Power Efficient H.263 Video Transmission Over Wireless Channels

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Abstract— **In this paper, we introduce an approach for adaptive minimization of the total power consumption in wireless video communications subject to a given level of quality of service. Our approach exploits tradeoffs between the power consumption of the H.263 codec, the Reed-Solomon channel encoder and the transmitter. We utilize the rate-distortion models and power consumption models we developed for the H.263 video codec. Simulation results show that source channel coding parameters and transmit energy per bit should vary based on channel conditions. Optimized parameters and settings can reduce the total power consumption by at least a factor of 2 compared to a fixed parameter setting that does not match with the channel conditions.**

I. Introduction

Efficient use of power in portable multimedia communication devices is becoming more and more critical and complex, particularly when video signal processing is integrated. Traditionally, research and development for efficient use of power have focused on separate components, such as algorithm and circuit design to minimize power consumption of the video coder and the channel coder, the design of power-efficient transmit amplifiers and antennas. Recently, researchers started to explore the problem of power allocation among source coder, channel coder and transmitter [1], [2], [3], assuming each component has been designed to operate in a power efficient way. In [1], the authors found that, by judiciously selecting operating modes of the H.263 video coder in response to mobile environment, low power consumption can be achieved while maintaining a good video quality level. In [2], the authors attempted to minimize the total energy of a wireless image transmission system by dynamically reconfiguring the architecture. Significant improvement in performance was reported. Our previous work [3] recognizes that the optimum operating points of source coding and transmit energy depend on the mobile unit's location. When the mobile unit is far away from the base station, a high compression efficiency, thus a low transmission rate is preferred. This work considered transform coding on first order Markov sources and modeled the channel error by the additive white Gaussian noise. Channel coding was not taken into account.

In the present work we consider a practical wireless video commnunication system that uses the standard H.263 video codec [4] and the Reed-Solomon channel codec. The channel is characterized by the widely used two-state Markov model [5]. Our goal is to, for a given channel environment, find the optimal operating points in source coding, channel coding as well as transmission, to minimize the total power consumption while keeping a constant end-to-end distortion.

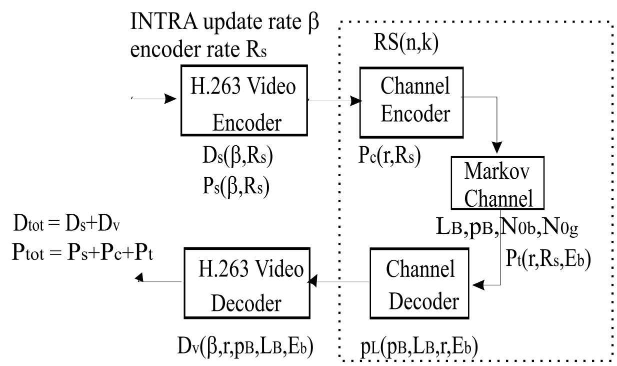

Fig. 1. The wireless communication system considered in this paper.

The main contributions of this work can be summarized as follows:

1. We developed a simple model for the power consumption of the H.263 source encoder. The model was validated by measurement data. The same methodology also apply to other video compression standards employing the block based hybrid coding framework.

2. We studied the optimal power allocation problem in a wireless communication system among the video coder, the channel coder and the transceiver.

The paper is organized as follows: Section 2 describes the models we employed for various components in a wireless communication system. Power consumption measurements and models are introduced in Section 3. Section 4 presents our formulation of the optimization problem for power allocation among system components and simulation results. Section 5 concludes this paper and proposes future work.

II. Performance Models for System Components

In this section we describe the models used to characterize various components in the wireless communication system considered in this paper. As illustrated in Fig.1, the system consists of the H.263 codec, the RS channel codec and the two-state Markov channel. At the transmitter the coded bit stream of the H.263 encoder first goes through the channel coder, and is then transmitted through a two-state Markov channel using binary differential phase shift keying (DPSK).

