Joint Power Control and Source-Channel Coding for Video Communication over Wireless Networks

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Abstract-**Video communication over wireless link is a challenging task due to the time-varying characteristics of a wireless channel and limited battery resource in the handheld devices. This paper proposes a power-optimized approach for video communication, which simultaneously controls the transmission power, source rate and error protection level to minimize the total power consumption for all users. The performance of the cellular CDMA system using our proposed scheme is compared with the one using a fixed power-control scheme. The simulation results show that our proposed joint power control and source-channel coding scheme achieves significant power saving compared to the fixed scheme.**

I . INTRODUCTION

Video over wireless networks has undergone enormous development recently, due to continuing growth of wireless communication. However, wireless video communication faces several challenges including bandwidth requirement and battery lifetime constraints. Minimizing average power consumption while keeping the quality of service (QoS) at mobile station (MS) is of great interest, because the next generation networks are to accommodate mobile users with portable and battery-powered equipment accessing to a wide array of information services.

Power control and joint source-channel coding (JSCC) are two effective approaches to supporting quality of service (QoS) for robust video communication over wireless networks. Power control is performed from group point of view by controlling the transmission power and spreading gain (transmission rate) of a group of users. Most power control schemes are designed to maintain a constant E_b/N_0 in the MS by decreasing the channel fading effect. The problem of power control and resource management has been discussed in [1-3], therein only transmission power is considered. On the other hand, JSCC is performed from individual user point of view by introducing redundancy to combat the transmission errors [4]. Most existing JSCC schemes are designed to minimize the distortion alone.

To the best of our knowledge, the techniques of power control and JSCC have been studied separately to date. In this paper, we simultaneously controls transmission power, source rate and error protection level to minimize the power consumption of the MS. Meanwhile, the desired QoS for video transmission is maintained in a single-cell multi-user environment.

II . JOINT POWER CONTROL AND SOURCE-CHANNEL CODING

In the video transmission scheme, the total power consumed in the MS consists of transmission power and processing power. Processing power is mainly determined by computational costs for source coding and channel coding. Transmission power, on the other hand, depends on the bit energy (ε_b) and total bit rate to deliver. Both transmission power and processing power should be controlled so as to adapt to the changing channel conditions. Reducing transmission power of a user will increase its battery lifetime, lower the interference to neighbors, and heighten bit error rate for its own transmission.

Figure 1 illustrates our proposed scheme with joint power control and source-channel coding. Besides the closed-loop power control scheme in UMTS [5], we introduce a novel functionality block, *power consumption minimization*. In our scheme, outer-loop power control and inner-loop power control operate in parallel.

The outer-loop is responsible for setting a target for signal-to-interference ratio (SIR) used by the inner-loop power control for each MS. This target is not only set on an individual basis for each MS according to the service requirement and channel protection level for each MS, but also affected by the feedbacks from the *power consumption minimization* blocks of all users in the cell. In addition, variable spreading factor (SF) is provided by the MS when performing rate control.

Meanwhile, the inner-loop power control mechanism adjusts the MS transmit power in order to keep the received uplink E_b/N_0 at the given E_b/N_0 target. The base station (BS) compares the received E_b/N_0 from the MS with the target E_b/N_0 and creates a multistep transmit power control (TPC) command for each MS in every time-slot. Furthermore, the multistep TPC command can enable the MS to perform accurate long range channel prediction [6] and be aware of the average interference caused by other users in the same cell. Moreover, each MS may adjust its transmission power with the step size, which is obtained by simultaneously considering the predicted channel condition and minimizing the power consumed in source coding, channel coding and transmission. In addition, a pilot channel between the BS and each MS is used to transmit the multistep TPC command and average interference information of other users. In the

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meantime, the feedback is received to determine the target SIR and SF.

The design of power-optimized video communication system for MS requires exploiting the tradeoff among data, redundancy, processing power, and transmission power according to the characteristics of time-varying channel. Based on the above consideration, we propose an architecture for power-minimized video communication over wireless channel, which is shown in Figure 2. The key components of the architecture include *network-aware power consumption optimizer* (NAPCO), *power-reconfigurable video encoder*, *UEP channel encoder*, and *power amplifier*.

