# Intra-Refresh Provision for Data-Partitioned H.264 Video Streaming over WiMAX

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***Abstract*- Mobile, broadband wireless access is increasingly being used for video streaming. This paper is a study of the impact of intra-refresh provision upon a robust video streaming scheme intended for WiMAX. The paper demonstrates the use of intra-refresh macroblocks within inter-coded video frames as an alternative to periodic intra-refresh video frames. In fact, the proposed scheme combines intra-refresh macroblocks with data-partitioned video compression, both error resilience tools from the H.264 video codec. Redundant video packets along with adaptive channel coding are also used to protect video streams. In harsh wireless channel conditions, it is found that all the proposed measures are necessary. This is because error bursts, arising from both slow and fast fading, as well as other channel impairments, are possible. The main conclusions from a detailed analysis are that: because of the higher overhead from cyclic intra macroblock line update it is better to select a low percentage per frame of intra-refresh macroblocks. The proposed video streaming scheme will be applicable to other 4G wireless technologies such as LTE.**

***Keywords*- Broadband Wireless Access; Error Resilience; H.264 Codec; Video Streaming; WiMAX**

## I. INTRODUCTION

Real-time, video rate delivery is needed for one-way video streaming applications such as Web TV, Internet Protocol TV (IPTV) in its various forms [1], and for two-way interactive video applications such as video conferencing and soft videophone, as well as all forms of user-to-user video streaming. There is also a growing interest in all forms of mobile TV, including networked IPTV with access over 4G broadband wireless technologies such as Long Term Evolution (LTE) [2] and IEEE 802.16e (mobile WiMAX) [3], and broadcast technologies such as Digital Video Broadcasting-Handheld (DVB-H), and MediaFlo. In fact, the Cisco Visual Networking Index [4] predicted that by 2017, 4G wireless will constitute 10% of the connections but 45% of the traffic and that two-thirds of mobile traffic will be video.

These networked video services can benefit from true-video streaming, rather than the progressive download of Apple Flash and now MPEG-Dynamic Adaptive Streaming over HTTP (DASH) [5]. True-streaming, unlike progressive download, is not prone to random retransmission delays whenever there is network congestion on the network path or packet errors on the wireless access link and also allows the buffer size on a mobile device to be reduced. Various wireless channel impairments are a significant feature of wireless access networks. These impairments include slow and fast fading due to multipath, shadowing through signal obstruction by large buildings, co-channel interference, and thermal noise on the receiver itself. If progressive download is employed, the underlying TCP transport protocol retransmits packets whenever a packet error occurs and does not allow the video display at the receiver to continue until the whole video segment, consisting of multiple packets, successfully arrives. In true streaming, as the UDP transport protocol is employed, if a packet is lost then the application can choose whether to re-transmit a lost packet or not. As a result, delays from packet re-transmissions are less likely to occur, which results in a continuous video display without freeze-frame effects. However, though true-streaming reduces delays that gain can come at a cost during periods of harsh channel conditions. Therefore, ways are sought to arrest error propagation across a video sequence and intra-refresh techniques provided by the video codec itself are a way to do so, along with other types of error resilience tools [6] provided by an H.264/Advanced Video Coding (AVC) codec [7].

Therefore, the H.264/AVC codec itself provides error resilience tools that can serve in the battle against wireless channel errors. H.264/AVC provides a better selection of error resilience tools compared to previous standard codecs and, indeed, compared to the emerging High Efficiency Video Coding (HEVC) codec [8], whatever other merits HEVC has. As well as source-coded error resilience, it is additionally possible to protect video packets with application-layer channel coding, otherwise known as Forward Error Correction (FEC). To test these H.264/AVC error resilience tools, especially in this paper, intra-refresh macroblocks (MBs), it is necessary to select a particular 4G broadband wireless technology and in this paper mobile WiMAX is selected. Therefore, WiMAX is the means by which the scheme is demonstrated, while H.264/AVC error resilience is one of the ways that the video stream is protected. The paper assumes that robust video streaming will take place under application-layer control at a WiMAX base station. One way this might occur is if IPTV is streamed from a local server, where the video content is cached as part of a content distribution network.

The proposed robust streaming scheme employs data-partitioned H.264/AVC video compression for graceful degradation in the face of channel error and additionally, in worsening channel conditions, redundant packets are transmitted. The scheme also uses application-layer FEC but redundant packets can also help, especially if congestion also occurs at the base station.

Fortunately, H.264/AVC data-partitioning does not require redundant packets for all packets in the stream, only for the more important packets.

In this robust scheme, a key consideration is how to protect against the temporal error propagation that can occur whenever predictively-coded P-frames are lost. A traditional way to do this is to insert periodic, intra-coded I-frames, usually every 12 or 15 frames that is every half-second according to frame rate. The spatially-encoded MBs of the I-frame halt the temporal error propagation and act as anchor points for a future set of frames. Unfortunately, the insertion of I-frames leads to sudden data transmission peaks due to the coding inefficiency of spatial referencing. These data transmission peaks in turn can result in buffering delays or even buffer overflow. Therefore, distributed insertion of intra-refresh (IR) MBs should be considered. In the JM implementation of the H.264/AVC codec, two main methods of distributed insertion are available: either random placement of IR MBs within each frame; or placing a line of IR MBs within each P-frame on a cyclic basis.

