QoE Enhancements in IEEE 802.11e EDCA for Video Transmission through Selective Queueing

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***Abstract*—This paper proposes a set of performance enhancements techniques aiming to improve the perceived performance of video transmission across the IEEE 802.11e network. The proposed mechanism preserves the video Quality of Experience (QoE) by protecting the I-Frames transmitted as part of the Group of Pictures (GoP) during queue congestion. The method is evaluated using the NS-3 simulator with the Evalvid module and the results demonstrate the video flows will have better Peak Signal to Noise ratio (PSNR) and less video frame drops compared to the original IEEE 802.11e queueing.**

Keywords*—*IEEE 802.11e; EDCA; QoE; NS-3; Evalvid

I. Introduction

Wireless Local Area network (WLAN) has been in strong and growing demand since the early 1990s [1][2][3] and remains the preferred network access while being widely used [4]. This is due to the low deployment costs, a variety of features, and ease of setup that provides an excellent platform for generic data transfer. As the network becomes more popular, the network load has become a critical issue. WLAN, which was originally designed and responsible to carry Best Effort (BE) services are now being used to carry heavy, real-time and multimedia traffic especially video.

Since the mid-2000s, the demand for video services over the Internet has increased significantly [5]. At the same time, the popularity of the Internet led to integrating video communications into the BE packet networks. Recent statistics showed a sharp increase of wireless video streaming, with wireless access likely to progressively replace wired networks. In 2010, [6] projected that 69% of the mobile traffic are accounted for video traffic. Meanwhile in 2011, [7] reported that video accounts for half of the total Internet traffic and projected that to increase by 2016. These predictions were confirmed in 2014, with users now spending more time watching video on a smartphone in 2014 compared to the previous year (2013) by 19.06% [8]. In 2015, [9] issued a Visual Networking Index (VNI) and predicted increase in video traffic across the Internet from 64% in 2014 to 80% by 2019. An increase of traffic from wireless and mobile devices was also predicted where it will represent 66% of IP traffic by 2019 compared to 46% in 2014.

Transmitting video traffic over dynamic environment such as wireless networks remains a challenging issue in spite of the progress made through the IEEE 802.11e framework and the associated research. Since WLANs are now heavily used to stream multimedia traffic, relying on QoS parameters is no longer sufficient.

In order to evaluate the user-perceived quality, looking to parameters beyond QoS is now vital. Thus, the term of Quality of Experience (QoE) has been introduced to expand the evaluation from the measurement of end-to-end performance at the services level to the impact these parameters have on the users' perception of the transmitted video. This new approach is required in order to define performance measurement while considering the subjective nature of the users [10].

II. Related Works

In order to fully understand the current state of the art in the area of wireless video QoE, this section will provide an overview of the video encoding process, the wireless queuing, and the efforts made to combine the two concepts in a communication architecture.

A. MPEG4 Group of Pictures (GoP)

MPEG-4 was developed mainly for storing and delivering multimedia content over the Internet [11]. MPEG-4 streams consist of three types of frames, namely I, P, and B, transmitted in a structure called Group of Pictures (GoP).

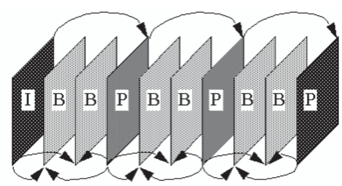

Fig. 1. The structure of an MPEG-4 Group of Picture

The I-Frames are independent of the rest of the stream, as they do not depend on other frames to allow decoding of the video stream. Meanwhile P-Frames and B-Frames only contain video information updates compared to the I-Frames. Because of their content, P-Frames and B-Frames have smaller sizes in comparison with I-Frames; they are also depending on the content of the I-Frame in order to allow the encoding of the video at the receiver.

B. IEEE 802.11e EDCA

Throughout the years, a lot of effort had been made to enhance the performance of the legacy IEEE 802.11 network. In spite of its benefits, the original IEEE 802.11 standard specification did include a number of inherent challenges including supporting QoS for video traffic. To address this issue, IEEE amended the original IEEE 802.11 and formed Task Group E. This group was assigned to enhance the IEEE 802.11 MAC to expand support for applications with QoS requirements. This resulted to a new amendment known as the IEEE 802.11e.

The IEEE 802.11e amendment introduced two new channel coordination functions: HCF Controlled Channel Access (HCCA) and Enhanced Distributed Channel Access (EDCA). HCCA is based on polling where the Access Point (AP) polls each Mobile Station (MS) to check whether it wants to send any data. In contrast, EDCA is a contention based channel coordination function that requires each MS to compete for accessing the wireless media.

