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 of wireless video communications subject to a given level of quality of service. Our approach exploits tradeoffs between the power consumption of the H.263 encoder, the Reed-Solomon channel encoder and the transmitter. Simulation results show that source and channel coding parameters and transmit energy per bit should vary based on channel conditions. Optimized settings can reduce the total power consumption by a significant factor compared to fixed parameter settings which do not match with the channel conditions.

1. 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. Recently, researchers started to explore the problem of power allocation among source coder, channel coder and transmitter [1, 2, 3, 4]. Our previous work [3] recognized that the optimum operating points of source coding and transmit energy depended on the mobile unit's location. We considered transform coding on first order Markov sources and we modelled the channel error by the additive white Gaussian noise.

In the present work we consider a practical wireless video communication system that uses the standard H.263 video codec [5] and the Reed-Solomon (RS) channel codec. The channel is characterized by a two-state Markov model [6]. We focus on the uplink application where a mobile sends compressed video to a base station, in which only the mobile is power-limited. Our goal is to find the optimal operating points for source and channel coding as well as transmission which minimize the total transmitter power consumption while keeping a constant end-to-end distortion.

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 applies to other video compression standards employing the block based hybrid coding framework.

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

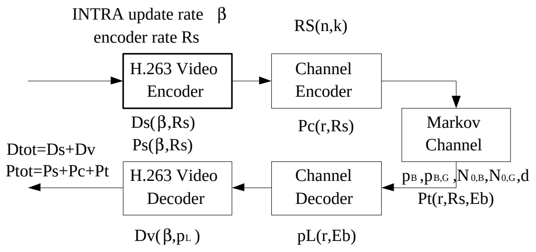


Fig. 1. The wireless communication system considered in this paper.

The paper is organized as follows: Section 2 describes the models employed in a wireless communication system. Power consumption models and measurements 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.

2. PERFORMANCE MODELS FOR SYSTEM COMPONENTS

In this section we describe the performance models used to characterize various components in the transmitter side of a wireless communication system considered in this paper. As illustrated in Fig. 1, the system consists of the H.263 codec, the RS codec and the two-state Markov channel.

The distortion and power consumption of the H.263 encoder are described respectively by $D_s(\beta, R_s)$ and $P_s(\beta, R_s)$, which depend on the *INTRA rate* β and the encoding rate R_s. The channel is characterized by p_B (the probability that a symbol is at bad state B), $p_{B,G}$ (transition probability from State B to G), $N_{0,B}$ and $N_{0,G}$ (noise powers at different states) and d, the distance between the mobile unit and the base station. The power consumed by the $RS(n,k)$ channel coder with a block size of n symbols and k information symbols 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 residual symbol error rate after channel decoding is $p_L(r, E_b)$. The distortion at the video decoder caused by transmission errors is described by $D_v(\beta, p_L)$. The overall distortion and power consumption are denoted by D_{tot} and P_{tot} respectively.

2.1. Rate-Distortion Performance of the Source Encoder

Stuhlmüller et al. [7] derived a Rate-Distortion model for an H.263 compliant coder based on simulation data. The INTRA update scheme forces a macroblock (MB) to be coded in the INTRA-mode after every $T-1$ MBs. The distortion model derived in [7] is:

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

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.

2.2. 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 transition probability on the symbol level from State B to G is $p_{B,G}$. The probability that one symbol is at State B is p_B. Furthermore, we use $N_{0,G}$ and $N_{0,B}$ to denote the noise power spectral density at good and bad states, respectively.

For binary DPSK, the probability of bit errors at state i is given by $p_{e,i} = \frac{1}{2}e^{-\mathrm{SNR_i}}$, where $\mathrm{SNR_i}$ denotes the signal to noise ratio at the receiver at state i. Since the received energy is proportional to $E_b d^{-\alpha}$, where α depends on the propagation medium, we have $\mathrm{SNR_i} = \frac{\mathrm{E_b}}{\mathrm{d^\alpha N_{0,i}}}$. Thus besides p_B and $p_{B,G}$, $N_{0,G}$, $N_{0,B}$ and d are another parameters modelling the channel condition.