In the latter forced IR method, the line size can be increased to a region or slice [9] in order to control the rate that the total picture area is refreshed. Against this suggestion must be balanced the overhead from including a complete line or region of MBs, as such MBs are costly to encode. In fact, in this paper it is suggested that despite the apparent advantages of the cyclic line method, at least in respect to data-partitioned video compression, random selection of IR MBs is preferable. Random IR refresh may on occasion duplicate IR MBs but it has the advantage that in the JM implementation of H.264/AVC the overhead from intra-coded MBs is readily controllable by pre-setting the total percentage of MBs within each frame. If a cyclic IR line is used then more IR MBs than those in the cyclic line may be inserted in a frame. This is because IR MBs are not the only form of intra-coded MBs, as encoders will also insert such MBs when new areas of a picture are revealed, as may happen when there is rapid motion within a sequence.

Thus, the forced IR method does not account for areas of the region that may already have been intra-coded. It also has another weakness in that future motion prediction may occur from regions of a prior picture to a region yet to be refreshed. This defect can be remedied, possibly by restricting the range of the motion vectors (MVs) within the refreshed region [10] or by observing the direction of motion within a sequence [11]. However, these alternatives [10, 11] add coding complexity to IR and may be unnecessary when processing a low-motion video sequence. Another possibility is to adaptively alter the extent of MB provision [12] according to scene content and channel conditions. This method is most suited to live encoding of video, such as when streaming sports' events.

One advantage of forced IR is that it provides a natural channel-swapping (or zapping) point at the start of each refresh cycle, just as periodic I-frames provided. If for channel swapping, Gradual Decoder Refresh (GDR) is performed instead of periodic refresh then growing the refresh area from an isolated region is preferable to random MB refresh, as the subjective visual effect is better. This facility was proposed to the Joint Video Team developing the H.264/AVC codec [13] but is not currently implemented, perhaps because a method of signaling a switching point is the subject of a patent.

The remainder of the paper is organized as follows. Section II reviews related work on intra-refresh. Section III, considers the complete video streaming scheme and includes an analysis of the impact of IR on packet size, prior to transmission over a WiMAX channel. This section also describes the simulation model that is used in the evaluation of Section IV. Finally, Section V makes some concluding remarks.

## II. RELATED WORK

The need for intra-refresh arises from the predictive nature of video coding, which exploits redundancies in the spatial and temporal domains, among other sources of redundancy. Intra-refresh can be viewed as a way of restricting the prediction range, and as such it has various applications some of which have been alluded to in the Section I.

Certainly in mobile transmission, IR can provide error resilience. Lost packets, when not replaced by erasure coding, or corrupted data (when errors go undetected and do not halt the decoder) can both create insecure prediction bases. Error concealment of affected areas is a partial remedy but can still lead to a difference between the encoder's view of the decoding process and that actually implemented by the decoder. Any areas that are unsafe can then be predicted from. This in turn leads to a corrupted area growing in spatial extent, at a maximum rate governed by the range of motion estimation.

There are various forms of IR. Historically, periodic insertion of I-pictures is the most common form, as it has been used in early digital broadcasting within the MPEG-1/2 codecs. In this form of IR, the sequence is periodically refreshed with a fully intra-coded picture (I-picture) at regular intervals. In the presence of a feedback channel, it is possible to send an I-picture whenever it is requested by the receiver in order to recover from transmission error or for channel zapping purposes. It is also possible [14] to send individual intra-refresh MBs on request through a feedback channel. Alternatively, if no feedback channel is available, in [15] the impact of each MB is calculated and MBs that might have a significant effect if lost are intra-coded. This method [15] avoids the need for a feedback channel but there is an obvious computational impact in calculating the impact of every MB.

GDR techniques take a different approach to periodic refresh. The video sequence is gradually updated with intra-coded MBs with a given number of MBs per picture. The selection of MBs to be intra coded and their number and pattern depends on the specific technique used. To improve the performance of this method, Constrained Intra Prediction (CIP) should be forced to prevent intra-coded MBs needing to use inter-coded samples for prediction.

GDR techniques can be further sub-divided into non-adaptive IR and adaptive IR. The main types of non-adaptive IR are circular IR and random IR, as used in this paper. Isolated region refresh [16] is somewhat different, as an entire picture region is initially intra-coded, with no need to set CIP, as the region is isolated in a coding sense from the rest of the picture. In practice, isolated regions must use Flexible Macroblock Ordering (FMO) [17], another H.264/AVC error resiliency tool [6, 7], in order to encapsulate the region within a video slice. However, as the isolated region changes its size on a frame-by-frame basis, it becomes necessary to transmit macroblock allocation maps to guide the receiver's decoder as to which MBs are within the isolated area.

In cyclic IR, the video sequence is updated with intra-coded MBs using a pre-defined scan order and a selected number of MBs per picture. In IR line, the sequence is refreshed with a line of intra-coded MBs moving either from top-to-bottom or from left-to-right. In random IR, the video sequence is updated with intra-coded MBs using a random pattern of MBs and a pre-set number of MBs per picture.

