MINIMIZE THE TOTAL POWER CONSUMPTION FOR MULTIUSER VIDEO TRANSMISSION OVER CDMA WIRELESS NETWORK: A TWO-STEP APPROACH

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ABSTRACT

In this work, we consider a CDMA cell with multiple terminals transmitting video signals. We minimize the sum of signal processing and transmitter power while the received quality at each terminal is guaranteed. The system parameters to be adjusted include video coding bit rate, video compression complexity and transmitter power. Instead of full search in the space of {bit rate, complexity, transmitter power} for all users, we design a two-step fast algorithm to reduce the computation burden in the base station. In our algorithm, the search in the base station is over the space of complexity only. Our results indicate that for the same class of video users, the one who is closer to the base station compresses at less complexity. This is used to further reduce the computation required by our algorithm.

1. INTRODUCTION

Effective radio resource management is essential to efficient operation of a cellular network. Most studies concentrate on optimization of speech transmission, especially in systems that employ code division multiple access (CDMA) [1]. In [1], the quality of service (QoS) objective is to maximize the number of simultaneous transmitters that meet a received signal-to-interference-noise ratio (SINR) requirement. It is shown that an algorithm that produces this optimum also possess a minimum transmission power property. Recent power control studies have examined the data transmission. In much of this work, the QoS objective is a "utility" function, defined as the number of bits successfully transmitted per unit energy [2].

There has been some recent work in optimization for video transmission as video services are integrated into the network. Efficiently managing resources in wireless video transmission is complex because of the large number of interrelated variables and multiple QoS measures. The parameters to be adjusted for the video transmission system are video compression parameters, including source bit rate and compression complexity, and the transmitter power of each terminal. Compression complexity is considered because it affects not only coding efficiency, but also error resilience and compression power consumption. The QoS measures are the received video quality at each terminal and the power consumed (either transmitter power alone, or sum of source compression power and transmitter power). One set of studies, confined to a single transmitter and receiver, minimizes the sum of signal processing power and transmission power in digital video and image transmission [3], [4]. Another set of studies minimizes transmitter power for multimedia system with multiple users [5]. Other research [6], [7] considers both signal processing power and transmitter power when there are multiple users in a system. In [6], an iterative algorithm is proposed. However, it is not clear if this algorithm converges to the global optimum. In our prior work [7], we propose an analytical framework based on simplified distortion-rate (DR) models. We consider the interference between two users and analytically derive the optimum {bit rate, complexity, transmitter power} for both users simultaneously. The optimum operating points of the two terminals are contained in a pair of non-linear equations. We illustrate our algorithms by the example of a transform coder processing signals for a Gauss-Markov source. It provides some insight for practical systems. However, it does not derive solutions for a practical encoder with complicated DR models.

This paper proposes a more practical fast algorithm. In Section 2, we describe our fast algorithm and analyze the computation required by our algorithm. In Section 3, this algorithm is applied to a practical H.263 compliant video coder [8]. We conclude this paper in Section 4.

2. MINIMIZING TOTAL POWER CONSUMPTION FOR MULTIPLE USERS

2.1. System description

Our study is confined to the uplink of a single cell in a CDMA cellular system. We consider the scenario where each of the N users in the cell is transmitting a live video to the base station. The raw live video sources are compressed and then transmitted by a CDMA system with a

