ERROR RESILIENT VIDEO COMMUNICATIONS IN WIRELESS ATM

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ABSTRACT

A combined source coding, channel coding, and packetization scheme is proposed for high performance video communications over wireless ATM. Three-dimensional significance-linked connected component analysis (3D-SLCCA) source codec significantly reduces error propagations while maintaining high coding efficiency. Channel coding is implemented by using Reed-Solomon codes for both within-cell and interlaced (cross-cell) forward error correction (FEC). While equal error protection (EEP) is applied for within-cell FEC, unequal error protection (UEP) is utilized for interlaced FEC. Finally, ATM cell interleaving is applied in order to spread the effects of burst errors. Correlated Rayleigh fading channel model with $E_s/N_0 = 14$ dB at 14 km/h speed are used in the computer experiments. For the "Foreman" sequence, interlaced UEP provides 2.69 dB peak signal-to-noise ratio (PSNR) improvement over interlaced EEP with significantly reduced PSNR variance thus providing a more consistent visual quality. Applying within-cell FEC with interlaced UEP further increases the objective quality measured by PSNR by 1.18 dB.

1. INTRODUCTION

Third and fourth generation wireless systems will provide data rates in the range of several mega bits-per-second (bps) enabling multimedia communications including text, speech, audio, video, graphics, etc. Video, perhaps, represents the most challenging multimedia application due to large volumes of data to be transmitted in a timely manner.

The widely deployed asynchronous transfer mode (ATM) protocol is especially well suited for multimedia communications due to quality of service guarantees and its short packet size resulting in low delay. Thus ATM is a key candidate for the protocol of future generation wireless systems. Since ATM is designed for wireline communications, the mismatch between the ATM protocol and wireless medium poses significant challenges, and thus wireless ATM has been attracting considerable research interest in recent years.

In the paper, an *integrated* video communication system is proposed. As such, the source codec, channel codec, and packetizer are jointly implemented. This provides full control over transmission error recovery, which not only results in high video quality, but also reduces system complexity. For source coding, we use our three-dimensional significance-linked connected component analysis (3D-SLCCA) [1, 2] video codec. In addition to high coding efficiency, 3D-SLCCA provides error resilience, scalability, and low computational complexity, which are highly desirable in the wireless scenario. Channel coding and packetization are implemented by using *unequal interlaced* forward error correction (FEC). The significance of the source bitstream, which is provided by 3D-SLCCA, is used during channel coding and packetization to distribute parity bits among ATM cells according to their importance.

The rest of the paper is organized as follows. The 3D-SLCCA source coding scheme is described in Section 2. Section 3 details the proposed packetization and channel coding techniques. Performance evaluation is given in Section 4 and the last section concludes the paper.

2. SOURCE CODING

In this research, we propose to use three-dimensional significance-linked connected component analysis (3D-SLCCA) [1, 2] for video coding. 3D-SLCCA is based on our previously developed high performance wavelet

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image codec termed significance-linked connected component analysis (SLCCA) [3, 4].

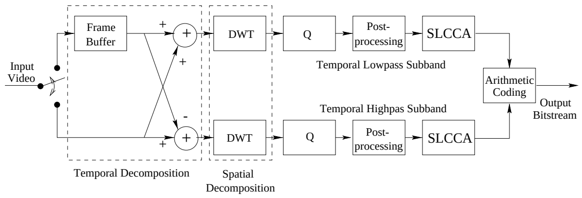

Figure 1: Encoder of the proposed 3D-SLCCA video codec.

The block diagram of 3D-SLCCA is shown in Fig. 1. As seen, two frames constitute a coding unit. The temporal lowpass and temporal highpass subbands are obtained as the sum and difference of two consecutive input frames, respectively. After dyadic spatial wavelet decomposition of each temporal subband, significant wavelet coefficients are organized and represented by using the SLCCA technique. As is evidenced by our experiments, applying dyadic wavelet decomposition on both temporal subbands not only slightly improves the performance, but also decreases the computational complexity. More importantly, the SLCCA data organization and representation strategy can be directly applied without any modification. Finally, both the significance map and magnitude of significant wavelet coefficients (in bit-plane order) are encoded by using adaptive arithmetic codec with space/scale-variant high order Markov source modeling. 3D-SLCCA is well suited for wireless communications providing high coding efficiency, robustness against transmission error propagation, scalability, and low computational complexity.

3. CHANNEL CODING AND PACKETIZATION

In the past decade, there have been intensive research in video transmission over ATM networks mainly focusing on the wireline case. In most of the developed schemes [5, 6, 7, 8], there is limited interaction among the source codec, channel codec, and packetizer, i.e., they usually apply equal error protection (EEP) making little use of the semantics of the video bitstream. Recently, unequal error protection (UEP) is proposed to increase the quality of the decoded video [9, 10].

