2008 5th International Multi-Conference on Systems, Signals and Devices

Error-Driven Adaptation for GOP Video Transport in Wireless Channel

Ghaida A. AL-Suhail
College of Engineering, Computer Engineering Department, Basrah University
Basrah, Iraq , Email: gaida_alsuhail@yahoo.com

Abstract - **In this paper, we develop a new error-driven adaptation scheme based on a classical error control used at the frame-level of Group of Picture (GOP) for MPEG-4 video stream on a noisy wireless channel. A model adds extra parity packets to the original GOP frames using Reed-Solomon Forward Error Correction (RS FEC) scheme. Various packet-correction codes are examined at high channel errors in order to achieve a maximum perceptual video quality at client. Further, we propose a scenario to adapt packet-errors with aim to improve the video quality under a condition that the video server can reduce the packet length once threshold error feedback report of TCP-Friendly protocol is delivered. The scheme reduces the video distortion at the decoder under bandwidth constraints. The reduction is achieved by efficiently protecting the different video frames from channel errors. Furthermore, this efficient decoding algorithm can reduce the decoding complexity of channel decoder. Numerical results clearly show that the proposed approach outperforms a classical RS FEC scheme.**

Index Terms – Wireless video, Video quality, TCP-Friendly, Quality of Service (QoS), FEC, Reed-Solomon code.

1. INTRODUCTION

During the past decade, there has been an increasing interest in multimedia communication over wireless channels [1]. This is mainly due to its commercial importance in many applications, such as video transmission and access via mobile telephones, broadcasting, personal digital assistance (PDAs), and video services over wireless channels. In contrary, such channels can not provide the necessary Quality of Service (QoS) guarantees that are needed to support high quality video transmission. In particular, the major challenges of video traffic are to deal with low bandwidth and high packet loss which is due to the congestion of buffer overflow and/or that due to physical channel errors introduced by the noise, interference, fading and shadowing. Effectively, the bit stream video over a noisy channel faces bit errors causing packets corruption. This leads to a significant degradation in the quality of reconstructed video sequence. Therefore, a robust transmission of real-time video over wireless channels is still open issue to provide a good perceptual quality at the client terminal end [1-2].

Unlike typical Internet traffic, streaming video is sensitive to delay and jitter, but can tolerate some data loss. In fact, video transmission can yield better video play-out when the underlying protocol provides smooth data rate than a bursty data rate. Thereby, video streaming applications often use UDP or TCP-Friendly as a transport protocol rather than TCP. Unfortunately, UDP does not reduce its data rate when an Internet router drops packets to indicate congestion. It means that there is no congestion control within UDP and no response to relieve the saturation of a bottleneck due to congestion. Thus recent research has proposed rate-based TCP-Friendly protocols for steaming media [3][4] as alternatives to UDP over wired/wireless networks.

To reduce the number of packet errors over wireless channel and to improve the video quality at client end, several error control approaches have been pursued including *adaptive rate control* [5], *Automatic Repeat reQuest (ARQ)* [6], *Interleaving* [7], *Forward Error Correction* (FEC) [8], and *adaptive modulation* [9]. These approaches are either employed separately, jointly, or cross multi-layers [1]. More precisely, FEC scheme is an effective way to combat not only bit errors but also packet loss at the hardware radio-link layer during wireless video transmission. In general, such scheme adds extra data to the original information with the aim to bring a data protection at bit/byte [8], packet /frame [10], and GOP-levels [11].

In this paper, to improve the video quality we employ a classical Reed Solomon forward-error correction (RS FEC) for a Group of Pictures (GOP) at the frame-level of MPEG-4 video stream over a limited wireless channel capacity. Note that an important subclass of non-binary Bose-Chadhuri Hocquenghem (BCH) codes is the Reed Solomon (RS) code [6]. An RS code groups the bits into blocks and thus achieves good burst error suppression capability.

To avoid the latency (delay) and variance in latency caused by re-transmission schemes of lost packets, RS code acts as an effective inter-protection control scheme in the application layer. In contrary, the hardware radio link layer can capture the channel errors by estimating the bit error rate (BER) performance via Signal-to-Noise Ratio (SNR) for an Additive White Gaussian Noise (AWGN) wireless channel. The feedback report of errors is delivered at the video server and is uploaded to the application layer to prepare the required RS correction-codes before transmission starts again. A typical TCP-Friendly protocol is considered to control the sending rate over the wireless channel. Various packet-correction codes are examined for several GOP patterns to search a maximum video quality in terms of a number of play-out frames. Furthermore, we suggest a simple error mitigation

978-1-4244-2206-7/08/$25.00 ©2008 IEEE

scenario to improve the video quality by reducing the packet length to the half size in the network setting once a feedback channel state report is delivered to the video server. Such delivery is in a separate channel transmission.

