

Cross-layer Adaptive H.264/AVC Streaming over IEEE 802.11e Experimental Testbed

Cheng-Han Mai Yin-Cheng Huang Hung-Yu Wei*

Department of Electrical Engineering and Graduate Institute of Communication Engineering
National Taiwan University, Taipei, Taiwan

* Corresponding Author: Email: hywei@cc.ee.ntu.edu.tw

Abstract—In recent years, the rapid development of wireless communication allows us to enjoy more multimedia services via wireless network. However, due to lack of QoS support and characteristics of wireless channel, there are still many challenges in wireless video streaming. In this paper, we implement a cross-layer architecture to enhance the QoS transmission of h.264/AVC video stream in IEEE 802.11e wireless environment. Cross-layer Adaptive Video Prioritization (CAVP) provides Application layer Video Frame Prioritization (VFP), which prioritizes packet according to PSNR influence level, and MAC-layer Adaptive Prioritization (MAP), which estimates the delay time of each access category (AC) and chooses the faster one. We also show the results of the experiments on real testbed. Our cross-layer architecture has better performance than the works before, especially when the channel is congested.

I. INTRODUCTION

Motivated by the widely spread of wireless communication, the demand of high quality video-on-demand and video streaming service is increasing in these years. However, the wireless service is still facing many obstacles such as high packet error rate and insufficient channel capacity. Therefore, IEEE 802.11e standard provides differentiated Quality of Service to enhance multimedia transmission. The significant packet as video stream can be transmitted with higher priority. Furthermore, H.264/AVC provides some significant advances for video streaming such as excellent coding efficiency and flexibility. The independent slice decoding and flexible NAL structure allow us to transmit video streams in various networks. In this work, we propose a cross-layer design to improve the H.264 video stream over IEEE wireless networks. It discovers the importance of packets and map the video packets to appropriate access categories with shortest expected waiting time. We conducted a mathematical model for estimated waiting time for each AC. The performance of our proposed design is evaluated in real testbed experiments.

The rest of this article is organized as follows. In section II, we give a brief overview for both IEEE 802.11e standard and H.264/AVC video codec. We also discuss related works for multimedia networking. We describe our proposed system in section III. Section IV shows the real testbed experiment and the results. Finally we conclude our work in section V.

II. BACKGROUND

A. IEEE 802.11e standard

In IEEE 802.11 Distributed Coordination Function (DCF), the basic medium access mechanism is Carrier Sense Multiple

Access with Collision Avoidance (CSMA/CA). A wireless station senses the wireless medium before transmitting any packet. If the station finds that the medium is occupied by other stations, it applies a random backoff mechanism to defer the wireless medium access. The backoff counter is randomly chosen between 0 and the current contention window (CW) value, which is initialized to the minimum window size (CW_{min}). The backoff counter begins to decrease when the station sense the medium is free for one DIFS (DCF Interframe Space). When the backoff counter is decreased to 0 and the medium is still idle, the station can access the medium. The CW value is reset to CW_{min} after a successful data transmission. Otherwise, the backoff counter CW is doubled when the data transmission is fail. The maximum value of CW can reach is the maximum contention window size (CW_{max}).

There is no quality of service is supported in the basic IEEE 802.11 DCF. All traffic contends for medium access with same DIFS, CW_{min} , and CW_{max} . In other word, there is no difference between any kinds of traffic. The Enhanced Distributed Channel Access (EDCA) in IEEE 802.11e [1][2] is developed for differentiated QoS support [1][2]. In EDCA, the traffic is sorted into four access categories (AC): AC_VO for voice transmission, AC_VI for video transmission, AC_BE for best effort traffic, and AC_BK for back-ground traffic. Different channel access parameter sets is given to each AC, such as CW_{min} , CW_{max} , Arbitration Interframe Space (AIFS), and duration of transmission opportunity (TxOP). With different parameter sets, each AC has different channel access probabilities. As a result, different QoS priorities are provided to different kinds of traffic.