The distortion and power consumption of the H.263 encoder are described by $D_s(\beta, R_s)$, $P_s(\beta, R_s)$, which depend on the *INTRA rate* β and the encoding rate R_s. The channel is described by p_B (the probability that a symbol is at bad state B), L_B (average burst length), N_{0b} and N_{0g} (noise powers at different states). The power consumed by the $RS(n,k)$ channel coder is given by $P_c(r, R_s)$, where $r = \frac{k}{n}$ is the *channel code rate*. The transmission power is $P_t(r, R_s, E_b)$, which depends on r, R_s and E_b, the radiated energy per transmitted bit. The distortion at the video decoder caused by transmission errors is described by $D_v(\beta, p_L)$, where p_L is the *residual word error rate* after channel decoding. The overall distortion and power consumption are denoted by D_{tot} and P_{tot} respectively. We defer the discussion of power consumption models to the next section and start with a description of distortion performance.

A. Rate-Distortion Performance of the Source Encoder

Stuhlmüller et al. [6] derived an RD model for an H.263 compliant coder [7] based on simulation data. No H.263 options are used, except that each GOB is encoded with a header to facilitate the decoder to regain syncronization after a transmission error. Each frame is encoded with a fixed quantization step size. Its INTRA update scheme forces a macroblock to be coded in the INTRA-mode after every $T-1$ macroblocks.

The distortion model derived in [6] is:

$$D_s(\beta, R_s) = \frac{\theta(\beta)}{R_s - R_0(\beta)} + D_0(\beta), \qquad (1)$$

where $\beta = \frac{1}{T}$ is the *INTRA rate*, R_s is the encoding bit rate in kbits/second and D_s is the distortion in terms of the mean square error (MSE) per source sample. The functions $\theta(\beta), R_0(\beta), D_0(\beta)$ depend on the INTRA rate β and six sequence-dependent parameters $\theta_P, \Delta\theta_{IP}, R_{0P}, \Delta R_{0IP}, D_{0P}$, and ΔD_{0IP}, i.e.,

$$\begin{aligned} \theta(\beta) &= \theta_P + \Delta\theta_{IP}\beta, \\ R_0(\beta) &= R_{0P} + \Delta R_{0IP}\beta, \\ D_0(\beta) &= D_{0P} + \Delta D_{0IP}\beta. \end{aligned} \qquad (2)$$

B. Two-state Markov Channel Model

In order to describe the wireless channel, we use the well-known two-state Markov model. The two states are denoted as good (G) and bad (B) states. The probability of bit error in State G is denoted by p_{eg} and in State B by p_{eb}. For binary DPSK, the probability of bit errors is given by $p_e = \frac{1}{2}e^{-\frac{E_b}{N_0}}$ [8], where N_0 is the noise spectral density. Assuming the noise power spectral densities at State G and State B are N_{0g} and N_{0b} respectively, we get different *bit error rates* for both states: $p_{eg} = \frac{1}{2}e^{-\frac{E_b}{N_{0g}}}, p_{eb} = \frac{1}{2}e^{-\frac{E_b}{N_{0b}}}$.

We will use an Reed-Solomon channel code of symbol size m bits. For simplicity we assume all bits of one symbol are at the same state. Then the symbol error rates are given by:

$$p_{eg,s} = 1 - (1-p_{eg})^m, p_{eb,s} = 1 - (1-p_{eb})^m.$$

The transition probability on the symbol level from State B to G is p_{BG}, from State G to B is p_{GB}. The probability that one symbol is at State B is $p_B = \frac{p_{GB}}{p_{GB}+p_{BG}}$ and the *average burst length* $L_B = \frac{1}{p_{BG}}$.

C. The Channel Encoder

Reed-Solomon codes are used to lower the effective symbol error. For symbols composed of m bits each, the RS(n,k) channel coder coverts every k information symbols into an n-symbol block by appending $(n-k)$ parity symbols. Any error pattern with less than $t_c = \lfloor \frac{n-k}{2} \rfloor$ symbol errors can be corrected.

