Enhanced Prioritization for Video Streaming over Wireless Home Networks with IEEE 802.11e

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***Abstract*—Cyclic intra refresh is able to mitigate temporal error propagation. This paper exploits the unequal error sensitivity introduced within individual video frames when using a cyclic intra refresh line of macroblocks. Slice-level priority is proposed based on the relative position of a slice with respect to the intra-refresh line. Two in-frame prioritization schemes are investigated: a region-based priority assignment and a packet-based priority assignment. The region-based scheme assigns packet priorities in the order of bitstream arrival to the packetizer, whereas the packet-based scheme assigns priorities within regions and does not follow bitstream arrival order to the packetizer. The proposed schemes do not add any bitrate or computational overheads and no decoder modification is required. Simulation results for streaming high-definition video over a quality-of-service enabled home wireless network show that the packet-based scheme can achieve quality gains up to 3 dB over sending video without applying priorities.**

I. Introduction

An H.264/AVC (Advanced Video Coding) codec [**?**] can use multiple previously-coded frames as predictive reference [**?**] for the current frame. This not only increases the compression efficiency but also the inter-frame dependency. Hence, errors in a distorted frame will propagate to the following frames, as error concealment may not clear-up some distorted areas. Additionally, as video compression efficiency improves with successive codec standards, error sensitivity increases, which in turn results in quality degradation when transmitting over error-prone channels, especially wireless networks.

To halt temporal error propagation, periodic intra-coded frames (I-frames) are commonly inserted into compressed video streams. This allows the decoder to re-synchronize with the encoder once an anchor picture is reached. However, this practice leads to data bursts due to the lower compression efficiency of spatial coding (for variable bit-rate delivery). For constant bit-rate (CBR) video, the increased number of I-frame packets leads to periodic delays [**?**] due to buffering and transmission overheads. Instead, intra-refresh macroblocks (MBs) can be dispersed across a picture sequence. It is even possible to combine dispersed intra-refresh MBs with video cassette recorder functionality, provided I-frames are spaced far apart using an extended Group of Pictures (GOP) structure to reduce the frequency of data bursts.

Intra-refresh MB assignment is possible without over complex selection of individual MBs [**?**], which can lead to delay, by the cyclic insertion of a line of such MBs on a per-picture basis so that the complete picture space is refreshed after all the MB rows have themselves been refreshed. However, a cyclic intra-refresh line results in non-uniform importance across the packets from the same picture. Namely, a packet containing recently intra-refreshed MBs should be better protected against drops, as these MBs will not be refreshed soon and may be used as a reference for up and coming pictures, sometimes many frames later on. On the other hand, MBs waiting to be refreshed in the short term represent a smaller threat of promoting error propagation as they are soon to be intra-coded. Hence, it is clear that there are three regions of unequal importance within the picture itself: 1) above, 2) at the position of, and 3) below the cyclic intra-refresh line. However, what is not so clear is what should be the ranking of these regions and how their prioritization should be managed.

The contributions of this paper are two schemes that exploit the correct prioritization of the regions. A region-based scheme assigns packet priorities in the order of the compressed bitstream's arrival to the packetizer, whereas the packet-based scheme assigns priorities within regions and does not follow bitstream arrival order to the packetizer. Therefore, the packet prioritization scheme breaks region boundaries, whereas the region-based scheme prioritizes according to the three regions formed by the dynamic position of the intra-refresh line. However, the maximum delay is just one video frame, which is incurred in the packet-based scheme while the packets are re-ordered prior to assignment of priorities. It should be emphasized that in the proposed schemes, data priority is not made according to an intuitive assignment of highest priority to the second region, the cyclic intra-refresh region. This is because we have found that the small area within a frame contributed to by a single (or multiple) intra-refresh line(s) within a frame has less effect on the reconstruction of a video sequence than the larger two regions. This is despite the role of the intra-refresh line in the reduction of temporal error propagation.