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chip rate of R_c chips/s. Distortion at the receiver is used as the quality measure. We consider source coders which have adjustable complexity β_i and bit rate $R_{s,i}$, each with the operational distortion-rate function $D_{s,i}(\beta_i, R_{s,i})$ [9] and power consumption profile $P_{s,i}(\beta_i)$ [1]. In our work, the common DR function is extended to include a complexity variable which affects not only coding efficiency [9], but also error resilience and compression power consumption. For example, in a H.263 video encoder [8] which employs periodic INTRA update scheme, each marcroblock is encoded in INTRA-mode at an interval of T frames, other macroblocks are encoded in INTER-mode. The INTER rate defined as $\beta = \frac{T-1}{T}$ is a compression complexity variable. Although other encoding parameters may also affect the complexity/efficiency trade-off, in our simulation with H.263 video, we only consider the INTER rate. The transmission channel is modelled by a distance-dependent path gain h_i and additive noise σ^2 and interference. We assume that the effects of modem and channel are embodied in the relationship of the error probability p_e to the channel SINR of user i, γ_i. In our numerical study, we assume differential phase shift keying (DPSK) with $p_e(\gamma_i) = 0.5e^{-\gamma_i}$. Transmitter power for user i is $P_{t,i}$. The distortion caused by transmission error $D_{t,i}(\beta_i, \gamma_i)$ is described as a function of compression complexity β_i and received SINR γ_i [5]. Received SINR γ_i is an important property of receiver i, and it can be written as

$$\gamma_i = \frac{R_c}{R_{s,i}} . \frac{h_i P_{t,i}}{\sum_{j \neq i} h_j P_{t,j} + \sigma^2}. \tag{1}$$

In the following, we would like to formulate our problem in terms of $\mathbf{\Gamma} = \{\gamma_i\}_{i=1,\cdots,N}$ instead of $\mathbf{P_t} = \{P_{t,i}\}_{i=1,\cdots,N}$. After we get the optimum $\mathbf{\Gamma}$ and $\mathbf{R_s} = \{R_{s,i}\}_{i=1,\cdots,N}$, we can derive the optimum $\mathbf{P_t}$ from Eq. (1).

In our work, we will minimize the total power consumption $P_{tot}(\boldsymbol{\beta}, \mathbf{\Gamma}, \mathbf{R_s})$ when keeping the received video quality at a target level. Notations used in this paper are described in Table 1.

To maintain an adequate quality at terminal i, there are multiple possible pairs of $\{R_{s,i}, \gamma_i\}$ for certain β_i. For instance, when more bits (larger $R_{s,i}$) are used by the video coder, the loss caused by video compression is lower, hence more distortion caused by transmission errors is tolerable, i.e., a lower γ_i is sufficient. In our prior work [5] where only transmitter power is considered, we define a quality factor for user i for a given β_i, denoted by q_i, to be inversely proportional to the product of $R_{s,i}$ and γ_i,

$$q_i(\beta_i, \gamma_i, R_{s,i}) = \frac{R_c}{R_{s,i}\gamma_i}, \tag{2}$$

where $R_{s,i}$ and γ_i must be chosen to satisfy the distortion target at β_i. The transmission power by each user can be

[1]Our prior investigation [4] has shown that the power consumption for video encoding is independent of the bit rate and can be described as $P_{s,i} = u_i\beta_i + v_i$, where u_i and v_i are constants.

Table 1. NOTATION FOR A MULTIUSER CDMA SYSTEM

Environment	N users
	path gain h_i
	chip rate R_c chips/s
	noise σ^2 (watts)
Adjustable parameters	source bit rate $R_{s,i}$ (bps)
	compression complexity β_i
	transmitter power $P_{t,i}$ (watts)
Dependent variables	signal processing power $P_{s,i}(\beta_i)$ (watts)
	compression distortion $D_{s,i}(\beta_i, R_{s,i})$
	transmission distortion $D_{t,i}(\beta_i, \gamma_i)$
	received SINR γ_i
QoS measures	total distortion $D_{tot,i}$ for user i
	total power consumption P_{tot} (watts)

expressed as

$$P_{t,i}(\boldsymbol{\beta}, \mathbf{\Gamma}, \mathbf{R_s}) = \frac{\sigma^2}{h_i[q_i+1]\left[1 - \sum_{j=1}^{N} \frac{1}{q_j+1}\right]} \tag{3}$$

