I- or P-frame may result

Table 1
IEEE 802.11e EDCA parameter set [1].

Priority	Access category	Designation	AIFSN	CW_{min}	CW_{max}	$TXOP_{limit}$
High	AC_VO	Voice	2	7	15	0.003008
↑	AC_VI	Video	2	15	31	0.006016
↓	AC_BE	Best effort	3	31	1023	0
Low	AC_BK	Background	7	31	1023	0

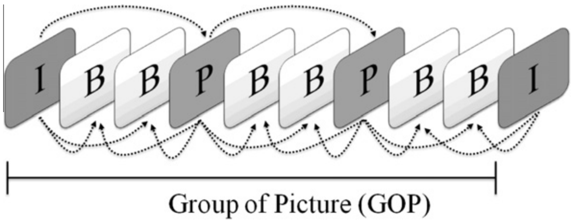

Fig. 2. Typical MPEG group of picture ($N = 9$ and $M = 3$).

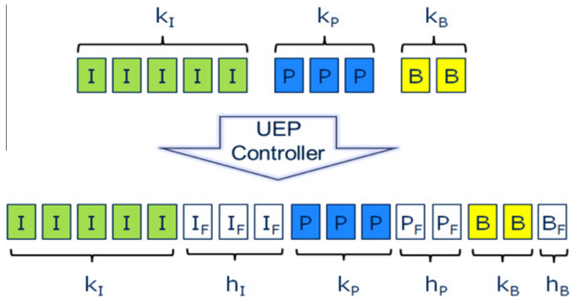

Fig. 4. Unequal Error Protection (UEP) loss recovery mechanism.

in more than one frame (or even an entire GOP) being lost. However, the loss of a B-frame has no significant effect on the quality of the received video [21,22].

2.3. FEC and UEP mechanisms

In the traditional FEC loss recovery mechanism, the k source packets are encoded on the sender side into n packets, as illustrated in Fig. 3. In other words, a total of $(n - k)$ redundant packets are added to the original source packets and injected into the network. Thus, the original source packets can be successfully recovered at the receiver side provided that a minimum of k packets are received, irrespective of whether the received packet are source or redundant packets.

The Unequal Error Protection (UEP) mechanism proposed in [18] provides a differential level of protection to different frames in accordance with their relative coding importance. In MPEG-4 video streaming, the frames are ranked in order of diminishing importance as follows: I-frame > P-frame > B-frame. Consider the example shown in Fig. 4, in which an I-frame is fragmented into five packets, while the P- and B-frames are fragmented into three and two packets, respectively. In accordance with the UEP mechanism proposed in [18], three redundant packets are added to the I-frame, two redundant packets are added to the P-frame, and one redundant packet is added to the B-frame. In other words, the UEP mechanism enhances the probability of the more critical frames being successfully recovered by scaling the degree of redundancy accordingly.

In practice, the importance of the data transmitted by the sender can be considered at different levels of the data structure, and thus various UEP mechanisms have been proposed, including slice-based [15], layer-based [16,17] and frame-based [18]. Shih and Tsai [15] proposed a UEP scheme in which each video frame was divided into Macroblocks (MBs), and the MBs were then mapped to slice groups (SGs); each with a different degree of protection. However, determining the optimal mapping of the MBs to the SGs is computationally complex, and the resulting delay reduces the quality of the received video stream. Ha et al. [16,17] proposed a layer-based UEP scheme for scalable video streaming applications. In scalable video streaming, the video stream is divided into several layers, i.e., the base layer and a number of enhancement layers. The base layer is more important than any of the enhancement layers since if the base layer is not decodable, none of the enhancement layers can be decoded either. Consequently, in the scheme proposed in [16,17], a higher level of protection was assigned to the base layer. However, in the event of network congestion, it is difficult for layer-based UEP schemes to drop the packets in the order of the coding importance due to the layered architecture of the coded video stream. Wu et al. [18] proposed a frame-based UEP scheme, designated as Adjust Forward

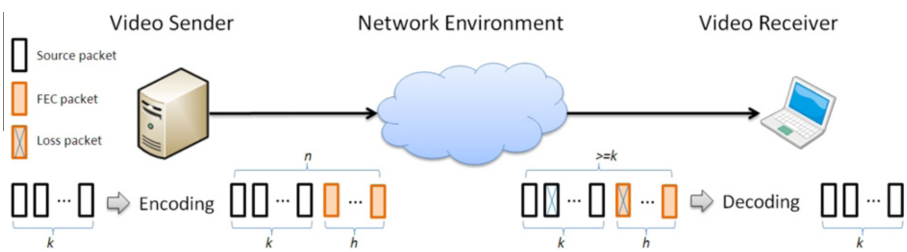

Fig. 3. Forward Error Correction (FEC) loss recovery mechanism.