The rest of paper is organized as follows. Section 2 describes system description followed by proposed approach in Section 3. Section 4 explains methodology and results analysis and finally Section 5 summaries the conclusions.

2. SYSTEM DESCRIPTION

2.1 Network Model

Most of studies on error control of video transmission today uses point-to-point model. This model is shown in **Fig. 1**. Various errors are encountered when two terminals are linked. These errors can mainly be classified as packet loss due to overflow buffer (congestion) and/or error bits due to wireless features environment [6]. Video input goes to encoder part of codec to form bitstream and is then transmitted to the network. At the decoder side, the video is received first by the decoder and then displayed on the terminal. We therefore consider a realistic wireless video transmission system which consists of a transmitter, a receiver, and a communication channel with a limited bandwidth B_w.

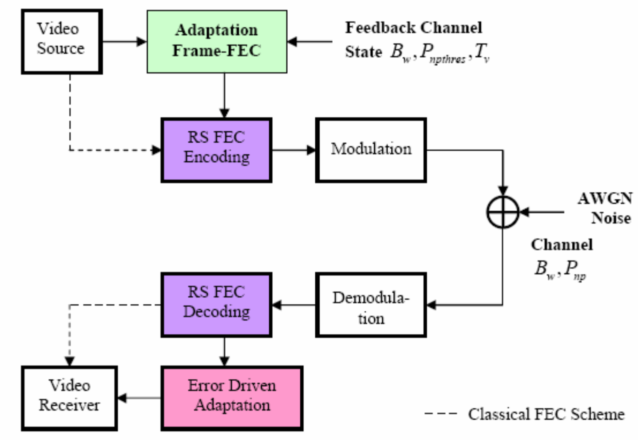


Figure 1: A typical proposed wireless video communication system corrupted by AWGN noise.

2.2 MPEG Video

We consider a Moving Picture Expert Group (MPEG-4) as a standard video compression for wireless channel. A typical Group of Pictures (GOPs) structure of an MPEG stream consists of three types of frames: I-, P- and B-frames. An I-frame (Intra coded) located at the head of a GOP is coded as a still image and serves as a reference for P and B frames. P-frames (Predictive coded) depend on the preceding I or P-frame in compression. Finally, B-frames (Bi-directionally predictive coded) depend on the surrounding reference frames, that are the closest two I and P or P and P frames. In fact, GOP pattern can be identified for MPEG-4 in similar manner in MPEG-2, for simplicity, as $G(N_P, N_{BP})$ and $N_B = (1+N_P)\times N_{BP}$, where N_B corresponds to the total number of B-frames, N_P corresponds to a number of P-frames in a GoP, and N_{BP} corresponds to the number of B-frames between I and P frames (for example, GOP(2,2) “IBBPBBPBB” where N_P =2 and N_{BP} =2. However, another error-resilient GOP pattern can be found in [12].

2.3 Forward Error Correction (FEC)

In this paper, we employ a classical Reed Solomon Forward Error Correction (RS FEC) code [10] in the application layer at the frame level of GOP MPEG video before emitting this coded video over a wireless network. RS encoder takes K original packets in each frame (e.g. I, P and B frames), then adds $(N-K)$ redundant packets, and sends the N packets out [13]. If any K or more packets are received, then all the original packets can be completely reconstructed

To analyse the effects of FEC on the application layer frames, the sending of packets is modelled as a series of independent Bernoulli trials. Thus, the probability $P_{video}(N,K,p)$ that a K packets video frame is successfully transmitted with $N-K$ redundant FEC packets along a network path with overall packet loss probability P_{np} is

$$P_{video}(N,K,p) = \sum_{i=K}^{N}\left[\binom{N}{i}(1-P_{np})^{i}\,P_{np}^{\;N-i}\right]. \qquad (1)$$

By considering the packet sizes of I, P, and B frames in GOP pattern, and the distribution of redundant FEC packets added to each frame type, equation (1) can be expressed to compute the probabilities of successful transmission probabilities for each frame type as following [11],

$$\begin{aligned} P_I &= P(S_I + S_{IF}, S_I, P_{np}) \\ P_P &= P(S_P + S_{PF}, S_P, P_{np}) \\ P_B &= P(S_B + S_{BF}, S_B, P_{np}) \end{aligned} \qquad (2)$$