To demonstrate the two proposed schemes, the paper applies both proposed variants of prioritization by 'position of intra-refresh line' in a general setting. Then the packet-based scheme is assessed in a home network scenario in which high definition (HD) video is streamed across a quality-of-service (QoS) controlled wireless LAN. Specifically, an enhanced IEEE 802.11e [**?**] access category (AC) assignment specialized to video streaming which spreads video packets across three of the 802.11e ACs. Packets are assigned to the 802.11e ACs according to 'position of intra-refresh line'.

The rest of the paper is organized as follows. Section II

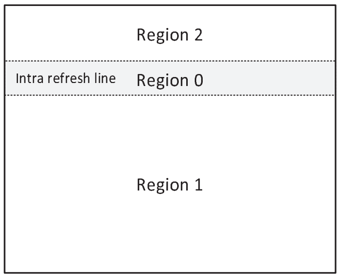

Fig. 1. Frame regions when using intra-refresh lines.

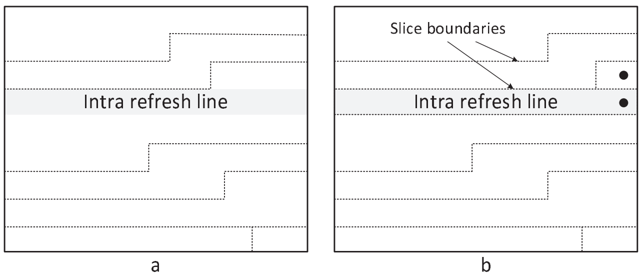

Fig. 2. a) Classic slicing. b) Proposed slicing scheme.

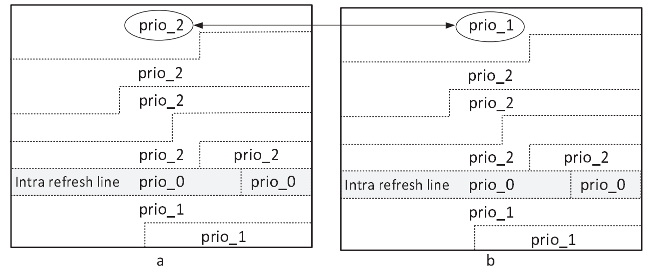

Fig. 3. a) Region-based priority assignment b) Packet-based priority assignment.

describes the two proposed ‘position of intra-refresh line’ prioritization schemes that exploit the unequal importance of different regions. Section III presents the results for uniform drops of different regions and the results of mapping the sliced HD video to different IEEE 802.11e ACs. Finally, Section IV draws some conclusions.

II. Proposed Schemes

A. Cyclic Intra Refresh

For mobile applications [**?**], cyclic intra refresh is preferred over whole frame update for the reasons advanced in Section I. Introducing cyclic intra-refresh lines implicitly divides the frame into three regions in terms of the potential for error propagation as shown in Fig. 1. The first region is located above the intra-refresh (Region 2) line and is the most sensitive region to errors. This is due to the fact that this recently refreshed (with intra coded blocks) region is used as a reference for predicting upcoming frames, and will not be refreshed soon. As a result, an error affecting this region propagates for a long period, introducing a significant quality loss. The second region is the intra refresh line itself (Region 0). Although a single cyclic intra refresh line represents a small portion of the frame area (22 MBs of the 396 total MBs in a Common Intermediate Format (CIF) frame), it uses a significant portion of the bit-rate share. Therefore, it was concluded in previous work by the authors [**?**] that if packets are to be discarded then intra refresh packets are the ones that introduce the smallest quality impact for the same loss percentage. Finally, the third region of the frame is located below the intra-refresh line (Region 1). This region has the smallest potential for error propagation, as an error in this region does not propagate for a long duration in time. If the intra-refresh line is cycling vertically, from top to bottom, those MBs below the intra-refresh line are to be intra coded in the following frames. Hence, even if errors occur in this region they will be cleaned sooner than those above the line, limiting the number of frames affected by prediction from the distorted reference frames. Overall, it can be said that cyclically intra-refreshed video has three regions with unequal impact on error propagation.