Turning to adaptive IR techniques, these are distinguished by whether a feedback channel is used or not. Clearly if a feedback channel is used, there are implications in terms of the need to provide that channel and the possible increased latency that may arise. Channel conditions can be taken into account in the selection of the coding mode of the MBs. Receiver statistics are used to indicate the channel conditions by means of feedback messages. On the other hand, non-adaptive techniques select the coding mode of each MB based on the combined optimization of both the rate and distortion, without feedback of channel conditions.

In [18], the encoder was required to keep track of which parts of the image area were recently refreshed. The encoder would then refresh those MBs which would have more of an impact on error propagation. In [19], once the decoder detects an error, it informs the encoder, which transmits intra-coded MBs to halt any error propagation. However, this procedure is unsuitable for conversational video services streaming over a long end-to-end path such as videophone or mobile teleconferencing because of the delay involved.

Other schemes [10, 11] improve upon the deterministic application of the cyclic refresh line method by resolving a problem that exists at the boundary between a cleansed area and an area yet to be cleansed by intra-refresh. Suppose the direction of motion within the sequence is from a potentially corrupted region to a cleansed region. Then motion compensated prediction could predict a cleansed region from a suspect region. In that case, the cycle needs to revisit those predicted areas in order to undo the new corruption.

In [20] randomized placement of MBs was proposed to be up to a percentage determined by the average lifetime of errors. Random insertion may result in the duplication of the error propagation property if the same MB is selected in successive pictures. To improve on random placement in [21], based on knowledge of the form of error concealment at the decoder, rate distortion analysis is performed on error-concealed pictures of an H.263 codec. Thus, well-concealed MBs are not considered for intra-refresh MB replacement.

## III. METHODOLOGY

### *A. Data-Partitioned Video and the Effect of IR MBs*

In H.264/AVC data partitioning [22], MVs are packed into a partition-A bearing Network Abstraction Layer unit (NALU), allowing motion-copy error concealment at the decoder to partially reconstruct a picture despite missing partition-C NALUs containing texture data (quantized transform coefficient residuals). Partition-B NALUs contain intra-coded (spatially encoded) MBs, which are substituted for inter-coded MBs according to encoder implementation (only the decoder input format is standardized in H.264/AVC). Therefore, when IR MBs are included alongside naturally intra-encoded MBs referred to in Section II, Partition-B slices grow in size. This means that data-partitioned video compression provides a convenient way to examine the effect of various amounts of IR MB provision. Once H.264/AVC has formed a NALU, it can also provide a Real-time Transport Protocol (RTP) header prior to encapsulation by IP/UDP.

A point to note is the different way that random IR MBs are specified in the H.264/AVC JM 14.2 implementation compared to that of cyclic IR line intra update. In random IR MB, a maximum percentage of IR can be specified, which percentage includes already encoded IR MB. If the given quota of IR MB is already largely occupied by naturally encoded MB, then only a small amount of extra randomly inserted MB will be added. In contrast, if a line of IR MB is inserted then these MBs are added in addition to those intra-coded MBs that have already been included by the encoder.

It should also be noticed that when random IR MBs are inserted in a frame, the JM algorithm ensures that they are not inserted in places that have already been occupied in previous frames. Thus, in a cycle of frames a complete refresh takes place and there is no coding inefficiency arising from random placement.

Table I is a comparison between the relative sizes of the partitions according to the Quantization Parameter (QP) employed to compress the video clip. The test sequence was *Football*, which is a scene with rapid movement and consequently has high temporal coding complexity. Because of this movement it is likely that the number of naturally intra-encoded MBs is higher than a sequence with less motion. Football was Variable Bit Rate (VBR) encoded at Common Intermediate Format (CIF) (352×288 pixel/picture), with a Group of Pictures (GOP) structure of IPPP….. at 30 frame/s, i.e. one initial I-picture followed by all predictive P-pictures. This common arrangement removes the complexity of bi-predictive B-pictures at a cost in an increased bit rate. The range of QP in H.264/AVC is 0–51 with higher values corresponding to higher compression ratios and lower quality video.

TABLE I MEAN SIZE OF DIFFERENT PARTITIONS IN BYTES FOR FOOTBALL AT VARIOUS QP

| QP | 2% Intra refresh MB | | | |
|---|---|---|---|---|
| | A | B | C | Total |
| 20 | *1842* | *2678* | *3889* | *8409* |
| 25 | *1687* | *1697* | *2533* | *5917* |
| 30 | *1459* | *1047* | *1496* | *4002* |
| 35 | *1117* | *572* | *688* | *2377* |
| QP | 5% Intra refresh MB | | | |
| | A | B | C | Total |
| 20 | *1845* | *2767* | *3867* | *8479* |
| 25 | *1690* | *1763* | *2511* | *5964* |
| 30 | *1463* | *1082* | *1482* | *4027* |
| 35 | *1120* | *595* | *682* | *2397* |
| QP | 6% Intra refresh MB | | | |
| | A | B | C | Total |
| 20 | *1846* | *2810* | *3850* | *8506* |
| 25 | *1696* | *1793* | *2502* | *5991* |
| 30 | *1467* | *1098* | *1479* | *4044* |
| 35 | *1123* | *604* | *681* | *2408* |
| QP | 25% Intra refresh MB | | | |
| | A | B | C | Total |
| 20 | *1893* | *3450* | *3669* | *9012* |
| 25 | *1746* | *2216* | *2379* | *6341* |
| 30 | *1505* | *1346* | *1405* | *4256* |
| 35 | *1146* | *729* | *646* | *2521* |
| QP | MB Line Intra Update | | | |
| | A | B | C | Total |
| 20 | *1885* | *3385* | *3683* | *8953* |
| 25 | *3683* | *2160* | *2400* | *8243* |
| 30 | *1498* | *1312* | *1414* | *4224* |
| 35 | *1143* | *716* | *652* | *2511* |

