ON CROSS-LAYER ADAPTIVE IEEE 802.11E EDCA MAC DESIGN FOR OPTIMIZED H.264 VIDEO DELIVERY OVER WIRELESS MESH NETWORKS

Byung Joon Oh1, Chang Wen Chen2, Ivica Kostanic3, Seung Ho Shin4 and Ki Young Lee5
1Dept. of Engineering, Link Communications, Ltd., Annapolis Junction, MD 20701 USA
2Dept. of Computer Science and Engineering, University at Buffalo, State University of New York, Buffalo, NY 14260 USA
3Dept. of Electrical and Computer Engineering, Florida Institute of Technology, Melbourne, FL 32901 USA
4Dept. of Computer Science and Engineering, University of Incheon, Incheon 042-749, South Korea
5Dept. of Information and Telecom Engineering, University of Incheon, Incheon 042-749, South Korea
byungjoonoh@lnkcom.com, chencw@buffalo.edu, Kostanic@fit.edu, {shin0354, kylee}@incheon.ac.kr

Abstract—We present in this paper a reliable optimized transmission of H.264 video streaming over IEEE 802.11e Wireless Mesh Networks (WMNs) based on a Cross-Layer Adaptive Enhanced Distributed Channel Access (CLA-EDCA) MAC architecture. The IEEE 802.11e EDCA offers a prioritized transmission to guarantee the minimum packets delay and drop rate needed for time bound applications, such as VoIP and Video. However, the standard EDCA scheme does not adapt to the network state to support time critical applications. In order to resolve the problems associated with standard EDCA, we highlight a novel adaptive architecture so as to change the Contention Window (CW) after each successful or unsuccessful transmission according to the current network conditions. We have integrated this cross-layer adaptive scheme leveraging smart forward error correction (FEC) schemes through channel state estimation (CSE) to achieve the optimal video transmission adapting to the network conditions. We have also explored several network level metrics, including bit rate, packets delay and drop rate, to evaluate the proposed scheme in comparison with IEEE 802.11e EDCA standard. Based on these extensive simulation results, we tested H.264 video transmission with both the proposed CLA-EDCA and the standard EDCA MAC. Simulation results have confirmed that the proposed CLA-EDCA outperforms the standard IEEE 802.11e EDCA by a significant margin with smart-FEC adapting to the network conditions over WMNs.

I. INTRODUCTION

Multimedia applications niches (VoIP, Video, Internet Protocol Television (IPTV), Video on Demand (VoD), Video Security and Surveillance Systems, and Mobile Digital Video Recorder (MDVR) Systems [2]) over IP were extensively developed so that the demand for Quality of Service (QoS) has been augmented as soon as the growth of Wireless Mesh Networks including infrastructure and ad hoc networks has been improved because of reliable service coverage, its cheap up-front cost, easy network configuration, and robustness [3]. Hence, Quality of Service (QoS) Support is critical to multimedia applications [8]. Time bounded services such as VoIP and Video typically require some specified bandwidth, delay and jitter guarantee, but can tolerate some losses. There are also many papers to innovate and complete QoS of H.264 transmission. Their challenge of improving high quality and QoS of H.264 is already emerging [1]-[5]. However, for a WMN to be all it can be, extensive research efforts for video delivery are still needed. Therefore, there are a few researches to tailor Media Access Control (MAC) and routing layer for video streaming [4] and [5]. Beginning with an overview of supporting high quality H.264 delivery in the Wireless LANs including Wireless Mesh Networks, we first discuss previous papers which proposed how to enhance the H.264 video transmission. Especially, in [1], the authors presented a cross-layer architecture based on IEEE 802.11e for QoS support. However, this scheme adopted only conventional EDCA as similar methods proposed in WMNs [4] and the H.264 error resilience tools (Data partitioning) for reliable H.264 video transmission and did not take into account Adaptive Approach of EDCA mixing with another H.264 error resilience tools. Zhu et al recently proposed in [5] an appropriate routing algorithm to improve the video quality over WMNs. However, they only addressed not the performance of MAC layer but an enhanced routing metric. Furthermore, a cross-layer mechanism improves an optimized H.264 video streaming over wireless ad hoc or mesh networks [1][3][6]-[8].

