JOINT SOURCE-CHANNEL CODING WITH POWER CONTROL FOR VIDEO TRANSMISSION OVER WIRELESS SYSTEMS

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ABSTRACT

In this paper, a joint source-channel coding with power control technique is proposed that will minimize the average end-to-end distortion amongst all users, subject to a constraint on the total bit rate used for source and channel coding. Each user in the system is arbitrarily assigned either a low-motion or a high-motion video sequence to transmit. To reduce the computational complexity of the solution, Universal Rate-Distortion Characteristics (URDC) are obtained experimentally to show the effect channel errors have on source coding using the MPEG4 codec. The URDCs are used in conjunction with channel characteristic plots obtained by using Rate-Compatible Punctured Convolutional (RCPC) codes for channel coding to optimally select an appropriate source coding rate, channel coding rate, and power level for each user in the system.

1. INTRODUCTION

Recently there has been a rapidly increasing demand for real-time video transmission over wireless channels. Code division multiple access (CDMA) systems allow several users to use the same frequency band at the same time and are particularly suitable for digital wireless services that require robust performance in bursty or fading channels. Wireless channels differ from traditional Additive White Gaussian Noise (AWGN) and wired networks in the types of errors they introduce, as well as, the severity of these errors. Problems like multipath fading and cochannel interference can cause high bit error rates that can result in a devastating degradation of the quality of the transmitted video. A single bit error in a compressed video file can result in visibly noticeable errors when the uncompressed video is viewed. Therefore, channel coding is employed to protect the compressed data from errors produced by wireless channels [1].

Recent studies have indicated that a cross-layer design approach that supports multiple protocol layer adaptivity and optimization can yield significant performance gains for wireless multimedia networks. Although Shannon's principle of separability states that it is possible to design source and channel coding separately without loss of optimality, the principle assumes that the source and channel codes are of arbitrarily long lengths. Since this assumption does not hold in practical situations due to limitations on computational power and processing delays, it is useful to consider source and channel coding jointly [2].

Typical Joint Source-Channel Coding (JSCC) algorithms do not address the interference-limited nature of CDMA networks. Since all users transmit on the same frequency, interference within a channel plays a significant role in determining the system's capacity and its quality-of-service (QoS). The transmit power for each user must be minimized to limit the interference experienced by other users in the system. At the same time, the user's power should be high enough to maintain its own quality [3].

In this paper, we combine JSCC with power control to allocate a source coding rate, a channel coding rate, and a power level to each user in a CDMA system that will minimize the average end-to-end distortion over all users. To create a more realistic system where users transmit video sequences with varying levels of motion, users are assigned either the low-motion video sequence, *Akiyo*, or the high-motion video sequence, *Foreman*. The optimization algorithm proposed uses URDCs along with channel characteristic plots to reduce the computational complexity.

The rest of the paper is organized as follows. In section 2, we describe the RCPC codes used for channel encoding. In section 3, the JSCC with power control optimization algorithm is explained. In section 4, experimental results are presented, and in section 5, conclusions are drawn.

2. CHANNEL CODING

In this work, we use Rate-Compatible Punctured Convolutional (RCPC) codes for channel coding. With convolutional coding, the source data is convolved with a convolutional matrix **G**. Unlike linear block codes that have a number of channel code symbols for a corresponding block of source symbols, convolutional coding generates one codeword for the entire source data. Convolution is the process of modulo-2 addition of the current source bit with previously delayed source bits. The generator matrix, **G**, specifies which delayed inputs to add to the current input. This process is equivalent to passing the input data through a linear finite-state register where the tap connections are defined by **G**. The rate of the convolutional code is defined as *k/n* where *k* is the number of input bits and *n* is the number of output bits.

Commonly, decoding convolutional codes is done with the Viterbi algorithm, which is a maximum-likelihood sequence estimation procedure [4]. There are two types of Viterbi decoding: soft and hard decoding. In soft decoding, decision statistics of the channel output are passed to the decoder. Usually, the distortion metric used is the Euclidean distance. In hard decoding, the decision of the received bit is made before the received data is input into the Viterbi decoder. The distortion metric commonly used for hard decoding is the Hamming distance [5].