S_I, S_P, and S_B are the sizes of I, P, and B frames respectively. S_{IF}, S_{PF}, and S_{BF} are the number of FEC packets added to each, I-frame, P-frame, and B-frame, respectively. The packets-based FEC are transmitted through the air and processed by the receiver. The RS decoder at the receiver is assumed to be able to detect all the errors in the received packets. (In practical some errors are not decodable, but this probability is small for reasonable value of $N-K$ and reasonable channel SNRs). Upon decoding the packet, the receiver sends an acknowledgment, either positive (ACK) or negative (NAK), back to the transmitter. For case of our analysis we assume this feedback goes through a separate control channel, and arrives at the transmitter instantaneously and without error. If the RS FEC decoder detects any error and issues a NAK, the transmitter uses a selective repeat protocol to resend the packet. It repeats the process until the packet is successfully delivered.

In **Fig. 1**, the source coder provides compression (usually lossy) of the video while the channel coder introduces redundancy in order to combat error caused by a noisy channel. The concealment stage is a post-processing stage (usually found only in lossy compression systems such as video) which is useful for reducing the effects of residual channel errors. In this stage, operations such as spatial or temporal filtering are carried out to improve the quality of corrupted video.

2.4 Error Concealment

Many approaches deal with error concealment at receiver. The easiest and most practical approach is to hold the last frame that was successfully decoded. Such technique has a long history; it has been available from H.261 and MPEG-2. Moreover, the best-known approach is to use motion vectors that can adjust the image more naturally when holding the previous frame [14]. The vector approach works well at a relatively high bit rate, because the amount of motion vector data is small, and moreover the motion vectors represent realistic object motions on the image. More sophisticated error concealment methods consist of a combination of spatial/spectral and temporal interpolations with motion vector estimation [15]. One can also add optimization techniques to feedback based error control, especially for streaming services in which a relatively large RTT is allowed [16]. This approach is basically for error mitigation by feedback where a feedback channel indicates which parts of video bit stream were received intact, and which parts of it could not be decoded and had to be concealed.

2.5 Error Adaptation

In this paper, we propose a simple scenario to adapt packet-errors at the current video frames received successfully but we also rely on the last feedback channel report delivered at sender in order to decode a current video frame rate correctly at high bit error rate. The details are explained in **Subsection 3.2**. The idea of our proposed scheme can fall into error-driven adaptation over wireless channel.

Furthermore, we do not consider a channel coding for a typical model of wireless video communication; whereby a video server sends a video stream to a receiver via a wireless channel corrupted highly by an AWGN, and no interference from other signals [17]. Since any bit in the packet results in a loss of the packet, the probability of packet success (PSR) is given in terms of the bit error rate P_e by,

$$PSR = [1 - P_e(\gamma)]^{S_{pkt}} , \qquad (3)$$

where $P_e(\gamma)$ refers to a BPSK in AWGN channels, S_{pkt} is packet length, and $\gamma = 2E_b/N_o$ represents the total channel SNR. E_b and N_o denote the bit energy and one-sided noise spectral density, respectively. To achieve the low channel SNR region in our simulation results, we assume PSR is independent on S_{pkt} whereas a whole packet is dropped once there is any bit error in the packet. Then,

$$P_e(\gamma) = P_{np} = Q\left(\sqrt{\gamma}\right) \qquad (4)$$

$Q(.)$ is the Gaussian cumulative distribution function [1]. On the other hand, to control a video flow over a channel, TCP-Friendly is considered if its data rate (throughput) does not exceed the maximum data rate of TCP connection in the same network conditions. In fact, the feedback channel delivers the network condition to the sender with the aim to adjust the sending rate to the desirable rate determined by an underlying TCP-Friendly Rate Control (TFRC). Hence, one can achieve the required video quality of video applications over a wireless link [5].