In exploring Adaptive advance of EDCA with cross-layer design in this paper, we will be limited to consideration of only the 802.11e EDCA over WMNs. Therefore, the present research question emerged from the question: traditional (EDCA) may not be optimal technique to implicitly transmit time critical services in WLANs as well as WMNs because the EDCA technique of IEEE 802.11e makes use of static reset to the CW (Contention Window). This static manner is a drawback since it does not tender any scope for adaptation to the network condition without the optimized cross-layer strategy. It also reduces the network practice and results in terrible performance and poor QoS whenever the demand for wireless access medium employment increases [8].

In [9], we proposed Adaptive EDCA and these extents only covered wireless Ad Hoc Networks. On contrast, in [10], authors only focused on the wireless infrastructure networks and MPEG-1/4 and H.263 streams. In addition, Adaptive EDCA scheme also was proposed in [9], where optimizing CW parameters brought about enhancing the network performance. In this context, it produced Adaptive EDCA structure that adapted CW to channel situation and adjusted
it dependent on the network operation and feat through cross-layers. Although the performance of the proposed scheme was evaluated compared to the original techniques of the IEEE 802.11a and 802.11e MAC Protocol, they only highlighted the network level performances (throughput, packet delay, and packet loss rate) and MPEG-4 streams without a cross-layer design.

The previous works [1], [4]-[5] and [9]-[10] did not intensely investigate wireless channel impairments. In particular, in our works, to implement more complicated channel model close to real world, we not only adopt Rayleigh fading statistical channel combined to Finite-state Markov channel models at the same time but also focus on the Wireless Mesh Networks, which constitute hybrid mesh mode (infrastructure and ad hoc) and EDCA MAC [8]. Moreover, our purpose of the presented paper is to offer an improvement of H.264 video transmission in cooperating with both the proposed Adaptive EDCA MAC based on a cross-layer design and smart Adaptive FEC mechanism perceiving network state and congestion to minimum overhead of FMO’s problem under wireless channel error model [11].

The rest of the paper is organized as follows. In section II, we propose the Cross-Layer Adaptive (CLA)-EDCA MAC scheme and Wireless Channel Error model (Rayleigh Statistical Channel and Finite-State Markov Channel model). Section III presents the experimental results highlighting the benefits of the proposed technique compared to original IEEE 802.11e standard. In section IV, we conclude this paper.

II. CROSS-LAYER ADAPTIVE EDCA MAC ARCHITECTURE AND SOPHISTICATED WIRELESS ERROR MODEL

As we mentioned before, the standard EDCA being short of adaptation mechanism so as to satisfy with QoS constraints in time critical applications. In this section, we present a Cross-layer Adaptive (CLA)-EDCA MAC scheme and Wireless Channel Error model (Rayleigh Statistical Channel and Finite-State Markov Channel model). Section III presents the experimental results highlighting the benefits of the proposed technique compared to original IEEE 802.11e standard. In section IV, we conclude this paper.

A. Dynamic adaptation of the CW parameter

Among the parameters of standard EDCA, we take a closer look at their operations in terms of both CW differentiation and AIFS differentiation. These costs may also be dynamically adapted according to network situations. Obviously, the smaller both the $AIFS_{i}$ and $CW_{\min,i}$ the higher the probability of winning the contention with the other ACs. According to [11], the capacity to dynamically adapt to network congestion without major performance mutilations makes $AIFS$ differentiation an enormously efficient strategy.