From the Table, it is apparent that, as the percentage of IR MBs is increased, the size in bytes of Partition-B increases for the same QP. As more MBs are assigned to Partition B, the size of Partition-C reduces. Because of the large amount of naturally intra-encoded MBs, this effect is gradual until 25% of random IR MBs are added. The higher amount of random IR MBs is shown in the Table, as this amount, 25%, approximately corresponds to the total Partition-B size if cyclic line intra update is turned on instead.

Another point to notice is that the total size of the stream declines significantly with coarser quantization due to a higher QP. Because intra-coding is less efficient, the total sizes increase as the percentage of IR MBs is increased.

### *B. Transmission Protection Scheme*

To protect transmission of the IP/UDP/RTP packets an adaptive rateless channel coding scheme was devised. Notice that header compression is often employed over wireless links, which for the headers mentioned is able to achieve [23] up to 97.5% compression. The form of rateless coding [24] was Raptor code [25], which has linear decode computational complexity. Because rateless decoding is probabilistic, the behavior was modeled statistically, according to the formulation in [26]. The adaptive rateless coding scheme relies on channel condition estimation but is robust against measurement noise. Further channel protection is afforded by an additional transmission of a fixed additional increment to the rateless code. However, retransmission only occurs once to reduce delay and the additional redundant data are piggybacked onto the next outgoing packet. Because the adaptive component is not the main focus of this paper, the reader is referred elsewhere [27] for details.

### *C. WiMAX Simulation*

To establish the behavior of the scheme under WiMAX the well-known ns-2 simulator augmented with a module from the Change Gung University, Taiwan [28] that has proved an effective way of modeling IEEE 802.16e's behavior.

The physical layer (PHY) settings selected for WiMAX simulation are given in Table II. The antenna is modeled for comparison purposes as a half-wavelength dipole. The Time Division Duplex (TDD) frame length was set to 5 ms in experiments as this is the only setting specified by the WiMAX Forum, though the IEEE 802.16e standard allows for a range of settings. The downlink (DL)/uplink (UL) sub-frame ratio is set to favor the base station (BS) as it must have more access when there are multiple mobile stations (MSs).

TABLE II IEEE 802.16E PARAMETER SETTINGS

| Parameter | Value |
|---|---|
| PHY | OFDMA |
| Frequency band | 5 GHz |
| Bandwidth capacity | 10 MHz |
| Duplexing mode | TDD |
| Frame length | 5 ms |
| DL/UL ratio | 3:1 |
| Max. packet length | 1024 B |
| Raw data rate | 10.67 Mbps |
| IFFT size | 1024 |
| Modulation | 16-QAM 1/2 |
| Guard band ratio | 1/8 |
| Channel model | Gilbert-Elliott |
| MS transmit power | 245 mW |
| BS transmit power | 20 W |
| Approx. range to SS | 1 km |
| Antenna type | Omni-directional |
| Antenna gains | 0 dBD |
| MS antenna height | 1.2 m |
| BS antenna height | 30 m |

OFDMA = Orthogonal Frequency Division Multiple Access, QAM = Quadrature Amplitude Modulation, TDD = Time Division Duplex MS=Mobile Station

In order to introduce sources of traffic congestion, an always available FTP source was introduced with TCP transport to the MS. Likewise a Constant Bit Rate (CBR) source with packet size of 1000 B and inter-packet gap of 0.03 s was downloaded to the MS. While the CBR and FTP occupy the non-rtPS (non-real-time polling service) queue, rather than the rtPS queue, they still contribute to packet drops in the rtPS queue for the video, if the 50 packet rtPS buffer is already full or nearly full, while the nrtPS queue is being serviced.

