Robust Video Broadcasting over 802.11a/g in Time-Correlated Fading Channels

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***Abstract*— In order to deliver video streams efficiently over WiFi to many thousands of consumer handheld devices, broadcast protocols must be employed. In this mode of operation the received video quality can deteriorate rapidly as a result of high application layer packet loss which occurs because MAC frame retransmission cannot be used. In this paper we develop a robust video solution that is used in conjunction with broadcast transmission over 802.11a/g. Using a cross-layer WiFi simulator in combination with an accurate time-correlated fading channel, the received video quality is evaluated for broadcast H.264 video sequences. Application layer cross-packet forward error correction is then used together with error concealment at the video client. The methods developed can be used to successfully broadcast video to many thousands of handheld terminals at large-scale spectator events.**

I. INTRODUCTION

IEEE 802.11 is increasingly used for multimedia distribution to mobile terminals. This paper investigates broadcast video streaming to handheld devices such as mobile phones and Personal Digital Assistants (PDAs). Our study is based on the results of VISUALISE. The aims of this project are given in [1]. Here, spectators were able to enhance their visual experience at sporting events using handheld consumer terminals. Live and recorded video streams were supplied with leader board, timing and GPS tracking data.

The 802.11a/g standard combines a Coded Orthogonal Frequency Division Multiplexing (COFDM) physical layer (PHY) with the legacy 802.11 Medium Access Control (MAC) layer. For unicast links, when the radio channel experiences a low signal to noise ratio (SNR) we observe an increase in the MAC frame loss rate (FLR), delay and jitter at the MAC layer. This increase in delay and jitter occurs as a result of variable MAC frame retransmission. When data is sent as a broadcast (or multicast) stream, MAC layer retransmission cannot be used since clients are no longer permitted to feedback frame acknowledgments to the server. While broadcasting allows many thousands of terminals to receive a video stream, the received FLR is often high (due to poor signal levels, no MAC frame retransmission, and dropped frames in the terminal).

Cross-layer MAC-PHY optimization for video transmission over WiFi has been explored by a number of authors. Several methods have been suggested to improve video quality. These include link adaptation, video rate adaptation, and the use of scalable video coding [2,3,4]. The wireless broadcast of video to multiple users in heterogeneous environments presents a number of new challenges. Most importantly, feedback from each receiver or video decoder is no longer possible. Each receiver experiences a unique radio channel and source adaptation in no longer an option. Few papers address the specific needs of broadcast video over wireless networks [5,6]. In this paper we evaluate the received broadcast video quality with and without application layer cross-packet Forward Error Correction (FEC). An $[n,k]$ erasure block code is used to protect the video payload. A novel MAC-PHY simulator is developed to model the transmission of a time series of queued MAC frames over the wireless channel [7].

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II. THE CROSS-LAYER SIMULATOR

An integrated 802.11a/g MAC-PHY simulator is used to model the MAC frame loss process. A time sequence of MAC frames is passed into the simulator. Outputs include *i*) MAC layer FLR, *ii*) MAC-to-MAC frame delay, and *iii*) throughput. These are evaluated as a function of the channel's average SNR and Power Spectral Density (PSD), the selected PHY layer link-speed and the maximum number of MAC layer retransmissions [7]. It is well-known that packet errors over a wireless medium are bursty in nature. Importantly, the packet error rate for contiguous packets is *not* independent and this has a significant effect on the performance of video error concealment. To replicate the bursty nature of the packet error process an accurate time-correlated channel model is implemented based on the PSD of a typical radio channel [7].

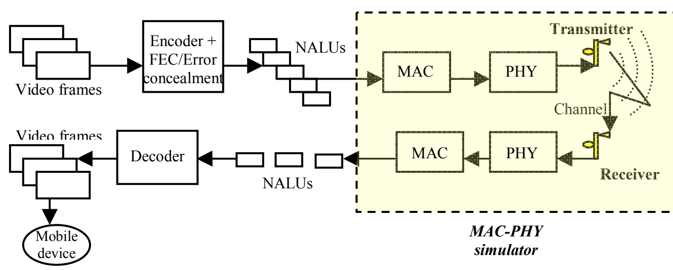

Fig. 1. Block diagram of the cross-layer simulator

The video transmission simulator (Fig. 1) evaluates the quality of the received video sequence in terms of Peak Signal to Noise Ratio (PSNR) and video FLR. The encoder translates each video frame into a number of Network Abstraction Layer units (NALU). For broadcast transmission an RTP/BCT/IP stack is assumed, with a 1:1 correspondence of video NALUs to IP packets and MAC frames.