3. PROPOSED APPROACH

The wireless link is characterized by the following *Proposed Scenario*: (*i*) The channel capacity is B_w and packet loss rate P_{np} is due to only bit errors ignoring the congestion effect due to opening concurrent TFRC connections in one video application. (*ii*) a minimum delay is fixed on only round-trip time (RTT) of TFRC protocol; (*iii*) the maximum network throughput (TFRC sending rate) must not be greater than available bandwidth; and (*iv*) the feedback channel from receiver to server is assumed to be error-free due to bit errors. In this scenario, the video sending rate is smaller than the wireless bandwidth and should not cause any network instability. Additionally, the optimal control should result in the highest possible throughput and the lowest packet loss rate. Hence, the target sending rate for only one TFRC connection becomes [13,17],

$$T \le \frac{S_{pkt}}{t_{RTT\min}\sqrt{\frac{2P_{np}}{3}} + t_{RTO}\sqrt{\frac{27P_{np}}{8}}P_{np}\left(1+32P_{np}{}^{2}\right)} < B_w \qquad (5)$$

P_{np} , S_{pkt} , t_{RTT} , and t_{RTO} represent the packet loss probability, the packet size [byte], the round-trip time [sec], and the TCP retransmit time out value [sec].

At the physical layer, the effective throughput can be expressed in terms of some design parameters such as modulation format, packet length, and channel coding. In our model, we assume BPSK for AWGN channel, long packet size, and no channel coding is considered. In order to fit these assumptions to the upper bound network throughput of (5), we consider,

$$T_{Phy} = A_{\max} \times [1 - P_{np}(\gamma)] \qquad (6)$$

The factor $A_{\max}$ represents the maximum achievable data rate [2]. If the TFRC network throughput T of (5) achieves $A_{\max}$, then (6) can be rewritten such as,

$$T_v = T \times [1 - P_{np}(\gamma)] \quad (7)$$

Let the limit of T_v is to produce the effective upper bound TFRC network throughput over a realistic wireless channel taking into account a discounting factor of the channel features in terms of $[1 - P_{np}(\gamma)]$ [9], then we can rely on T_v in frame-level FEC model in evaluating the effective video quality.

3.1 Frame-level FEC Model

In this technique, FEC packets are generated based on individual frames (I, P, and B). If each GOP includes one I-frame, N_P of P frames and N_B of B frames, the effective GOP transmission rate is given by [10],

$$G = T_{pkt} / S_{GOP}\,, \quad (8)$$

where $T_{pkt} = T_v / S_{pkt}$ denotes a network throughput [packet per sec], and S_{GOP} is a size of the coded GOP using RS FEC arrangement,

$$S_{GOP} = (S_I + S_{IF}) + N_P(S_P + S_{PF}) + N_B(S_B + S_{BF}) \quad (9)$$

By regarding T as the available bandwidth for video streaming and adjusting the video traffic, the high-quality video play-out at a receiver can be expected. The total play-out frame rate by Wu *et al.*'s technique is given by,

$$R_F = G.P_I.P_B.\left(1 + \chi_P + N_{BP}.P_B.[\chi_P + P_I.P_P^{N_P}]\right) \quad (10)$$

with, $$\chi_P = \frac{P_P - P_P^{N_P+1}}{1 - P_P}\,. \quad (11)$$

P_I, P_P, and P_B are the probabilities of the successful transmission of I, P, and B frames, respectively.

3.2 Proposed Error-Driven Model

The frame-based FEC technique above provide a good error resiliency performance over wireless channel but with appropriate selection of parameters such as S_{IF}, S_{PF} and S_{BF}. A problem in this approach is that the location of FEC packet of each type of frame is static. To solve this problem, Yuan *et al.* [11] suggested a GOP-level FEC technique by encoding a whole GOP with RS code instead of frame-level. In fact, the technique can improve the play-out video in a lossy (due to only congestion) wired network, but it suffers from computation complexity about 5-7 times that of Wu's technique [10].

In this paper, to improve the play-out video quality at the client end, we first employ Wu's technique over a noisy wireless channel to reduce the effects of bit errors. Second, we propose a simple scenario to adapt the video flow rate at the server (sender) once error feedback report is delivered to the application layer [15]. Hence, transport layer on both video terminals will maintain the previous upper throughput as a reference available bandwidth; in contrary the sender will reduce the packet size to the half and allows RS encoder to add the appropriate static FEC codes to each video frame. Although reducing packet size, in this case, will reduce the overall transmission rate, but the expected bit errors over wireless in consequence will decreases. In this scenario, we keep the last network conditions (upper bound throughput and round-trip time) same when it comes to improve video quality at a receiver. Hence, the expected successful transmission probabilities of video's frames will increase by numerically solving (6) to obtain the corresponding bit error rate. As a result, such predicted bit error rate becomes low and then eventually a significant improvement in video quality is obtained. **Figure 3** illustrates the flow-chart details. This scheme is called frame-FEC based error-driven adaptation.

