Efficient Mobile Video Access in Wireless Environments

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Abstract— **A novel middleware-based system providing effective and efficient video access for mobile users communicating over low bandwidth error-prone wireless links is proposed. The middleware, implemented as mobile proxy server located at the mobile support station, is chosen for the seamless integration of mobile users and video servers by hiding the specific details of the underlying system. For efficient video transmission, our three-dimensional significant-linked connected component analysis video codec well suited for wireless environments, is used. To cope with wireless transmission errors, we propose multilayer error control mechanism, which incorporates synchronization, unequal forward error protection, and retransmission. As a result, mobile users experience better picture quality, less jerky video, and shorter delays when accessing video files.**

I. Introduction

Recent technological developments have led to several mobile systems aimed at personal communications services, which support not only speech but also data transmission. One of the most promising applications is video communications, whose importance is also evidenced by extensive research in both academia and industry resulted in large number of standards (H.261, H,263, H.236+, MPEG-1, MPEG-2, MPEG-4, etc.) being adopted. But, most of the these standards are mainly designed for wired visual communications and would not be effective if straightforwardly applied to the wireless case [1].

In the paper, a middleware-based system is developed that allows the user of a mobile computer to control the way the data from the video server is retrieved and dynamically transformed, being totally transparent to both the mobile user and video server. The mobile proxy server (MPS) [2], located at the boundary of the wired and wireless network is used to transform the video into the format most suitable to the mobile client. All details of the underlying source and channel coding algorithms are hidden to both the mobile client and video server. For source coding, we use our high performance low computational complexity wavelet video coding algorithm termed three-dimensional significance-linked connected component analysis (3D-SLCCA) [3], [4]. 3D-SLCCA is well applicable for wireless communications due to its high robustness against channel error propagation. Finally, multilayer error control coding mechanism is implemented to cope with wireless transmission errors, which represents the extension of our robust still image coding scheme [5] to error resilient video compression. The proposed technique includes synchronization, unequal forward error correction (FEC), and retransmission.

The rest of the paper is organized as follows. Related work in mobile information access is presented in Section II. While the mobile proxy server is presented in Section III, the source and channel coding schemes are described in Sections IV and V, respectively. Performance evaluation is given in Section VI and the last section concludes the paper.

II. Related Work

A considerable amount of work has been done in the area of information access from mobile platforms. The client-proxy-server model has featured in many mobile applications to overcome the challenges faced in the mobile computing scenario.

In GloMop [6], the proxy performs distillation of the document received from the server before sending it to the client. For instance, it performs transcoding of motion JPEG to sub-sampled intra H.261 (motion estimation and motion compensation are replaced by conditional replenishment) for video data. A more formal model for proxy functionality along with an overview of their system is described in [7]. More recently, this group has used a similar approach to create a split browser [8] for the PalmPilot PDA.

The Mowgli model [9] consists of two mediators, the Mowgli Agent and the Mowgli Proxy located on the mobile host and the mobile-connection host, respectively. They use the Mowgli HTTP protocol to communicate with each other. A specialized transport service, the Mowgli Data Channel Service is used for reliable communication between the mobile-connection host and the mobile host. Mowgli WWW reduces the data transfer over the wireless link in three ways: data compression, caching, and intelligent filtering. For example, it performs GIF to JPEG conversion, and large embedded images are not transferred at all to the mobile host.

In Odyssey system [10], the proxy is developed in the

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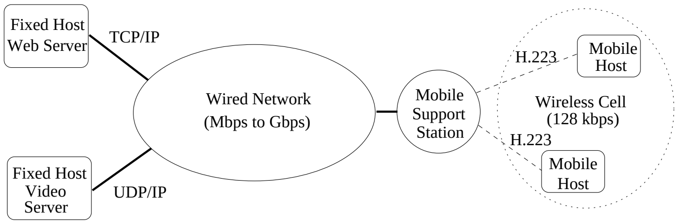

Fig. 1. System architecture.

context of what the authors term *agile application aware adaptation*. Odyssey is characterized by a set of extensions of the NetBSD system. Basically, the system allows an application to register with the operating system about its expectations of a resource and the variability it may tolerate. The Odyssey system monitors resources and informs the application when a resource value strays outside the previously decided bounds. The application can then adapt its behavior. However, this approach is specific to the Odyssey file system and requires a modified version of the NetBSD kernel.

