H.264 Error Resilience Performance for Wireless Video Conversational Services

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ABSTRACT

Application layer error resilience techniques in video communication are a relatively lightweight way of countering both isolated and burst error patterns. This paper systematically investigates their role. Flexible Macroblock Ordering (FMO) is shown to be an effective form of protection when errors are isolated but when burst errors are likely increasing the level of slicing is preferable. The paper considers which form of FMO produces the most gains in conjunction with error concealment. Video quality is shown to be content dependent, which may indicate a strategy for successful provision of conversational services for mobile devices.

Categories and Subject Descriptors

C.2.1 [**Computer-Communication Networks**]: Network Architecture and Design -*Wireless communication.*

General Terms

Algorithms, Performance, Experimentation

Keywords

Burst errors, error resilience, conversational video services

1. INTRODUCTION

For robust video communication over wireless channels, error-resilience measures offer an effective alternative to Forward Error Correction (FEC) [1], as in particular burst errors may be difficult to guard against with FEC alone. Because of motion-compensated inter-frame prediction, compressed video is vulnerable to error propagation, because any lost frame-bearing packets cause the encoder to hold a different sequence of frames to those reconstructed by the decoder. Additionally, error resilience source coding [2] is a way of protecting compressed video with generally reduced overhead/bandwidth in comparison to FEC, if video-rate decoding is to take place. In this paper, the performance of H.264/ Advanced Video Codec (AVC) error resilience is assessed for both isolated errors in good channel conditions and burst errors in poor conditions.

The H.264/AVC has a range of error resilience mechanisms [3], including some like Flexible Macroblock Ordering (FMO) that have not previously featured in a standard codec. Error resilience was introduced into H264 with wireless communication in mind [4]. Isolated errors can be caught with differing effectiveness according to error resilience scheme, as shown in Section 4. However in [5], the effect of differing frame burst lengths was studied, showing how the pattern of losses in an error prone channel was an important contributor to video distortion.

The principal focus of the research in [5] was the ability of packet interleaving to alleviate the impact of burst losses, whereas in this paper we assess how other forms of error resilience might counteract both isolated and burst errors. For burst errors, we consider those schemes that do not require a feedback channel. Through source-encoder-independent error concealment at the decoder, error resilience techniques can aid the reconstruction of a frame without the need for feedback, even if some packets are lost. The emphasis in the paper is on low bitrate video coding as applicable to mobile devices. Coding complexity and storage requirements are also relevant. Low-latency options are emphasized as these allow conversational or interactive applications such as mobile teleconferencing and videophoning.

Therefore, this paper's contribution is recommendations for effective error resilience according to channel condition. It is noticeable from our results that measures that are effective for isolated errors may not be so if there are burst errors. In particular, packet size is also an important determinant of performance, which should be taken into account along with choice of error resilience measure. As an encoded video frame is split into slices each slice of which is the basis of a packet, then including more slices results in smaller packet sizes, though there is a trade-off between increasing the number of slices (reducing the packet size) and increasing per packet overhead. Video content is also important. The coding complexity should be appropriate to wireless communication and the shot type should easily be displayed on a physically small screen.

Error resilience and FEC can be combined, though we concentrate on error resilience alone because of the risk to low bit-rate video of high packet loss rates in wireless networks. Error control through various forms of application layer Automatic Repeat

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Request (ARQ) is also possible but the added latency involved in sending an ARQ packet back to the source of the video stream is a concern. The playout buffer size may be limited on some mobile devices as the need for energy conservation restricts the size, since buffering memory is both an active and passive consumer of energy. Larger buffers are also an impediment to conversational services. All methods of protection can take advantage of error concealment at the decoder [6] if this does not require feedback from the source encoder, which could also introduce delay leading to packet drops at the decoder.

The remainder of this paper is organized as follows. Section 2 considers some related work in this field and Section 3 introduces error resilience techniques. Section 4 considers the impact of isolated errors and the ability of different FMO types to catch these errors. Section 5 complements the results in [5] for burst errors by examining types of error resilience other than packet interleaving. Finally, Section 6 draws some conclusions and gives recommendations for future work.

