Adaptive FMO Map Generation using Cross Video Coding-MAC Layer Consideration

Tien Huu Vu, Supavadee Aramvith
Department of Electrical Engineering
Chulalongkorn University
Bangkok, Thailand
Vuhuu_tien@yahoo.com
Supavadee.a@chula.ac.th

***Abstract*— Recent researches in video transmission over heterogeneous networks move toward cross-layer design to realize optimal video quality. In this work, we investigate the cross layer approach between H.264 video coding layer and IEEE 802.11e Medium Access Control (MAC) layer, how to improve error resiliency of H.264 video using Flexible Macroblock Ordering (FMO), and how to reduce packet dropping rate at MAC layer. We propose an adaptive FMO map generation to separate high and low important macroblocks to different priority queues based on the overflow state of MAC layer queues. The arrival rate of packets to queues is thus changed to reduce queue overflow. It results in decrease of packet dropping rates at queues. Experimental results show that using the proposed scheme can reduce the packet drop rate at the queues resulting in the reduction of packet loss rate and the improvement of the average PSNR.**

I. INTRODUCTION

Video transmission over heterogeneous networks has become an integral part of the present telecommunication network's applications. Despite of higher capacity in recent broadband wired and wireless networks, video data suffers from several constraints in transmission such as error propagation constraints as an effect of intra-frame and inter-frame video coding and delay constraints, etc.

Recent video coding standard such as H.264 has addressed these constraints by including several error resilience options. One option is Flexible Macroblock Ordering (FMO) in which the transmission order of macroblocks (MBs) allows to change based on the FMO map generated from each frame. Beneficial from using FMO map is the reduction of the number of undecodable MBs. In previous researches, several indicators have proposed in the explicit FMO map generation. The works in [1] proposed the indicator to express the importance of MBs but do not involve network consideration. The other work in [2] consider network feedback and calculate the prediction of future network state to help generate more meaningful FMO map and select appropriate parameters such as intra refresh rate in video encoding. It has been shown that by cooperatively utilizing information across layers could optimize the system performance and video quality indeed.

Cross layer video coding has been proposed in research community to improve OSI model in controlling the parameters and operation of each layer in conjunction with the others to achieve optimum system performance. There are many researches related to the interaction between Application (APP) and MAC layer with objective to reduce the packet loss rate.

In [3], a method is proposed to support QoS in wireless LAN (WLAN) by using data partition (DP) in video coding layer. In this method, the video packets are classified into different priority queues depending on the importance of partitions. However, the number of bits spent for higher important partition such as header of slice is smaller than the number of bits spent for coefficients and inter/intra coded block pattern in that slice. Hence, the number of packets arriving at higher priority queue is smaller than the number of packets arriving at lower priority queue. Consequently, the high priority queue is always empty while the others are full. This causes the unnecessary packet dropping and delay in the lower priority queue. To overcome this issue, the work in [4] proposes a method to balance the number of traffic coming to queues. In this method, video traffic and best effort traffic are mapped into separated queues. However, if the queue length is greater than the upper threshold, the video traffic is directly mapped to lower priority queues of the best effort traffics. Thus, the loss rate of video packets is reduced.

With another cross-layer approach, in [5]-[6], different FMO types are varied to find out which pattern provide the best video quality for a given packet loss scenario, typical for WLAN environments. The results show that the "dispersed" FMO type provides the best PSNR for the case of moderate packet loss. In addition, the length of slice is selected to achieve the highest average PSNR. However, in these works, the FMO map at APP layer is not changed to adapt with the requirements of the lower layers.

In this paper, we consider the scenario of how FMO will work effectively with MAC layer to reduce the number of dropped packets. This work focuses on a method to generate explicit FMO map based on overflow state of queues at MAC layer. The encoding order of higher and lower important slice groups are adjusted by changing FMO map for the current frame. Consequently, the arriving order of packets to queues is changed in such a way that the arrival rate of packets to the full queue is reduced and arrival rate of packets to empty queue is increased. Hence, the number of dropped packet at MAC layer is minimized.

The rest of the paper is organized as follows. In Section II, the concept of FMO and 802.11e standard are introduced. The proposed method to generate FMO map is described in Section III. Section IV gives the experimental results and analysis. Finally, conclusions are drawn in Section V.

II. BACKGROUND

In this section, the methods to generate an explicit FMO map are introduced. In addition, the classification mechanism for queues at IEEE 802.11e MAC layer is explained.