The influence of transmission errors using the RS code is described by the *residual word error rate* p_L, which is the probability that a block cannot be corrected after the channel decoder. It can be calculated as:

$$p_L(r, p_B, L_B, E_b) = \sum_{k=t_c+1}^{n} p_d(n,k), \qquad (3)$$

where the *block error density* $p_d(n,k)$ denotes the probability of k symbol errors within a block of n symbols. Derivation of p_L can be found in [9].

D. Distortion at the Video Decoder

While motion compensation yields significant gains in coding efficiency, any residual transmission error will cause interframe error propagation. Stuhlmüller et al. [6] proposed a model for distortion introduced by transmission errors, including the effects of INTRA coding and spatial loop filtering:

$$D_v(\beta, r, p_B, L_B, E_b) = \sigma_{u0}^2 p_L(r, p_B, L_B, E_b) \sum_{t=0}^{T-1} \frac{1-\beta t}{1+\gamma t}, \qquad (4)$$

where *leakage* γ describes the efficiency of loop filtering to remove the introduced error, and σ_{u0}^2 describes the sensitivity of the video decoder to an increase in error rate.

The overall distortion D_{tot} at the video decoder is then $D_{tot} = D_s + D_v$.

III. Power Consumption Models and Measurements

A. Power Consumption Estimation

We estimated processing power consumed by a software program by assuming the currents used by different instructions are the same. We measured the total consumed energy by an oscilloscope and counted the number of used instructions by a profiling analysis program IPROF [10]

TABLE I

PARAMETERS FOR THE SOURCE ENCODER POWER CONSUMPTION

A_s(Watts)	B_s(Watts)	C_s(Joules/Kbits)
78.20	29.56	0.014

for the same program, thus getting the current consumption by each instruction.

From the measurement we determined that each million instructions (MI) consumed $I_{prof} = 0.3577mA$ at a constant voltage of $V_c = 12.3V$ on a laptop (IBM Thinkpad with a 360 MHz Pentium II microprocessor). Then we ran the H.263 encoder and channel coder at different parameters, calculating the power consumption for them based on the values of I_{prof}, V_c and the instruction counts.

B. Power Consumption of the Source Encoder

We derived the power consumption model of the H.263 encoder based on several assumptions. For an INTRA macroblock, we model the computational expense by $C_I = C_{DCT} + C_Q$, where C_{DCT} denotes the expense for computing DCT, and C_Q for quantization and variable length coding (VLC). For a macroblock coded in INTER mode, the computational expense is modeled by $C_P = C_{DCT} + C_Q + C_{ME}$, where C_{ME} denotes the computational expense of motion estimation.

We assume C_{DCT}, C_{ME} are constants. While the computations for quantization is independent of the bit rate, with small quantization step size, we need more computation for VLC due to the increased number of nonzero coefficients. Hence we assume C_Q is proportioned to R_s. Then the average power consumption is:

$$\begin{aligned} P_s(\beta, R_s) &= C_{es} f_r N_{MB} V_c I_{prof} \frac{C_I + (T-1)C_P}{T} \\ &= C_{es}(A_s - B_s\beta + C_s R_s)(watts), \qquad (5) \end{aligned}$$

where N_{MB} is the number of macroblocks in one frame, f_r is the frame rate, C_{es} is a scaling factor which depends on the actual implementation of the coder.

Equation (5) says that the encoder power consumption is a linear function of *INTRA rate* β and the source rate R_s(kbps). That is as expected: when β increases, i.e., less motion compensation is conducted, less power is necessary; when R_s increases, more power is consumed in VLC.

Using the measured power consumption of a software-implemented H.263 coder operating at different β and R_s, we derived the constants A_s, B_s, C_s as in Table I (assuming C_{es}=1). Fig.2 shows that (5) matches well with the measurement data.