\begin{equation}
    \text{Rate}_{\text{est},i} = \frac{[CW_{\text{prevest},i} - CW_{\min}]}{[CW_{\max} - CW_{\min}]} \tag{1}
\end{equation}

where $Rate_{\text{est},i}$ stands for the estimated collision rate occurring at class $i$. To reduce the bias against transitory collisions, we adopt an estimator of Exponential Moving

Fig. 1. Flowchart of proposed CLA-EDCA MAC algorithm

Above all, so as to respond to the current network conditions, we monitor that the contention window size is closely related to networks link status and can be adjusted. Specially, it is desired to fix the $CW$ values close to $CW_{\min}$. When the network is not actually prepared for the intended media access demand, we will implicitly enable $CW$ to count on the current network condition with such adjustment so that we can diminish the time spent for the unnecessary attempt, failure and waiting (Idle time) phase. Consequently, depending on the channel congestion level, the proposed manner is based on adapting the values of $CW$. Therefore, it is practical to calculate the channel conflict rate by testing at present value of $CW$. Firstly, assuming that $CW$ values are in the range of $[CW_{\min}, CW_{\max}]$. Then we estimate its relative distance $[CW_{\text{prevest}} - CW_{\min}]$ as comparing with the maximum range $[CW_{\max} - CW_{\min}]$. As an indicator for channel congestion status, we conduct the ratio between these two values. In this fashion, it pursues that the indicator for $Rate_{\text{est},i}$ can be derived as:
Average (EMA) to smoothen the estimated values resulting from developed equations. Note that the above Rate$_{inst,j}$ is always in the range of [0, 1].

$$Rate_{avg,j} \leftarrow (1 - \alpha_j) \times Rate_{avg,j} + \alpha_j \times Rate_{inst,j}$$  \hspace{1cm} (2)

where Rate$_{avg,j}$ represents the average collision rate at class $j$. And we utilize variable $\alpha_j$ (weight, also called the smoothing factor) reflecting the confidence of the channel evaluation to optimize Rate$_{avg,j}$. Lastly, according to its priority level (we denote this factor by Adaptive Factor or AF) each class should employ different factor to pledge that the priority relationship between different classes is conducted when a class renews its $CW$.

$$AF_j = \min(\frac{Rate_{avg,j} \times (1 + 2 \times j)}{0.8})$$  \hspace{1cm} (3)

Note that AF factor is used to reset the $CW$ should not pass the previous $CW$, we limit the maximum value of AF to 0.8. According to a wide set of simulations done with several scenarios in the following Fig. 2, we can see this variable. To clarify, the $\alpha_j$ would be highly weighted if the differentiation in time between estimation and transmission is in the range of milliseconds.

![Effect of the smoothing factor on the Bit Rate](image)

![Effect of the smoothing factor on Average Delays](image)

**Fig. 2. Effect of the smoothing factor ($\alpha_j$)**

In this work, for simplicity, the weight $\alpha_j$ is fastened to a rate of 0.8. In order to support H.264 video streaming, which is illustrated by transmission occurring at millisecond time intervals, its selection is reliable with the time-critical applications.

We first observe the setting parameters for contention window to be steady with the standard IEEE 802.11e EDCA. After each successful transmission, the choice of new window to be steady with the standard IEEE 802.11e EDCA.

$$CW_{original, new,j} = ((CW_{present,j} + 1) \times PF_j) - 1$$  \hspace{1cm} (4)

where $PF_j$ is the persistence factor that lessens whenever each station obtains higher priority in original IEEE 802.11e EDCA MAC. In a similar approach, after each successful transmission, the adjustment of contention window size $CW_{adaptive, new,j}$ can be described as:

$$CW_{adaptive, new,j} = \max(CW_{min,j}, CW_{present,j} \times AF_j)$$  \hspace{1cm} (5)

With this designation, $CW_{adaptive, new,j}$ is always greater than or equal to the minimum contention window size $CW_{min,j}$ and the priority access to wireless access medium is therefore promised.