B. H.264/AVC Video Codec

The H.264/AVC video codec has been used for video transmission over various networking environments. Joint Video Team (JVT) in the Video Coding Experts Group (VCEG) of International Telecommunications Union Telecommunication Sector (ITU-T) and the Moving Picture Experts Group (MPEG) of International Standards Organization (ISO/IEC) jointly developed H.264/AVC [3][4]. There are two major layers of H.264/AVC codec: The video coding layer (VCL) and the network abstract layer (NAL). VCL contains specifications of the video-encoding engine including motion compensation, transform coding of coefficients, and entropy coding. NAL is responsible for the encapsulation of the coded slices into

transport entities of the network. A macroblock is the basic coding block of H.264/AVC and can be encoded in intra or inter mode. A video frame is coded to one or few slices, which contains several fixed-size macroblocks. A slice is the minimal self-decodable unit which can be decoded independently. I-slices contain only intra-mode macroblocks. P-slices contain intra-mode macroblocks and at least one inter-mode macroblock referencing another frame. B-slices contain both intra-mode and inter-mode macroblocks referencing other frames. Typically, I-slices contain more video information and can be the reference for other frames. P-slice and B-slice have higher compression ratio by referencing other macroblocks.

C. Multimedia Networking with H.264/AVC

With the advantage of the macroblock design and independent slice decoding, H.264/AVC is suitable for video transmission over networks. H.264/AVC is also viewed as the master stream video standard for wireless networking environments. Superior performance can be achieved with H.264/AVC codec even in error-prone network environments [5]. H.264/AVC has excellent compression efficiency and its benefit in wireless transmission environments have been shown in many works. In error-prone network transmission, H.264 video packet prioritization affects the video reception quality [6][7][8]. An analytical model on packet loss error distortion in video is proposed by Politis et al. [6]. The work of Liu et al. [7] suggested to measure the quality of packet-loss video with both PSNR and error length to have a more accurate measurement. The work of Krause et al. [8] on frame loss showed that the perception of viewer on frame loss depends on the content of video, and the quality degradation due to certain frame loss is tolerable. Cross-layer design that integrates IEEE 802.11e and H.264/AVC is investigated [9][10][11][12]. Based on centralized IEEE 802.11e HCCA (HCF Controlled Channel Access) protocol, van der Schaar et al. introduced the concept of subflow and admission control on channel access [9]. POACQG, introduced by Lagkas et al. [13], is based on HCCA and is to realize bandwidth allocation and admission control to maintain minimum quality requirements of multiple users. Shankar and van der Schaar's work [10] focused on the airtime fairness and MAC/PHY parameters optimization in packet delivery. Xiao et al. introduced a frame-based approach [11] to control the EDCA parameters based on the type of video packets, and drop all related P- and B-type frames when the I-type frame is lost. Ksentini et al. proposed the QoS Architecture [12], where transmission depends on the type of video packets or non-video packets. Chilamkurti et al. also prioritize the video packets according to I/P/B types [14][15]. They employ downward probabilities to map some of less significant packets to lower priority ACs when the queue length of high priority AC exceed some fixed threshold. They use the built-in IEEE 802.11e Access Categories to realize the prioritization delivery on packets.

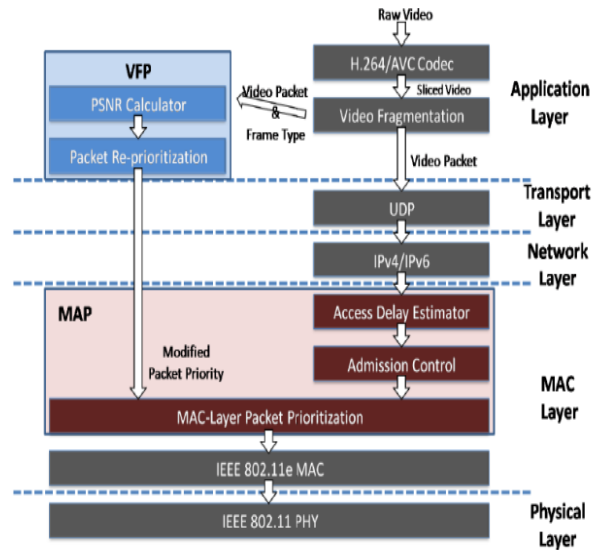


Fig. 1. CAVP system architecture

III. SYSTEM OVERVIEW

The motivation of this paper is to implement a wireless system for H.264/AVC with QoS requirement. We combine two mechanisms to implement on real testbed: Video Frame Prioritization (VFP) on application layer and MAC-layer Adaptive Prioritization (MAP) on MAC layer. The system structure is shown in Figure 1.