A. Flexible Macroblock Ordering

FMO allows an image can be divided into slice groups. Each slice group can be further divided in several slices which containing a sequence of MBs. These MBs are processed in a scan order (left to right and top to bottom) and a slice can be decoded independently to the other slices. By using FMO, each MB can be assigned freely to a slice group using an macroblock allocation map (MBAmap). The MBAmap consists of an identification number for each MB of the image that specifies which slice group the MB belongs to. The number of slice groups is limited to 8 for each image to prevent complex allocation schemes. If FMO is not used, the images will be composed of a single slice with the MBs in a scan order.

There are six default types of FMO maps from type 0 to type 5. FMO type 6 is called the explicit FMO. This type allows the full flexibility of assigning MBs to any slice, as long as the mapping is specified in the MBAmap. The general procedure on how to use explicit FMO to design a specific MB-to-slice group mapping is as follows:

- Parameter Specification: Find a parameter to quantify the importance of a MB.
- MB Classification: Classify the MBs to slice groups using the chosen parameter.
- MBAmap design: The result of the classification process determines the MB-to-slice group map.

Selecting the indicator to measure the importance of MBs is a key step in using FMO method. In this work, the role of FMO in mitigating the packet dropping rate at MAC layer is taken into account. Thus, for simplicity, residual is used as the indicator in importance evaluation of MBs. Further details of FMO can be found in [1].

B. The IEEE 802.11e standard

In the 802.11 standard, the operation of the MAC layer is controlled by a mechanism named Distribution Coordination Function (DCF), which is based on carrier sense multiple access with collision avoidance. In the DCF scheme, each station contends for the channel access by using a parameter, called backoff time, that is a random number in the interval *[0, CW]*. Initially, if channel is busy, Contention Window *CW* is set to CW_{min}. The wireless station (WS) starts a counter at value CW_{min} and begins countdown. When counter reaches zero, the WS transmits packets. If a collision occurs, *CW* is doubled (up to the value of CW_{max}). On a successful transmission, *CW* is reset to the value CW_{min}. Whenever the packet is not correctly acknowledged by the receiver, the WS retransmits it until the maximum number of retry-limit (RL) is reached.

To support QoS in WLAN, the 802.11e standard is proposed with operation of Enhanced Distributed Channel Access (EDCA) replacing DCF. In DCF, all WS compete for the wireless medium with the same priority. However, in EDCA, this mechanism is extended to four levels of priorities or access categories (AC). Each AC has its own transmission queue and its own set of channel access parameters. ACs are differentiated by setting different CW_{min}, CW_{max}, arbitrary inter-frame space (AIFS) which is the period of time the WS has to wait for starting counter when the medium is idle, and RL. If one AC has a smaller [$AIFS$, CW_{min}, CW_{max}, RL], the AC has more chances in competing medium access.

III. GENERATING FMO MAP USING CROSS-LAYER APPROACH

In this method, firstly, overflow state of queues is computed. Based on this information, encoder generates an explicit FMO map for the current frame to adjust the arrival rate of packets coming into queues.

A. Oveflow rate

At the MAC layer, packet losses occur due to two reasons: link erasures and queue overload. In the scope of this work, we assume that link erasure is zero. The queues used in MAC layer are drop tail queue. Thus, the packet drop rate at the queues depends on the arrival rate and service rate of the queues. If the arrival rate is greater than the service rate, the queue is occupied quickly by waiting packets. If this state occurs for a long time, queue is felt into full state and the arrival packets are dropped. This state is overflow state of the queue.

In this work, we use a simplified buffer analysis based on fluid model. Let L_r be the link retry limit, and P_e be the packet error rate (PER) of the link (without retry), then the mean number of transmissions for a single packet until it is either successfully received or it reaches its retry limit can be calculated as [7]:

$$
\begin{aligned}
s(L_r, P_e) &= 1(1-P_e) + 2P_e(1-P_e) + \cdots + (L_r+1)P_e^{L_r} \\
&= \frac{1-P_e^{L_r+1}}{1-P_e}
\end{aligned}
\qquad (1)
$$

Let λ be the arrival rate (in packets/s). In the fluid model, we calculate the overflow rate as shown in Eq. (2),

$$
\sigma(L_r, P_e) = \frac{s(L_r, P_e)\lambda - C}{s(L_r, P_e)\lambda} \qquad (2)
$$

, where C is the service rate of the link (packets/s). Eq. (2) shows that overflow occurs only when $\lambda s > C$.