3.3 Performance Evaluation

Upon the scenario above, we evaluate our proposed model at the receiver by estimating the amount of improvement in the number of play-out frames with respect to the original video source. Therefore, a simple PFR percentage formula is used as,

$$PFR \text{ (in \%)} = \frac{R_F}{Source\ Frame\ Rate} \times 100 \quad (12)$$

4. SIMULATION RESULTS

To demonstrate the effectiveness of our scheme, we simulate the functionality of frame-FEC model at a receiver using Matlab programming. The network constraints includes a maximum link capacity with 1 Mbps bandwidth and overall network delay is only a minimum round-trip-time for error-free transmission, otherwise a TCP time out is not more than four times of a round-trip time. The TFRC packet size starts with 1000 bytes and if a high errors report is delivered at sender, then sending rate uses 500 bytes for the encoded video frames. At the receiver, a scenario of **Fig. 2** must be applied to estimate the predicted bit error rate (or packet loss rate) which eventually enhances the perceptual video quality at client. Thus simulation results are come up using Table (1) that defines GOP parameters and various packet-correction FEC codes.

Figure 3 illustrates a predicted packet loss rate in case of halving packet length under a condition that the last upper bound of network throughput is not changed at client using the proposed scenario (See **Fig. 2**). A clear improvement in the range of packet rate consequently increases the successful transmission probability of video frames. This leads to achieve a desired video quality at receiver as shown in **Fig. 4**. When packet size changes from 1000 bytes to 500 bytes according to feedback report, an improvement in the number of play-out frames is clearly achieved in the low channel SNR region (high channel bit errors). A small FEC(1,1,0) introduces a good performance for any packet size as compared to both medium and large FEC codes; the only increase expected is up to 1 or 1.5 [fps], on average in case of FEC(4,2,0) or FEC(8,4,1) codes. However, there is a significant degradation in PFR % when channel SNR is beyond 6 dB (i.e., high channel SNR region) whereby the limited wireless channel capacity does not allow PFR increases more than 82% of full-motion video play-out 25 [fps]. As a result, it is noticed that chosen value of S_{PF} or S_{BF} has a slightly effect on the resultant PFR as compared with chosen values of S_{IF}.

When a feedback error report involves a threshold bit error rate $P_{npthres}$, then sender changes 1000 bytes to 500 bytes to provide a lowest bit error at a receiver through the error-driven in reconstructed transmission frames' probabilities. When packet size returns back to 1000 bytes there is no effective change in predicted video frames at high bit error rates, but a maximum quality achievable will not be more than 11 [fps] at lowest error probability of 1x10^{-2}.

Table 2 explains the effectiveness of our proposed scheme under various wireless channel states **C1-C7** and small FEC(1,1,0) error-correction condition. First, we compare a classical frame-FEC when packet size starts with 1000 bytes. It is noticed that a video frames quality at low channel SNR region **C4-C7** can improve via a small FEC. For example, **C6** (3.2 dB, 2x10^{-2} random error) under a small FEC provides nearly a twice PFR value when there is no using FEC. In contrary, in **Table 2 (b)**, a proposed scheme works well as an error adaptation at low channel SNR region **C4-C7**, where asignificant channel gain can be achieved up to 1.9 dB in **C7**. As a result, error adaptation in packet errors will eventually increase the video quality. A **C7** starts with SNR of 1.3 dB (5x10^{-2} random error) and after applying error adaptation, it results 2.85 [fps] when packet size changes to 500 bytes. A quality improvement in this case is not more than 1 (fps) or 1.3 (fps) for **C7** in Table 2.
On the other hand, at high channel SNR region, it is found that a maximum play-out frame rate achieves a higher value 21 [fps] in **C1-C3** even when our proposed mitigation error is applied. This maximum frame rate comes from the channel capacity limitation. Therefore we can extract a threshold bit error rate $P_{npthres}$ to be equal 5x10^{-3} when a wireless channel is highly corrupted by noise then a feedback error report must contain such threshold rate. It means that once a channel state achieves **C4** in **Table 2 (a)**, error adaptation scheme must be met at the reconstructed frames.

Table 3 compares the video quality under various packet-error rates. We can see that under all error rates our scheme can achieve significantly a reasonable performance with the other works based TFRC protocol on wire line [10,11]. The proposed frame-FEC model can achieve 42%-44.4% of full motion video at client under error probability 1x10^{-2}.