Mowser [11] is a proxy-based system to support web browsing from mobile clients over wireless networks. It performs active transcoding of data on both upstream and downstream traffic to present web information to the mobile user according to the parameters set by the user. Images are transcoded to GIF format due to the low computational complexity of the decoder. Mowser also uses content negotiation mechanisms of HTTP/1.1 to request multimedia content at various fidelities from the web server. This not only minimizes network traffic on the wired side, but also reduces the computational burden of the proxy.

IBM's WebExpress [12], Intel's QuickWeb [13], and Spectrum Information's Fastlane [14] are examples of commercial systems to provide improved WWW access over slow network connections by using compression and transcoding technologies.

III. Mobile Proxy Server

We use the popular mobile networking model [15], which consists of fixed hosts and mobile hosts (MHs). Fixed hosts communicate with each other on a high bandwidth reliable wired network. MHs are supported by some designated fixed hosts termed as mobile support stations (MSSs), which act as gateways between the wired and wireless networks. Mobile hosts have very limited resources, they usually communicate over wireless links characterized by lower bandwidths, higher bit error rates (BER), and more frequent disconnections in comparison to wired networks. Moreover, in a mobile environment, changes in network bandwidth occur quite common [16].

The developed system extends the basic MSS-MH model by adding a proxy server as a middleware to each MSS as shown in Fig. 1. The *mobile proxy server* (MPS) is responsible for providing effective and efficient video communications between the video server and the MH. The functionalities of the MPS include:

- protocol switch for video data;
- video transcoding;
- video streaming whenever necessary;
- error control coding;
- caching and retransmission;
- maintaining the capabilities of the MHs.

In the proposed system, no assumption is made as to how the video is provided by the video server, i.e., it is downloaded by the MPS by using the protocol supported by the video server (Fig. 1). However, between the MSS and MH, at the data link layer, we exclusively use the H.223 Recommendation [17] for transferring video data, which provides quality of service (QoS) parameters and minimal overhead for short packets, thus being highly applicable for low bit rate video communications.

The MPS downloads the usually MPEG encoded video stream from the video server, reconstructs the video sequence, and reformats it appropriately according to the allowable spatial resolution, frame rate, and quality based on both the bandwidth and display hardware of the MH. The reformatted video sequence will be encoded exclusively by using our (3D-SLCCA) video coding technique. The reconstructing, reformatting, and encoding by 3D-SLCCA compose the so-called *transcoding*. 3D-SLCCA is advantageous over MPEG due to its high error resilience, which is absolutely necessary for transmission over error-prone wireless channels.

By using video streaming, downloading, decoding, and displaying occur simultaneously at the MH, which considerably reduces both the storage requirement for the MH and the waiting time. When the video server cannot support streaming, the MPS downloads the entire video file from the video server and streams it to the MH. As usual, work-ahead at the MH is used to hide the delay effect caused either by retransmission due to burst errors, lost packets, or by connection reestablishment.

In the proposed wireless video communications system, H.223 is used at the data link layer, which provides checksum mechanism, but corrupted packets are still delivered to the application with error indication. In the developed system, both bit errors and burst errors are efficiently handled by using our multilayer error control coding mechanism. This means that the MPS embeds parity bits into the bitstream during transcoding.

The MPS is also responsible for caching and retransmission. Most packet losses occur at the "edges" of the network (typically at the MPS, where high bandwidth wired network meets low bandwidth wireless network) instead of at the high bandwidth backbone [18]. Therefore, locating caches at MPS not only protects other parts of the network from frequent retransmission, but also consider-

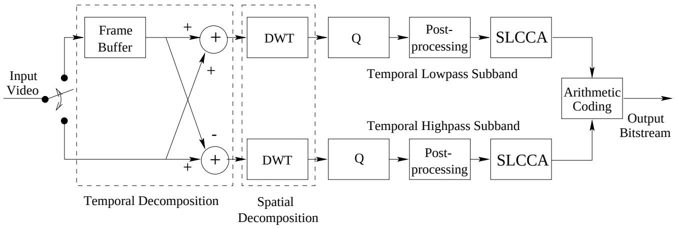

Fig. 2. Block diagram of 3D-SLCCA encoder.

ably reduces latency. This is due to the fact that the lost data is to be retransmitted only from the MPS, which is located in the vicinity of the MH, and not from the video server.

Finally, the MPS maintains information about each client. The preferences can be updated by the user of the MH whenever there is a change in the network connection or available resources. Preferences include resolution, frame rate, color depth, etc.

IV. Source Coding

In the proposed system, our three-dimensional significance-linked connected component analysis (3D-SLCCA) [3], [4] wavelet video coding technique, is used for video coding. 3D-SLCCA represents the extension of our previously developed high performance wavelet image codec significance-linked connected component analysis (SLCCA) [19], [20], [21], [22], [23], [24].