2.3. The Channel Codec

The RS(n, k) channel coder converts 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 *residual symbol error rate* p_L, which is the probability that a block cannot be corrected after the channel decoder can be calculated as:

$$p_L(r, E_b) = \sum_{k=t_c+1}^{n} p_d(n, k), \tag{2}$$

where the *block error density* $p_d(n, k)$ denotes the probability of k symbol errors within a block of n symbols, which depends on r, E_b and channel parameters. The derivation of p_L can be found in [7].

2.4. 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. [7] proposed a model for distortion introduced by transmission errors:

$$D_v(\beta, p_L) = \sigma_{u0}^2 p_L \sum_{t=0}^{T-1} \frac{1-\beta t}{1+\gamma t}, \tag{3}$$

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 $D_{tot} = D_s + D_v$.

3. POWER CONSUMPTION MODELS AND MEASUREMENTS

3.1. Power Consumption Model of the Source Encoder

We derive the power consumption model of the H.263 encoder based on several assumptions. For an INTRA MB, we model energy consumption by $\mathrm{E_I} = \mathrm{E_{DCT}} + \mathrm{E_Q}$, where $\mathrm{E_{DCT}}$ denotes the energy consumed by DCT, and $\mathrm{E_Q}$ by quantization and variable length coding (VLC). For an MB coded in INTER mode, the energy consumption is modelled by $\mathrm{E_P} = \mathrm{E_{DCT}} + \mathrm{E_Q} + \mathrm{E_{ME}}$, where $\mathrm{E_{ME}}$ denotes the energy consumption of motion estimation. We assume $\mathrm{E_{DCT}}$ and $\mathrm{E_{ME}}$ 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 $\mathrm{E_Q}$ is proportioned to R_s, i.e., $\mathrm{E_Q}$=$C_q R_s$. Then the average power consumption is:

$$\begin{aligned} P_s(\beta, R_s) &= \epsilon_{e,s} f_r N_{MB} \frac{E_I + (T-1)E_P}{T} \\ &= \epsilon_{e,s}(a_s - b_s\beta + c_s R_s)(watts), \end{aligned} \tag{4}$$

where N_{MB} is the number of MBs in one frame, f_r is the frame rate, and $a_s = f_r N_{MB}(E_{DCT} + E_{ME}), b_s = f_r N_{MB} E_{ME}, c_s = f_r N_{MB} C_q$. The weighting factor $\epsilon_{e,s}$ is introduced to allow scaling of the model based on the actual power consumption by a particular implementation.

3.2. Verification of the Power Consumption Model

We measured the power consumption for encoding "foreman.qcif", using a software H.263 encoder at different β's and R_s's on an IBM Thinkpad with a 360 MHz Pentium II processor. We then used the least-square-error fitting technique to determine the parameters in Eq. 4, setting $\epsilon_{e,s} = 1$. Fig. 2 shows the fitting result, which is quite good.

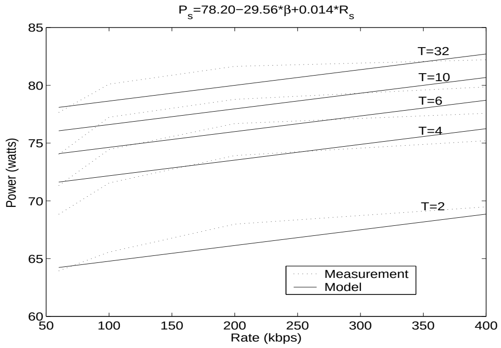


Fig. 2. Power consumption for coding "foreman.qcif"

3.3. Power Consumption Model of the Channel Coder

The energy consumption per bit of an (n,k) Reed-Solomon encoder can be modelled by [2]:

$$E_c = \epsilon_{e,c} \frac{2t_c}{m} (joules/bit), \tag{5}$$

where $\epsilon_{e,c}$ is a constant that depends on the actual implementation. Thus, the power consumption of the RS encoder acting on a compressed stream with bit rate R_s is

$$P_c(r, R_s) = E_c R_s = \epsilon_{e,c} \frac{n(1-r)R_s}{m} (watts). \tag{6}$$

3.4. Power Consumption of the Transmitter

The total transmission power is given by

$$P_t(R_s, E_b) = \epsilon_{e,t} R_c E_b, \tag{7}$$

where $R_c = \frac{R_s}{r}$ is the total bit rate, and $\epsilon_{e,t}$ is a scaling factor that translates the radiated energy into the actual power consumption for transmission in a wireless device.