### *D. IEEE 802.16e Channel Model*

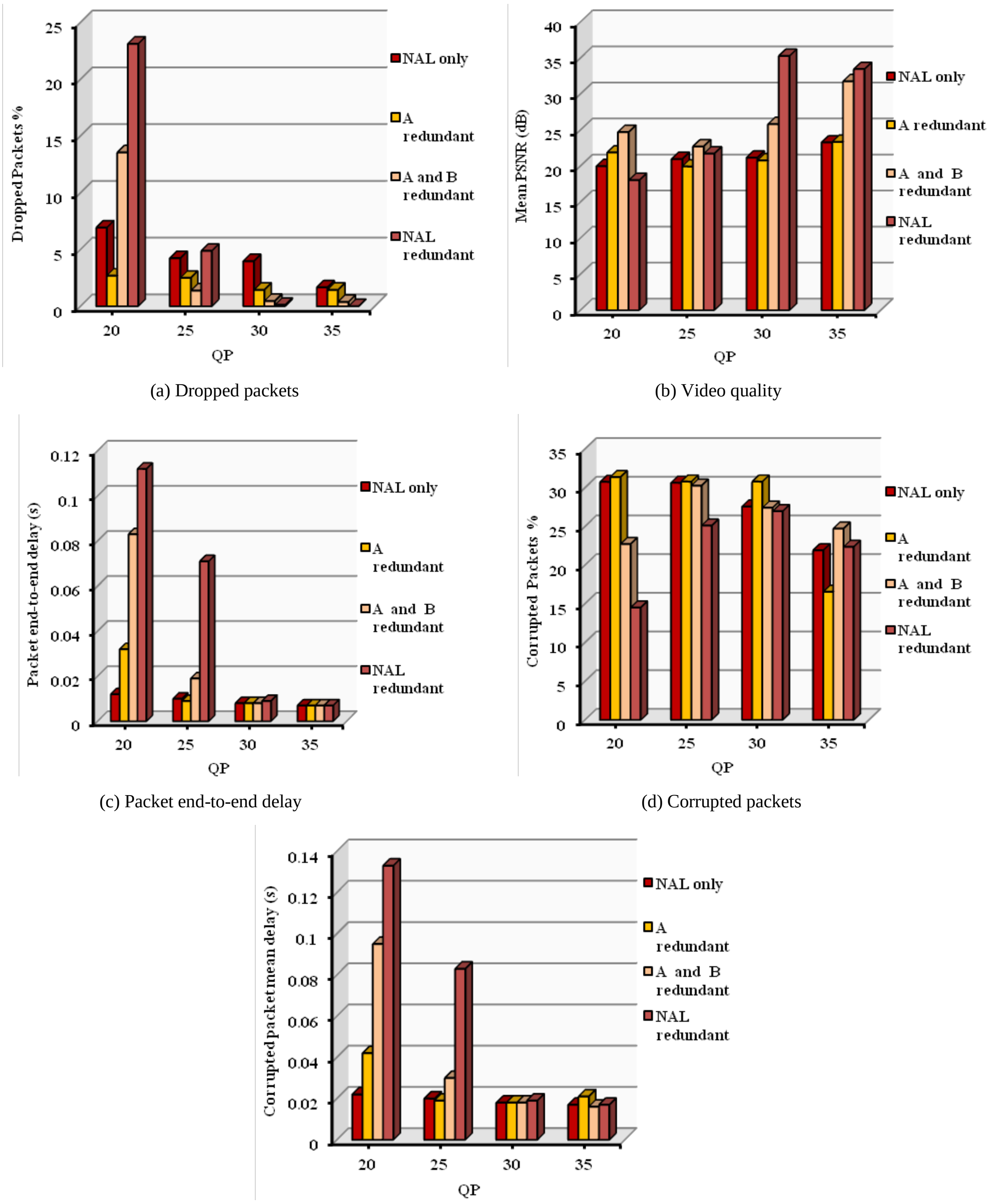
A two-state Gilbert-Elliott channel model [29] was introduced into the physical layer of the simulation to simulate the channel model for WiMAX. To model the effect of slow fading at the packet-level, the PGG (probability of staying in a good state) was set to 0.96, PBB (probability of staying in a bad state) = 0.95, PG (probability of packet loss in a good state) = 0.01 and PB (probability of packet loss in a bad state) = 0.02 for the Gilbert-Elliott parameters. Notice that PGB (probability of leaving the good state) is 1 – PGG, and similarly PBG = 1-PBB.

It is still possible for a packet not to be dropped in the channel but nonetheless to be corrupted through the effect of fast fading (or other sources of noise and interference). This byte-level corruption was modeled by a second Gilbert-Elliott model, with the same parameters (applied at the byte level) as that of the packet-level model except that PB (now probability of byte loss) was increased to 0.165.

## IV. EVALUATION

Before looking at the impact of different amounts of IR MBs, Fig. 1 examines the effect of differing forms of packet redundancy upon the transmission of data-partitioned packets over the IEEE 802.61e channel. 'NAL only' refers to the streaming without any packet redundancy, whereas 'NAL redundant' means that all NALU-bearing packets are duplicated in the stream. Other columns refer to the replacement of Partition-A or both Partition-A- and Partition-B-bearing packets. The redundant packets were scheduled to be transmitted within the same sending interval as their original counterparts. This implies that there is no latency effect from including redundancy but there is an increase in throughput for a given QP. This might seem a heavy penalty but an important point to notice is that, from Table I, going from QP 20 to 30 for 5% IR MB results in more than a halving of the size of the stream. Thus, duplicating the stream at QP = 30 results in a similar throughput to not duplicating the stream at QP = 20.

One reason that duplication is necessary is that dropped packets arising from buffer overflow at the sender or complete packet loss from fast fading cannot be redressed by application-layer FEC. Unfortunately, it is also possible in 'bursty' error conditions that both the original and the redundant replacement are lost. This can occur when the percentages of dropped packets is large. The size of packets is the most important factor affecting the percentage of dropped packets, as is evident from the decrease in dropped packet percentages as the QP increases. Packet end-to-end delay is the mean delay of those packets unaffected by channel conditions. The results show that this is generally small in duration, though with a tendency to increase due to the propagation delay of larger packets at lower QP and the effect of the extra packets in the 'NAL redundant' scheme, as queuing delay is increased. Delays below 100 ms are acceptable even for interactive video applications if they are the only component of the path delay.