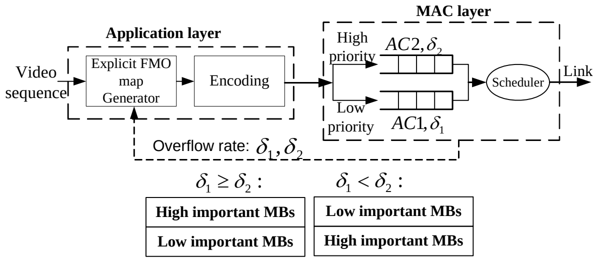

Figure 1. Cross-layer architecture of the proposed method

By substituting Eq. (1) into Eq. (2), we have

$$\sigma(L_r,P_e)=1-\frac{1}{\rho(P_e)}\frac{1}{1-P_e^{L_r+1}} \tag{3}$$

, where $\rho(P_e)=\dfrac{\lambda}{C(1-P_e)}$ is the effective utilization factor of the link.

B. Adaptive FMO Map Generation

For simplification, we assume that there are two queues in the MAC layer: AC2 and AC1. The priority of AC2 is higher than that of AC1. Assuming that L_r and P_e are constant, from Eq. (2) and (3), we can see that $\sigma(L_r,P_e)\sim\dfrac{\lambda}{C}$. Therefore, to reduce the overflow rate of a queue, the arrival rate of that queue should be reduced.

To adjust the order of arrival packets, we can adjust the encoding order of MBs in a frame by using explicit FMO map. If the higher important MBs are encoded first, the higher important packets will go out of the encoder and be mapped into high priority queue first. The lower important MBs are encoded later, and thus the lower important packets are mapped into low priority queue slower than the higher important packets. Inversely, if the lower important MBs are encoded first, the lower important packets will be mapped into the low priority queue sooner than the higher important packets mapped into the high priority queue.

Fig. 1 describes the architecture of system using cross-layer scheme to generate the explicit FMO map. In this system, after encoding, sequences of video packets are mapped into queue AC1 and queue AC2, respectively. After encoding each frame, the overflow states of two queues are sent to encoder. Based on this information, encoder decides the FMO map for the next frame to adapt with states of queues.

In case of overflow rate of queue AC1 is higher, i.e., $\sigma_1 \geq \sigma_2$, to reduce the arrival rate of packets coming to queue AC1, FMO map is generated in such a way that the higher important MBs are encoded before the lower important MBs. Therefore, the lower priority packets will come to queue AC1 later than the higher priority packets coming to queue AC2. In other word, the arrival rate, λ_1, is decreased and the arrival rate, λ_2, is increased. Consequently, σ_1 is decreased and σ_2 is increased.

In case of $\sigma_2 > \sigma_1$, to reduce the arrival rate of packets to queue AC2, FMO map is converted. The lower important MBs are encoded first. And thus the higher priority packets will come to queue AC2 later than the lower priority packets coming to queue AC1. Hence, λ_2 is decreased and λ_1 is increased. Consequently, σ_2 is decreased and σ_1 is increased.

Table I shows the residual value of MBs in frame 10 of “akiyo” sequence. In this case, the importance is measured by the residual of MBs. MBs having importance zero belong to background of frame. MBs having high importance belong to the region of interesting (ROI) of frame. We can see that, the order of high important MBs and low important MBs are interlaced. Thus, the order of packets arriving to the high priority queue and low priority queue is out of controlled.

To adjust the order of arrived packets, we can adjust the order of encoding MBs in a frame by using explicit FMO map. Table II shows an example of changing encoding order and Table III shows the explicit FMO map appropriately. According to this FMO map, MBs with high importance (gray MBs) are encoded first. After that, the low important MBs (white MBs) are encoded. Therefore, the high important packets will be mapped into high priority queue first. And then, the low important packets are mapped into low priority queue. In the case of the explicit FMO map is converted. The low important MBs are encoded first, and then is the high important MBs.