4. POWER OPTIMIZATION AND ALLOCATION

For a given channel environment, i.e., given $p_B, p_{B,G}, N_{0,G}$, $N_{0,B}$ and d, the power allocation problem is to find the best set of parameters $\{\beta, R_s, r, E_b\}$ so that

$$P_{tot}(\beta, R_s, r, E_b) = P_s(\beta, R_s) + P_c(r, R_s) + P_t(R_s, E_b) \tag{8}$$

is minimized subject to

$$D_{tot}(\beta, R_s, r, E_b) = D_s(\beta, R_s) + D_v(\beta, p_L) \leq D_0 \tag{9}$$

4.1. Choice of Parameters

We set the total allowed distortion to be $D_0 = 60$. The block length for the RS coder is $n = 222$ symbols, where each symbol is represented by $m = 8$ bits.

The channel is parameterized by p_B, $p_{B,G}$, $N_{0,G}$, $N_{0,B}$ and d. Instead of $p_{B,G}$, we use the burst length $L_B = \frac{1}{p_{B,G}}$. Usually, L_B is large for indoor environments and small for outdoors. In this paper, we show the optimization results obtained for both situations, by setting $L_B = 8$ and $L_B = 32$ respectively, but keeping p_B fixed at 1%. Furthermore, we assume $N_{0,B} = 10N_{0,G}$, and $\alpha = 3.6$. In each simulation, we fix p_B, L_B, $N_{0,G}$, and vary the distance d, so that we can evaluate how the optimal operating parameters change when a mobile moves away from a base station.

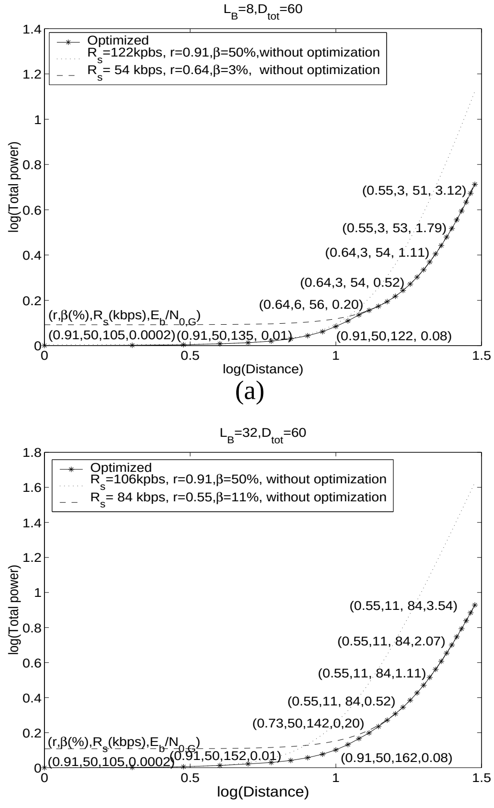
The weighting factors $\epsilon_{e,s}$, $\epsilon_{e,c}$, and $\epsilon_{e,t}$ depend on the actual implementations of the source and channel coders and the power amplifier efficiency of the radio transmitter. From the measurement of the actual power consumptions by the software source and channel coder, we find that P_c is negligible to P_s. We believe this is also true when they are implemented in hardware. Therefore, we set $\epsilon_{e,c} = \frac{1}{100}\epsilon_{e,s}$, essentially ignoring P_c in our total power calculation. To set $\epsilon_{e,s}$ and $\epsilon_{e,t}$, we consider two scenarios, one in which P_s roughly equals to P_t, simulating a case that video encoder is implemented in ASIC or DSP; another in which P_s is much larger than P_t, assuming the video coder is implemented in software by a general CPU.