Functionally, EDCA is derived from the legacy Distributed Coordination Function (DCF) of IEEE 802.11, with several enhancements. Four new different Access Categories (AC) namely the AC3, AC2, AC1 and AC0 were introduced, where they were intended to refine the granularity of the queue, based on the traffic priority. AC3 is reserved for voice stream (AC_VO), AC2 for video (AC_VI), AC1 for best effort traffic (AC_BE) and AC0 for background traffic (AC_BK). The priority ranks from the highest to the lowest, respectively. These streams will be treated differently in the EDCA mechanism. In this paper, focus was given on this particular feature where we further refine the AC_VI queue to manage the video traffic better.

The introduction of IEEE 802.11e EDCA has significantly improved the QoS provision for wireless network [12][13] by offering differentiated performance between AC. EDCA has been purposely designed to be selective towards the high priority AC.

However, several issues still need to be addressed before EDCA can really support QoS as well as QoE for video traffic. Multiple ACs in the queue lead to individual ACs competing with each other and can cause internal collision. Meanwhile, the current standard treats all video the same regardless of the content type while no fine prioritization has been given towards the different type of video frames.

C. Previous Works

Over the years, significant amount of work has been done to improve the performance of video traffic in the IEEE 802.11e EDCA.

Several papers improve the video transmission performance by adjusting the parameters of the IEEE 802.11e EDCA mechanism such as the Contention Window (CW), Transmission Opportunity (TXOP) and the Arbitrary Inter-frame Space (AIFS). These alterations reduce the waiting time to access the wireless media for the high priority traffic, but do not exploit the significance of specific traffic type such as video that needs an adaptive treatment due to the nature of its variability in data rates. For example, [14] aimed to enhance the QoS level in EDCA to for medical video communication in order to provide the required medical-grade QoS of various medical applications and ensure accurate visualization of the patient condition. By considering two metrics (packet delay and ratio of late/ receive packets), the AIFS were adjusted to improve network performance.

Rather than enhancements focused on the 802.11 standards, several papers considered a cross-layer approach, individually tagging packets according to their priority level and offering appropriate preference and fairness. As a result, queueing systems may identify the types of the video packets and treat them selectively. The authors of [15] proposed a new static mapping where I-Frame is mapped to AC_VI while P- and B-Frames are mapped to AC_BE and AC_BK respectively. Through this technique, I-Frames are given the highest priority and this prevents them from being dropped whenever the queue is congested. However when the video traffic load is light, channeling P- and B-Frames to AC_BE and AC_BK causes unnecessary delay for the video flow.

An alternative approach was used in [16] by introducing dynamic video frame mapping. The mapping is based on the significance of the video data and the traffic load. In video traffic, problems will arise when there is a sudden burst of video packets where the queue will suddenly be congested. Packets that are incoming toward the queue will have high probability to be dropped. Through this dynamic mapping, any incoming video packet will be channeled to AC_BE or AC_BK if AC_VI is full and video traffic will not interfere with the AC_VO, the highest priority AC. The evaluation tests indicate that the proposed mechanism increases the PSNR for video traffic by 8.11% to 11.80%.

Also in the context of cross layer approaches, [17] introduced a design to ensure better QoE for H.264 with Scalable Video Coding (SVC) video. The proposed mechanism involves three layers - APP, MAC and PHY. The APP and PHY layers are made aware of each other's condition. The receiver will send ACK to indicate whether packets were received correctly. Based on the ACK records, online QoS-QoE mapping was proposed. The PHY layer adapts to provide unequal error protection for each video layer based on the proposed mapping. Meanwhile, the APP layer is updated on the buffer starvation of the channel by the PHY and adjusts its rates accordingly. The simulation scenarios indicate that the architecture successfully avoids buffer starvation while handling channel and buffer fluctuations to achieve a 30% increase in video capacity. However in this experiment, only SVC videos were considered and the exact wireless network technology was not mentioned.

Adaptive Mapping Mechanism (AMM) was introduced in [18], based on the earlier work from [16]. It proposes a number of enhancements, allowing AMM to check the congestion level of all the voice, video, best effort and background queues before assigning video packets to the other queues. The main reason for the enhancement is to stop the video traffic from monopolizing the access control for the station. The study also introduces differentiated queuing depending on frame type, with I-Frames assigned to the highest AC priority, AC_VO and, depending on the mapping control module, P-Frames assigned to AC_VO or AC_VI and B-Frames assigned to AC_VI or AC_BE. Through simulation, the AMM proved to have less packet loss ratio, especially compared to EDCA.