The block diagram of 3D-SLCCA is shown in Fig. 2. In 3D-SLCCA, the Haar wavelet is used for temporal filtering, i.e., in the time domain, the temporal lowpass and temporal highpass subbands are obtained as the sum and difference of two consecutive frames, respectively. After dyadic spatial decomposition of each temporal subbands, wavelet coefficients are quantized with a uniform scalar quantizer and clusters of significance coefficients are eliminated by area thresholding to increase the coding efficiency. Then, the SLCCA technique is applied on each temporal subband separately to organize and represent significant wavelet coefficients as 2-D clusters. The significance map, which specifies the status of wavelet coefficients (significant or insignificant) is encoded by using four symbols. POS and NEG symbols are used to encode the sign of significant wavelet coefficients. ZERO symbol is used to encode insignificant coefficients and a special SL symbol is used to denote the significance-link. The magnitude of significant wavelet coefficients are encoded in bit-plane order. Both the significance map and magnitude of significant coefficients are encoded by using adaptive arithmetic coder with *space-scale* variant high-order Markov source modeling.

The advantages of 3D-SLCCA include (1) scalability supporting MHs with different hardware resources, (2) low computational complexity, which is necessary to support low power consumption of the MH and to reduce the computational load of the MSS, and (3) error resilience, due to the elimination of both the spatial prediction and recursive coder architecture.

TABLE I
Applied shortened RS codes.

Bit-Plane	Codec 0	Codec I	Codec II
6	(120,120)	(104,120)	(80,120)
5	(120,120)	(104,120)	(80,120)
4	(120,120)	(110,120)	(84,120)
3	(120,120)	(110,120)	(84,120)
2	(120,120)	(110,120)	(84,120)
1	(120,120)	(114,120)	(88,120)
0	(120,120)	(114,120)	(88,120)

V. Channel Coding

Error control coding is only applied between the MSS and MH, where the video is transmitted by using the H.223 data link layer protocol, which delivers erroneous packets to the application. Since our goal is to transmit video over low bandwidth erroneous channels, the tradeoff between the bandwidth increase due to adding parity bits to the 3D-SLCCA source bitstream and error correction capability must be made. This is achieved by using our three-layer error control coding mechanism:

- algorithmic protection with synchronization;
- unequal forward error correction;
- retransmission.

Synchronization is necessary due to adaptive arithmetic coding applied in 3D-SLCCA. Synchronization is implemented by both transmitting the size of the source file of each bit-plane in the beginning of the bitstream with the highest degree of error protection and inserting synchronization characters into the transmitted bitstream. Since the model of adaptive arithmetic coding is initialized for every bit-plane, decoding can continue from the next bit-plane in the case of uncorrectable error occurring in the current bit-plane [5].

Shortened Reed-Solomon (RS) codes over GF(256) are used for unequal forward error correction. In the proposed system, the total number of parity bits is allocated among bit-planes based on the importance, which is proportional to the contained energy. The significance map and most significance bit-planes, which carry the majority of the information, are allocated more parity bits than less significant bit-planes.

In the proposed system, Codec I and Codec II are designed for average BER = 0.001 and BER = 0.01, respectively. Codec 0 (no channel coding is applied) is used to evaluate the error resilience of the 3D-SLCCA source coding algorithm. The applied channel codes are tabulated in Table I. The resulting bit rates for the "Akiyo" and

TABLE II

Bit allocation for the “Akiyo” sequence.

Codec	Rate [kbps]			Noiseless PSNR [dB]
	Source	Parity	Total	
Codec 0	10.01		10.01	28.40
Codec I	7.93	2.08	10.01	27.84
Codec II	6.64	3.40	10.04	27.17

TABLE III

Bit allocation for the “Foreman” sequence.

Codec	Rate [kbps]			Noiseless PSNR [dB]
	Source	Parity	Total	
Codec 0	48.05		48.05	28.77
Codec I	41.89	6.21	48.10	28.06
Codec II	33.13	15.02	48.15	27.40

“Foreman” test video sequences are shown in Tables II and III, respectively.

As seen from Tables II and III, for the noiseless case, Codec II results in only 1.23 dB and 1.37 dB loss in peak signal-to-noise ratio (PSNR) for the “Akiyo” and “Foreman” sequences, respectively, when about 30% of the total bit budget is used for error protection.