Clearly from Eq. (3), when $\boldsymbol{\beta}$ is given, by choosing γ_i and $R_{s,i}$ that maximizes $q_i(\beta_i, \gamma_i, R_{s,i})$ for each user, we can minimize the transmitter power of each user. This maximum quality factor for user i is expressed as

$$q_{i,max}(\beta_i) = \max_{R_{s,i},\gamma_i} q_i(\beta_i, \gamma_i, R_{s,i}), \tag{4}$$

and the minimum transmission power for user i is

$$P_{t,i}(\boldsymbol{\beta}, \mathbf{\Gamma}, \mathbf{R_s}) = \frac{\sigma^2}{h_i[q_{i,max}(\beta_i)+1]\left[1 - \sum_{j=1}^{N} \frac{1}{q_{j,max}(\beta_j)+1}\right]} \tag{5}$$

Since maximizing q_i also reduces interference to other users, the transmission power of all users

$$P_{t,tot}(\boldsymbol{\beta}) = \sum_{i=1}^{N} P_{t,i}(\boldsymbol{\beta}, \mathbf{\Gamma}, \mathbf{R_s}) \tag{6}$$

is also minimized. This indicates that, for each given β_i, we should choose $R_{s,i}(\beta_i)$ and $\gamma_i(\beta_i)$ so that (1) a target distortion is met: $D_{s,i}(\beta_i, R_{s,i}) + D_{t,i}(\beta_i, \gamma_i) = D_{tot,i}$; and (2) $q_i(\beta_i, \gamma_i, R_{s,i})$ is maximized. When the expression for both $D_{s,i}(\beta_i, R_{s,i})$ and $D_{t,i}(\beta_i, \gamma_i)$ are complicated, it is not easy to get $q_{i,max}(\beta_i)$ in closed form. Numerical search can be used to find $q_{i,max}(\beta_i)$ when there is no closed-form solution. Since $q_{i,max}(\beta_i)$ does not depend on the channel condition, this can be computed off line for different content characteristics when we have the knowledge of the video codec and modem. Then when β_i is configurable, among possible β_i we should choose the one leading to the maximum $q_{i,max}(\beta_i)$.

In this work, we further consider the power consumed by video compression. The sum of signal processing and transmitter power will be minimized when the received video quality is kept at a target level:

$$\text{Minimize } P_{tot}(\boldsymbol{\beta}, \boldsymbol{\Gamma}, \mathbf{R_s}) = \sum_{i=1}^{N} [P_{s,i}(\beta_i) + P_{t,i}(\boldsymbol{\beta}, \boldsymbol{\Gamma}, \mathbf{R_s})]$$

subject to

$$D_{s,i}(\beta_i, R_{s,i}) + D_{t,i}(\beta_i, \gamma_i) = D_{tot,i}, \ i = 1, \cdots, N.$$

2.2. Two-step fast algorithm

Given complexity $\boldsymbol{\beta} = [\beta_1, \beta_2, \cdots, \beta_N]$, [5] shows that the minimum transmitter power consumption for N users occurs at $\mathbf{Q_{max}}(\boldsymbol{\beta}) = \{q_{i,max}(\beta_i)\}_{i=1,\cdots,N}$. Since source compression power for this set of complexity is fixed at $\mathbf{P_s}$ = $[P_{s,1}(\beta_1), \cdots, P_{s,N}(\beta_N)]$, the total power (the sum of signal processing power and transmitter power) for all terminals is also minimized at $\mathbf{Q_{max}}(\boldsymbol{\beta})$ as

$$P^*_{tot}(\boldsymbol{\beta}) = \sum_{i=1}^{N} \left\{ \frac{\sigma^2}{h_i[q_{i,max}(\beta_i)+1]\left[1 - \sum_{j=1}^{N} \frac{1}{q_{j,max}(\beta_j)+1}\right]} + P_{s,i}(\beta_i) \right\} \quad (7)$$

It is clear that we can optimize over only $\boldsymbol{\beta}$ after we get $\mathbf{Q_{max}}(\boldsymbol{\beta})$. Now we propose our two-step fast algorithm to minimize the total power consumption:

First, for each possible compression complexity β_i of terminal i, we find $R_{s,i}(\beta_i)$ and $\gamma_i(\beta_i)$ which satisfy the distortion constraint $D_{s,i}(\beta_i, R_{s,i}) + D_{t,i}(\beta_i, \gamma_i) = D_{tot,i}$ and maximize $q_i(\beta_i, \gamma_i, R_{s,i})$, i.e., $q_{i,max}(\beta_i)$. Because it is not easy to get $q_{i,max}(\beta_i)$ in closed form, numerical search can used. Since $q_{i,max}(\beta_i)$ is independent of channel conditions, it is possible that we can classify video characteristics and compute $q_{i,max}(\beta_i)$ for each class of video characteristics off line for a certain video codec.

Then in the base station we search over the space of complexity only for N users, not the entire space of {bit rate, SINR, complexity}, to find the optimum $\boldsymbol{\beta}$, denoted by $\boldsymbol{\beta}^*$ = $\{\beta^*_i\}_{i=1,\cdots,N}$. $R^*_{s,i}(\beta^*_i)$ and $\gamma^*_i(\beta^*_i)$ recorded for this optimum β^*_i are together taken as the operating parameters. This is illustrated in Fig. 1.

2.3. Required computation

Without loss of generality, we assume each video user has the same number of choices for each parameter. Let the dimensions of $\boldsymbol{\beta}$, $\mathbf{R_s}$ and $\boldsymbol{\Gamma}$ be M_β, M_R and M_γ, respectively. When the DR model is simple, for each user we can only search two parameters and derive the other parameter. But for a more complicated system, we need search all possible $\boldsymbol{\beta}$, $\mathbf{R_s}$ and $\boldsymbol{\Gamma}$ to find the triplet for each user which satisfies the distortion constraint and minimizes the overall power consumption. Here we assume more complicated scenario in which the dimension of the full search for a system with N users is $(M_\beta \times M_R \times M_\gamma)^N$.

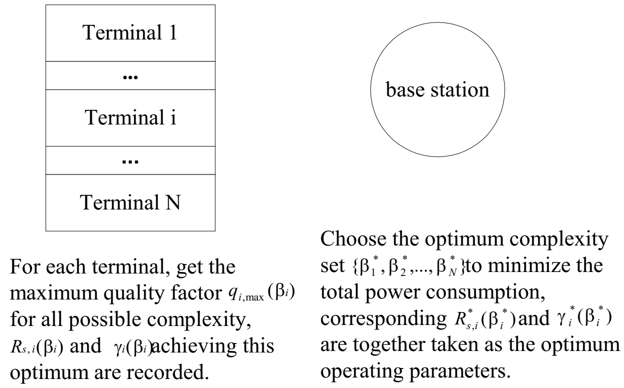

Fig. 1. Description of the two-step fast algorithm.

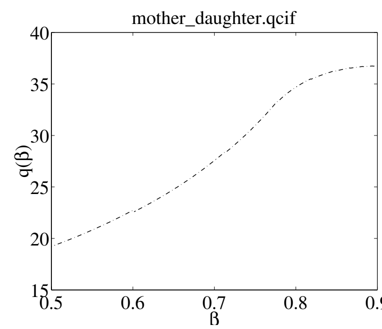

Fig. 2. $q_{max}(\beta)$ for a H.263 video encoder

For our two-step algorithm, the search is over complexity space only and has a dimension of M^N_β, which is much lower than $(M_\beta \times M_R \times M_\gamma)^N$ by the full search. In the following section, we apply this algorithm to an example system.