Error Correction (AFEC), to provide the optimal degree of redundancy for each video frame in TCP-Friendly MPEG streaming. However, AFEC ignores the effects of network congestion and the bit rate constraint in TCP-Friendly schemes.

2.4. Queue mapping mechanisms

When transmitting video traffic, IEEE 802.11e always assigns the video packets to the AC_VI queue. In the event that the AC_VI queue is almost full, incoming video packets are simply dropped; even if space is available at the other AC queues. Ksentini et al. [23] proposed a static mapping algorithm to support the provision of differentiated QoS services and to avoid congestion at the AC_VI queue by mapping the incoming video packets to different ACs in accordance with their coding significance. Specifically, the I-frames/packets, P-frames/packets, and B-frames/packets were mapped to the AC_VI, AC_BE and AC_BK queues, respectively. However, the static mapping approach results in a poor utilization of the AC queue space. For example, if the AC_VI channel has only a light load (i.e., the queue is almost empty), the P-frame and B-frame packets are still mapped to the lower priority queues, and thus their transmission is unnecessarily delayed. Thus, in [21], an adaptive cross-layer mapping scheme was proposed in which the video packets were mapped dynamically to the most appropriate AC queue in accordance with both their coding significance and the network traffic load in the MAC layer.

2.5. Contributions of present study

The major contribution of the present study is to propose Cross-Layer Mapping Unequal Error Protection (CLM-UEP) mechanism for improving the quality of video transmissions over IEEE 802.11e WLANs. The literature contains many proposals for unequal error protection schemes [15–17], which provide different redundancy rates for different types of video data in video streaming. However, the literature [15–17] does not take the effects of the network traffic load on packet loss into consideration. In the proposed approach, the CLM-UEP mechanism mitigates the effects of wireless transmission losses by applying a differential level of protection to the individual frames based on their coding significance. Moreover, the CLM-UEP algorithm maximizes the utilization efficiency of the AC queues and reduces network congestion by dynamically mapping not only the video packet, but also the redundancy packets to an appropriate queue in accordance with both their coding significance and the traffic load in the MAC layer. By adopting this approach, the CLM-UEP mechanism significantly improves the video quality and the utilization of AC queues.

3. Cross-layer mapping with unequal error protection mechanism

3.1. System overview

The aim of the CLM-UEP mechanism proposed in this study is to mitigate the effects of wireless transmission errors and congestion losses in the streaming of video data over IEEE 802.11e WLANs. As shown in Fig. 5, the CLM-UEP mechanism comprises two major components, namely a UEP controller and an adaptive mapping algorithm. The UEP controller determines the type of each frame in the video stream by inspecting the "Frame_Type" header field at the application layer. For each frame, the controller then determines the optimal redundancy rate in accordance with the feedback packet loss rate, the structure of video stream and the results obtained from an analytical model of the Playable Frame Ratio (PFR) (see Section 3.2.1). Finally, the adaptive mapping algorithm dynamically maps the coded video packets to an appropriate AC queue at the MAC layer in accordance with the frame type and the current load at each queue.

3.2. CLM-UEP mechanism

3.2.1. Analytical model of playable frame ratio with unequal error protection

As described above, the proposed UEP mechanism determines an appropriate degree of redundancy for each frame type utilizing an analytical model of the PFR. In the FEC error recovery process, the k source packets are encoded on the sender side into n packets. The original source packets can be successfully recovered at the receiver side provided that a minimum of k packets are received, irrespective of whether the received packet are source or redundant packets. Accordingly, the block recovery rate (F) [11] is given as

$$F = \sum_{i=k}^{n} C_i^n \times (1-p)^i \times p^{n-i}, \tag{1}$$

where p is the packet loss rate and C_i^n denotes all possible combinations of i packets successfully received in a whole block. (Note that the various notations used in the analytical

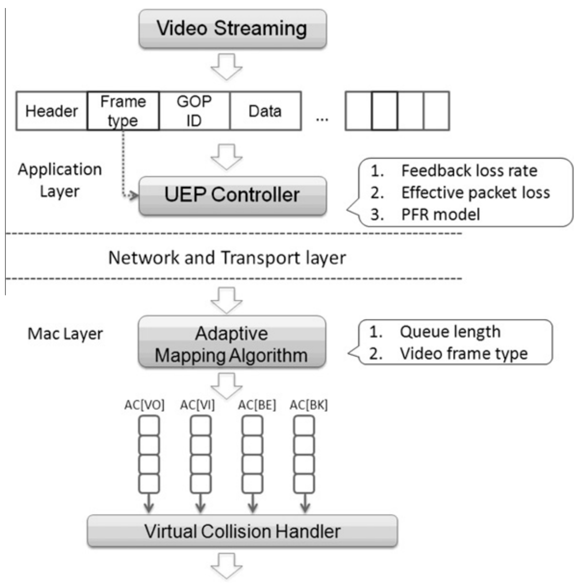

Fig. 5. System overview of CLM-UEP mechanism.