Most of the previous study suggested and agreed that for video transmission, it is important to protect the I-Frames from being dropped. Channeling I-Frames to AC_VO increased the I-Frame's priority. However, P- and B-Frames will still have the same old priority. This means, although the I-Frame arrives first at the receiver, it still needs to wait for the consecutive P and B-Frames to be reconstructed to a video. This will cause delay especially in a scenario where the network is loaded with voice traffic (P and B-Frames needs to give way to the voice traffic). And if the I-Frame does not wait for the P and B-Frames, bandwidth has been wasted to transport the unused P and B-Frames to the receiver.

III. PROPOSED SCHEME

The I-Frame is the most important frame in the GoP of an MPEG-4 video, therefore protecting the I-Frame ensures a high probability of the video quality being preserved. In this paper, focus is given in a scenario where the AC_VI queue is congested. This can occur especially when there is a sudden increase in video flow or when the network traffic is highly loaded.

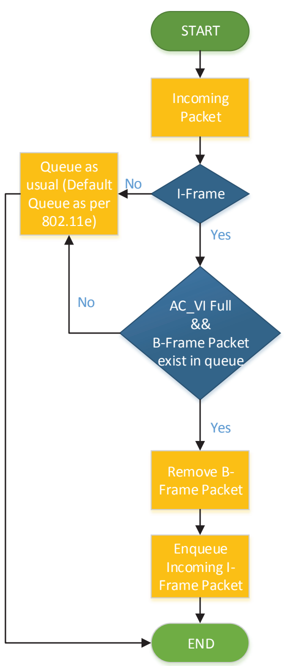

Fig. 2. The flow chart of *MFM* mechanism

In this scenario, incoming packets carrying I-Frame information are due to be queued but are dropped due to the queue being full. This is undesirable because the following P- and B-Frames will carry unusable video information, given the I-Frame needed to reconstruct the video is lost. The follow-up P and B frames will not only congest the queue but will also contribute to bandwidth congestion as they do not serve any purpose.

Given the above scenario, the objective of the proposed scheme is to protect the I-Frames from being dropped by discarding the B-Frames from the AC_VI queue during congestion. In a preliminary experiment conducted, we have discovered that B-Frame packets can be dropped or discarded to a certain level without notably affecting the PSNR.

In the proposed mechanism, *MPEG-4 Frame Manager (MFM)*, packets with P- and B-Frame information (Pkt_P and Pkt_B) are queued using the default EDCA queueing mechanism *(DefaultQueue)*, but packets carrying I-Frame information (Pkt_I), are treated differently by going through a two-step queue testing. First is the AC_VI congestion level. If the AC_VI queue is not full, Pkt_I will be queued as usual using *DefaultQueue*. However if the AC_VI queue is full, the second queue testing will take place, which is to check whether there is a Pkt_B of that particular video flow available in the AC_VI to be removed. If it is positive, the Pkt_B will be removed from the queue and will be replaced by the incoming Pkt_I. The mechanism flow chart can be shown as in Fig. 2.

IV. NETWORK SIMULATION SETUP

A simulation study based on NS-3.22 was conducted to test the *MFM* mechanism against *DefaultQueue*. The network scenario is in a wireless infrastructure mode where it consists of four MS and an AP. However, only one sender and one receiver are involved during the course of data transmission. The wireless links use IEEE 802.11e (QoS enabled) and every station is within each other's coverage which means no hidden terminal is involved. Meanwhile, the request to Send/ Clear to Send (RTS/ CTS) mechanism is disabled to minimize the number of control packets involved.

The experiment was conducted using the publicly available video sequence "highway.yuv" [19]. This video was selected because it contains 2000 frames and will most probably cause queue congestion. This is important because the proposed mechanism is intended to address the issue of video queue congestion. The video is in a CIF format with a resolution of 352 x 288.

Evalvid [20] was imported into the NS-3 simulator to simulate real video frames transmission across the simulation scenario. Several other tools were also used for the simulation such as ETMP4, FFMPEG and PSNR to encode/ decode and evaluate the video quality used in the simulation. The video used in this experiment is encoded with a GoP size of 9.