In the proposed system, there is strong interaction among the source codec, channel codec, and packetizer. Instead of using a predefined ATM adaptation layer (AAL), in addition to source coding, the application is responsible for channel coding and packetization as well. Then, cells are directly passed to the ATM layer, which is responsible for transmission. Full control over transmission error recovery not only improves the visual quality of the decoded video, but also reduces the complexity of the video communication system.

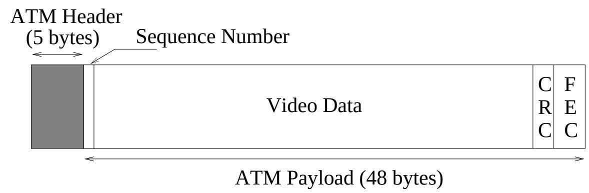

Figure 2: ATM cell structure.

Since designed for highly reliable wireline networks, ATM protocol does not provide means to ensure the integrity of the transmitted data. In order to enable error control over unreliable wireless links, *overhead* information is added to the payload of each ATM cell as shown in Fig. 2. This overhead information includes sequence number (SN), cyclic redundancy code (CRC), and an optional within-cell forward error correction (FEC) code. One byte SN is used to detect lost cells due to corrupted ATM header. Two byte CRC is used to detect transmission errors in the payload of each ATM cell. Finally, FEC may be added to each ATM cell, for which Reed-Solomon (RS) codes over GF(255) are employed. As shown in Fig. 3, for a correlated Rayleigh fading model, at low signal-power-to-noise-power ratio (E_s/N_0), the probability of few symbol errors within an ATM cell is quite high. Thus applying within-cell FEC is highly beneficial. The cell loss probability can be reduced by about 8% by applying (45,48) shortened RS code for each ATM cell. This within-cell FEC overhead results in about 2.25% bit rate increase per parity symbol. At higher E_s/N_0, however, this bit rate increase cannot be justified.

The payload of each ATM cell that can be used for transmission of video is reduced to 42–45 bytes, depending on the applied within-cell FEC. In order to facilitate synchronization after transmission errors between the encoder and decoder, each ATM cell contains information pertaining to only one bit-plane.

The packetized bitstream is then divided into interleaved blocks as shown in Fig. 4. Each block is protected by using an interlaced (cross-cell) FEC code. Again, we use RS codes over GF(255). By using both SN and CRC in each ATM cell, all the lost cells (corrupted ATM header or uncorrectable error in the payload) appear as erasure errors (known location) in the interlaced direction. As shown in Fig. 4, each block is protected by a *different* interlaced RS code. The code is determined by the importance of ATM cells. Since the source bitstream is ordered in decreasing importance by 3D-SLCCA, ATM cells in the beginning of

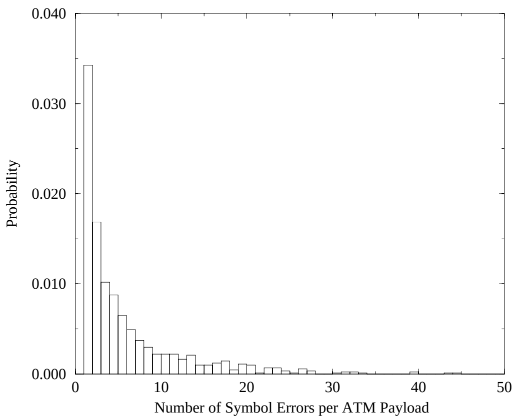

Figure 3: Payload error probability of received ATM cells at $E_s/N_0 = 14$ dB. The probability of error-free payload is 0.89.

the bitstream are always more important than ATM cells at the end of the bitstream. The total number of parity cells among the blocks are distributed according to the source significance information provided by the 3D-SLCCA codec. As we will show in Section 4, this interlaced UEP results in significance performance gain over EEP.

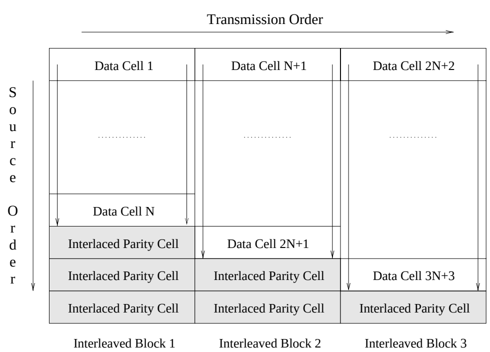

Figure 4: Source packetization with block interleaving and interlaced error protection.

As usual, in order to spread the effects of burst errors most common in the wireless scenario, cell interleaving is applied. ATM cells are organized in a 2-D matrix as shown in Fig. 4. The source bitstream produced by 3D-SLCCA is packetized into ATM cells in column major order. After interlaced unequal FEC, ATM cells are directly sent to the ATM layer (bypassing the AAL) in row major order. The ATM layer is responsible for adding the usual five-byte header to each cell.