To exploit this unequal error sensitivity of the cyclically intra-refreshed frames, it is logical to treat the three parts of a frame differently. When slicing the frames with a maximum slice size limit, it is likely that some slices will contain MBs from more than one image region as illustrated in Fig. 2a. The next section presents an enhanced slicing scheme that can slice the image such that all three image regions can be separated and differentiated during transmission in order to offer different protection levels.

B. Slicing for Error Robustness

In order to slice an image into three distinct regions according to Fig. 1, the slice structuring of the encoder was modified to accommodate a new set of rules for slicing. These rules prevent packing of a mixture of MBs from different regions into the same slice. They also define when the current slice should be terminated or if more macroblocks should be packed into it. In addition to the original maximum packet size criterion, the first newly introduced rule checks if the current MB is the last MB before the start of an intra-refresh line and terminates the slice if this is true. The second new rule checks if the MB being encoded is the last MB of the intra-refresh line, closing the slice, as for the previous rule, if this is true. These positions can be determined if the frame width and the intra refresh position for the current frame are known in advance. Fig. 2b shows the check points (black dots) tested by the two new rules added to the slicing mechanism.

To signal the intra-refresh line packets (Region 2) to the network, the priority bits (nal_ref_idc) in the NAL [**?**] header are modified. In packetizing slices containing MBs from the intra refresh line, the nal_ref_idc field is set to 1 for easy identification by the network. In all other cases this field is not altered.

It should be emphasized that this slicing scheme does not require any decoder modification as it is compliant with the H.264/AVC codec standard. We now present two methods to assign priorities based on the relative position of the intra refresh line.

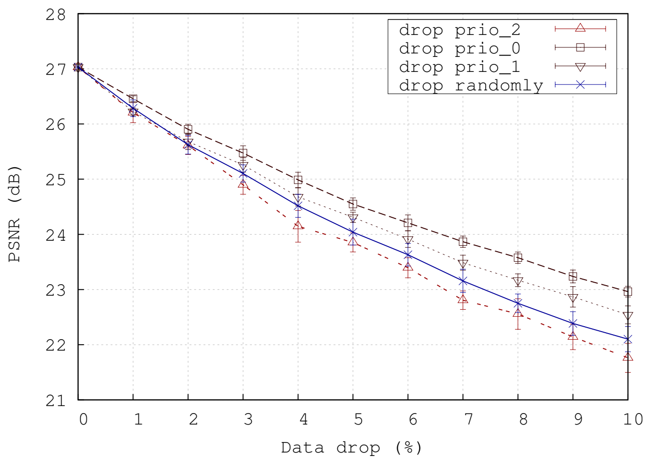

Fig. 4. Video quality obtained when dropping different priority packets (region-based priority) for *Parkrun* HD sequence.

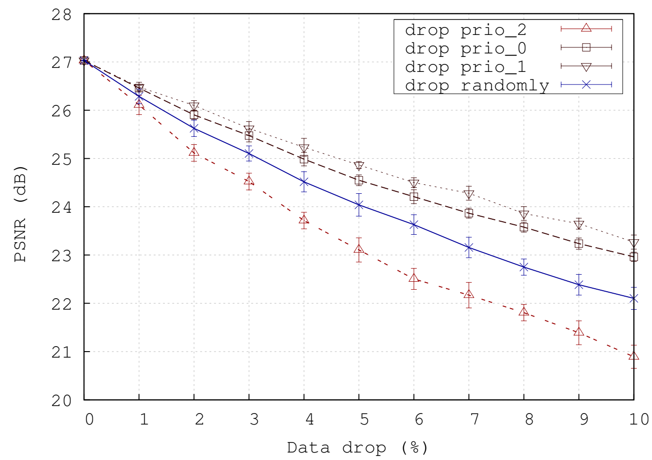

Fig. 6. Video quality obtained when dropping different priority packets (packet-based priority) for *Parkrun* HD sequence.