Punctured convolutional codes were mainly developed to simplify Viterbi decoding for rate k/n with two branches arriving at each node instead of 2^k branches. Puncturing is the process of deleting bits from the output sequence in a predefined manner so that fewer bits are transmitted than in the original code. This leads to a higher coding rate. The idea of puncturing was extended to include the concept of rate compatibility. Rate compatibility requires that a higher-rate code be a subset of a lower-rate code, or that lower-protection codes be embedded into higher-protection codes. This is accomplished by puncturing a "mother" code of rate $1/n$ to achieve higher rates. One major benefit of these RCPC codes with the same mother code is that they all can be decoded by the same Viterbi decoder [6].

Using RCPC codes allows us to utilize Viterbi's upper bounds on the bit error probability, P_b, given by

$$P_b \leq \frac{1}{P} \sum_{d=d_{free}}^{\infty} c_d P_d \qquad (1)$$

where *P* is the period of the code, d_{free} is the free distance of the code, c_d is the information error weight, and P_d is the probability that the wrong path at distance *d* is selected[6]. An additive white Gaussian noise (AWGN) channel with binary phase-shift keying (BPSK) modulation has a P_d given by

$$P_d = Q\left(\sqrt{\frac{2dR_cE_b}{N_0}}\right) \qquad (2)$$

where R_c is the channel coding rate and E_b/N_0 is the energy-per-bit normalized to the single-sided noise spectral density in Watts/Hertz.

Ignoring thermal noise and background noise due to spurious interference allows us to assume that N_0 is entirely due to interference from other users in the systems [3].

User *i* has an associated power level in Watts, $S_i = E_iR_i$. R_i is the information bit rate which is taken to be the total bit rate used for source and channel coding. Assuming N users, R_i can be expressed as

$$R_i = \frac{R_{s,i}}{R_{c,i}}; i = 1, 2, 3, ..., N \qquad (3)$$

where $R_{s,i}$ is the source coding rate for user i and $R_{c,i}$ is the channel coding rate for user i [1]. The energy-per-information bit to Multiple Access Interference (MAI) ratio becomes

$$\frac{E_i}{N_0} = \frac{\frac{S_i}{R_i}}{\sum_{j \neq i}^{N} \frac{S_j}{W_T}}; i = 1, 2, 3, ..., N \qquad (4)$$

where E_i is the energy-per-information bit, $N_0/2$ is the two-sided noise power spectral density due to MAI with units, Watts/Hertz, S_i is the power of the user-of-interest in Watts, R_i is the information bit rate in bits per second, S_j is the power of the interfering user in Hertz, and W_T is the total bandwidth in Hertz [3].

3. OPTIMAL RESOURCE ALLOCATION

The formal statement of the problem we are solving is as follows: Given an overall chip rate, R_{budget}, optimally allocate a source coding rate, R_s, a channel coding rate, R_c, and a power level, *S*, to all users such that the overall distortion D_{s+c} over all users is minimized.

$$\min D_{s+c} \text{ subject to } R_i = R_{budget} \qquad (5)$$

where R_i is the chip rate for each user and D_{s+c} is the resulting *expected* distortion averaged over all users in the system which is due to both source coding errors and channel errors. Our constraint is that the chip rate be the same for all CDMA users. Since every user has the same processing gain in our system, this translates into a constraint on the information bit rate given in (3). Since R_s is bits per second and R_c is a dimensionless number, R_i will be in bits per second. [1]. Assuming *N* users, D_{s+c} becomes

$$D_{s+c} = \frac{1}{N} \sum_{i=1}^{N} D_{s+c,i} \qquad (6)$$

The distortion due to source coding is as a result of the quantization process and is deterministic. However, the distortion due to channel errors is stochastic. Thus, the total distortion for each user is also stochastic and we use its expected value. The problem is a discrete optimization problem, that is, R_s, R_c, and S can only take values from discrete sets $\mathbf{R_s}$, $\mathbf{R_c}$, and $\mathbf{S}$, respectively, i.e., $R_s \in \mathbf{R_s}$, $R_c \in \mathbf{R_c}$, $S \in \mathbf{S}$.