TABLE I. RESIDUAL VALUES OF MBS IN FRAME 10TH OF “AKIYO” SEQUENCE

0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	**461**	**936**	**479**	0	0	0	0
0	0	0	0	**1268**	**1769**	**771**	0	0	0	0
0	0	0	**1**	**3056**	**2253**	**1120**	**219**	0	0	0
0	0	0	0	**789**	**2238**	**684**	**347**	0	0	0
0	0	0	**179**	**510**	**2023**	**1595**	**678**	**700**	**51**	0
0	**3**	**81**	**4**	**229**	**1186**	**812**	**438**	**163**	**471**	0
0	0	**250**	**301**	**157**	**1092**	**510**	**267**	**282**	**800**	0
0	**124**	**250**	**6**	**6**	**610**	**752**	**402**	**609**	**147**	0

TABLE II. THE IMPORTANCES OF MBS IN FRAME 10TH OF “AKIYO” SEQUENCE AFTER ARRANGING

461	**936**	**479**	**1268**	**1769**	**771**	**1**	**3056**	**2253**	**1120**	**219**
789	**2238**	**684**	**347**	**179**	**510**	**2023**	**1595**	**678**	**700**	**51**
3	**81**	**4**	**229**	**1186**	**812**	**438**	**163**	**471**	**250**	**301**
157	**1092**	**510**	**267**	**282**	**800**	**124**	**250**	**6**	**6**	**610**
752	**402**	**609**	**147**	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

TABLE III. THE EXPLICIT FMO MAP OF FRAME 10TH OF "AKIYO" SEQUENCE

16	**17**	**18**	**27**	**28**	**29**	**37**	**38**	**39**	**40**	**41**
49	**50**	**51**	**52**	**59**	**60**	**61**	**62**	**63**	**64**	**65**
68	**69**	**70**	**71**	**72**	**73**	**74**	**75**	**76**	**80**	**81**
82	**83**	**84**	**85**	**86**	**87**	**90**	**91**	**92**	**93**	**94**
95	**96**	**97**	**98**	1	2	3	4	5	6	7
8	9	10	11	12	13	14	15	19	20	21
22	23	24	25	26	30	31	32	33	34	35
36	42	43	44	45	46	47	48	53	54	55
56	57	58	66	67	77	78	79	88	89	99

IV. SIMULATION RESULTS AND ANALYSIS

A. *Experimental Setup*

In this work, a frame is divided into 8 slice groups. The higher important MBs are contained in four slice groups and the other four slice groups are spent for the lower important MBs. Each slice group is contained in a packet. As a result, there are two types of packets: the high priority packets and the low priority packets as shown in Fig. 1. The high priority packet is mapped into AC2 and the other is mapped into AC1.

In the simulations, video sequences with 100 frames in length are encoded at 20 fps with bitrates of 64 kbps, 128 kbps and 384 kbps. To examine the efficiency of the cross layer mechanism, we conduct experiments over an 802.11e WLAN by using network simulator (NS2) [8] and [9]. In order to evaluate performance, the proposed method is compared with two other methods in term of PSNR and packet loss rate. The first method uses DP [3] and the second method uses FMO without adaptability. In the method using DP, there are 3 queues are used. However, the queue AC3 contains parameter set information with a very small number of bits. Thus, we can consider that all packets are mapped into two other queues in which packets containing partition A are mapped into queue AC2. Packets containing partition B and C are mapped into queue AC1. In the method using FMO without adaptability (non-adaptive FMO), the FMO map is fixed with 8 slice groups including 4 higher important slice groups and following is 4 lower important slice groups. Because FMO map is fixed thus the arrival rates of packets to queues are considered as constant in this case.

We do experiments in a high loaded network with 0.3 Mbps background traffic including one voice source (using the highest priority queue AC3) with bit rate of 64 kbps, one video source (using the second and the third priority queue: AC2 and AC1), two applications CBR and FTP with bit rate of 300 kbps (using the fourth priority queue AC0).

B. *Result Analysis*

1) *Average queue length*

Fig. 2 describes the length of queues in the method using DP [3]. The result shows that AC1 (containing packets in partition B and C) is always in full state. While state of AC2 is not used effectively. This unbalance causes unnecessary in packet dropping of AC1. Fig. 3 shows the queue lengths in the method using non-adaptive FMO. It shows that the state of two queues always are unbalance.

Result in Fig. 3 shows that in the proposed method, because the arrival traffics depend on overflow state of queue, the fullness of AC1 (for high important packets) queue is reduced significantly. This is because when AC1 having signal of overflow, the traffic of packets to queue AC1 is relayed to AC2. Hence, the packet drop rate of AC1 queue is reduced in the proposed method. Because of sharing between two queues, the average length of AC2 in the proposed method is increased. However, this increment is not significant therefore the drop rate of AC2 is not affected.

Fig. 5 describes the average length of queues in three methods when "akiyo" sequence is used. From these measurements, we can see that the higher priority queue AC1 in the method using non-adaptive FMO and DP are always in full state. While state of AC2 is not used effectively. This unbalance causes unnecessary in packet dropping of AC1.