The last layer of the developed error control coding mechanism is retransmission. Generally, the main problem with retransmission is the introduced time delay. However, in the proposed system, the time delay is substantially reduced by locating the MPS (which caches the video) in the vicinity of the MH. Due to small time delay and decoder work-ahead, retransmission can be successfully applied in the developed system in the case of severe transmission errors occurring at important part of the bitstream. Since least significant bit-planes only marginally contribute to the visual quality, retransmission is only applied when uncorrectable packet errors occur at the few most significant bit-planes.

VI. Performance Evaluation

The H.223 simulator [25] was extended to incorporate sequence numbering and back channel for retransmission request as specified in the H.223 Recommendation. The wireless link is modeled by Rayleigh fading errors at Doppler speed of 1.4 km/h and 14 km/h. For each speed, the signal-power-to-noise-power ratio $E_s/N_0 = 14$ dB and $E_s/N_0 = 24$ dB are used resulting in average BER = 0.01 and BER = 0.001, respectively (Table IV). Channel C0 is represents the noiseless channel and used as a benchmark in the performance evaluation.

As mentioned before, two test video sequences are used in the performance evaluation. “Akiyo” is sampled at 5 frames-per-second (fps) and coded at 10k bits-per-second (bps). “Foreman” is sampled at 7.5 fps and coded at 48 kbps.

TABLE IV

Four different channel error profiles used in the computer experiments.

Symbol	Speed [km/h]	E_s/N_0 [dB]	Average BER
C1	1.4	24	8.99×10^{-4}
C2	1.4	14	9.33×10^{-3}
C3	14	24	1.09×10^{-3}
C4	14	14	9.79×10^{-3}

TABLE V

Performance evaluation (PSNR [dB]) of the three codecs for the “Akiyo” test sequence among five different channel conditions.

Channel	Codec 0	Codec I	Codec II
C0	28.40	27.84	27.17
C1	28.17	27.61	27.03
C2	27.24	27.04	26.69
C3	27.72	27.42	27.02
C4	25.01	25.56	25.95

The coding results among the five different channel conditions are shown in Tables V and VI for the “Akiyo” and “Foreman” sequences, respectively. As seen, the importance of error protection increases with increasing scene motion, decreasing E_s/N_0, and increasing Doppler speed. For the “Akiyo” test sequence, all the three codecs have approximately similar performance. For the “Foreman” test sequence, Codecs I and II show similar performance and both outperform Codec 0, especially for lower E_s/N_0. The relatively good performance of Codec 0 demonstrates the excellent error resilience of the proposed 3D-SLCCA source coding algorithm.

The number of lost packets (uncorrectable error) for the “Foreman” sequence for the C1 channel is shown in Fig. 3. Although the majority of the packet errors occur at the least significant bit-planes, some packet errors still occur at more significant bit-planes due to deep fades, that cannot be fully corrected by the proposed error control mechanism.

VII. Conclusions

In the paper, an effective and efficient system is proposed for supporting mobile access to video information in wireless environments. The mobile proxy server located at the mobile support station is responsible for obtaining the video from the server and presenting it to the most suitable form to the mobile host. Our source and channel coding algorithms are jointly applied to ensure high quality video over error-prone wireless connections. Com-

TABLE VI

Performance evaluation (PSNR [dB]) of the three codecs for the "Foreman" test sequence among five different channel conditions.

Channel	Codec 0	Codec I	Codec II
C0	28.77	28.06	27.40
C1	27.32	27.43	26.85
C2	22.78	25.24	24.94
C3	26.15	26.84	26.75
C4	18.33	22.15	23.18

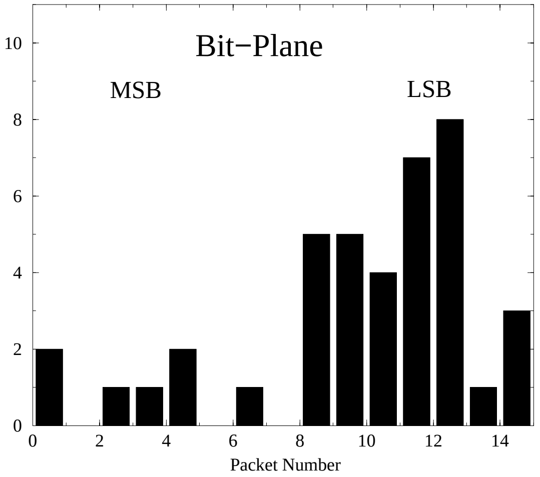

Fig. 3. Uncorrectable packet error histogram for the "Foreman" sequence with channel C1.

puter experiments demonstrate that the proposed system is capable of providing high quality video to mobile users communicating over low bandwidth error-prone wireless links. Further research directions include more realistic wireless channel modeling and more efficient joint source-channel coding.

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