model of the PFR are summarized in Table 2.) Based on Eq. (1) and taking the coding dependency into account, the recovery rate of each I-frame is given as

$$F_I = \sum_{i=k_I}^{n_I} C_i^{n_I} \times (1-p)^i \times p^{n_I - i}, \tag{2}$$

where n_I is the number of I-frame packets in one block. Meanwhile, the recovery rate of each P-frame is given as

$$F_{P(j)} = F_I \times \left[\sum_{i=k_P}^{n_P} C_i^{n_P} \times (1-p)^i \times p^{n_P - i} \right], \tag{3}$$

where n_P is the number of P-frame packets in one block and $F_{P(j)}$ is the recovery rate of the jth P-frame in the GOP.

As described earlier, the B-frames in each GOP are coded using information relating to the previous or subsequent I- or P-frame. Consider the GOP shown in Fig. 6, with a structure of IBBPBBPBB. Let the sequence numbers of the frames within the GOP be assigned as follows: $IB_1B_2P_1B_3B_4P_2B_5B_6$. B_1 and B_2 are referring to I-frame and P_1 frame. In the same GOP, P_1 frame is decodable based on I frame decodable or not. Accordingly, the recovery rate of B_1 and B_2 frame is indirectly determined by P_1 frame. The recovery rate of each B-frame in the GOP is given as:

$$\begin{aligned} F_{B_1} &= F_{B_2} = F_{P_1} \times \left[\sum_{i=k_B}^{n_B} C_i^{n_B} \times (1-p)^i \times p^{n_B - i} \right] \\ F_{B_3} &= F_{B_4} = F_{P_2} \times \left[\sum_{i=k_B}^{n_B} C_i^{n_B} \times (1-p)^i \times p^{n_B - i} \right] \\ F_{B_5} &= F_{B_6} = F_{P_2} \times \left[\sum_{i=k_B}^{n_B} C_i^{n_B} \times (1-p)^i \times p^{n_B - i} \right] \times F_{I\_next}. \end{aligned} \tag{4}$$

In other words, two different recovery rates can be defined for the B-frames in the GOP, namely

$$F_{B_{(j)}} = \begin{cases} F_{Bx} = F_{P\left(\frac{j}{M-1}\right)} \times \left[\sum_{i=k_B}^{n_B} C_i^{n_B} \times (1-p)^i \times p^{n_B - i} \right] \\ F_{By} = F_{P\left(\frac{j}{M-1}-1\right)} \times \left[\sum_{i=k_B}^{n_B} C_i^{n_B} \times (1-p)^i \times p^{n_B - i} \right] \times F_{I\_next} \end{cases}, \tag{5}$$

where F_{By} is the recovery rate of the last set of B-frames in the GOP and F_{Bx} is the recovery rate of the other B-frames in the same GOP.

Table 2
Notations used in PFR model.

p	Packet loss rate
n_I, n_P, n_B	Total number of I, P and B frame packets (both source and redundant) in a block
k_I, k_P, k_B	Number of I, P and B frame source packets in one block
F_I	Recovery rate of I-frame
$F_{P(j)}$	Recovery rate of number jth P-frame
$F_{B(j)}$	Recovery rate of number jth B-frame
M	I-to-P frame distance
N	I-to-I frame distance
N_I, N_P, N_B	Number of I, P and B frames in a GOP

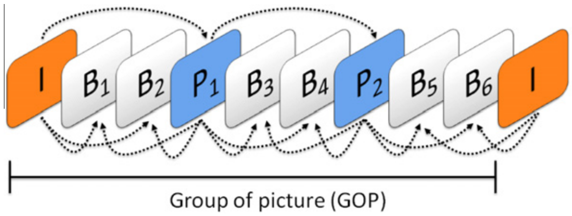

Fig. 6. Sequence numbers of video frames in typical GOP.

Collectively, Eqs. (2), (3) and (5) enable the total number of decodable frames within a GOP to be determined. The PFR of the video stream with UEP protection can then be evaluated as

$$PFR = \frac{F_I \times N_I + \frac{\sum_{j=1}^{\frac{N}{M}-1} F_{P(j)}}{\frac{N}{M}-1} \times N_P + \frac{\sum_{j=1}^{N-\frac{N}{M}} F_{B(j)}}{N-\frac{N}{M}} \times N_B}{N_I + N_P + N_B}. \tag{6}$$

Finally, the UEP controller could determines the redundancy rate for each video frame based on the Eq. (6) in accordance with both the feedback packet loss rate (p) and the video structure to support the QoS of video streaming.