(a) Dropped packets

(b) Video quality

(c) Packet end-to-end delay

(d) Corrupted packets

(e) Corrupted packet end-to-end delay

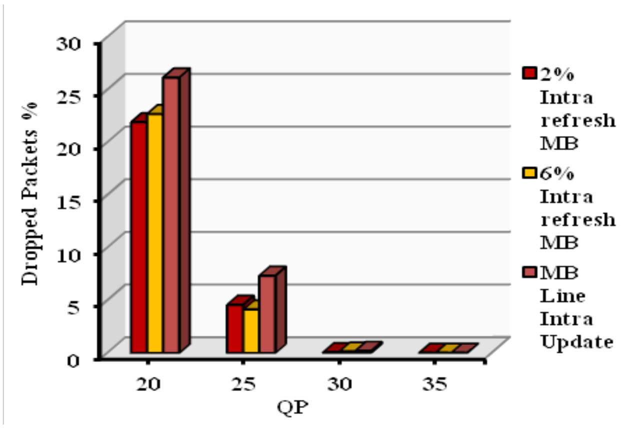
Fig. 1 Mean performance metrics for various redundant NALUs protection schemes used with 5% intra-refresh MBs

However, there are larger percentages of corrupted packets. These are packets that have not been repaired completely by the adaptive channel coding scheme. When redundant copies of the packet are not available then additional redundant data are requested by an ARQ, though this will not always be sufficient. Because of the additional transmission, the mean end-to-end delay of corrupted packets is higher than other packets. In fact, it is the extent of the delay that is the main contribution of corrupted packets.

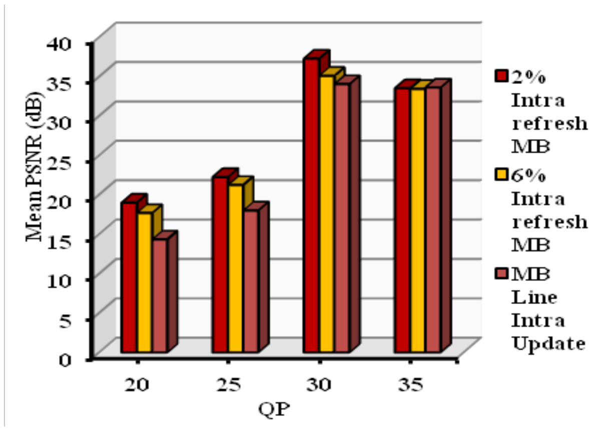
One can see that the video quality expressed objectively as the Peak Signal-to-Noise Ratio (PSNR) is generally below 25 dB, and hence would probably be ranked as 'poor' under the ITU P.800's recommendation [30], originally intended for subjective testing. However, for the higher QPs of 30 and 35 under the 'NAL redundant scheme', the video quality is actually 'good' (above 31 dB) on the ITU scale. Comparing with the percentage of dropped packets for these QPs under 'dropped packets', the percentage of dropped packets is low. This implies that the real gain of the redundant schemes is from replacement of corrupted packets, removing the risk of further loss after retransmission. Because the gain comes at the higher

QP, the impact on throughput is limited. Thus, for these schemes it is preferable to avoid low QPs.

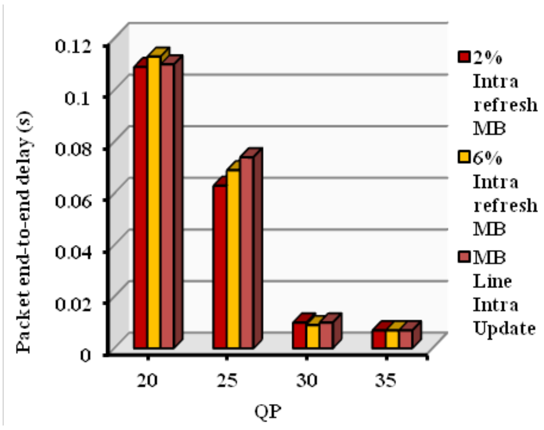
Fig. 2 now retains the ‘NAL redundant’ scheme of Fig. 1 but varies the provision of IR MBs. Increasing the provision of IR MB above 5% to 6% and the equivalence of around 25% in the case of MB line intra update, increases the throughput and, hence, the bandwidth requirements in respect to co-existing traffic. 6% rather than 5% IR MB refresh is chosen because without naturally encoded IR MBs, then one line of MBs corresponds to about 6% of a CIF picture. A 25% IR commitment is large due to the coding inefficiency of spatial reference coding. From the PSNR results it can be seen that reducing the IR MB percentage to 2% actually improves the PSNR at QPs 30 and 35. Other values in this Figure do not differ noticeably from the ‘NAL redundant’ columns in Fig. 1. The main effect of reducing the percentage of IR MBs is that the size of partition-B-bearing packets is reduced. In turn, this makes these packets less likely to be affected by channel conditions, especially burst errors arising from the simulated fast fading. During bursts it is possible that a packet and its redundant replacement are both affected by channel noise. Thus, extra redundant data are transmitted in an attempt to reconstruct the packet.  However, if the retransmitted packet is itself dropped or corrupted then the original packet cannot be repaired.