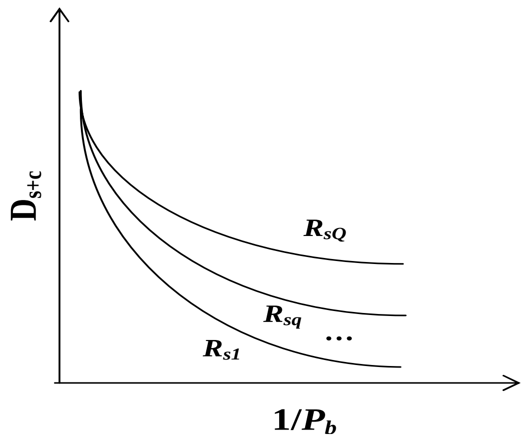

Fig. 1. Universal Rate-Distortion Characteristics

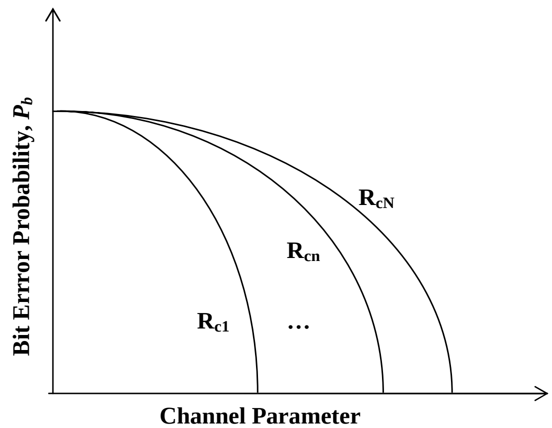

Fig. 2. Channel Characteristics Plots

Our problem reduces to finding the Operation Rate-Distortion Functions (ORDF). We then experimentally obtain the expected distortion for each user for all possible combinations of source coding rate, channel coding rate, and power level. This would become prohibitively complex for even a small number of admissible source coding rates, channel coding rates, and power levels. Instead we have chosen to relax the optimality of the algorithm and utilize Universal Rate-Distortion Characteristics (URDC). These characteristics show the expected distortion as a function of the bit error rate after channel coding. In this paper, we assume the following model for the URDC for each user *i*

$$D_{s+c,i} = a\left[\log_{10}\left(\frac{1}{P_b}\right)\right]^b \qquad (7)$$

where *a* and *b* are such that the square of the approximation error is minimized. Thus, instead of calculating the URDCs based on experimental results for every bit error rate, we instead experimentally calculate the expected distortion for a few bit error rates. We then create a model to approximate the distortion for other bit error rates and power levels. The distortion for a particular user, $D_{s+c,i}$, given a particular source coding rate, $R_{s,i}$, is a function of the bit error rate. Therefore, URDCs will give a family of $D_{s+c,i}$ versus $1/P_b$ curves given a set of source coding rates for each type of user. An illustration plot is shown in Fig 1.

In conjunction with URDCs, we use plots that show the channel bit error probability as a function of the channel parameters. These plots will be called channel characteristic plots. The probability of error, P_b, is calculated using equations (1)-(4) for the set of channel coding rates and power levels. It acts as a reference for the performance of channel coding over the specified channel with the given parameters. An illustration plot showing the performance of channel coding as a function of given channel parameters is shown in Fig 2 for a set of channel coding rates R_{cn},$n = 1, ..., N$ [7].