2. RELATED WORK

Though Shannon information theory states that the source and channel coding can work in isolation, this recommendation does not take account of the latency necessary to optimize channel coding. Therefore, source coding is deliberately made less efficient in order to limit the effect of error propagation [7]. Apart from the need to protect against error propagation across frames (mentioned in Section 1), protection against single bit errors in variable length coding (VLC) is required to prevent loss of decoder synchronization. However, each partition into a slice interrupts any entropic coding processes.

H.264's Baseline profile is intended for mobile devices, as it has a smaller code footprint, with reduced computational complexity. Apart from error resilience methods explored in our paper, this profile also supports redundant slices coded with coarser quantization than the primary slices. In [8], redundant slices were combined with FMO along with FEC, in a scheme that addressed the 'cliff effect' of traditional FEC, whereby there is a sudden loss of protection once errors exceed a certain threshold. Clearly when bandwidth is restricted then redundant slices are not advisable. Arbitrary slice ordering (ASO) is useful when packets might be received out of order and it is also possible to send side information within the bit-stream, though we did not test this feature of the Baseline profile, it could be useful as an aid to error concealment.

The Extended profile is required for another error resilience feature we tested, data-partitioning, but discussion of this feature is deferred to Section 3. Unfortunately, many software encoders, apart from the reference JM encoder, do not implement many of the error resilience features of H.264/AVC. For example, Vanguard Software Solution's implementation (refer to `http://www.vsofts.com/`) is apparently one of the few that implement FMO even though this is part of the Baseline profile.

Work in [9] is an investigation of error resilience for cellular networks. Rather than test each technique separately, error resilience strategies were applied, combining several techniques. Spatial error concealment combined with previous frame replacement occurred, whereas in our work a more sophisticated form of error concealment was applied. For the video streaming strategy a feedback channel was employed to allow long-term memory motion compensated prediction, assuming several seconds of latency is tolerable and assuming a fixed source. For conversational services, a frame rate of 15 Hz (frame/s) and Quarter Common Intermediate Format (QCIF) resolution was tested.

3. ERROR RESILIENCE

3.1 Flexible Macroblock Ordering

For FMO error resilience, compressed frame data is normally split into a number of slices each consisting of a set of macroblocks. In the MPEG-2 codec, slices could only be constructed from a single row of macroblocks. Slice resynchronization markers ensure that if a slice is lost then the decoder is still able to continue. Therefore, a slice is a unit of error resilience and it is normally assumed that one slice forms a packet, after packing into a Network Abstraction Layer unit (NALU) in H.264. Each NALU is encapsulated in an RTP packet. Consequently, for a given frame, the more slices the smaller the packet size.

In H.264/AVC, by varying the way in which the macroblocks are assigned to a slice (or rather group of slices), FMO gives a way of reconstructing a frame even if one or more slices are lost. Within a frame up to eight slice groups are possible. A simple FMO method is to continue a row of macroblocks to a second row, Fig. 1a, but allow disjoint slice groups [10]. Regions of interest are supported, Fig. 1b. Checkerboard slice group selection, Fig, 1c allows one slice group to aid in the reconstruction of the other slice group (if its packet is lost) by temporal (using motion vector averaging) or spatial interpolation. Assignment of macroblocks to a slice group can be general (type 6) but the other six types predefine an assignment formula, thus reducing the coding overhead from providing a full assignment map.

The checkerboard type stands apart from other types, as it does not employ adjacent macroblocks as coding references, which decreases its compression efficiency and the relative video quality after decode. However, if there are safely decoded macroblocks in the vicinity of the lost error concealment can be applied.

3.2 Other types of error resilience

Prior to FMO in H.264, slice structuring was possible but without breaching the raster-scan order of macroblock formation. This scheme maintains the syntactic and semantic resynchronization information in slice headers but without any macroblock assignment mapping overhead from FMO (refer to Section 5).

Data partitioning in H.264/AVC separates the compressed bitstream into: A) configuration data and motion vectors; B) intra-coded transform coefficients; and C) inter-coded coefficients. This data forms A, B, and C partitions which are packetized as