3.2.2. Adaptive queue mapping of video packets

In order to provide a higher transmission priority to the more important video packets, the CLM-UEP mechanism utilizes an adaptive mapping algorithm to dynamically map the individual source and redundant packets to an appropriate AC queue in accordance with their coding significance and the traffic load. (Note that the redundant packets are assumed to have the same degree of coding significance as the corresponding source packets.) The mapping algorithm utilizes the parameter *Prob_TYPE*, referred to hereafter as the downward mapping probability, to define the probability of a particular video packet being mapped to a lower priority AC queue when the queue to which the packet would ideally be allocated is nearly full. The downward mapping probabilities of the less significant video frames are assigned a higher value than those of the more important video frames. In other words, the downward mapping probabilities of the video frames in the GOP are ordered as follows: *Prob_B* > *Prob_P* > *Prob_I*. As a result, the frames with a greater coding significance are assigned to a queue with a higher priority than those with a lower coding significance, and have an increased probability of accessing the wireless medium as a result.

In addition to the *Prob_TYPE* parameter, the mapping algorithm utilizes two parameters to minimize congestion-induced losses, namely *threshold_low* and *threshold_high*.

$$Prob\_New = Prob\_TYPE \times \frac{qlen(AC(N)) - threshold\_low}{threshold\_high - threshold\_low}. \tag{7}$$

As shown in Eq. (7), the predefined downward mapping probability of each video frame type (*Prob_TYPE*) is adjusted adaptively based on the relationship between the current queue length and the assigned threshold values. (Note that the various notations used in the adaptive cross-layer mapping algorithm are summarized in Table

3.) Specifically, *Prob_TYPE* is increased when the AC queue is more heavily loaded, but decreased when the AC queue is more lightly loaded. Table 3 lists the various notations used in the mapping algorithm.

Fig. 7 presents the pseudo code of the proposed CLM mapping algorithm. Note that to simplify the notations, AC_VI, AC_BE and AC_BK are denoted as AC (2), AC (1) and AC (0), respectively. If the queue length of AC (2) is less than the corresponding lower threshold value (*threshold_low*), all of the video packets are mapped to AC (2). However, if the AC (2) queue length falls between *threshold_low* and *threshold_high*, the video packets are assigned to either AC (2) or AC (1) in accordance with the downward mapping probability obtained from Eq. (7). Finally, if the AC (2) queue length exceeds the *threshold_high* value, i.e., the queue is almost full, the video packets are mapped to AC (1) or AC (0) in accordance with their respective *Prob_TYPE* values and the queue length of AC (1). Table 4 presents a qualitative comparison of the proposed CLM-UEP scheme and two existing mapping algorithms, namely EDCA [1] and Static Mapping [23]. As described previously, the CLM-UPE scheme maps the video packets to an appropriate AC queue in accordance with both the frame type and the current load at each queue. By contrast, IEEE 802.11e EDCA [1] always maps the video packets to AC (2), while Static Mapping [23] maps the I-frames/packets, P-frames/packets, and B-frames/packets to the AC (2), AC (1) and AC (0) queues, respectively.

Table 3
Parameter notations in proposed adaptive mapping algorithm.

Prob_TYPE	Downward mapping probability of each type of video packet, i.e., Prob_I, Prob_P or Prob_B
Prob_New	New downward mapping probability
threshold_low	Lower threshold of queue length
threshold_high	Upper threshold of queue length
RN	Random number from Uniform function [0.0, 1.0]
AC (N)	Access category N, i.e., AC (3), AC (2), AC (1) or AC (0).
qlen (AC (N))	Queue length of access category N, i.e., qlen (AC (3)), qlen (AC (2)), qlen (AC (1)) or qlen (AC (0))

When video frame packets arrive:

RN = a random number generated from Uniform function (0.0, 1.0)

If (qlen(AC(2)) < threshold_low)

  video packet → AC(2)

Else if (qlen(AC(2)) < threshold_high)

{

$$Prob\_New = Prob\_TYPE \times \frac{qlen(AC(2)) - threshold\_low}{threshold\_high - threshold\_low}$$

  If (Prob_New < RN)

    video packet → AC(2)

  Else

    video packet → AC(1)

}

Else if (qlen(AC(2)) > threshold_high)

{

$$Prob\_New = Prob\_TYPE \times \frac{qlen(AC(1)) - threshold\_low}{threshold\_high - threshold\_low}$$

  If (Prob_New < RN)

    video packet → AC(1)

  Else

    video packet → AC(0)

}

Fig. 7. Pseudo code of adaptive cross-layer mapping algorithm.

Table 4
Comparison of CLM-UEP and related mapping schemes.