A. Video Frame Prioritization

Video frame prioritization is the first step of CAVP in Application Layer. In this paper, we use Peak Signal-to-Noise Ratio (PSNR) as the metric to evaluate video quality. The general idea of VFP is to compute the PSNR value when only one packet is lost. In that way, the importance level of a packet can be determined by the degradation level of PSNR. For example, we make only the first packet lost and compute the PSNR of modified group of picture (GOP) of the packet, and set the measured PSNR of the first packet be the computed PSNR value. We do this computation to all of the packets of the video, so the measured PSNR of each packet can be determined. The above method is called first-order estimation. A video packet is more important when the corresponding PSNR estimation is lower. Then we sort all packets by the average measured PSNR. If the packet belongs to the top one-third of sorted PSNR (i.e. with higher PSNR value) then the packet is marked priority 1 (lower priority). If the packet belongs to the medium one-third of sorted PSNR, the packet is marked priority 2. If the packet belongs to the bottom one-third of sorted PSNR, the packet is marked priority 3, the highest priority. The output of VFP will be packets with determined priority.

B. MAC-layer Adaptive Prioritization

1) *MAP*: In original IEEE 802.11e standard, packets are sent to different access categories (AC) according to the

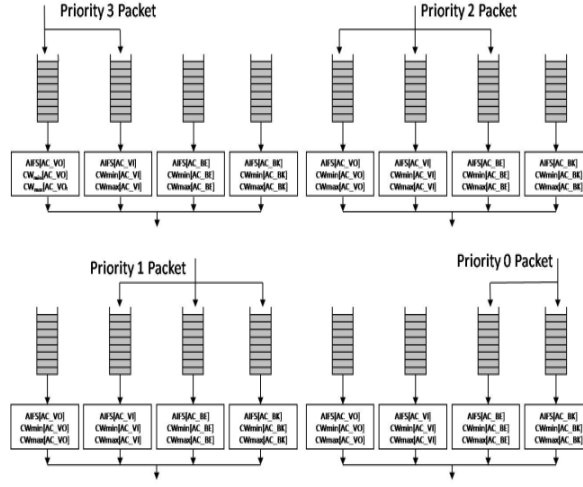


Fig. 2. The system architecture of MAP

applications. The four AC's are AC_VO for voice (i.e. the highest priority), AC_VI for video, AC_BE for best effort, and AC_BK for background. In some previous work [12], QoS Architecture Mechanism is also on the demand of transmitting video packets with the priority of frame types. That is to say, I-frames should be sent to AC_VO, P-frames be sent to AC_VI, B-frames be sent to AC_BE, and last, non-video traffic will be sent to AC_BK. The AC will have higher probability to successfully access channel. However, the size of I-frame is usually much larger than the size of the others. Therefore, there may be much more packets sent to AC_VO. The waiting time of packets could be very long due to busy queue of AC. To avoid this, we should prevent from sending packets into the AC with a long waiting queue. MAP will estimate the access waiting time of each AC, and select destination AC with the smallest expected access waiting time for each packet. After we get the estimated access waiting time of all AC's, current packet should be sent to the AC with the shortest waiting time. However, if some important packets are sent to the AC with low priority, it will have much higher probability to have large latency even if the estimated access waiting time is short. Therefore, MAP provides arbitrary candidate AC's for packets with different priority level. Figure 2 shows how MAP works. For example, packets with priority 3 (the highest priority) can only go to AC_VO or AC_VI.

Since video application is delay-sensitive, the packet received after decoding deadline is useless. MAP decides whether to transmit a packet according to the estimated delay of that packet. If the estimated access delay of a packet will make the arriving time of the packet exceed the decoding deadline, MAP at the sender will drop this packet.

2) *Estimated Access Waiting Time*: In order to compute the estimated access waiting time E_i for i -th AC, we need to denote some variable first. The i -th access categories is denoted by AC_i , $0 \leq i \leq 3$. The access parameters of AC_i includes CW_{min}^i , CW_{max}^i , and $AIFS_i$. CW_i denotes the

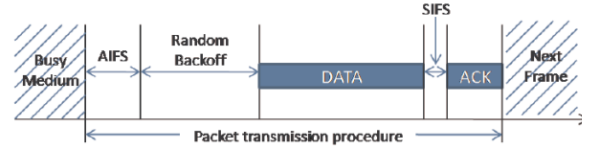


Fig. 3. IEEE 802.11e packet transmission procedure

current contention window size of AC_i . The backoff counter of AC_i is τ_i , the queue length of AC_i is l_i , the transmission rate of the transmitter is r_t , the packet size of the k -th packet in AC_i is $s_{i,k}$, and the IEEE 802.11e slottime is t . A standard packet transmission in IEEE 802.11e is shown in Figure 3. Therefore, we can compute the transmission time T_p of the k -th packet in AC_i as the following equation.