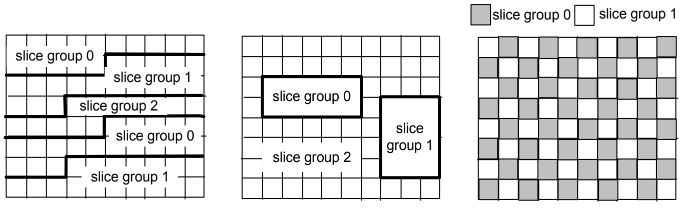


Figure 1. Example FMO slice groups and types (after [10]) a) Continuing row (type 0) b) geometrical selection (type 2) c) checkerboard selection (type 1)

separate NALUs. This arrangement allows a frame to be reconstructed even if the inter-coded macroblocks in partition C. are lost, provided the motion vectors in partition A survive. Partition A is normally strongly FEC-protected and in the simulations in Section 5 this was assumed. Notice that in codecs prior to H.264, data partitioning was also applied but no separation into NALUs occurred. The advantage of integral partitioning is that additional resynchronization markers are available that reset entropic encoding. This mode of data partitioning is still available in H.264 and is applied to I-frames.

The insertion of intra-coded macroblocks into frames normally encoded through motion-compensated prediction allows temporal error propagation to be arrested if matching macroblocks in a previous frame are lost. Intra-refresh through periodic insertion of I-frames with all macroblocks encoded through spatial reference (intra-coded) is the usual way of catching error propagation. However, I-frames cause periodic increases in the datarate when encoding at a variable bitrate. They are also unnecessary if channel switching point or VCR functions are not required. In the simulations in Section 5, each row of macroblocks was intra-coded in turn in a rotating order on a frame-by-frame basis.

This brief review by no means exhausts the error-resilience facilities in H.264, with redundant frames, switching frames, and flexible reference frames considered in [2].

4. ISOLATED ERRORS

We initially examined the impact of H.264 error resilience methods upon isolated errors, as may occur in good wireless channel conditions. Previous work on isolated errors [11] has modeled error propagation, according to the packet loss rate, with the intention of arriving at an optimal inter/intra frame ratio. That research [11] analyzed the amelioration of error propagation by macroblock intra-refresh despite spatial filtering of the type that now exists as a result of H.264's deblocking filter. In [12], the assumed wireless channel's bit-error-rate (BER) was projected upon the video data as a way of predicting the likely video quality consequent upon error propagation. The analysis assumed data partitioning of motion vectors protected through FEC (convolutional coding) and temporal error concealment. However, the relative overhead arising from FEC at low bit-rates does not seem to have been assessed in [12]. In our paper, by way of comparison a scheme using data-partitioning was also tested for isolated errors.

4.1 Experimental Conditions

For these experiments, the Foreman video clip was encoded at QCIF video resolution (176×144 pixel/frame) with 4:2:0 sampling, encoded with the reference JM 14.1 software for H.264/AVC. The video sequence 'Foreman', intended for assessing video communication between mobile devices, exhibits the typical features of a hand-held camera and, because of camera pans, exhibits high to medium coding complexity. As a comparison with Foreman, the 'Bridge' sequence (the closed version) was also encoded in the same format as Foreman. Bridge is largely static but has some small areas of activity where people cross the bridge. The type of camera shot in Bridge is least likely to be acceptable to users of mobile devices because of the lack of close-up detail [13]. However, it is typical of video available from a CCTV surveillance camera.

The frame rate of the video stream was set at a slow scan rate of 15 Hz, as this reduces the data-rate presented to a wireless channel. The Baseline Profile of H.264/AVC was mostly selected with the frame type structure of an I-frame followed by all P-frames, i.e. IPPP… In fact, I-frames aid in channel swapping and provide video cassette recorder (VCR) facilities but are also themselves a form of error resilience. Instead, H.264's facility for distributing intra-coded macroblocks within a sequence was tested.

In the Baseline Profile, Context Adaptive Variable Length Codes (dynamic Huffman entropic coding) is employed for simplicity (rather than Context Adaptive Binary Arithmetic Coding), with some reduction in latency for interactive applications. B-frames are also omitted in the Baseline profile to reduce coding latency. The encoder was set to output at a Constant Bit-Rate (CBR) (with fixed quantization parameter for any one frame to achieve a constant buffering latency and to prevent the occurrence of high maximum rates).

In experiments with FMO, no more than two slice groups for a checkerboard pattern were used, which is feasible for QCIF resolution frames. To reduce overhead, it is also preferable to choose the option in H.264 that prevents reference outside the slice group, though at some cost in coding efficiency. The nature of inter-slice dependencies that occur if they are not suppressed is reported in [14].