4.2. Results

First, in Fig. 3 we show the results when the weighting factors are set so that P_s roughly equals to P_t for L_B=8 and L_B=32, respectively. Power consumption is normalized such that the minimum power is 1 when $L_B = 8$. Each point in the solid curve represents the combination of (r, β, R_s, E_b) that yields the lowest P_{tot} for the given distance.

We observe that when the mobile is far away from the base station, we need to adopt higher E_b for each transmitted bit to send them reliably. At the small distances, source coding takes significantly more power than transmission. Therefore, in this range, it is better to use a high β to reduce the source coding power P_s (50% is the highest value in the range of β we considered). As the distance and hence the noise power increases slightly, it is not effective to reduce the channel error rate, by increasing E_b to keep the same SNR at the receiver or reducing r. Rather, it is better to reduce source coding distortion by increasing R_s. For large distances, the trend is slightly different. Now it is more expensive to send each bit correctly to guarantee a particular video quality, so the source coder tries to reduce the bit rate by using a lower β, and the channel coder adds more redundancy to reduce channel errors. Hence at large distances, as the distance increases, R_s, β and r all decrease to get minimal power consumption.

On the same plot we also show two scenarios in which R_s, r and β are fixed. We vary E_b to reach the same D_0. As expected, fixed high R_s performs well when the mobile



(a)

(b)

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

is close to the base station. Conversely, a low R_s is better suited when the mobile is far away from the base station. In both cases the total power dissipations are larger than the optimized scenario. As can be seen, by choosing the operating parameters based on the distance, total power consumption can be reduced significantly, sometimes by a factor of 4 in the range we considered.

Comparing Fig. 3 (a) and (b), we see as L_B increases, that is as the channel stays at the bad state for a longer time, β increases for more error resilience. Also either decrease of r or increase of E_b is needed. Overall, more power is consumed. The saving from the optimal energy allocation compared to the fixed allocation is more significant.

We would like to note that the optimal operating points depend critically on $\epsilon_{e,s}$, $\epsilon_{e,c}$ and $\epsilon_{e,t}$. The previous results assume hardware implementation of both source and channel coders. Fig. 4 shows the results obtained with larger $\epsilon_{e,s}$ and $\epsilon_{e,c}$, so that P_s is roughly ten times P_t, simulating a case where the source and channel coders are consuming significantly more power than transmission, which can be the case, e.g., when the source and channel coders are implemented using software. A higher β must be used to reduce the energy caused by the source encoder. Since a higher β makes the compressed bit stream more resilient to transmission errors, we can increase r.

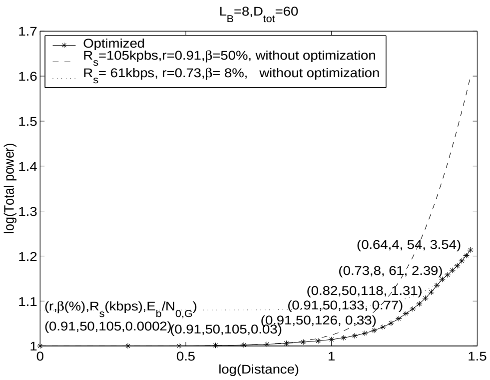


Fig. 4. Total power consumption when the weighting factors are chosen so that P_s roughly equals to $10P_t$

5. CONCLUSION AND FUTURE WORKS

In this paper we have provided a framework for minimizing total power consumption of a mobile video transmitter subject to a given end-to-end distortion. We observe that optimum operating points are channel quality dependent. Simulation results show that the optimized parameter settings can reduce the total power consumption significantly.

We mainly focus on the power consumed in the transmitter in an uplink mobile-to-base-station scenario. Future work will consider receiver power which is important in a base station to mobile downlink scenario.

6. REFERENCES

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