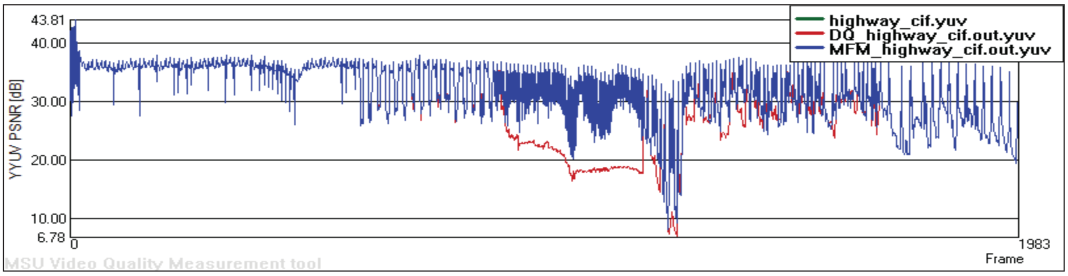

Fig. 3. Overall PSNR overlay between *DefaultQueue* and *MFM*

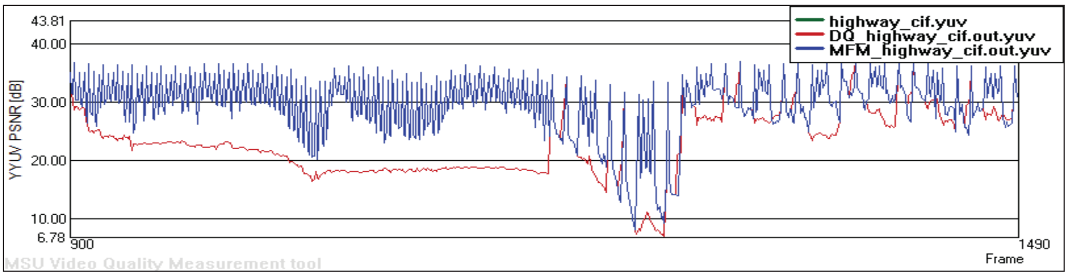

Fig. 4. PSNR overlay between DefaultQueue and MFM for the frames 900-1490.

V. RESULTS AND FINDINGS

Following the simulations, the video streams collected at the receiver are evaluated in terms of metrics analysis and visual comparison between the proposed queueing mechanism and the default queueing mechanism of the IEEE 802.11e. As part of the objective evaluation, Peak Signal to Noise Ratio (PSNR) and Structural Similarity (SSIM) were run against the video at the receiver's end to evaluate the quality. In addition, frame loss was also considered to evaluate the effectiveness of *MFM* in preventing I-Frame packets from being dropped.

A. Metrics analysis

Fig. 3 and Fig. 4 present the PSNR of the reconstructed video stream, following transmission using the default queue of IEEE 802.11e (red) and the proposed *MFM* method (blue). Fig. 3 presents the measured values over the entire video, while Fig. 4 expands on the frame 900 – 1490 interval, which included the most dynamic sequence and therefore was most affected by the encountered congestion loss.

During the course of Frame 900 to 1490, the queue has been congested which has been reflected by the PSNR readings. At this specific range, the proposed mechanism has been activated. Most of the I-Frames that were dropped in the IEEE 802.11e default queueing mechanism are now being recovered in *MFM*. While the PSNR and SSIM reading for *DefaultQueue* has dropped significantly to 23.03 and 0.69 respectively, MFM had a far better PSNR and SSIM reading of 29.20 and 0.84. This is shown as in TABLE I.

TABLE I. OVERAL RESULTS OF THE VIDEO QUALITY AND FRAME LOSS BETWEEN QUEUEDEFAULT AND *MFM*

Mechanism	PSNR		SSIM		Frame loss (%)		
	Overall	Specific	Overall	Specific	I	P	B
DefaultQueue	29.52	23.03	0.82	0.69	36.04	33.63	44.14
MFM	31.43	29.20	0.86	0.84	9.01	33.63	61.56

In terms of frame loss, *MFM* had significantly improved the probability of I-Frame being dropped where only 9% of I-Frames were loss compared to 36.04% as in *DefaultQueue*.

B. Visual Comparison

Fig. 5 presents a visual comparison of the video quality for three different frames. The quality of video delivered using *MFM* significantly improved the video quality in comparison to *DefaultQueue*.

VI. CONCLUSION AND FUTURE WORK

This paper proposes a selective queuing method that enhances the performance of MPEG-4 video transmission in the IEEE 802.11e environment. The mechanism proposed preemptively drops B-Frame packets in the queue during congestion in order to prioritize the I-Frame packets. The validation experiments demonstrated that the proposed mechanism has the ability to provide enhancements in video transmission and thus offers better video QoE in the IEEE 802.11e.

This is a work in progress where in the future development, the proposed system would be able to differentiate the content of the video in a multiple video flow environment and

Fig. 5. Visual comparison of the reconstructed video at the receiver's end

prioritize the video frames accordingly. Meanwhile, PSNR is currently being used as the metric to compare the effectiveness of the proposed scheme. Although it is not the most ideal metric to be used to compare QoE, it provides a simple benchmark to compare the effectiveness of the proposed scheme. In the future, subjective metrics such as Mean Opinion Score (MOS) will be taken into account to provide a more realistic result as to the effectiveness of the proposed scheme.

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