Mapping scheme	Video frame type	Mapping to AC queue
CLM-UEP	I-frame and I-redundant P-frame and P-redundant B-frame and B-redundant	Depends on adaptive mapping algorithm
IEEE 802.11e EDCA [1]	I-frame P-frame B-frame	AC (2) AC (2) AC (2)
Static mapping [23]	I-frame P-frame B-frame	AC (2) AC (1) AC (0)

4. Performance evaluation

4.1. Experimental environment and parameter settings

The performance of the proposed CLM-UEP mechanism was compared with that of three existing loss recovery methods [1,18,24] by performing a series of NS-2 [24,25] simulations using the topology shown in Fig. 8. Note that the nodes in the wireless sections of the network were assumed to access the wireless medium using the EDCA mode prescribed in IEEE 802.11e. The simulations were performed using the "Foreman" video trace [26], encoded in a YUV QCIF (176 pixels × 144 pixels) format. The number and type of the video frames and packets within the trace are indicated in Table 5. The GOP structure of the video trace was as follows: IBBPBBPBB ($N = 9$, $M = 3$). The video was streamed in packets with a size of 1000 bytes at a rate of 30 frames per second. Besides the video stream, three traffic streams were also transmitted over the network, namely voice traffic, FTP traffic (TCP) and Exponential traffic (UDP). The quality of the transmitted video was evaluated under both light load and heavy load conditions. The parameter settings of the CLM algorithm were specified as follows: *threshold_low*: 20 packets; *threshold_high*: 40 packets; *Prob_I*:0;*Prob_P*: 0.6; and *Prob_B*: 0.8. Finally, the maximum queue length at each AC was set as 50 packets.

4.2. Determination of appropriate UEP redundancy rate

Fig. 9 shows the variation of the PFR metric (as determined from Eq. (6)) with the packet loss rate given various

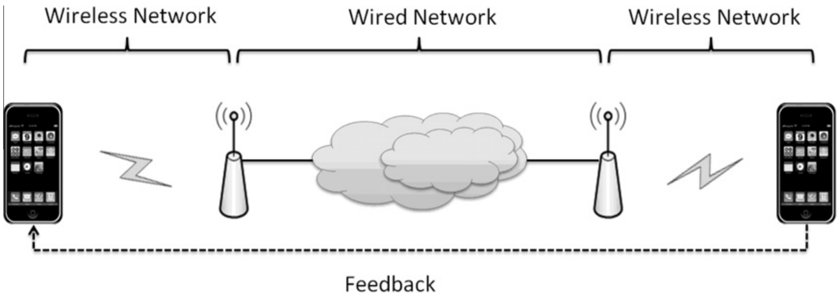

Fig. 8. Topology of experimental environment.

Table 5
Parameters of encoded video source.

Video	Format	Frame number			Total frame	Packet number			Total packet
		I	P	B		I	P	B	
Foreman	QCIF	45	89	266	400	237	149	273	659

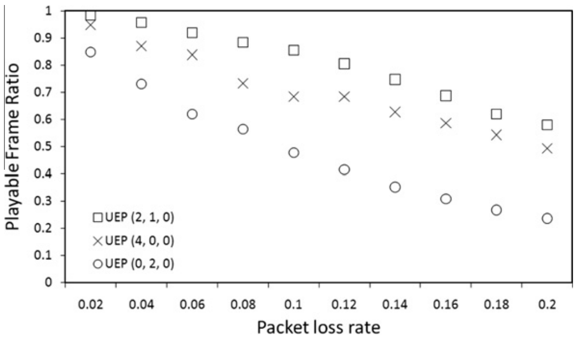

Fig. 9. Determination of appropriate UEP protection strategy.

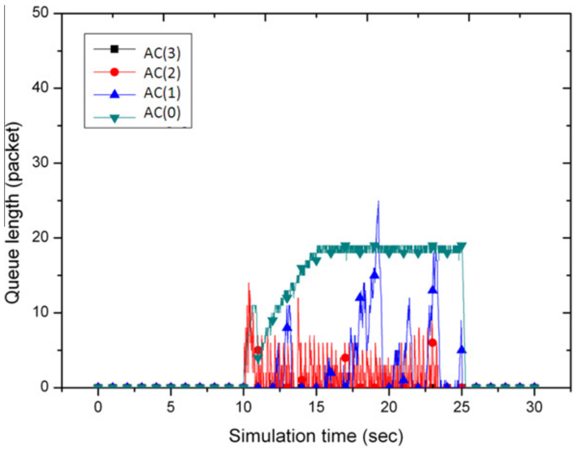

Fig. 10. Variation of AC queue length under light load.

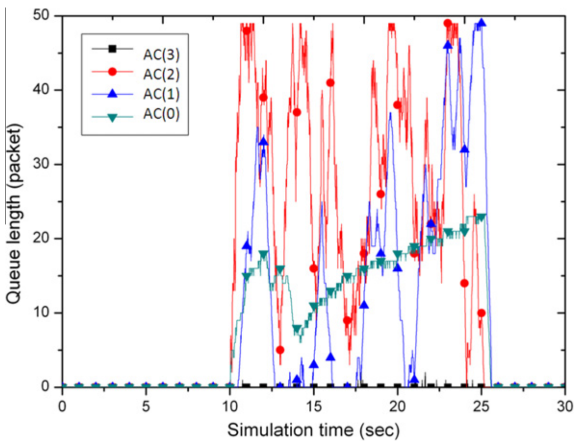

Fig. 11. Variation of AC queue length under heavy load.