For error concealment in H.264/AVC [15] the motion vectors of correctly received slices are computed if the average motion activity is sufficient (more than a quarter pixel). Research in [15] gives details of which motion vector to select to give the smoothest block transition. It is also possible to select the intra-coded frame method of spatial interpolation, which provides smooth and consistent edges at an increased computational cost. In the experiments, though experience shows a motion-vector-based method performs best except when there is high motion activity or frequent scene changes [12], we employed both methods and selected the superior result in terms of average (arithmetic mean) Peak Signal-to-Noise Ratio (PSNR) across the video sequence. In a live situation, it is possible to choose the method that best reduces 'blockiness' at macroblock boundaries by measuring picture continuity. When the 'checkerboard' pattern of FMO is employed then adjacent macroblocks in one slice (containing the 'white' macroblocks) aid the reconstruction of the other slice (containing the 'black' macroblocks) if each slice occupies a separate packet. Rather than simple replacement from the previous frame, the potential role of error concealment, in improving video quality was highlighted in [4].

4.2 Comparisons

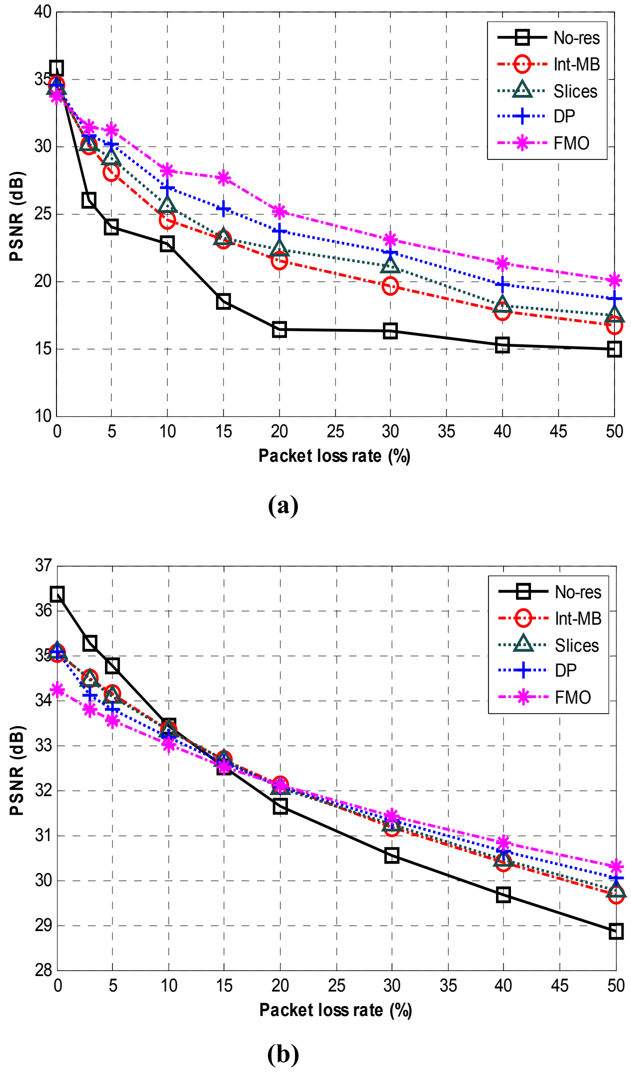
Fig. 2 is a comparison between the luminance PSNR resulting from different error resilience techniques upon Foreman and Bridge (closed), as the packet loss rate was varied. 100 simulation runs with different starting seeds were averaged to ensure convergence of the results. Packet losses in Fig. 2 followed a Uniform probability distribution function, i.e. isolated packet losses. Each slice occupied a single H.264 NALU. It is assumed that protocol headers may be compressed and afforded extra protection such as transmission at a basic rate.

As previously stated, the FMO checkerboard slices were transmitted as two packets. At zero-error packet loss-rate it was apparent that FMO results in the lowest video quality, because of its greater overhead, resulting in a lower coding efficiency for a given date-rate. This is most apparent in Fig. 2b. Structured partitioning of each frame into three independently-coded slices (‘Slices’ in Fig. 2) each within its own packet was seen to be effective at lower loss rates, as the risk of packet error is lower for shorter packet lengths. Data-partitioning (‘DP’ in Fig. 2) was found to be most effective at higher packet loss rates. Insertion of Intra-coded Macroblocks (‘Int-MB’ in Fig. 2) was most found to be most effective at lower packet loss rates. However, notice that Foreman will have some macroblocks encoded in intra-mode when coding is difficult, as occurs during the camera pan. When there is no error resilience (‘No-Res’ in Fig. 2), each frame was coded as a single slice. Because the impact of isolated errors in respect to PSNR alone is limited at low bit-rates for Bridge (closed), it appears that there is some point in not applying error resilience in these regimes. However, the results for Foreman show that for this type of sequence even in good channel conditions error resilience is worthwhile. Finally, notice again that for the same CBR rate, at relatively low data-rates, the overhead arising from error resilience has a significant effect.