The standard IEEE 802.11e EDCA merely double the parameter $CW$ in the case of unsuccessful transmission challenge:

$$CW_{original, new,j} = \min(CW_{min,j}, 2 \times CW_{present,j})$$  \hspace{1cm} (6)

Note that with the constraint, the new contention window size is less than the maximum contention window $CW_{max}$.

After successful transmission, pursuing our designation for new contention window size, in the case of failed transmission challenge, we can identify the contention window adjustment as:

$$CW_{adaptive, new,j} = \min(CW_{max,j}, CW_{present,j} \times AF_{SN})$$  \hspace{1cm} (7)

The updating equation $CW_{adaptive, new,j}$ is enriched with $AF_{SN}$, from the above adaptation fashion. $AF_{SN}$ of high priority traffic and that of low priority traffic has 2, 7, respectively along with [1]. This makes sure that high priority traffic, rather than low priority traffic, is guaranteed giving priority right to admit wireless medium. Essentially, the merged updating procedure for either successful or failed transmission effort facilitates the desired adaptation for time bound applications such as H.264 video transmission over wireless mesh networks (WMNs).

### B. Dynamic adaptation of the $AF_{SN}$ parameter

In order to achieve QoS, we have proposed another method for future work in terms of $AF_{SN}$ parameter. So, we can ensure that the priority relation between classes is still operated after each traffic class initializes the $AF_{SN}$ value with a value included in its $AF_{SN}$ interval.

$$AF_{SN_{present,j}} = (AF_{SN_{max,j}}, AF_{SN_{min,j}})$$  \hspace{1cm} (8)

$$AF_{SN_{max,j}} \leq AF_{SN_{min,j}+1}$$  \hspace{1cm} (9)

Note that the priority $j$ is always higher than the priority $j+1$ regarding $AF_{SN_{max}}$. Therefore, we can change the $AF_{SN_{present,j}}$ with regard to Rate$_{avg,j}$ (the average collision rate). In short, our algorithm is described in the following procedures:

If Rate$_{avg,j}$ parameter is in the range of $[0 \sim 0.5]$, $AF_{SN_{present,j}}$ of higher priority class is increased by 1, on the contrary, $AF_{SN_{present,j}}$ of lower priority class is decreased by 1 to give even lower priority class transmission opportunity. On the other hand, If Rate$_{avg,j}$ parameter is in the range of $[0.6 \sim 1]$, $AF_{SN_{present,j}}$ of higher priority class is decreased by 1, on the converse, $AF_{SN_{present,j}}$ of lower priority class is increased by 1 to assure higher priority class’s transmission...
opportunity. This work is reminded in future research direction which is associated with an adaptive cross-layer structure design.

Furthermore, previous existed works [1], [4]-[5] and [10] also did not address how to tackle wireless error model to estimate the performance of proposed algorithms. However, in this research, we exploit the Rayleigh statistical channel that is one of the statistical channel models and finite-state Markov channel that is one of the well-known channel models used to measure the burst error prototype. Fig. 3 shows a state illustration for a finite-state Markov channel model. In the “good” state (G) losses happen with lower probability \( p_G \) while in the “bad” state (B) they happen with higher probability \( p_B \) so that \( p_{GB} \) is the probability of the state transportation from a bad state to a good state. The stable state probabilities of being in states G and B are described as follows:

\[
\pi_G = \frac{p_{BG}}{p_{BG} + p_{GB}} \quad \text{and} \quad \pi_B = \frac{p_{GB}}{p_{BG} + p_{GB}}
\]

Hence, we can acquire the average packet loss rate generated by the finite-state Markov model as followed formula:

\[
p_{avg} = p_G\pi_G + p_B\pi_B
\]

Moreover, to employ Rayleigh fading channel model, we also launch the Ricean distribution pdf(\( \rho \)) derived as:

\[
pdf(\rho) = \frac{\rho}{\sigma^2} e^{-\frac{\rho^2}{2\sigma^2}} I_0(2K\rho)
\]

where \( K \) is the distribution factor describing the strength of the line of sight part of the received signal and \( I_0(\cdot) \) is the modified Bessel function of the 1st kind and zero-order. If \( K = 0 \), the Ricean distribution lessens to the Rayleigh distribution, in which there is no-line-of-sight part [8].