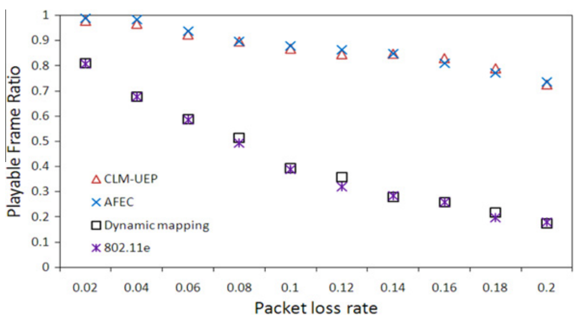

Fig. 12. Variation of PFR under light load.

UEP protection strategies. Actually, the analytical model (in the Section 3.2.1) could provide the means to determine the FEC redundancy rate (n_I, n_P, n_B) required to guarantee the QoS requirements of video transmissions over lossy wireless networks. Here, an assumption is made that each GOP has a structure of G (9, 3) and is assigned four redundant packets. Thus, UEP (2, 1, 0) indicates that two redundant packets are generated for each I frame, one redundant packet is generated for each P frame and no redundant packets are generated for the B frames. As the results shown in Fig. 9, the UEP protection strategy (2, 1, 0) consistently achieves a better video quality (i.e., a higher PFR) than other UEP protection strategies (i.e. UEP (4, 0, 0) and UEP (0, 2, 0)), despite the fact that the GOP is assigned the same number of redundant packets. The lower performance of the UEP (4, 0, 0) and UEP (0, 2, 0) strategies arises since loss recovery is limited only to the I- or P-frames.

4.3. Performance analysis of CLM-UEP mechanism

Fig. 10 shows the dynamic variation in the length of the AC queues when the MAC layer is lightly loaded (i.e., the queue length at each AC is less than half the maximum permissible queue length (50 packets)). Fig. 11 presents the equivalent results for the case in which the MAC layer is heavily loaded (i.e., the queue length at each AC is close to the maximum queue length). The performance of the proposed CLM-UEP mechanism was further evaluated by comparing the results obtained for the PFR and Peak Signal-to-Noise Ratio (PSNR) [27] during the streaming of the Foreman trace with those obtained from three existing methods, namely 802.11e (EDCA) [1], AFEC [18] and Dynamic Mapping [21].

As described previously, the CLM-UEP mechanism not only mitigates the effects of wireless transmission losses by applying a differential level of protection to the individual frames, but also maps the video packets adaptively to an appropriate AC queue based on the video frame type and the network load. By contrast, the 802.11(EDCA) [1] ignores the packet losses due to wireless errors and network congestion, while the AFEC [18] and Dynamic Mapping [21] schemes consider either the wireless error or the network load, but not both. In the simulations, the MAC layer method used for AFEC is in the same as IEEE 802.11e EDCA which always maps the video packets to AC (2).

In the proposed CLM-UEP scheme, the UEP controller determines the redundancy rate for each video frame in accordance with both the feedback packet loss rate and the video structure to support the QoS of video streaming. Supposing that when the packet loss rate is less than 0.05, there are four redundant packets generated in one GOP and the redundancy of each frame type is set as UEP (2, 1, 0). When the packet loss rate is greater than 0.05, the number of redundant packets will increase to maintain the QoS requirement (packet loss rate under 0.05). The parameter settings of the queue mapping of the CLM-UEP were specified as the settings of the Dynamic Mapping in [21]: *threshold_low*: 20 packets; *threshold_high*: 40 packets; *Prob_I*: 0; *Prob_P*: 0.6; and *Prob_B*: 0.8. Finally, the maximum queue length at each AC was set as 50 packets. Under light loads, the video quality is determined principally by the number of packet losses caused by wireless errors. Thus, as shown in Figs. 12 and 13, the Dynamic Mapping and 802.11e methods both yield a low PFR and PSNR since neither method provides a robust protection against wireless transmission errors. By contrast, AFEC and CLM-UEP both inject redundant packets in optimal redundancy rate for each video type into the data stream, and thus the performances (PFR and PSNR) of AFEC and CLM-UEP are significantly improved and very close.

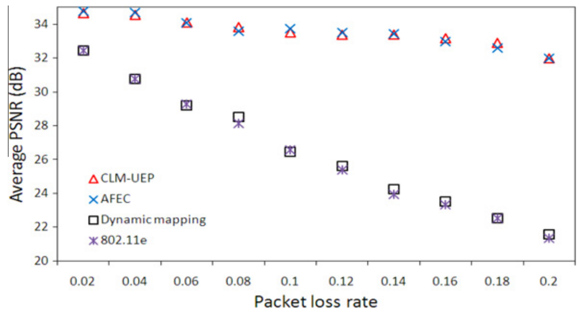

Fig. 13. Variation of PSNR under light load.