In the error conditions simulated, at higher loss rates checkerboard FMO was the most effective method, though delivered video quality can no longer be considered good for Foreman at a 10% packet loss rate and beyond (below 30 dB). However, users may accept quality at 25 to 30 dB [16] if it is in a mobile application. For Bridge, quality is good even at 15% loss rates because of the ability of error concealment to reconstruct a largely static scene. However, PSNR figures alone exaggerate the gain, as visual inspection suggested that most of the distortion is in areas that it is difficult for error concealment to reconstruct accurately, i.e. movement of people along the bridge. FMO is still superior at higher loss rates but its main gain is seen for the more complex Foreman sequence.

Fig. 3 shows that checkerboard (‘check’ in the legend) is superior to other FMO patterns at higher packet loss rates, when coding the two QCIF sequences with two slices. At lower loss rates, FMO is somewhat weaker but the quality is anyway good with whatever FMO pattern for both sequences. The gain is less apparent for the largely static Bridge sequence. However, for Bridge it is possible to reconstruct with adequate quality at very high (30%) packet loss rates. Put another way, largely static sequences do not provide a test of the effectiveness of error resilience measure.

Other FMO patterns[1] in Fig. 3 are: selection of foreground in one slice group and the remainder in another (‘Forg’ in Fig. 3); row interleaving (‘Int’); raster scan ordering with two groups (‘Raster’); and selection of columns or part columns (‘Wipe’).



(a)

(b)

Figure 2. Comparison between several H.264/AVC error resiliency methods and no resilience (No-Res) with isolated errors, for (a) Foreman and (b) Bridge (closed).

5. BURST ERRORS

5.1 Experimental Conditions

In these comparisons three video sequences were tested. ‘Foreman’ was again encoded with the same settings as in Section 3.1, except that the frame rate was somewhat reduced to 10 Hz to improve test turnaround times. In addition, the Akiyo news reader sequence, with low coding complexity was encoded in the same way as Foreman. News sequences as a video genre are known [17] to be acceptable to viewers at lower CBR rates provided audio quality is good. The CBR rate for Foreman and Akiyo was 64 kbps. However, the Mobile sequence with high coding quality, both spatially and temporally, was encoded at a rate of 128 kbps, though with the same format as Foreman and Akiyo. This larger bit-rate ensured that the average quality was around 30 dB PSNR, though of course video quality is variable within a CBR-encoded sequence. Though largely static sequences such as Akiyo, as previously remarked of Bridge – closed, do not provide a good illustration of the value of error resilience, they are popular with mobile users [17]. Mobile illustrates the potential effect of error resilience but is a complex sequence to code. Therefore, both sequences are tested along with Foreman, which is a typical mobile sequence.

A selection of the error resilience schemes in Section 4, were tested for their ability to withstand burst errors, with only DP