The major enhancements of the proposed scheme over [6, 8] include (1) SN and CRC to detect lost ATM

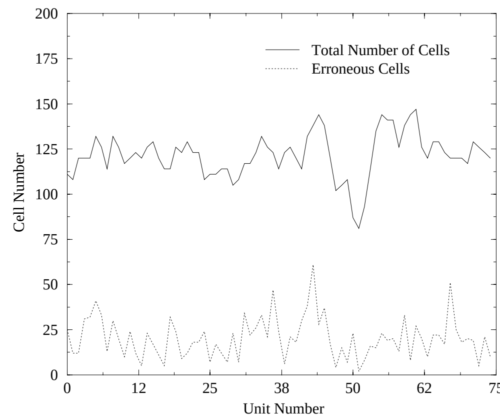

Figure 5: Transmitted and erroneously received ATM cells per coding unit.

cells, so as to double the error correction capability of the interlaced RS code, (2) within-cell FEC to reduce the cell loss ratio, and (3) unequal interlaced FEC by using the source significance information provided by 3D-SLCCA.

4. PERFORMANCE EVALUATION

As opposed to most papers published in the literature [5, 6, 8], where the end-to-end transmission system is modeled by a two-state Markov chain with given cell loss probabilities, we directly apply bit error profiles to the transmitted bitstream. Transmission errors are generated by correlated Rayleigh fading model at Doppler speed of 14 km/h with $E_s/N_0 = 14$ dB. Performance evaluation is carried out on the high motion "Foreman" sequence in QCIF (176×144 pixels) resolution sampled at 15 frames-per-second (fps) and coded at 384 kbps. No rate control algorithm is used. The quantizer step size in 3D-SLCCA is adjusted to match the target bit rate.

The total number of ATM cells (source cells and in-

Error Protection	None	EEP	UEP	UEP+ FEC
Source Rate [kbps]	303.6	255.8	255.8	237.4
Total Rate [kbps]	386.9	387.3	387.3	385.9
Noiseless PSNR	36.09	34.89	34.89	34.39
Noisy PSNR	20.63	27.24	29.93	31.11
Noisy PSNR Var	5.51	7.95	4.47	3.91

Table 1: Performance evaluation (PSNR, [dB]) of different error protection strategies for the "Foreman" sequence.

terlaced error protection cells) and the number of lost cells in each coding unit (two frames per coding unit) are shown in Fig. 5. The average cell loss rate of the wireless connection is about 17%. Average peak signal-to-noise ratio (PSNR) values are given in Table 1. As seen, the proposed source packetization without error protection results in about 20% overhead. This is due to the five-byte ATM header, sequence number, and CRC. Transmitting the unprotected bitstream over error-prone wireless channels results in significant performance degradation. UEP results in 2.69 dB PSNR increase over EEP with the same channel coding budget. Finally, within-cell FEC further provides 1.18 dB PSNR gain. As seen, the proposed channel protection and packetization strategy not only significantly increases the PSNR by 3.87 dB on average in comparison to EEP, but also significantly reduces the PSNR variance providing a more consistent visual quality. The frame-by-frame PSNR comparison for the noiseless codec, EEP, and the proposed interlaced UEP with within-cell FEC are given in Fig. 6.

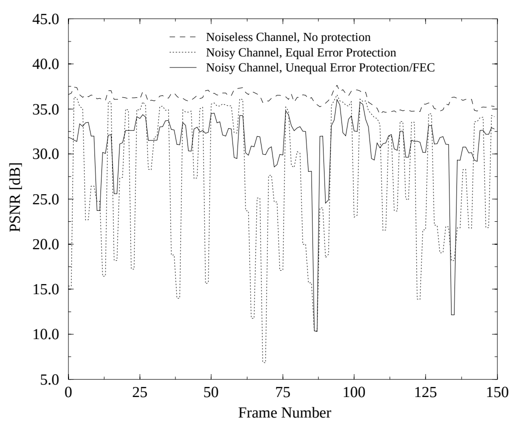

Figure 6: Performance comparison of different error protection strategies for the "Foreman" sequence.

5. CONCLUSIONS

In the paper, a combined source coding, channel coding, and packetization scheme is proposed. The applied 3D-SLCCA source codec provides several desirable features such as high coding performance, error resilience, scalability, and low computational complexity well suited for the wireless scenario. Packetization is carried out with channel coding by using the source significance information provided by 3D-SLCCA. Unequal interlaced FEC ensures that more important parts of the bitstream are transmitted more reliably. Computer experiments by using actual channel error profiles not only show 3.87 dB average PSNR increase for the "Foreman" sequence in comparison to EEP, but also results in more consistent visual quality by significantly reducing the PSNR variance.

Future research directions include the development of more error resilient packetization schemes and the application of error concealment techniques as well.

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