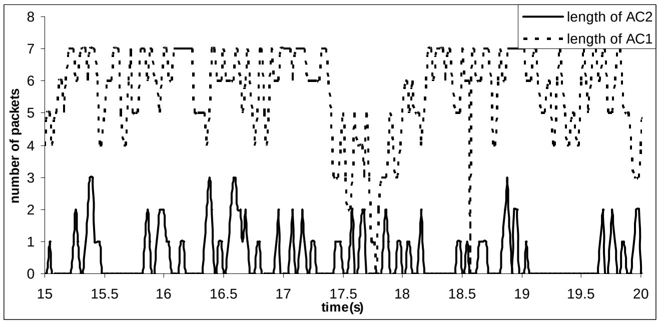

Figure 2. Queue length of the method using data partition with "coastguard" sequence at 64kbps.

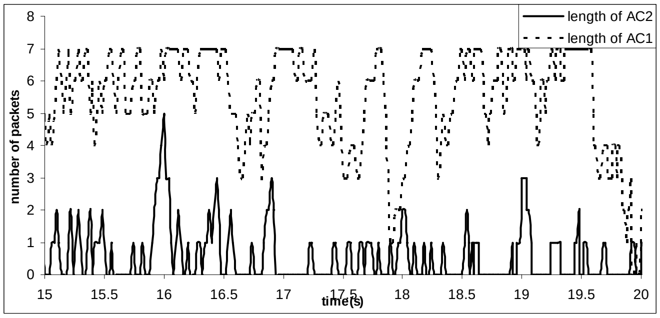

Figure 3. Queue length of the method using FMO without adaptability with "coastguard" sequence at 64kbps.

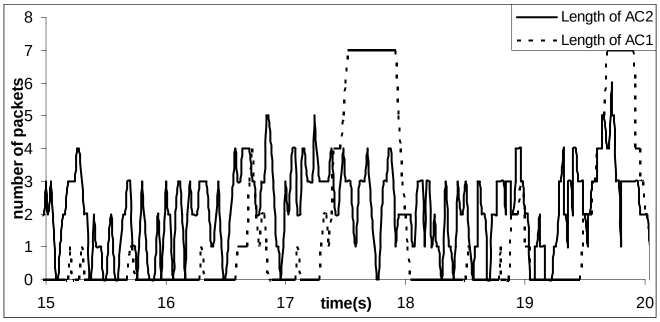

Figure 4. Queue length of the proposed method using adaptive FMO with "coastguard" sequence at 64kbps.

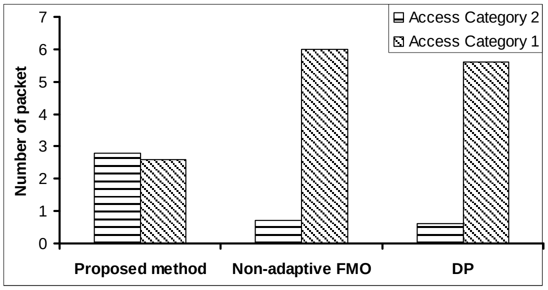

Figure 5. Average length of queues for "Akiyo" sequence at 128 kbps

TABLE IV. COMPARISON OF DROP RATE AT QUEUES FOR "COASTGUARD" SEQUENCE

	64 kbps		128 kbps		384 kbps	
COASTGUARD	AC1	AC2	AC1	AC2	AC1	AC2
DP [3]	0.1	0	0.17	0.01	0.48	0.0
Non-adaptive FMO	0.22	0.02	0.28	0.03	0.45	0.07
Adaptive FMO	**0.03**	**0.01**	**0.03**	**0.01**	**0.3**	**0.07**
AKIYO						
DP [3]	0.24	0.0	0.2	0	0.3	0
Non-adaptive FMO	0.25	0.03	0.3	0.04	0.3	0.04
Adaptive FMO	**0.02**	**0.01**	**0.02**	**0**	**0.2**	**0.02**
FOREMAN						
DP [3]	0.2	0	0.2	0	0.3	0
Non-adaptive FMO	0.25	0.03	0.3	0.04	0.4	0.08
Adaptive FMO	**0.02**	**0.01**	**0.02**	**0**	**0.2**	**0.07**