$$T_p(i, k) \leq \frac{s_{i,k}}{r_t} + (AIFS_i + CW_i + SIFS + ACK) * t$$

Next, we need to compute the access probability p_i of AC_i . For AC_i , there are $(CW_i + 1)$ possible value of backoff counter. For all ACs, the number of the combinations of backoff counter is

$$\prod_{j=0}^3 (CW_j + 1).$$

An AC_i wins the internal contention only if its backoff counter τ_i is the smallest for all ACs. The upper bound of the backoff counter for other AC_k , $k \neq i$, is $(AIFS_k + CW_k)$ and the lower bound is $\tau_i + 1$. Thus, the number of possible backoff counter for AC_k is $(AIFS_k + CW_k - \tau_i)$. As a result, the total combinations of backoff counter when AC_i wins the contention with τ_i is

$$\prod_{k=0, k \neq i}^3 (AIFS_k + CW_k - \tau_i).$$

Moreover, since AC_0 has the highest priority among all ACs. AC_i can never win the internal contention when $\tau_i > AIFS_0 + CW_0$, the upper bound of τ_0 . Therefore, the upper bound of τ_i when AC_i wins the contention is $AIFS_0 + CW_0$ and the lower bound is $AIFS_i$. In conclusion, the access probability p_i can be expressed as

$$p_i = \frac{\sum_{AIFS_i}^{CW_0 + AIFS_0} \prod_{k=0, k \neq i}^3 (AIFS_k + CW_k - \tau_i)}{\prod_{j=0}^3 (CW_j + 1)}.$$

To estimate the waiting time, we need to know the number of transmitted packets in all ACs before the new packet is transmitted. The new packet in AC_i can be transmitted only when all the packets already in the queue of AC_i are transmitted. The number of transmitted packets before new packet p_{i, l_i+1} is l_i . For other AC_j , the relative ratio of successful packet transmission is $\frac{p_j}{p_i}$, which means the expected number of transmitted packets for AC_j is $l_i \times \frac{p_j}{p_i}$. The expected number of transmitted packets $n_{i,j}$ for AC_j before the new packet of

AC_i can be expressed as the following equation.

$$n_{i,j} = \begin{cases} l_i \times \frac{p_j}{p_i}, & \text{if } l_i \times \frac{p_j}{p_i} \leq l_j \\ l_j, & \text{otherwise.} \end{cases}$$

Finally, the transmission time T_p of the new packet p_{i,l_i+1} is

$$T_p = \frac{s_{i,l_i+1}}{r_t} + (AIFS_i + CW_i) * t$$

The ACK time is not taken into consideration because it is transmitted after p_{i,l_i+1} . To conclude, the estimated waiting time E_i can be express as the new packet transmission time plus the transmission time of other packet before it.

$$E_i = T_p + \sum_{j=0}^3 n_{i,j} * \frac{\sum_{k=0}^{l_k} T_p(j, k)}{l_k}$$

All in all, CAVP combines the PSNR-based application layer prioritization with the dynamic MAC layer prioritization, which adaptively optimizes access delay based on current MAC layer status. MAP can further balance the load of MAC layer AC's.

IV. EXPERIMENT AND RESULTS

In order to implement the CAVP design on the real testbed, several modifications should be made for both the network layer and MAC layer. After the PSNR calculation, we use Click modular router version 1.70[16] to fill the TOS field in IP header which is an identifier to mark the importance of the packet. The temporal information of packets is also recorded by Click. We choose madwifi[17] as the wireless LAN interface driver on Linux kernel. Madwifi is one of the most advanced open-source WLAN drivers available for Linux. It is designed to cooperate with devices with Atheros chips. In MAP mechanism, we need to know the queue length and other AC parameters (for example: CWmax, CWmin, and AIFS) to compute the estimated access delay of all ACs. Therefore, we modify madwifi driver to gather all the required information in MAC layer. When a packet arrivals to the MAC layer, the madwifi driver allocate the packet to the proper AC according to the estimated delay. Then the madwifi driver updates the estimated delay of all ACs with the new queue lengths immediately.