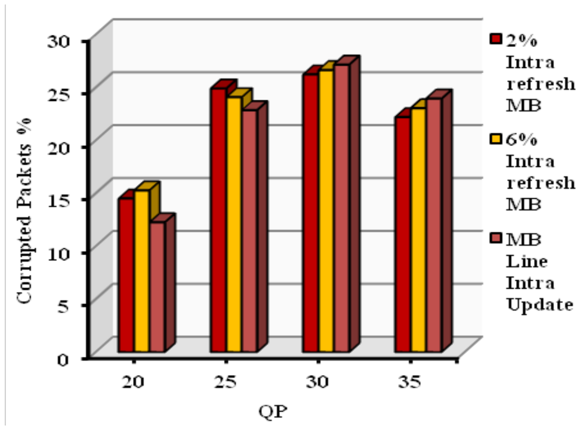

(a) Dropped packets



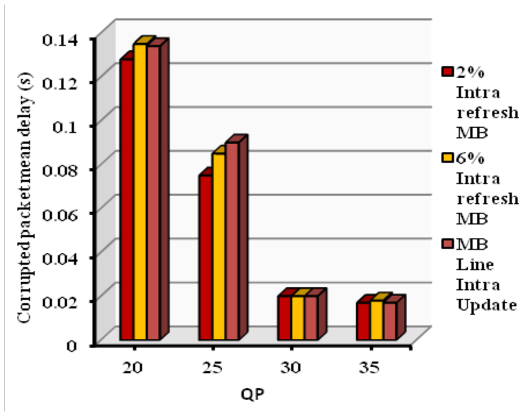

(b) Video quality




(c) Packet end-to-end delay




(d) Corrupted packets




(e) Corrupted packets end-to-end delay

Fig. 2 Mean performance metrics for redundant NALU protection scheme used with 2%, 6% intra-refresh MBs and MB line intra update

Table III analyzes the numbers of dropped packets to illustrate the effect of packet size. Because the packet sizes are reduced for higher QPs, few packets are dropped at these QPs. From Table I, at high QPs, the packet size is in reverse order to the priority of the data. For example, at higher QP, partition-A packets are smaller than partition-B and –C packets. This affects the number of packets of the different types dropped. For the IR MB schemes between 2% and MB line intra update there is a definite increase in the number of Partition-B packets dropped but statistical variation accounts for the counter figures going between 2% and 6% IR MBs at QP = 25. Where the higher numbers of dropped Partition-B packets has an impact is when the original and its duplicate are both lost in the redundant NAL schemes.

TABLE III NUMBER OF DROPPED NALUS UNDER DIFFERENT SCHEMES

| QP | No. of Dropped NAL UNITS | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1 Slice A redundant | | | 1 Slice A & B redundant | | | 1 Slice NAL redundant | | |
| | A | B | C | A | B | C | A | B | C |
| 20 | *0* | *8* | *20* | *26* | *80* | *70* | *57* | *121* | *183* |
| 25 | *0* | *7* | *19* | *2* | *0* | *16* | *7* | *22* | *47* |
| 30 | *0* | *5* | *10* | *0* | *0* | *6* | *1* | *0* | *1* |
| 35 | *0* | *6* | *9* | *1* | *0* | *4* | *0* | *0* | *0* |
| QP | 2% Intra refresh MB | | | 6% Intra refresh MB | | | MB Line Intra Update | | |
| | A | B | C | A | B | C | A | B | C |
| 20 | *48* | *108* | *185* | *33* | *122* | *197* | *48* | *157* | *202* |
| 25 | *14* | *20* | *37* | *10* | *15* | *39* | *28* | *34* | *57* |
| 30 | *0* | *1* | *0* | *2* | *0* | *0* | *0* | *1* | *2* |
| 35 | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* | *0* |

## V. CONCLUSION

The main concentration of this paper has been on IR provision as a way of mitigating errors occurring across WiMAX wireless channels. In that respect, it is shown that it is better to include a small percentage of IR MBs that can build their effect over time than employ the cyclic IR line update scheme. In fact, the random MB scheme used is more compatible with the isolated region based gradual decoder refresh, which allows for the full functionality of the replaced periodic I-frames. An interesting observation is that there is a need to reduce packet size to reduce packet loss despite the combined effect of redundant packets and application adaptive channel coding. This is because during 'bursty' error conditions (as simulated by the Gilbert-Elliott channel model) it is possible that both the original packet and its redundant counterpart may be dropped or corrupted. Selecting a moderate quality initially may be better than selecting a higher quality video stream only to see its quality degraded by the harsh channel conditions, the effect of which is packet size dependent.

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## REFERENCES

[1] W. Simpson, *Video over wireless*, Focal Press, Burlington, MA, 2008.

[2] K. Ekström, et al. "Technical solutions for the 3G Long-Term Evolution," *IEEE Communs. Mag.*, vol. 44, no. 3, pp. 38-45, 2006.

[3] L. Nuaymi, *WiMAX technology for broadband wireless access*, Wiley, Chichester, UK, 2007.

[4] Cisco Systems Inc., *Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2012–2017*, Cisco Systems Inc., San Jose, CA, 2012.