5. CONCLUSION

In this paper, an efficient approach for inter-protection error control in the application layer is presented based on frame-FEC scheme over a noisy wireless channel. The proposed approach introduces a robust video transmission over wireless channel using Reed-Solomon FEC code. A video is streamed using underlying transport protocol of TCP-Friendly Rate Control (TFRC). Therefore, the error adaptation has been proposed to improve the successful transmission frame probabilities at low channel SNR region. As a result, the lower bit error rates have been gained at the receiver at low channel SNR region. A threshold error rate is predicted to equal 5x10^{-3} when a wireless channel is highly corrupted by AWGN. It is also found that a small FEC is enough to introduce a reasonable improvement in the video quality performance in terms of play-out frame rate. Furthermore, a proposed scheme outperforms the classical frame-FEC scheme at high bit errors and is limited up to 82% in high channel SNR region. Further work can involve the effect of channel code to provide more robust wireless video transmission.

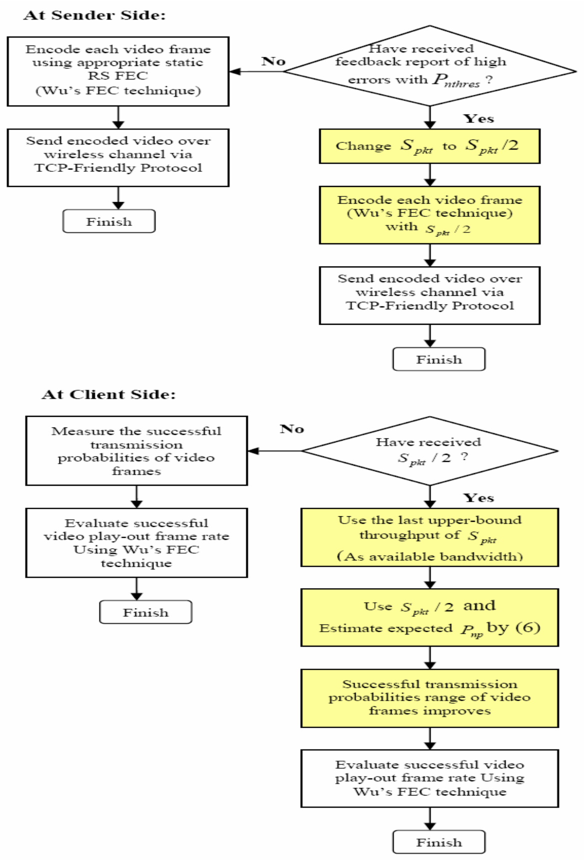


Figure 2: Flow-chart for our proposed Frame-FEC model based error-driven adaptation over noisy wireless channel.

Table 1: A typical GOP parameters and packet-correction FEC codes used in simulation.

GOP parameters and Frame-level FEC code	
I-frame S_I = 25 packets	Small FEC (1,1,0)
P-frame S_P = 8 packets	Medium FEC (4,2,0)
B-frame S_B = 3 packets	Large FEC (8,4,1)

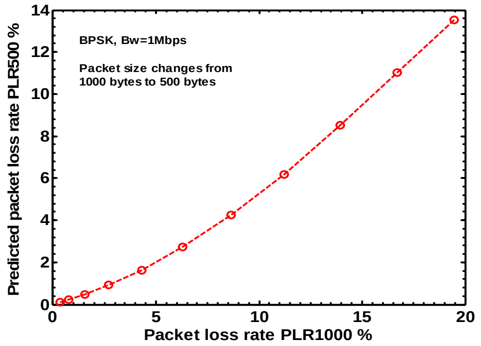


Figure 3: Predicted packet loss rate using a proposed error-adaptation to improve reconstructed video frames.