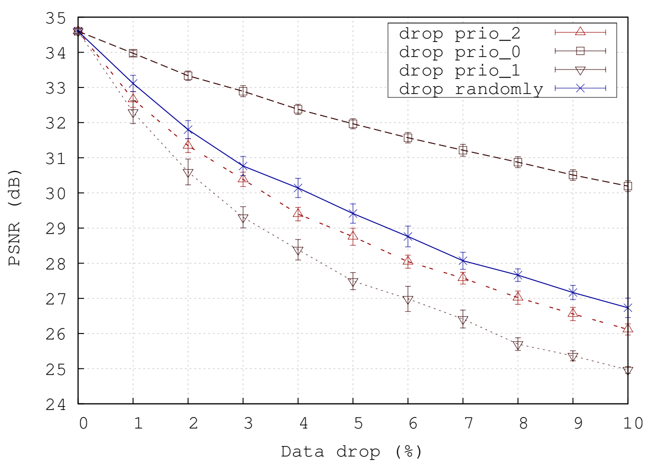

Fig. 5. Video quality obtained when dropping different priority packets (region-based priority) for *Mobile Calendar* HD sequence.

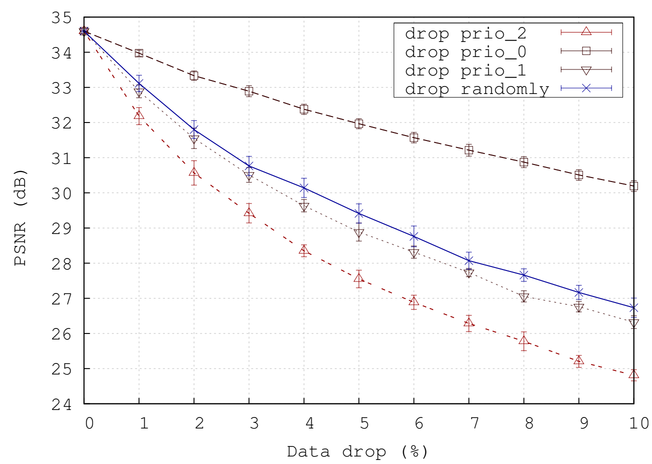

Fig. 7. Video quality obtained when dropping different priority packets (packet-based priority) for *Mobile Calendar* HD sequence.

C. Region- and Packet-Based Priority Assignment

The first method, shown in Fig. 3a, assigns priorities based on the different regions created by the refresh line. The highest priority ($prio\_2$) is assigned to packets above the intra-refresh line and an intermediate priority ($prio\_1$) to packets below the intra refresh line while the intra refresh line packets are assigned the lowest priority ($prio\_0$). However, as the cyclic refresh line moves down, the size of region 1 starts to decrease until it vanishes when the line reaches the bottom of the frame. The same is true for region 2. Therefore, $prio\_1$ and $prio\_2$ packets are not always present or they are not close in number.

To overcome the above shortcoming of the region-based priority assignment scheme, another scheme is proposed, as shown in Fig. 3b. Three priorities are assigned. Again, intra-refresh line packets are assigned the lowest priority ($prio\_0$). The rest of the packets are divided into two halves, the first half (an integer-valued division by two is performed) consists of the packets (of slices) closer to be refreshed and these are assigned an intermediate priority ($prio\_1$). The remaining packets (of recently refreshed slices) that will take longer to be refreshed are assigned the highest priority ($prio\_2$).

In an implementation of the packet-based scheme, once the intra-refresh line has been received (identified through the NALu header) and the frame's packets are formed in a single frame buffer, then all packets from before the intra-refresh line in order of formation in time are moved to after any packets formed after the intra-refresh packets. Then the aforementioned division into $prio\_1$ and $prio\_2$ packets occurs. The packets can then be selected from the one-frame buffer in order of formation in time, with the earliest in time transmitted first.