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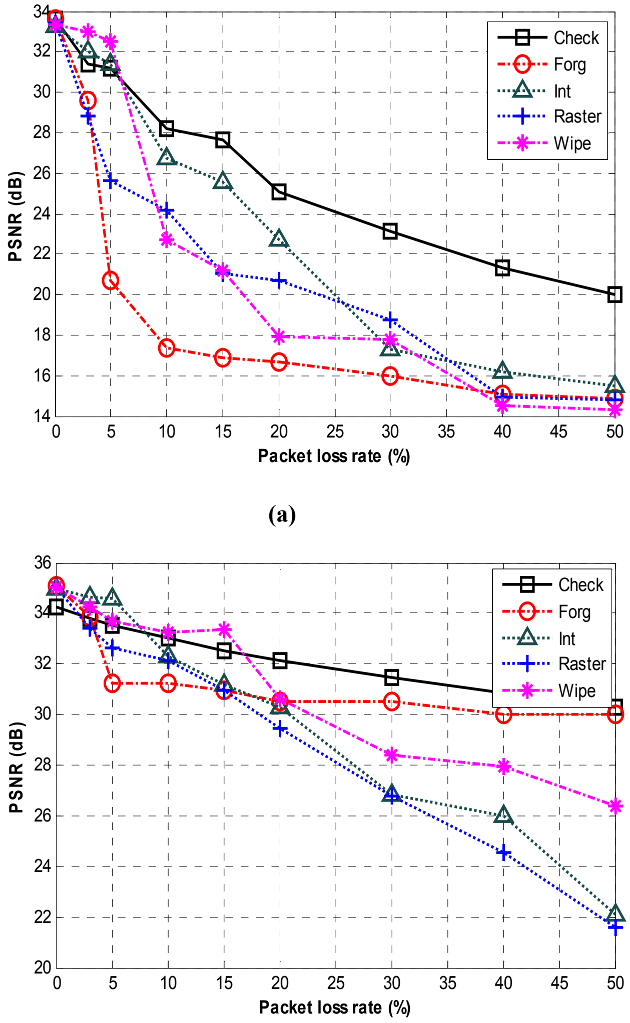
[1] The ‘box’ pattern was also tested but failed to decode with the version of the reference JM 14 decoder software available.



(a)

(b)

Figure 3. The resulting video quality from five different FMO patterns within H.264 with Uniform errors, for (a) Foreman and (b) Bridge (closed).

omitted. Recall that in Section 4's tests it was artificially assumed that the motion vectors in the partition A were protected, whereas if this does not happen DP is not as likely to be effective. DP is also not available in the Baseline profile and for that reason is unlikely to be implemented in mobile devices. In tests involving more than one slice per frame (and hence more than one packet per frame) the number of packets was extended to test the influence of burst lengths on packetisation policy. For FMO, 2, 3, 4 and 5 slices per frame were created. In the 'Slices' scheme, sending 3, 9 and 11 slices per frame was tested. The latter option implies one row of QCIF macroblocks per frame. Clearly in these multi-slice schemes the packet size is much reduced.

A single burst of a given length was inserted at random positions within the sequence, again by means of the JM H.264 codec software, after modification to generate bursts. The effect of burst position was again averaged out by taking the mean of 100 independent tests for each data point.

5.2 Comparisons

From the results in Fig. 4 to 6, it is apparent that though error resilience still has a role to play in improving video quality, dividing a frame among a number of packets is also important. This observation is supported by Fig. 4 in which the single-slice per frame intra-refresh scheme ('Int-MB' in Fig. 4) certainly improves upon not employing error resilience ('No-res' in Fig. 4).

However, with as many as 11 slices per frame in Fig. 4, the delivered video quality is much improved. Recall that FMO with checkerboard slice pattern was superior to slicing in the isolated error tests of Section 4. This is no longer the case when slicing results in more packets per frame than FMO. The reason behind the poor performance of the FMO is that in burst losses at least two packets are lost, which may be from the same frame affecting the ability of FMO to conceal lost macroblocks by means of the dispersed macroblocks of the available packets. The probability of losing more than one packet of the same frame increases with the increase in the burst length, reducing the effect of error concealment.

In general, our results accord with those quoted in [4] to determine the packet loss probability according to packet length and error pattern. The same work [4] determined that unlike the Internet in which slice sizes below the Maximum Transport Unit (MTU) size were known to have little effect, slices in wireless communication lead to a significant gain in PSNR. Our simulations have exposed how significant this effect can be according to burst length.

There is also an impact of overhead and in Fig. 5 this is apparent as 9 slice/frame mostly proves superior to 11 slice/frame. In Table 1, for the same burst length at approximately the same CBR, it is apparent that when there are no errors the effect of including FMO's overhead along with slicing (for three slices) reduces the resulting video quality. Intra-refresh overhead is also significant at low bit rates.

By way of a casual visual check only, Fig. 7 shows matching frames from Foreman for a burst length of 16. The two schemes illustrated are FMO with 3 slices, and simple slicing with 11 slices.

6. CONCLUSIONS

Low-latency, low bit-rate conversational video services will increase the attractiveness of wireless devices. However, the wireless channel may support a limited bitrate and the mobile devices will have limited storage and computational resources. In this paper, good and bad channels were simulated in order to bracket the possible conditions. Error resilience techniques provided in the H.264/AVC are scalable, do not introduce excessive latency, and can work with reduced overhead.