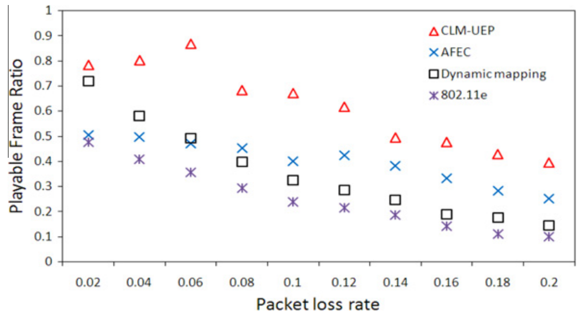

Fig. 14. Variation of PFR under heavy load.

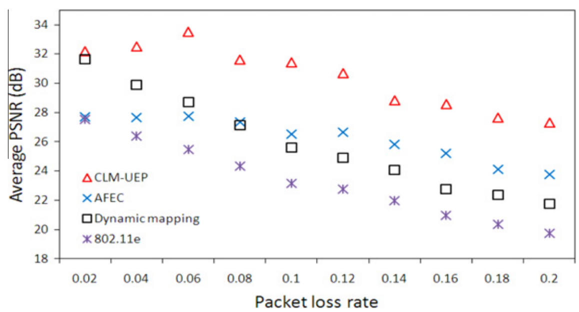

Fig. 15. Variation of PSNR under heavy load.

Under heavy loading conditions, the video quality is reduced as the result of both wireless transmission losses and congestion losses. As shown in Figs. 14 and 15, the Dynamic Mapping method yields a better video quality than the 802.11e method due to its improved ability to deal with congestion losses. As described previously, the CLM-UEP mechanism not only adjusts the redundancy rate dynamically in accordance with the video frame type and packet loss rate, but also maps the video packets adaptively to an appropriate AC queue based on the video frame type and the network load. At a moderate packet loss rate of 6%, the CLM-UEP scheme achieves a high PFR and PSNR by increasing the number of redundant packets in order to maintain the QoS requirement (packet loss rate under 5%). Under heavy network loads, the redundant packets add to the network congestion and lead to further congestion losses. As a result, the PFR and PSNR fall slightly. Nonetheless, the CLM-UEP mechanism yields a better video quality that the AFEC scheme, which deliberately reduces the number of redundant packets produced under heavy load conditions in order to avoid congestion-induced losses.

5. Conclusions

This paper has proposed a Cross-Layer Mapping Unequal Error Protection (CLM-UEP) mechanism for improving the quality of video streaming over IEEE 802.11e wireless networks. The proposed mechanism comprises two major components, namely a UEP controller and an adaptive mapping algorithm. The UEP controller dynamically adjusts the redundancy rate applied to each type of frame in accordance with changes in the packet loss rate caused by wireless errors. Meanwhile, the adaptive mapping algorithm improves the utilization of the AC queues and reduces congestion-induced packet losses by assigning the coded packets to appropriate AC queues in accordance with the corresponding frame type and the network traffic load in the MAC layer. The simulation results have shown that the CLM-UEP mechanism yields a significant improvement in both the Playable Frame Ratio and the peak signal-to-noise ratio compared to existing methods.

Future studies will focus on two main issues, namely (1) taking the network load (i.e., the queue length) into account when determining the optimal redundancy rate for each frame type; and (2) examining the feasibility of extending the CLM-UEP mechanism proposed in this study to IEEE 802.11p (Wireless Access in Vehicular Environment) networks [28].

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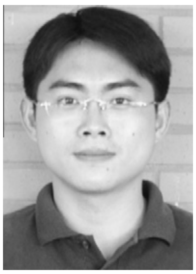
References