Naturally priorities $prio\_1$ and $prio\_2$ should be interchanged when using bottom-up moving intra-refresh lines rather than top-down moving lines.

III. EVALUATION

A. Video configuration

To evaluate the performance of the proposed scheme, 300 frames of HD sequences (1280 × 720 pixels/frame) *Shields*, *Mobile Calendar*, *Stockholm* and *Parkrun* were coded at a 30 Hz frame rate using the H.264/AVC JM 15.1 [**?**] reference software. For error robustness purposes, three adjacent horizontal cycling lines of intra-refresh MBs (cycling from top to bottom) were included. The coding structure IPPPP has been used with a single reference frame, for the reasons discussed in [**?**]. The H.264/AVC Network Abstraction Layer unit (NALu) size was limited to a maximum of 1300 B to prevent network fragmentation. Constrained intra predication was enabled so that the intra-refresh lines can effectively clean errors. The video was coded with a target bitrate of 5 Mbps.

B. Uniform Random Loss Results

Initially four tests were conducted. In the first test, only $prio\_0$ packets (belonging to the intra refresh line) were dropped (drop $prio\_0$). For the second test, only $prio\_2$ packets were dropped (drop $prio\_2$) and for the third test, $prio\_1$ packets were dropped (drop $prio\_1$). In the fourth test, used as a benchmark for comparison, packets were dropped randomly from all regions (drop randomly). A motion copy error concealment technique was used to reproduce the lost slices.

Fig. 4 and Fig. 6 present the results of these tests for the *Parkrun* test sequence for region- and packet-based prioritization respectively. Each data point in the Figures is the average (arithmetic mean) video quality assessed over 20 runs and the error bars represent the standard deviations from the mean. The Figures show different priority packets have a different effect on video quality. Additionally, the Figures show that the packet-based priority assignment scheme can better discriminate between the impact of lost packets of different priority in terms of their effect on video quality. In both Figures, dropping $prio\_2$ packets has the worst effect, as these packets contain data from recently refreshed MBs. Overall, dropping packets belonging to are newly refreshed slices introduce a significant quality drop when compared with the benchmark of dropping packets randomly. This is due to the fact that any error in these recently refreshed slices (with intra coded blocks) will propagate for several frames until they are intra coded again.

Dropping $prio\_0$ (intra-refresh line) packets shows less of an impact on video quality. Although intra-refresh lines play an important role in mitigating error propagation, these intra-coded blocks are very costly in terms of the data rate, while only representing a small portion of the image area. Thus, a high loss rate from this region corresponds to a small picture area that can be easily concealed by the decoder. However, in the region-based Fig. 4, dropping $prio\_0$ packets does not necessarily result in better quality than dropping other packets, whereas in packet-based Fig. 6 it does.

Figs. 5 and 7 present the results for the *Mobile Calendar* HD test sequence. In these Figures, dropping $prio\_0$ packets does

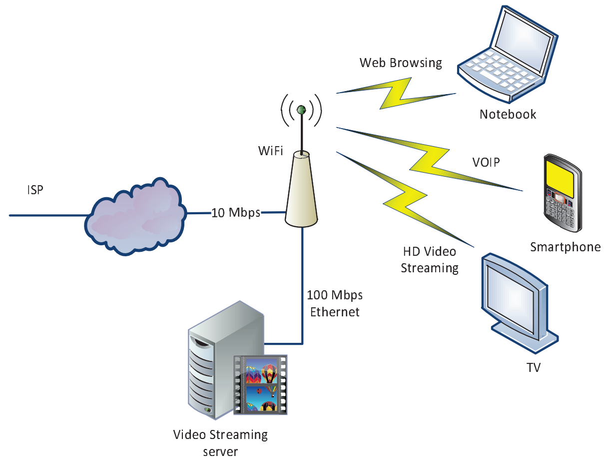

Fig. 8. Simulated network scenario.