The main VISUALISE demonstration was held at the World Rally Championships in 2007. The following results were generated for a video sequence taken from inside a rally car. The sequence of 410 frames was encoded using H.264 to produce an overall 256kbps IP stream at the application layer, with, and without cross-packet FEC. Equal frame protection FEC with a depth of 6 packets and code rates of 0.875 and 0.75 was used. The average received SNR over the wireless channel was varied between 5 and 25dB. All of the 802.11a/g

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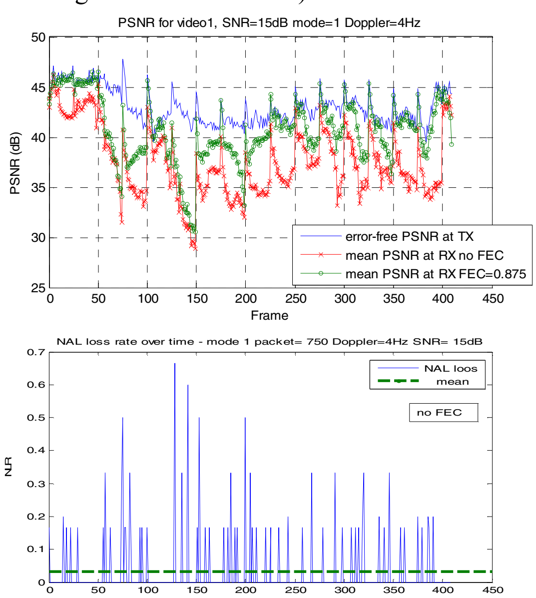
link-speeds were simulated. Since broadcast transmission was used, no MAC layer retransmissions were permitted. Mobility in the wireless channel was modelled for walking spectators and slow motion up to 30km/h, using a maximum Doppler shift of 4Hz, 10Hz and 65Hz. All results were averaged over 7 different channel realizations.

III. Analysis of Results

The video transmission simulator evaluates PSNR per received video frame for different link-speeds, mean channel SNR values and Doppler shifts. Fig. 2a shows the PSNR per frame for a rally car video sequence broadcast over WiFi from a static access point using link-speed 1 (BPSK, ½ rate code). The mean SNR at the receiver was 15dB and the maximum Doppler shift was 4Hz. The blue plot (no marker) shows the error-free PSNR per frame, as computed at the encoder. This can be used as an upper bound at the receiver. The mean received PSNR for video encoded without application layer FEC is shown by the red plot (cross marker). The green plot (circle marker) shows the received video protected using FEC at a rate of 0.875. Clearly the use of cross packet FEC improves the mean received PSNR since a number of lost packets can be recovered prior to video decoding. The simulator can output the number of lost MAC frames (and hence NALUs) per video frame at the receiver prior to the application of cross packet FEC. Fig. 2b shows the bursty nature of the NALU loss rate (NLR). Each NLR value is averaged over 132ms (one video frame). Figs 2a and b are time-aligned to allow a direct comparison between the NLR and the video PSNR on a frame-by-frame basis. Regions of high NLR result in low video PSNR. Errors in a P-frame without FEC propagate in the following frames, decreasing PSNR during low NLR regions. With cross packet FEC the received PSNR per frame can be seen to improve (approaching the error free value).



(a)

(b)

Fig. 2. a) PSNR per frame with/without FEC, b) NLR per frame

To compare video quality at each of the 802.11a/g link-speeds and for different maximum Doppler shifts, the average PSNR of the entire video sequence is computed as the sum of the PSNR per frame (for those sequences that were decoded) over the entire sequence.

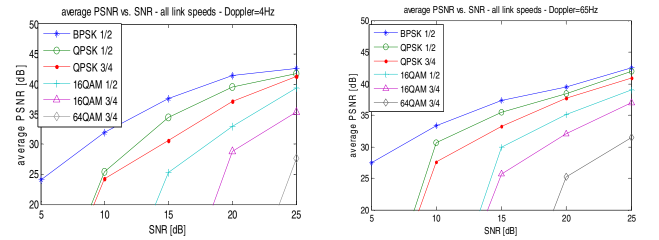


Fig. 3. Average PSNR per video sequence versus average channel SNR for all link-speeds (no FEC). Left: max Doppler 4Hz, right: max Doppler 65Hz

Fig. 3 shows the average PSNR of the entire video sequence as a function of the mean channel SNR, for all link-speeds and for maximum Doppler shifts of 4Hz and 65Hz. In this case no cross packet FEC was applied. When the mean channel SNR at the receiver is greater than 15dB we see that link-speeds 1-4 (BPSK and QPSK) achieve an average PSNR ≥30dB for the 65Hz channel. For the 4Hz channel only link-speeds 1-2 (BPSK) meet this target. Furthermore, at the high Doppler shifts link-speed 1 achieves a higher average PSNR for SNR ≤15dB. For high Doppler values the video quality improves since the fast fading decorrelates faster in time, thus reducing the time between successful NALU transmissions. At high Doppler values the error burst length is much reduced, making the lost NALUs easier to conceal.

IV. Conclusions

For broadcast transmissions, lost MAC frames (or NALUs) are inevitable. However, with the use of application layer cross-packet FEC the NLR can be reduced and the video quality can be improved. Results have shown that the degree of motion in the radio channel can effect the error burst length, and hence the decoded video quality. In combination with error concealment, good quality broadcast reception over 802.11a/g can be achieved for average SNR values of 15dB or better at the receiving terminal (assuming a worst case fast fading channel). A wireless video transmission system based on WiFi was developed within VISUALISE.

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