4. EXPERIMENTAL RESULTS

We performed the optimization procedure discussed in Section 3 using the proposed model for URDCs. Three data points were used to obtain the parameters *a* and *b* for each ORDF. Those points corresponded to bit error rates 10^{-9}, 10^{-8}, and 10^{-7}. The data points were obtained by running 100 repeated experiments with the MPEG4 codec and taking the average distortion. There were 10 users in the system, five were assigned a low-motion video clip, the *Akiyo* sequence, and the other five were assigned a high-motion video clip, the *Foreman* sequence. We created two sets of URDC curves for the two types of users.

The modulation scheme was Binary Phase Shift Keying (BPSK)/ Rate-Compatible Punctured Convolutional (RCPC) codes with mother code rate 1/4 from [6] were used for channel coding. We set $R_{budget} = 384000$ bits per second. We chose the set of admissible source coding rates to be $R_s \in \{128kbps, 192kbps, 256kbps\}$ and the corresponding set of channel coding rates to be $R_c \in \{1/3, 1/2, 2/3\}$. The power levels in Watts were chosen from $S \in \{5, 10, 15\}$.

In Tables 1 and 2, we show the $D_{s+c,i}$'s for various power combinations when $R_{s,i}$=128kbps and $R_{c,i} = 1/3$. S_i is the power assigned the user-of-interest and S_j is the power assigned the interfering users. We see that as a result of *Akiyo* being a low-motion video, its expected distortions are significantly lower than those of *Foreman* at any R_s. We expect that users with the *Akiyo* sequence will create less interference than the users with the *Foreman* sequence.

Table 3 shows the combinations of R_s, R_c, and S for both user types that result in the lowest average end-to-end distortion due to source and channel coding over all users

S_i	$S_j = 5$	$S_j = 10$	$S_j = 15$
5	4.1478	5.6126	7.0689
10	3.3678	4.1478	4.8882
15	3.0922	3.6343	4.1478

Table 1. Expected Distortions for *Akiyo* with $R_{s,i}$=128kbps and $R_{c,i} = 1/3$

S_i	$S_j = 5$	$S_j = 10$	$S_j = 15$
5	18.238	20.251	21.935
10	16.968	18.238	19.305
15	16.474	17.422	18.238

Table 2. Expected Distortions for *Foreman* with R_s=128kbps and $R_{c,i} = 1/3$

in the system. The combinations are ordered by increasing distortion, with the first combination being the optimal solution and the next two combinations being sub-optimal solutions. We see that combinations that result in a minimal distortion of the system require that the *Foreman* sequence always be assigned the highest R_s. A drop in R_s causes such a significant increase in its distortion that even using a better channel coding rate will not be enough to offset this increase. We also see that *Akiyo* is assigned a higher power in all cases. Since *Akiyo's* distortion is considerably lower, raising its corresponding user's power reduced its distortion without causing a substantial increase in the interference experienced by *Foreman* users.

5. CONCLUSIONS

In this paper, we have presented a method for assigning a source coding rate, R_s, a channel coding rate, R_c, and a power level, S to each user transmitting a video sequence in a wireless system. Our system assumes that all noise experienced by a user is due entirely to the interference due to other users in the system. To create heterogeneous system, each user in system was assigned either a low-motion video sequence or a high-motion video sequence. By utilizing the parametric model for the Universal Rate-Distortion Characteristics, we found each user's expected distortion for only a small number of bit error rates and power levels and used the model to estimate the distortion for other bit error rates and power levels. This reduced the computational complexity of the solution significantly. We presented the combinations of $\{R_s, R_c, S\}$ for each user that results in minimal average end-to-end distortion over all users in the system.

R_{s1}	R_{c1}	S_1	R_{s2}	R_{c2}	S_2	D_{s+c}
192000	1/2	15	256000	2/3	10	5.7832
192000	1/2	10	256000	2/3	5	5.8119
256000	2/3	15	256000	2/3	10	5.8783

Table 3. Optimal Resource Allocation $R_i = 384000$ bps with *Akiyo's* parameters as R_{s1}, R_{c1}, and S_1 and *Foreman's* parameters as R_{s2}, R_{c2}, and S_2

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