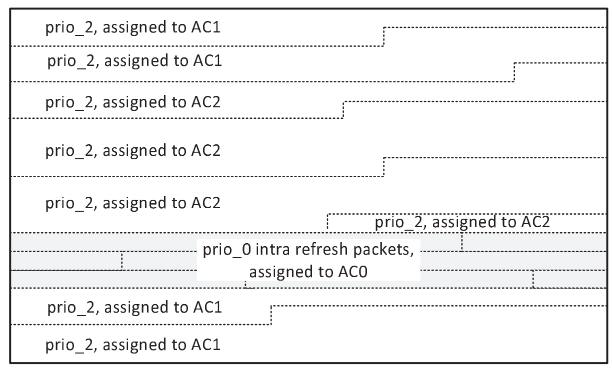

Fig. 9. The proposed slice mapping to different IEEE 802.11e access categories.

indeed result in superior video quality under both schemes. However, the region-based assignment in Fig. 5 has again resulted in a re-ordering of the quality for priorities 1 and 2, whereas packet-based assignment results in the same order as was logically derived according to the relative proximity in time of the frame data to intra-refresh time.

C. Home Network Application Scenario

The packet based-scheme was further tested in a more realistic home network scenario. A home network (HN) [**?**] is the final element in Internet Protocol TV's (IPTV's) path from a video hub office over a metro network to a video serving office [**?**], which distributes the video stream across an access network prior to entry into the home [**?**]. To avoid rewiring issues in the HN, IEEE 802.11 systems frequently distribute video content, which must compete with other traffic such as best-effort HTTP and background file transfers.

An application scenario in Fig. 8 shows one television receiving high-definition video streamed from a Network Attached Storage (NAS) plugged-in at the wireless router and a smartphone sending voice over IP traffic to the Internet Service Provider's network. Simultaneously, there is one computer

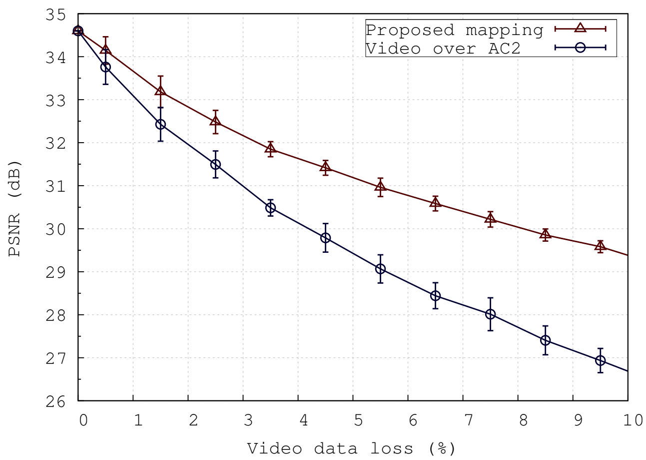

Fig. 10. Video quality obtained using the proposed mapping scheme as compared to sending video over AC2 for *Mobile Calendar* HD sequence.

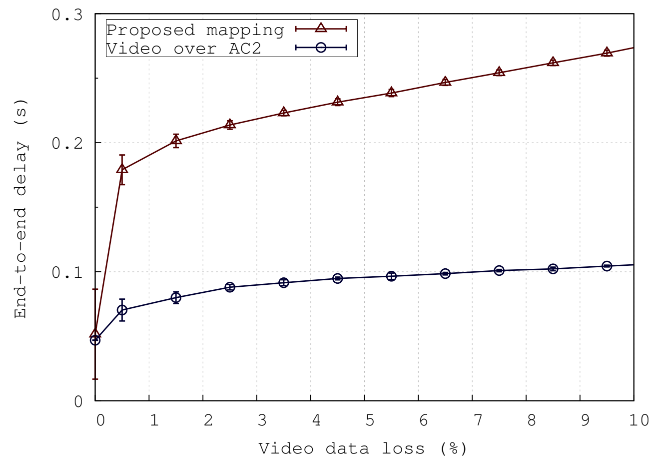

Fig. 11. . Packet end-to-end delay when using the proposed mapping scheme as compared to assigning video to AC2 for *Mobile Calendar* HD sequence.