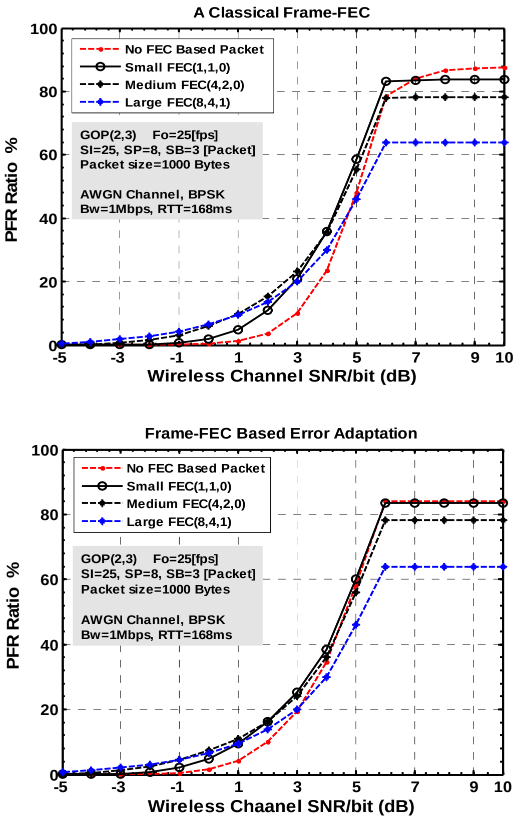


Figure 4: Video play-out ratio under various packet-correction FEC codes

REFERENCES

[1] X. Zhu and B. Girod, "Video Streaming Over Wireless Networks", Proc. EUSIPCO-07, pp. 1462-1466, Poznan, Poland, Sep. 2007.

[2] D. Krishnaswamy and M. Schaar, "Adaptive Modulated Scalable Video Transmission over Wireless Networks with a Game Theoretic Approach," *IEEE MMSP2004*, 2004.

[3] M. Chen and A. Zakhor, "Multiple TFRC Connections Based Rate Control for Wireless Networks", *IEEE Trans. On Multimedia*, vol. 8, no. 5, pp. 1045-1062, Oct. 2006.

[4] F. Yang, Q. Zhang, W. Zhu, and Y.Q. Zhang, "End-to-End TCP-Friendly Streaming Protocol and Bit Allocation for Scalable Video over Wireless Internet", IEEE J. on Selec. Area In Comm., vol. 22, no. 4, May 2004.

[5] S. Aramvith, I. Pao and M. Sun, "A Rate-Control scheme for Video Transport over wireless Channels," IEEE Trans. on Circuit and System for Video Tech. , vol. 11, no. 5, pp. 569-580, May 2001.

[6] T. Wang, H. Fang, and L. Chen, "Low-Delay and Error-Robust Wireless Video Transmission for Video Communications," *IEEE Trans on Circ. and Sys. for Video Tech*., vol. 12, no. 12, pp. 1049-1058, Dec. 2002.

[7] R. Tripathi, "Pre-interleaving Error-Correction Coding for Reliable Transmission over Fading Channels", Dept. of Elec. and comp. Eng, University of Texas, pp. 1-11, 3 May 2002.

[8] T.-W. Lee, S.-H. Chan, Q. Zhang, W.-W. Zhu, and Y.-Q. Zhang, "Optimal Allocation of Packet-Level and Byte-Level FEC in Video Multicasting over Wired and Wireless Networks," *GLOBECOM'01 and IEEE*, vol. 3, pp. 1994-1998, 2001.

[9] X. Tong, W. Gao, and Q. Huang, "A Novel Rate Control Scheme for Video Streaming over Wireless Networks," Proc. ICIG'04 IEEE, 2004.

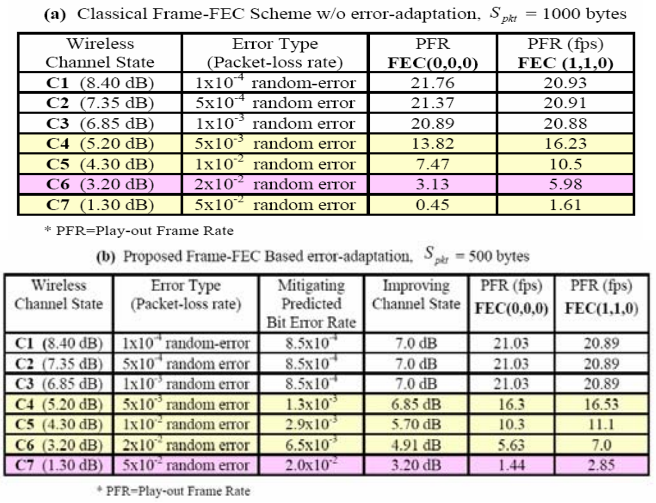
[10] H. Wu, M. Claypool, and R. Kinicki, "Adjusting Forward Error Correction with Quality Scaling for Streaming MPEG," *NOSSDAV'05*, pp. 111-116, June 2005.

[11] Y. Yuan, B. Cockburn, T. Sikora, and M. Mandal, M "A GoP Based FEC Technique for Packet Based Video Streaming," *Proc. 10th WSEAS Inter. Conference on Comm*., Greece, pp. 187-192, July 0-12, 2006.

[12] T. Fang, L. Chau, "An Error-Resilient GOP Structure for Robust Video Transmission," *IEEE, Trans. On Multimedia*, vol. 7, no. 6, pp. 1131-1138, Dec. 2005.