3. PERFORMANCE EVALUATION

We consider a practical H.263 video encoder [8] using periodic INTRA update scheme. Each marcroblock is encoded in INTRA-mode at an interval of T frames, other macroblocks are encoded in INTER-mode. The INTER rate $\beta = \frac{T-1}{T}$ is taken as the complexity. While motion estimation is used effectively to remove spatial redundancy, it makes a compressed bit stream very sensitive to transmission errors and causes error propagation. This additional distortion at the decoder is usually described by a complicated formula [9]. This makes it extremely hard to get analytical results for video transmission in wireless network. In this work, by using our two-step fast algorithm, the computation required by numerical search is significantly reduced. Further more, we take the first order and second order derivatives [2] with respect to $P_{tot}(\boldsymbol{\beta})$ and find that: (1) the optimum $\boldsymbol{\beta}$ is either on the boundary; or (2) when there are more than one terminals transmitting video data

[2] $\boldsymbol{\beta}$, $\boldsymbol{\Gamma}$ and $\mathbf{R_s}$ are considered as continuous variables here.

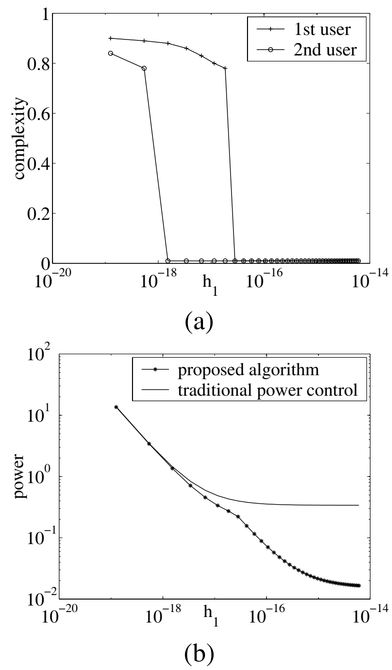

Fig. 3. (a) The optimum complexity when a H.263 video encoder is used for “mother_daughter.qcif”, (b) the total power consumed by a traditional power control algorithm and our algorithm.

with similar characteristics in one cell, the one closer to the base station (h_i is larger) works on lower complexity (β_i is smaller).

This is used to restrict the search range. If $h_i > h_j$, only those $\beta_i < \beta_j$ and boundary β_i need to be considered when user i and j have similar video characteristics. For two users, the search computation is reduced from M_β^2 to $M_\beta(M_\beta + 1)/2$. The computation saving becomes more significant when there are more users in one cell.

In our simulation for two users, we assume both users transmit the same video sequence “mother_daughter.qcif”. $q_{max}(\beta)$ is described for it in Fig. 2. Stuhlmüller’s model for distortion caused by both compression and transmission error are used [9]. We target a total distortion of $D_{tot,i} = 50$, $i = 1, \cdots, N$ (This corresponds to PSNR = 31 dB). The chip rate is set to be $R_c = 1.4 \times 10^7$ chips/s. We fix $h_2 = 0.5 \times 10^{-15}$ and carry out the optimization for various h_1. The optimal complexity is shown in Fig. 3(a). For our setup, when $h_1 < h_2$ the first user has no less complexity than the second user. When h_1 is large, the channel seen by the system is good, and both user work at the lowest compression complexity. In Fig. 3(b) we compare our algorithm with a traditional power control algorithm where a common γ_{target} = 9.6 dB and source parameters are fixed for both users at $R_{s,i}$ = 50 kbps, and β_i = 84%, i=1, 2. Though it adapts to the small h_1 very well, it consumes significantly more power than our algorithm as h_1 gets large.

4. CONCLUSION

In this work, we propose a two-step fast algorithm to minimize the sum of source compression and transmitter power for a multiuser CDMA cellular network transmitting live videos. Distortion at the receiver is used as the QoS measure. The parameters to be adjusted are source coding bit rates, compression complexity, and transmitter power for all users. Our algorithm moves away from completely centralized resource allocation by introducing the concept of a compression complexity dependent quality factor. Each terminal finds the maximum quality factor for all its possible complexities, and the base station searches in the space of compression complexity. Source coding bit rates, and transmission power corresponding to the best compression complexity are taken together as the operating parameters. This algorithm can reduce the computation load of the base station significantly because of the reduced search space. Our simulation result shows a sizable portion of power can be saved compared with a traditional power control algorithm for certain channel conditions.

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