C. Power Consumption of the Channel Coder

The power consumption of an (n,k) Reed-Solomon encoder is modeled in [2]. There energy consumption of a

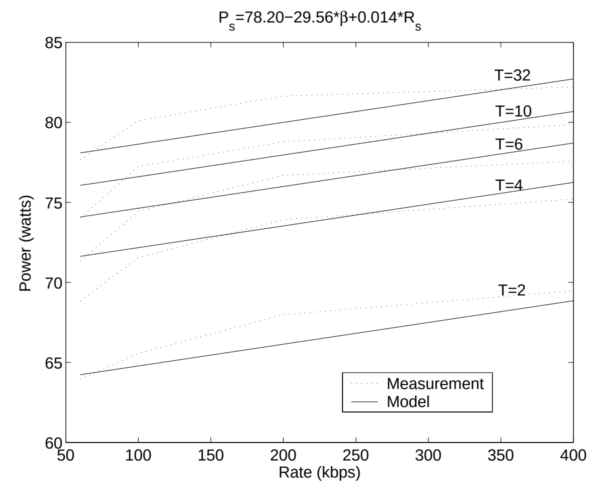

Fig. 2. Power consumption for coding "foreman.qcif", with a software implementation of the H.263 coder running on an IBM thinkpad with a 360 MHz Pentium II processor.

bit-parallel RS encoder architecture is given as

$$E_c = C_{ec} \frac{(n-2t_c)2t_c}{(n-2t_c)m} = C_{ec} \frac{2t_c}{m} (joules/bits). \qquad (6)$$

Thus, the power consumption of the RS encoder acting on a compressed stream with bit rate R_s is

$$P_c(r, R_s) = E_c R_s = C_{ec} \frac{n(1-r)R_s}{m} (watts), \qquad (7)$$

where C_{ec} is a scaling factor that depends on the actual implementation.

We measured the power consumption for a software-based RS coder on the same laptop and found that it was much less than that of the H.263 encoder. Hence we chose C_{ec} so that P_c was much smaller than P_s.

D. Power Consumption of the Transmitter

Let E_b represent the radiated energy per bit at the transmitter antenna. The total transmission power is modeled by

$$P_t(R_s, E_b) = C_{et} R_c E_b, \qquad (8)$$

where $R_c = \frac{R_s}{r}$ is the total bit rate, and C_{et} is a scaling factor that translates the radiated energy into the actual power consumption for transmission (including modulation and signal amplifiers) in a wireless device.

IV. Optimization of Power Allocation

Combining the effects of source quantization and transmission error, the total end-to-end distortion D_{tot} can be expressed as

$$\begin{aligned} &D_{tot}(\beta, R_s, r, p_B, L_B, E_b) \\ &\quad = D_s(\beta, R_s) + D_v(\beta, r, p_B, L_B, E_b) \\ &\quad = \frac{\theta(\beta)}{R_s - R_0(\beta)} + D_0(\beta) + \sigma_{u0}^2 p_L \sum_{t=0}^{T-1} \frac{1-\beta t}{1+\gamma t}. \qquad (9) \end{aligned}$$

The total power consumed by the mobile devices consists of power dissipated by the source encoder, the channel encoder and transmitter. Therefore

$$P_{tot}(\beta, R_s, r, E_b) = P_s(\beta, R_s) + P_c(r, R_s) + P_t(R_s, E_b)$$
$$= C_{es}(A_s - B_s\beta + C_sR_s) + \frac{C_{ec}nR_s}{m}(1-r) + \frac{C_{et}R_sE_b}{r}. \quad (10)$$

For a given channel environment (i.e., N_{0g}, N_{0b}, p_B and L_B are known), the power allocation problem can be defined as finding the best set of source coding (R_s, β), channel coding (r) and transmitter (E_b) parameters so that P_{tot} is minimized subject to $D_{tot} \leq D_0$.

A. Choice of Parameters

Total allowed distortion D_0 will be different for different applications. Here we set it to be $D_0 = 60$ for a video source (PSNR=30.38dB, which corresponds to good but not excellent video quality). The INTRA rate β is selected from {3, 4, 6.25, 8.33, 11.11, 20, 33.33, 50}[%]. The encoding rate R_s is chosen to satisfy the distortion constraint.