[13] M. Miyabayashi, N. Wakamiya, M. Murata, and H. Miyahara, "Dynamic Quality Adaptation Mechanism for TCP-Friendly MPEG-4 Video Transfer ," Osaka University, 2002.

Table 2: Video quality performance under various wireless channel states and small FEC for GOP(2,3)



(a) Classical Frame-FEC Scheme w/o error-adaptation, S_{pkt} = 1000 bytes

Wireless Channel State	Error Type (Packet-loss rate)	PFR **FEC(0,0,0)**	PFR (fps) **FEC (1,1,0)**
C1 (8.40 dB)	$1x10^{-4}$ random-error	21.76	20.93
C2 (7.35 dB)	$5x10^{-4}$ random error	21.37	20.91
C3 (6.85 dB)	$1x10^{-3}$ random error	20.89	20.88
C4 (5.20 dB)	$5x10^{-3}$ random error	13.82	16.23
C5 (4.30 dB)	$1x10^{-2}$ random error	7.47	10.5
C6 (3.20 dB)	$2x10^{-2}$ random error	3.13	5.98
C7 (1.30 dB)	$5x10^{-2}$ random error	0.45	1.61

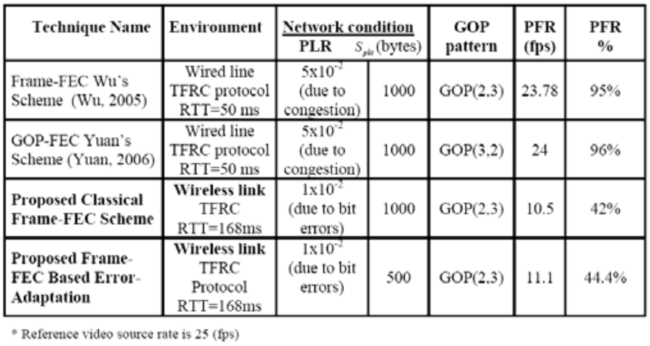
* PFR=Play-out Frame Rate

(b) Proposed Frame-FEC Based error-adaptation, S_{pkt} = 500 bytes

Wireless Channel State	Error Type (Packet-loss rate)	Mitigating Predicted Bit Error Rate	Improving Channel State	PFR (fps) **FEC(0,0,0)**	PFR (fps) **FEC(1,1,0)**
C1 (8.40 dB)	$1x10^{-4}$ random-error	$8.5x10^{-4}$	7.0 dB	21.03	20.89
C2 (7.35 dB)	$5x10^{-4}$ random error	$8.5x10^{-4}$	7.0 dB	21.03	20.89
C3 (6.85 dB)	$1x10^{-3}$ random error	$8.5x10^{-4}$	7.0 dB	21.03	20.89
C4 (5.20 dB)	$5x10^{-3}$ random error	$1.3x10^{-3}$	6.85 dB	16.3	16.53
C5 (4.30 dB)	$1x10^{-2}$ random error	$2.9x10^{-3}$	5.70 dB	10.3	11.1
C6 (3.20 dB)	$2x10^{-2}$ random error	$6.5x10^{-3}$	4.91 dB	5.63	7.0
C7 (1.30 dB)	$5x10^{-2}$ random error	$2.0x10^{-2}$	3.20 dB	1.44	2.85

* PFR=Play-out Frame Rate

Table 3: Video performance comparison among schemes under small FEC(1,1,0) condition.



Technique Name	**Environment**	**Network condition** **PLR**	S_{pkt} (bytes)	**GOP pattern**	**PFR (fps)**	**PFR %**
Frame-FEC Wu's Scheme (Wu, 2005)	Wired line TFRC protocol RTT=50 ms	$5x10^{-2}$ (due to congestion)	1000	GOP(2,3)	23.78	95%
GOP-FEC Yuan's Scheme (Yuan, 2006)	Wired line TFRC protocol RTT=50 ms	$5x10^{-2}$ (due to congestion)	1000	GOP(3,2)	24	96%
Proposed Classical Frame-FEC Scheme	**Wireless link** TFRC RTT=168ms	$1x10^{-2}$ (due to bit errors)	1000	GOP(2,3)	10.5	42%
Proposed Frame-FEC Based Error-Adaptation	**Wireless link** TFRC Protocol RTT=168ms	$1x10^{-2}$ (due to bit errors)	500	GOP(2,3)	11.1	44.4%

* Reference video source rate is 25 (fps)