**C. Smart-FEC Algorithm based on Channel State Estimation**

With the feedback of the channel state estimation, a smart-FEC algorithm can be designed after blocks of packets are received. The channel state estimation algorithm also illustrated in [11] in detail. In this case, the MR (Mesh Router) calculates packet retry based on CSE results under the assumption that packet retransmission time completely reflects the information of wireless channel status.

\[
\alpha = 1 - \frac{\text{queue\_high\_threshold\_of\_retry} - \text{retry}}{\text{queue\_high\_threshold\_of\_retry} - \text{queue\_low\_threshold\_of\_retry}}
\]

\[
\text{FEC}_{no} = \text{FEC}_{no} \times \alpha
\]

MR reduces the number of redundant FEC packets based on the current retry time: retry (weighted moving average retry time) = (1 - rweight) * current_retry (current retry time) + rweight * retry. Note that queue_low_threshold of retry and queue_high_threshold of retry are 5 and 15, respectively. Consequently, the number of smart-FEC is implemented as shown in Fig. 4.

\[
\begin{align*}
\text{If (retry < queue\_low\_threshold\_of\_retry)} & : \\
& \text{FEC}_{no} = \text{FEC}_{no} \times \alpha \quad \text{(adaptive factor)}; \\
\text{Else} & : \\
& \text{FEC}_{no} = \text{FEC}_{no}; \\
\end{align*}
\]

Fig. 4. Pseudo code of smart-FEC Algorithm

**III. EXPERIMENTAL RESULTS**

In this section, we will compare the performance of original EDCA with that of the proposed Adaptive EDCA MAC without the cross-layer design. Especially, we implement hybrid mesh mode topology (infrastructure and ad hoc) that consists of 14 nodes: 4 mesh clients and 4 conventional clients, 6 mesh routers, a data rate of 11 Mbps and other important system parameters are based on physical layer used in IEEE 802.11b standard. The test video sequence is Carphone (100 frame) and Akiyo (100 frame). Hence, Station 1 has the highest priority and Station 4 also has the lowest priority in this topology as shown in Fig. 5. Note that smart-FEC as Cross-layer strategy is added depending on the state of wireless channel in Mesh router (right side) where it is easy to determine how many redundant FEC packets should be produced based on the current network condition.

Fig. 5. Topology of wireless hybrid mesh network

![Fig. 6. Bit Rate Comparison between EDCA and AEDCA](image-url)
In Fig. 6, the performance of bit rate in destination nodes is represented using NS-2 Simulation [12] in that we can manifest that, when time is beyond 30 sec, the EDCA cannot satisfy stable hybrid mesh structure in Station 1, 2 regarding various priority parameters. Therefore, it has some reasons why the congestion exists in the Mesh router so that the Mesh router should transmit all traffic over the wireless channel, which is a significant traffic load whereas, the proposed scheme would resolve the problem of Mesh router reducing collision of each node with regard to adaptation of the network state. It also supports more steady system rather than IEEE 802.11e EDCA standard based on WMNs.

![Fig. 7. Drop Rate between EDCA and AEDCA](image)

Fig. 7. Drop Rate between EDCA and AEDCA

As the same topology described above is used, Fig. 7 shows the simulation results of the drop rate for EDCA and Adaptive EDCA MAC, respectively. We can demonstrate that the drop rate of EDCA experiences heavier oscillations and disorders in problems of Mesh router, wireless channel conditions and MAC. However, as the Fig. 7 is shown, the proposed AEDCA outperforms EDCA so that it definitely diminishes the drop rate similar to the performance of bit rate. The simulation results disclose the bad performance of IEEE 802.11e EDCA similar with the results of Ad-Hoc mode [6]-[9]. The QoS metric of EDCA can not guarantee H.264 transmission over WMNs without a cross-layer design thus, adaptive and original EDCA MAC could be cooperated with a cross-layer algorithm for optimized H.264 video delivery.