[5] T.C. Thang, Q.-D. Ho, J.W. Kang, and A.T. Tham, "Adaptive streaming of audiovisual content using MPEG DASH," *IEEE Trans. Consumer Electronics*, vol. 58, no. 1, pp. 78-85, 2012.

[6] T. Stockhammer, and W. Zia, "Error resilient coding and decoding strategies for video communication," In M. van der Schaar and P.A. Chou (Eds), *Multimedia over IP and wireless networks*, Academic Press, Burlington, MA, pp. 13-58, 2007.

[7] S. Wenger, "H.264/AVC over IP," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 13, no. 7, pp. 645-655.

[8] T. Schierl, M.M. Hannuksela, Y.-K. Wang, and S. Wenger, "System layer integration of High Efficiency Video Coding," *IEEE Trans. Circuits Syst. Video Technol.*, vol. 22, no. 12, pp. 1871-1884, 2012.

[9] T. D. Tran, L.-K. Liu, and P.H. Westering, "Low-delay MPEG-2 video coding," in *Proc. SPIE - Int. Soc. Opt. Eng. (USA)*, 1997, vol.3309, pp. 510-16.

[10] E. Krause et al., "Method and apparatus for refreshing motion compensated sequential video images", US 5,057,916, United States Patent Office, 1991.

[11] R.M. Schreier, and A. Rothermel, "Motion adaptive intra refresh for the H.264 video coding standard," *IEEE Trans. Consumer Electronics*, vol. 52, no. 1, pp. 249-253, 2006.

[12] Y.J. Liang, K. El-Maleh, and S. Manjunath, "Upfront intra-refresh decision for low-complexity wireless video telephony," in *Proc. of IEEE Int. Symposium on Circuits and Systems*, 2006.

[13] Y.K. Wang, and M.M. Hannuksela, "Gradual decoder refresh using isolated regions," *3rd Meeting of the JVT*, Doc. JVT-C074, May 2002.

[14] N. Färber, E. Steinbach, and B. Girod, "Robust H.263 compatible transmission over wireless channels," in Proc. of Int. Coding Picture Symposium, 1996, pp. 575-578.

[15] J. Liao and J. Villasenor, "Adaptive intra update for video coding over noisy channels," in *Proc. IEEE Int. Conf. on Image Processing*, 1996, pp. 763-766.

[16] M.M. Hannuksela, Y.K. Wang, and M. Gabbouj, "Isolated regions in video coding," *IEEE Trans. Multimedia*, vol. 6, no. 2, pp. 259:267.

[17] P. Lambert, W. De Neve, Y. Dhondt, and R. Van de Walle, "Flexible macroblock ordering in H.264/AVC," *J. of Visual Commun. and Image Representation*, vol. 17, no. 2, pp. 358-375, 2006.

[18] J. Jiang, B. Guo, and W. Mo, "Efficient intra refresh using motion affected region tracking for surveillance video over error prone networks," in *Proc. Int. Conf. on Intelligent System Design and Applications*, 2008., pp. 242 –246.

[19] J.-T. Wand, and P.-C. Chang, "Error-propagation prevention technique for real-time video transmission over ATM networks," *IEEE Trans. Circuits Syst. Video Technol.*, vol.. 9, no. 3, pp. 513-523, 1999.

[20] P. Haskell, and D. Messerschmitt, "Resynchronization of motion compensated video affected by ATM cell loss," in *Proc. IEEE Int. Conf. Acoustics, Speech, and Signal Processing*, 1992, pp. 545-548.

[21] G. Côté, and F. Kossentini, "Optimal intra coding of blocks for robust video communication over the Internet," *EUROSIP J. of Image Commun.*, vol. 15, pp. 25-34, 1999.

[22] S. Mys, P. Lambert, and W. De Neve, "SNR scalability in H.264/AVC using data partitioning," in Proc. Pacific Rim Conf. in Multimedia, 2006, pp. 329-338.

[23] A.B. Effnet, "An introducton to IP header compression," White Paper, Bromma, Sweden, Feb. 2004.

[24] D. J. C. MacKay, "Fountain codes," *IEE Proc.: Communications*, vol. 152, no. 6, pp. 1062–1068, 2005.

[25] A. Shokorallahi, "Raptor codes," *IEEE Trans. Information Theory*, vol. 52, no. 6, pp. 2551-2567, 2006.

[26] M. Luby, T. Gasiba, T. Stockhammer, and M. Watson, "Reliable multimedia download delivery in cellular broadcast networks," *IEEE Trans. Broadcasting*, vol. 53, no. 1, pp. 235-246, 2007.

[27] L. Al-Jobouri, M. Fleury, and M. Ghanbari, "Adaptive rateless coding for data-partitioned video streaming over a broadband wireless channel," in *IEEE Wireless Advanced*, 2010, pp. 1-6.

[28] F.C.D. Tsai, et al., "The design and implementation of WiMAX module for ns-2 simulator," in *Proc of Workshop on ns2: the IP network simulator*, 2006, article no. 5.

[29] G. Haßlinger and O. Hohlfeld, "The Gilbert-Elliott model for packet loss in real time services on the Internet," in *Proc. of 14th GI/ITG Conf. on Measurement, Modelling, and Evaluation of Computer and Commun. Systs.*, 2008, pp. 269-283.

[30] ITU-T Rec. P.800 Methods for subjective testing of video quality, 1996.


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