competing for bandwidth, while performing web browsing. In situations like this, IEEE 802.11e was developed to offer prioritized access to delay-sensitive applications by prioritizing traffic over higher priority queues in order to reduce packet drops through buffer overflow. Unfortunately, if all video traffic is sent over its assigned AC2 then self-congestion can occur.

D. Proposed Packet Mapping

IEEE 802.11e [4] Enhanced Distributed Channel Access (EDCA) adds Quality-of-Service (QoS) support to legacy IEEE 802.11 wireless networks by introducing four Access Categories (ACs); AC0, AC1, AC2, and AC3 for Background (BK), Best-Effort (BE), Video (Vi) and Voice (Vo) respectively in order of increasing priority. To exploit the unequal error sensitivity introduced by the intra-refresh lines, this paper proposes mapping different region packets across the IEEE 802.11e EDCA ACs as an effective alternative to assign the complete stream to AC2.

Fig. 9 shows the mapping of different priority packets to the IEEE 802.11e ACs. Priority 2 packets (recently refreshed slices) are mapped to AC2, the default access category for video. The least important $prio\_0$ packets (intra-refresh line packets) are mapped to AC0 while $prio\_1$ packets (to be refreshed soon) are mapped to AC1.

E. Network Simulation

For network simulations, the scenario shown in Fig. 8 was employed. Various HD sequences were employed according to the configuration of Section III.A. In detail, a smartphone

sends Voice-over-IP (VOIP) traffic (assigned to AC3) to the Internet. The rate of VOIP traffic was varied from 48-256 kbps so that the impact of different drop percentages could be assessed. The notebook exchanges 500 kbps CBR traffic over TCP (assigned to AC0) to the Internet. The wireless radio data rate was set to 11 Mbps for convenience of simulation. For channel propagation, the shadowing model has been employed with path loss exponent set to 4 and a shadowing deviation of 6.8 dB. The video traffic was either sent over AC2, the default access category for video traffic, or was applied to different access categories as shown in Fig. 9.

Fig. 10 shows the objective video quality at different rates of video data loss for the Shields HD test sequence. Applying the proposed mapping can give over 3 dB quality gain when compared to assigning the whole video stream's packets to AC2. However, packets assigned to lower priority access categories will encounter higher delays. Therefore, Fig. 11 shows higher average end-to-end delays when mapping packets using the scheme, as compared to sending them over AC2.

IV. Conclusion

This paper presented a novel slicing technique for enhanced error robustness based on 'position of intra-refresh line'. It was found that when intra-refresh lines are used as an error mitigation tool, unequal error sensitivity appears within the frame. This fact is described in this paper and new prioritization assignment schemes exploiting this characteristic were presented herein. The region-based and packet-based prioritization schemes were compared. The packet-based scheme was found to more closely track the long-term logical priority ordering within a frame. However, the packet-based scheme incurs a one frame delay in transmission due to the need to assembles packets prior to priority assignment. In a home wireless network scenario, the packet-based scheme was shown to result in a 3 dB improvement in objective video quality compared to non-prioritized assignment to IEEE 802.11e QoS access categories. to offer an increased objective video quality of up to 3 dB. Unlike other previous solutions for access category assignment, the current implementation does not introduce any computational or bitrate increases. The slicing scheme proposed in this paper adds the possibility of unequal error protection using forward error correction codes, quality of service assignment, or simple packet duplication.