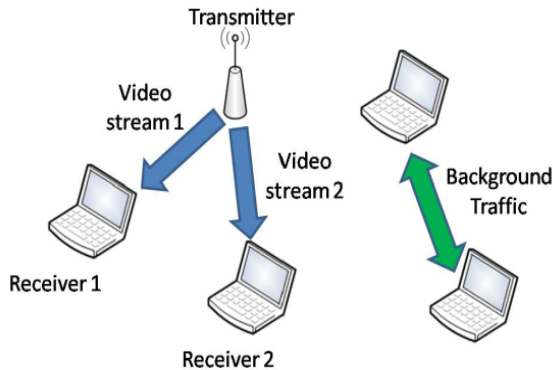


Fig. 4. CAVP system experiment setting

We use Asus EeePC 900 as our transceivers. EeePC 900 has built-in Atheros WLAN chip that can work functionally with modified madwifi driver. The operating system running on EeePC 900 is Ubuntu 8.04. The WLAN interfaces have their default value of IEEE 802.11e EDCA parameters. The WLAN is switched to ad-hoc mode. DHCP and ARP information is preset, so there was no DHCP or ARP response delay in the experiments. We use H.264/AVC JM reference software to encode and decode the video. The video we choose to transmit is Foreman, a standard video sequence used for video and picture evaluation purposes. It is a QCIF 30 fps format video with 400 frames. The packet sizes are not more than 1000 bytes. Video is encoded with group of picture (GOP) length being 6, which is suggested in [18]. The experiment scenario is shown in Figure 4. One transmitter sends two video streams at the same time. The two video streams are transmitted under the same scheme (CAVP, QoS, or EDCA). Two wireless stations transmit background traffic with AC_VI priority. All the stations are work in the same channel, with 1 Mbps transmission rate. We designed the scenario to compare the performance of several schemes:

1. Traditional IEEE 802.11e EDCA. Packets are sent to AC_VI.
2. QoS architecture mechanism mentioned in section I.[12].
3. Proposed CAVP.

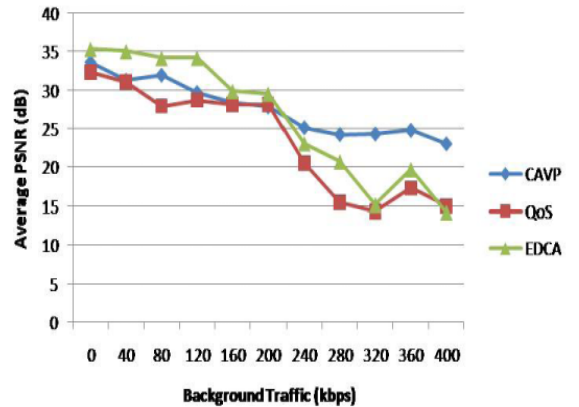


Fig. 5. The PSNR result(CAVP, QoS and EDCA)

The PSNR result is shown in Figure 5. When the background traffic load is smaller than 200 kbps, EDCA outperforms the other two modified schemes. As the background traffic grows, the advantage of CAVP reveals. For EDCA and the QoS scheme, once the channel saturated, the performance of video stream dropped acutely. We can see that both EDCA and the QoS scheme show a sudden drop immediately after the background traffic is larger than 200 kbps. In comparison, CAVP shows a graceful drop in PSNR. CAVP provides higher priority to the important packets, and only transmits the timely packets. Hence, once the channel is saturated, CAVP can provide higher Quality of Service than the other two schemes.

Figure 6 shows the packet loss of each scheme according to the VFP priority. We can observe that the loss of higher priority packets is much less than lower priority packets in CAVP. On the contrary, the losses of three kinds of packets are almost the same in the other two schemes. In other word, transmitting video packets with the priority of frame types in QoS architecture doesn't guarantee the successful delivery of important packets. Different from other schemes, there is very few overdue packets in CAVP. This improvement can be traced to the feature of MAP. MAP estimates the delay, chooses best queue for transmission and drops overdue packets. Therefore, the packets transmitted are likely to be in time.

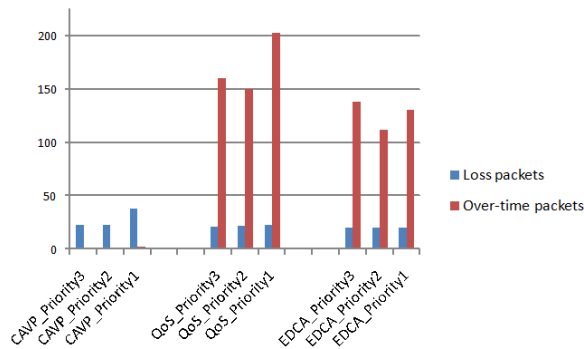


Fig. 6. The packet loss under 280kbts/sec background traffic

V. CONCLUSION

In this paper, we implement a cross-layer system for H.264/AVC video streaming over IEEE 802.11e wireless networks. Our design can provide higher video quality even when the channel is congested. Moreover, the MAP mechanism avoids sending over-time video packets. Therefore, the radio resource can be used more effectively. We have implemented the proposed design with Click kernel module and Mad-WiFi 802.11 network interface driver. The implementation demonstrates the practical feasibility of the proposed scheme. The experimental textbed measurements show the enhanced performance of the proposed scheme.