TABLE V. COMPARISON OF AVERAGE PSNR

		64 kbps	128 kbps	384 kbps
Coastguard	DP [3]	25.15	22.25	21.2
	Non-adaptive FMO	25.95	24.86	22.19
	Adaptive FMO	**28.49**	**27.49**	**22.45**
Akiyo	DP [3]	38.52	38.20	36.20
	Non-adaptive FMO	37.38	35.20	33.32
	Adaptive FMO	**42.60**	**43.81**	**36.78**
Foreman	DP [3]	32.30	24.50	**29.16**
	Non-adaptive FMO	27.38	27.59	25.29
	Adaptive FMO	**40.33**	**29.56**	25.81

2) Drop rate and Average PSNR

Table IV shows the packet drop rate compared among three methods for "Coastguard" sequence at different bitrates. The results show that the drop rates at AC1 in non-adaptive FMO and DP methods are much higher than the drop rate at AC2. This is because, in DP method, AC2 has higher priority while the number of packets coming to this queue is smaller to the number of packets coming to queue AC1. It results in the drop rates at AC2 are almost zero while the drop rates at AC1 are larger. In non-adaptive FMO method, the numbers of packets arriving two queues are equal. Nonetheless, there is no adjustment scheme is carried out when the queues are overload. Thus, the drop rates at both queues in this method are higher than the other methods. In the proposed method, the arrival rates of packets are adapted with the state of queues. Thus, the drop rates at both queues are almost the same and lower than the drop rates of the other methods.

Table V show the average PSNR of three methods. Because the decrease of drop rate at both queues, the average PSNR of the proposed method is the highest. However, the average PSNR tends to decrease when the bit rate is increased. Because the arrival rate of packets is increased while the serving rates at outputs of queues are constant. Hence, the drop rates at queues are raised as shown in Table I. Since the drop rates of both types of high and low important packets are high. Thus, the average PSNR of non-adaptive FMO method is the lowest.

V. CONCLUSION

In this work, a new method using cross-layer approach is proposed to reduce dropping packet rate. Based on feedback information from queues at MAC layer, encoder changes FMO map in such a way that the arrival rate of packets is changed following the overflow rate of queues. In particular, video packets are classified into two types of priority and mapped into two queues at MAC layer. If the overflow rate of a queue is high, the arrival rate of packets to that queue is reduced by changing FMO map and vice versa. The proposed method is compared to method using data partitioning and method using non-adaptive FMO. The results show that the proposed method is effective in reducing the packet dropping rate and can improve the PSNR up to 5 dB.

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REFERENCES

[1] W. Hantanong and S. Aramvith, "Analysis of macroblock-to-slice group mapping for H.264 video transmission over packet-based wireless fading channel," *8th Midwest Sympsium on Ctkt and System*, 2005, pp. 1541-1544.

[2] T.H. Vu and S. Aramvith, "An error resilience technique based on fmo and error propagation for H.264 video coding in error-prone channels," *Proc. of the 2009 IEEE international conference on Multimedia and Expo*, 2009, pp. 205-208.

[3] A. Ksentini, M. Naimi, and A. Gueroui, "Toward an improvement of H.264 video transmission over IEEE 802.11e trhough a cross-layer architechture," *IEEE Communications Magazine*, vol. 44, no. 1, pp. 107-114, 2006

[4] C.-H.Lin, C.-K.Shieh, C.-H.Ke, N.K. Chilamkurti, and S. Zeadally, "An adaptive cross-layer mapping algorithm for MPEG-4 video transmission over IEEE 802.11e EDCA," *Springer Netherlands*, vol. 42, no. 3-4, pp. 223-234, 2009

[5] Y.P. Fallah, D. Koskinen, A. Shahabi, F. Karim, and P. Nasiopoulos, "A cross layer optimization mechanism to improve H.264 video transmission over WLANS," *proc. of Consumer, Communications and Networking Conference (CCNC)*, 2007, pp. 875-879.

[6] S. Benayoune, N. Achir, K. Boussetta, and K. Chen, "A MAC centric cross layer approach for H.264 video streaming over HSDPA," *Journal of Communications*, vol. 4, no. 9, pp. 691-699, 2009.

[7] Q. Li and M. van der Schaar, "Providing adaptive qos to layered video over wireless local area networks through real-time retry limit adaptation," *IEEE Trans. on Multimedia*, vol. 6, no. 2, pp. 278-290, 2004.

[8] The network simulator ns-2. [Online]. Available: http://www.isi.edu/nsnam/ns/

[9] Evaluation of video stream quality over IEEE 802.11e EDCF. [Online]. Available:http://140.116.72.80/~smallko/ns2/ns2.htm