Table 1. Video quality (PSNR) at zero-error, showing the impact of overhead according to error resilience scheme.

Resiliency scheme	Foreman (dB)	Akiya (dB)	Mobile (dB)
No-res	34.81	45.55	30.52
Int-MB	33.93	43.26	29.36
FMO2	34.32	45.31	30.31
FMO3	34.20	45.25	30.27
Slice3	34.66	45.41	30.44

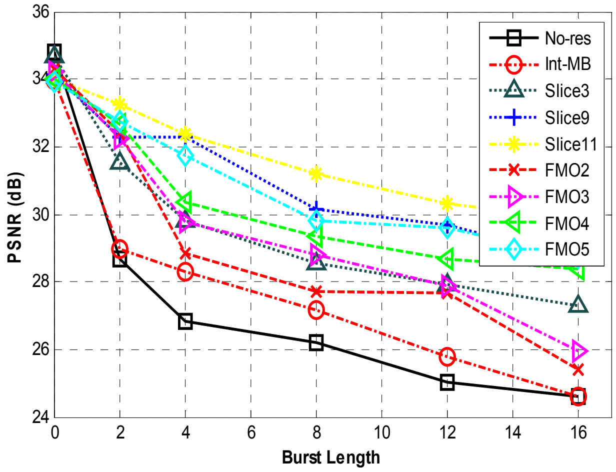


Figure 4. Video quality (PSNR) depending on frame burst length for Foreman.

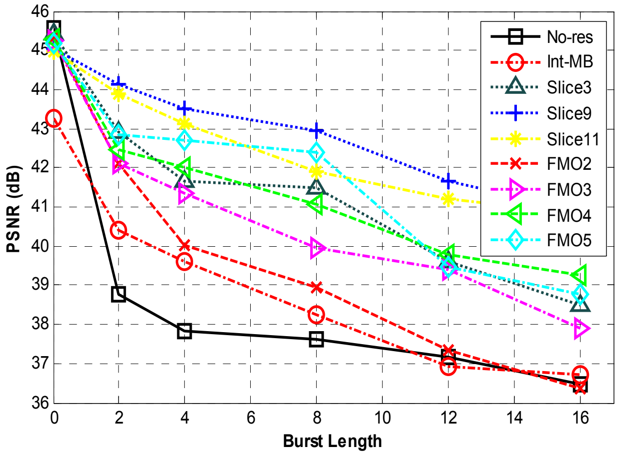


Figure 5. Video quality (PSNR) depending on frame burst length for Akiyo.

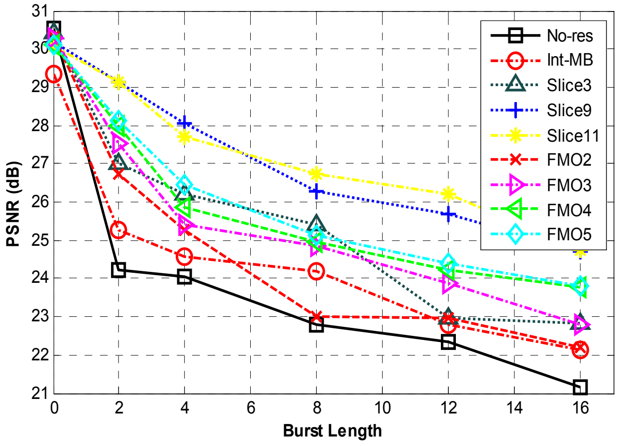


Figure 6. Video quality (PSNR) depending on frame burst length for Mobile.

(a) **(b)**

Figure 7. Sample frames from Foreman for a burst length of 16 (a) 11 slices, (b) 3 FMO slices.

However, it was found that the main gains arose in good channel conditions (isolated) errors, whereas when burst errors of increasing severity occur it is packet size that is most important. In good channel conditions, FMO was effective as it can be combined with advanced error concealment. As in prior studies, we recommend non-normative error concealment despite the implications for computational complexity at the decoder. If savings in complexity are to be made then these can come from H.264's Baseline profile rather than default error concealment. Small, slice-bearing packets in poor conditions are effective and some improvement may come from combining with FMO but we note that increased overhead will reduce the relative advantage of combining techniques in an error resilience strategy.

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