ACKNOWLEDGMENT

This work was supported by in part by the National Science Council of Taiwan under Grant 97-2221-E-002-138-MY2. The authors would like to thank Chih-Yu Wang and Fu-Wang Chang for their valuable discussions and contribution in the preliminary stage of this research project.

REFERENCES

- [1] IEEE Standard for Information Technology - Telecommunications and Information Exchange Between Systems - Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications - Amendment 8: Medium Access Method (MAC) Quality of Service Enhancements, IEEE Std 802.11e-2005 (Amendment to IEEE Std 802.11-1999).
- [2] S. Mangold, S. Choi, G.R. Hiertz, O. Klein, B. Walke, "Analysis of IEEE 802.11e for QoS support in wireless LANs," IEEE Wireless Communications, vol.10, no.6, pp. 40-50, Dec. 2003.

- [3] I. Richardson, "H. 264 and MPEG-4 video compression: video coding for next-generation multimedia," John Wiley & Sons Inc, 2003.
- [4] T. Wiegand, G.J. Sullivan, G. Bjontegaard, A. Luthra, "Overview of the H.264/AVC video coding standard" IEEE Transactions on Circuits and Systems for Video Technology, vol.13, no.7, pp. 560-576, July 2003.
- [5] T. Stockhammer, M.M. Hannuksela, "H.264/AVC video for wireless transmission," IEEE Wireless Communications, vol.12, no.4, pp. 6-13, Aug. 2005.
- [6] I. Politis, M. Tsagkaropoulos, T. Pliakas, T. Dagiuklas, "Distortion optimized packet scheduling and prioritization of multiple video streams over 802.11 e networks," Advances in Multimedia, 2007.
- [7] T. Liu, Y. Wang, J.M. Boyce, Z. Wu, H. Yang, "Subjective Quality Evaluation of Decoded Video in the Presence of Packet Losses," IEEE International Conference on Acoustics, Speech and Signal Processing, 2007, vol.1, pp. 1125-1128, 15-20 April 2007.
- [8] M. Krause, M. van Hartkamp, E. Aarts, "A quality metric for use with frame-rate based bandwidth adaptation algorithms," Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 6806, pp. 48, 2008.
- [9] M. van der Schaar, Y. Andreopoulos, Z. Hu, "Optimized scalable video streaming over IEEE 802.11 a/e HCCA wireless networks under delay constraints," IEEE Transactions on Mobile Computing, vol.5, no.6, pp. 755-768, June 2006.
- [10] N.S. Shankar, M. van der Schaar, "Performance Analysis of Video Transmission Over IEEE 802.11a/e WLANs," IEEE Transactions on Vehicular Technology, vol.56, no.4, pp. 2346-2362, July 2007.
- [11] Y. Xiao, X. Du, F. Hu, J. Zhang, "A cross-layer approach for frame transmissions of mpeg-4 over the ieee 802.11e wireless local area networks," IEEE Wireless Communications and Networking Conference (WCNC), pp. 1728-1733, 2008.
- [12] 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, vol.44, no.1, pp. 107-114, Jan. 2006.
- [13] T.D. Lagkas, G.I. Papadimitriou, P. Nicopolitidis, A.S. Pomportsis, "Priority-Oriented Adaptive Control With QoS Guarantee for Wireless LANs," IEEE Transactions on Vehicular Technology, vol.56, no.4, pp. 1761-1772, July 2007.
- [14] N. Chilamkurti, S. Zeadally, R. Soni, G. Giambene, "Wireless Multimedia Delivery over 802.11e with Cross-Layer Optimization techniques," Springer Multimedia Tools and Applications, pp. 1-17.
- [15] 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 802.11 e WLAN," Springer Telecommunication Systems, pp. 1-12.
- [16] Click Modular Router. <http://read.cs.ucla.edu/click/>.
- [17] The Madwifi Project. <http://madwifi-project.org/>.
- [18] A. Lombardo, G. Morabito, G. Schembra, "Modeling intramedia and intermedia relationships in multimedia network analysis through multiple timescale statistics," IEEE Transactions on Multimedia, vol.6, no.1, pp. 142-157, Feb. 2004.