Note that in Fig. 8 the average packets delay results for the EDCA and the Adaptive EDCA MAC under various priorities. It can be observed that a decrease in packets delay of lowest priority station 4 is completed by proposed Adaptive EDCA. It leads to better network deployment keeping less packets delay of other stations (1, 2 and 3). Therefore, we can identify that the high bit rate of high priority station sustains other stations transmit their packets to destination nodes rapidly.

As a result, the proposed algorithm supports all priority stations, even lowest priority station under variation of network conditions. In contradict, the IEEE 802.11 EDCA only holds up the high priority stations so that it takes place lower priority station suffer heavier congestion, packet drop and packet delay subject to network bandwidth starvation in Mesh router. We would tailor the network level performance of stringent QoS metric both original EDCA and Adaptive EDCA MAC over wireless hybrid mesh networks.

![Fig. 8. Average Packets Delay between EDCA and AEDCA](image)

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![Fig. 9. Evaluation of Video Streaming Transmissions](image)

Fig. 9. Evaluation of Video Streaming Transmissions

Fig. 9 illustrates the evaluation of H.264 video transmission in both EDCA and Adaptive EDCA MAC in terms of two sequences. We can observe that EDCA achieves a poor video quality at the receiving node with decreased average 1.45dB rather than the video quality of Adaptive EDCA MAC without smart-FEC (Cross-Layer scheme). Therefore, the proposed CLA-EDCA MAC scheme associated with optimal smart-FEC strategy also outperforms conventional EDCA in that the outstanding improved transmission of video quality is performed by the proposed Adaptive EDCA highlighting the time bound multimedia applications with high priority under Rayleigh fading distribution channel and finite state Markov chain channel models. Although Adaptive EDCA is an insufficient for providing scalability character of MAC requirements in wireless mesh networks, we can recognize its possibility with this experiment.
We conduct experiments to show the reconstructed average PSNR of the decoded video sequences over WMNs so that Fig. 10 depicts the objective video quality measurements of average reconstructed PSNR (luminance component) for two video streams, “Carphone” and “Akiyo”, which are tested under the two schemes. It is clearly seen that our proposed scheme achieves better video quality with increased average 1.45dB than original EDCA leveraging with the optimal smart-FEC on application layer, which are dynamically added based on both network traffic load and wireless channel state under wireless error-prone channel.

Therefore, our introduced proposed CLA-EDCA with smart-FEC can improve the video delivery because it accepts network situations. Finally, we can conclude that our introduced architecture gets a better H.264 video quality rather than EDCA scheme.

IV. CONCLUSIONS

We described in this paper a novel cross-layer adaptation strategy of MAC protocol for a reliable delivery of the H.264 video streaming over wireless mesh networks. Therefore, we have also developed a new adaptive architecture for adjusting contention window (CW) after each successful and unsuccessful transmission regarding network conditions. We also demonstrate several network level QoS metrics (bit rate, packets delay and drop rate) to evaluate the proposed algorithm compared to IEEE 802.11e EDCA based on WMNs.

Based on the preliminary simulation results, H.264 video streaming is transmitted via both proposed Adaptive EDCA and EDCA MAC. As a result, simulation results have validated that our proposed technique definitively achieves better video quality with increased average 1.45dB by cooperating with smart-FEC on application layer as a cross-layer strategy adapted network conditions through Channel State Estimation (CSE) on the physical layer. In the future, we will study the Scalable MAC for Wireless Mesh Networks including WLAN and Ad hoc mode because Adaptive EDCA MAC is lack of scalable characteristic while it also supports time-bounded services as above experiments.

REFERENCES