The channel parameters are selected as follows. The average burst length L_B is set to 8 symbols, where each symbol is represented by $m = 8$ bits. The probability for a symbol at State B, p_B, is chosen from the set {0.5, 1, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20}[%].

The block length for the RS coder is set to the average GOB size when $R_s = 200$kbps, resulting in n=222 symbols. The channel code rate r varies among {0.18, 0.27, 0.36, 0.45, 0.55, 0.64, 0.73, 0.82, 0.91}.

The transmission SNR per bit E_b/N_{0g} at State G, denoted by SNR_g, is chosen from $4 - 12$dB. N_{0b} is assumed to be $10N_{0g}$, thus the corresponding SNR_b is $(SNR_g - 10)$ in dB.

The scaling factors C_{es}, C_{ec} and C_{et} can affect the optimization results significantly. The power consumption measurement that we obtained for source and channel coders are based on non-optimized software implementations. On the other hand, it is known that in today's wireless devices, the power consumptions by base-band signal processing and by transmission are roughly the same [11]. Therefore, we chose C_{es} so that P_s and P_t are on the same order of magnitude, and we chose C_{ec} so that P_c is much smaller than P_s and P_t. Based on the datasheet of the wireless LAN card from Symbol Technology, we chose C_{et} so that P_t is 1.65 watts at $R_c = 100$kbps.

B. Results

In Fig.3(a), we consider $p_B = 0.5\%$, modelling a scenario in which the channel quality is good. The optimum operating point is at $r = 0.55, \beta = 3\%, R_s = 49.8$kbps, and $SNR_g = 6$dB. The bit error rate comes down when SNR_g increases, fewer check symbols are necessary for the same distortion which results in a higher *code rate* r.