[1] IEEE Standard 802.11e, Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications Amedment 8: Medium Access Control (MAC) quality of Service Enhancements, 2005.
[2] P. Agrawal, J.-H. Yeh, J.-C. Chen, T. Zhang, IP multimedia subsystems in 3GPP and 3GPP2: overview and scalability issues, IEEE Communicaions Magazine 46 (1) (2008) 138–145.
[3] Y.-F. Huang, C.-Y. Chiu, Dynamically adjusting MPEG4 video streams based on network bandwidth, Multimedia Toos and Applications 36 (3) (2008) 267–284.
[4] A. Kantarc, Streaming of scalable h. 264 videos over the Internet, Multimedia Toos and Applications 36 (3) (2008) 303–324.
[5] H. Luo, M.-L. Shyu, S.-C. Chen, Video streaming over the internet with optimal bandwidth resource allocation, Multimedia Toos and Applications 40 (1) (2008) 111–134.
[6] Z. Naor, Multicast video streaming for 4G wireless networks: research articles, Wireless Communications & Mobile Computing 7 (2) (2007) 173–185.
[7] H. Sun, A. Vetro, J. Xin, An overview of scalable video streaming, Wireless Communications & Mobile Computing 7 (2) (2007) 159–172.
[8] C. Tan, J. Zou, M. Wang, R. Zhang, Network lifetime optimization of wireless video sensor networks with network coding/ARQ hybrid adaptive error-control scheme, Computer Networks 55 (9) (2011) 2126–2137.
[9] Q. Li, M. Van Der Schaar, Providing adaptive QoS to layered video over wireless local area networks through real-time retry limit adaptation, IEEE Transactions on Multimedia 6 (2) (2004) 278–290.
[10] M.-F. Tsai, T.-C. Huang, C.-K. Shieh, K.-C. Chu, Dynamical combination of byte level and sub-packet level FEC in HARQ mechanism to reduce error recovery overhead on video streaming over wireless networks, Computer Networks 54 (17) (2010) 3049–3067.
[11] C.-H. Lin, C.-K. Shieh, N.K. Chilamkurti, C.-H. Ke, W.-S. Hwang, A RED-FEC mechanism for video transmission over WLANs, IEEE Transactions on Broadcasting 54 (3) (2008) 517–524.
[12] C.-H. Lin, C.-H. Ke, C.-K. Shieh, N.K. Chilamkurti, An enhanced adaptive FEC mechanism for video delivery over wireless networks, in: Proceedings of the International Confernce on Networking and Service (ICNS 2006), Silcon Valley, CA, 2006, pp. 106–111.
[13] M. Elaoud, P. Ramanathan, Adaptive use of error-correcting codes for real-time communication in wireless networks, in: Proceedings of the IEEE International Confernce on Compurter Commnunications (INFOCOM 1998), San Francisco, CA, 1998, pp. 548–555.
[14] A. Nafaa, A. Mehaoua, Joint loss pattern characterization and unequal interleaved FEC protection for robust H.264 video distribution over wireless LAN, Computer Networks 49 (6) (2005) 766–786.
[15] J. Shih, W. Tsai, A new unequal error protection scheme based on FMO, Multimedia Tools and Applications 47 (3) (2010) 461–476.
[16] H. Ha, C. Yim, Layer-weighted unequal error protection for scalable video coding extension of H. 264/AVC, IEEE Transactions on Consumer Electronics 54 (2) (2008) 736–744.
[17] E. Maani, A. Katsaggelos, Unequal error protection for robust streaming of scalable video over packet lossy networks, IEEE Transactions on Circuits and Systems for Video Technology 20 (3) (2010) 407–416.
[18] H. Wu, M. Claypool, R. Kinicki, Adjusting forward error correction with temporal scaling for TCP-friendly streaming MPEG, ACM Transactions on Multimedia Computing, Communications, and Applications 1 (4) (2005) 315–337.
[19] S. Lee, C. Yoo, Hop-based priority technique using 802.11e for multimedia streaming, IEEE Transactions on Consumer Electronics 56 (1) (2010) 48–53.
[20] T. Li, D. Leith, D. Malone, V. Badarla, Achieving end-to-end fairness in 802.11e based wireless multi-hop mesh networks without coordination, ACM Mobile Networks and Applications 16 (1) (2011) 17–34.
[21] C.-H. Lin, C.-K. Shieh, C.-H. Ke, N.K. Chilamkurti, S. Zeadally, An adaptive cross-layer mapping algorithm for MPEG-4 video transmission over IEEE 802.11e WLAN, Telecommunication Systems 42 (3) (2009) 223–234.
[22] P. Ferre, D. Agrafiotis, D. Bull, A video error resilience redundant slices algorithm and its performance relative to other fixed redundancy schemes, Signal Processing: Image Communications 25 (3) (2010) 163–178.
[23] A. Ksentini, M. Naimi, A. Gueroui, Toward an improvement of H. 264 video transmission over IEEE 802.11e through a cross-layer architecture, IEEE Communications Magazine 44 (1) (2006) 107–114.
[24] NS Simulator, <http://nsnam.isi.edu/nsnam/index.php/Main_Page>.
[25] NS-2 simulator, <http://hpds.ee.ncku.edu.tw/~smallko/ns2/ns2.htm>.
[26] YUV video sequence, <http://www.tkn.tu-berlin.de/research/evalvid/qcif.html>.
[27] C.-H. Ke, C.-H. Lin, C.-K. Shieh, W.-S. Hwang, A Novel Realistic Simulation Tool for Video Transmission over Wireless Network, IEEE International Conference on Sensor Networks, Ubiquitous, and Trustworthy Computing (SUTC 2006), Taichung, Taiwan, pp.275-283.
[28] M. Gerla, L. Kleinrock, Vehicular networks and the future of the mobile Internet, Computer Networks 55 (2) (2011) 457–469.



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