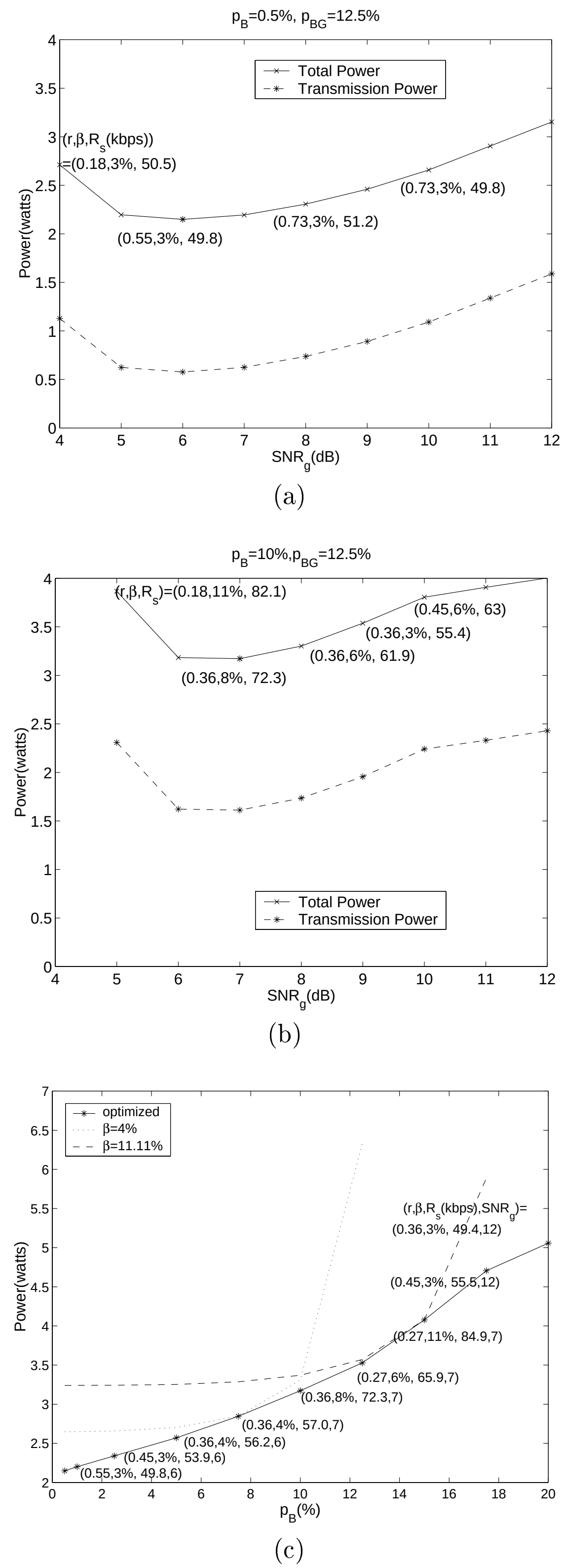

Fig. 3. Power minimization for a wireless communication system.

Fig.3(b) shows the total power and transmit power for $p_B = 10\%$, which corresponds to a bad channel. The optimum operating point is at $r = 0.36, \beta = 8.33\%, R_s =$ 72.3kbps, and $SNR_g = 7$dB. We observe that since the channel quality is poor, we need to adopt higher SNR for each transmitted bit at a lower r to send them reliably through the channel. Similarly, when SNR and r are the same, we need to use a higher β to stop error propagation. To keep the same overall distortion the encoder rate increases. Comparing Fig.3(a) and Fig.3(b), we see that when the mobile channel quality get worse, more power is necessary to meet the same total distortion, as expected.

Fig.3(c) summarizes the minimum total power consumption as a function of p_B. On the same plot we also show two scenarios in which not only the overall distortion is kept constant at $D_0 = 60$ but the *INTRA rate* β and *code rate* r are also fixed. As expected, fixed high INTRA frame rate performs well for bad channel quality. Conversely, a low *INTRA rate* algorithm is better suited for good channel quality. In both cases the total power dissipations are larger than the optimized scenario at other operating points. As can be seen, by varying the operating parameters based on the channel conditions, we can reduce the total power consumption significantly, sometimes by a factor of more than 2.

V. Conlusion and Future Works

We provide a framework for minimizing total power consumption of a mobile transmitter subject to a given end-to-end distortion. We observe that optimum operating points are channel quality dependent. When the channel is good, the optimum strategy is to have a low SNR for each transmitted bit. When the SNR is fixed, large *code rate* r and small *INTRA rate* β are preferred for a good channel, resulting in a low encoding bit rate R_s. We would like to note that the optimal operating points depend critically on the scaling factors C_{es}, C_{ec} and C_{et}, which in turn depend on the actual implementations/configurations of source and channel coders and the transmitter. The results obtained here were based on the assumption that the source coder and the transmitter consume about the same amount of power, and that the power consumption by the channel coder is negligible. This assumption is expected to hold true for applications where the video encoder is implemented by power efficient ASIC or DSP implementations.

In this paper, we considered the minimization of the total power consumption subject to a total distortion constraint. When a mobile terminal is operating at a very low power status, minimizing the total distortion subject to a total power constraint may be more appropriate. Processing and transmission delay is another important criterion to consider for real-time applications.

We mainly focused on the power consumed in the transmitter in an uplink mobile-to-base-station scenario. In this case source encoding and transmission power dominate over channel encoding. Future work will consider receiver power which is important in a base station to mobile downlink scenario. We expect that the power spent for channel decoding will play a more significant role.

In this work, a constant average burst length $L_B = 8$ bytes is assumed for the channel. This number can be much longer for indoor mobile users. Models for the source encoder used in this project, such as the rate-distortion and power consumption of the H.263 encoder rely on the sequences for their parameters. In this project one common test sequence "foreman.qcif" with strong motion is used. To gain more insights more sequences should be evaluated.

We assumed in our paper that the channel conditions are known so that we can dynamically adjust the operating parameters accordingly to optimize the power consumption. Reliable estimation of channel conditions is itself a challeging issue.

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