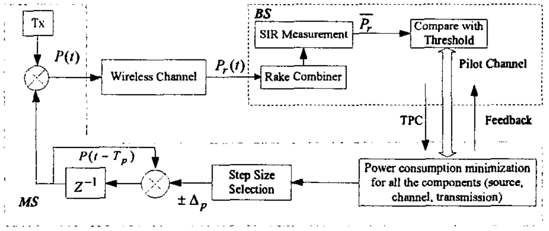

Figure 1. Diagram of joint controls in BS and MS.

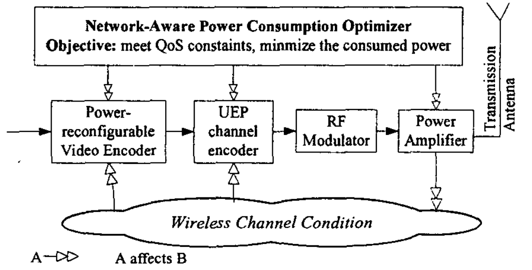

Figure 2. Architecture for joint power control and rate control in MS.

In order to minimize the total power consumption while satisfying the QoS requirements for each user, NAPCO is responsible for understanding the current channel status and periodically adjusting the video rate, protection rate, transmission power update step, and target E_b/N_0.

In video encoder, motion estimation (ME) is most computationally intensive (up to about 50% of the entire system). The computation complexity and the residual distortion of ME vary in a large range with different block matching precisions. In our work, a partial-distortion -measure based hierarchical block motion estimation algorithm [7] is adopted in power-reconfigurable video encoder to provide several power consumption levels with different MSEs (Mean Square Error).

It is known that different portions of compressed bitstreams have different importance to the quality of the reconstructed video. In our work, unequal error protection (UEP) scheme based on Reed Solomon (RS) codes is used to protect the compressed video bitstream. The computation complexity and video transmission distortion vary with different levels of error protection codes.

The transmission power of each user is related to the transmission bit energy and the total bit rate. Adjusting the transmission bit energy of an MS will not only affect its own channel condition, but also change the channel status of other users in the same cell.

From the above analysis, we can see that all those three components have the relation with total bit rate and channel condition. Hence, joint source channel coding based on power control algorithm is proposed in our proposed system to decrease the transmission power consumption.

III. POWER CONSUMPTION ANALYSIS

3.1 Power consumption for video encoding

As studied above, hierarchical partial distortion search (HPDS) algorithm [7] can provide different computation complexities with different motion estimation precisions. It is implemented by choosing appropriate parameter combinations of (S_1, n_1, S_2, n_2), where S_i and n_i $(i=1, 2)$ are respectively the decimation parameters of the original motion block and the number of the selected motion vectors at the i^{th} subsampling procedure. Different parameter sets determine different power levels on the source side.

Suppose there are $M \times N$ blocks in a frame, and the size of each block is 16×16. Then, the total energy consumption of motion estimation in a frame can be represented as

$$\varepsilon_{s,ME} = M \times N \times \varepsilon_{s,block}, \qquad (1)$$

where $\varepsilon_{s,block}$ is the energy consumed for matching a block, which can be described as

$$\varepsilon_{s,block} = T_s \times \varepsilon_{sub} + T_a \times \varepsilon_{add}. \qquad (2)$$

Where T_s, T_a are the numbers of operations of absolute difference and addition, respectively, and ε_{sub}, ε_{add} are the energy consumed for an absolute difference and an add operations, respectively.

The numbers of the operations of addition and subtraction are related to the parameters in HPDS, which are respectively defined as

$$T_s = \frac{256}{S_1} \times (2W+1)^2 + \frac{256}{S_2} \times n_1 + 256 \times n_2 \qquad (3)$$

and

$$T_a = T_s - (n_1 + n_2) - (2W+1)^2, \qquad (4)$$

where W is the size of the search window.

Note that 2D block based architecture [8] and gate-level simulator [9] are used for calculating $\varepsilon_{s,ME}$.

3.2 Power consumption for UEP

Several techniques have been developed for reliable transmission of data in fading channels with finite power. Coding and interleaving techniques are common methods to improve the performance in fading channels.

The energy consumption of *RS(n, k)* encoder is given by

$$\varepsilon_{rsenc}(t) = 2t(2^m - 1 - 2t)(\varepsilon_{gfmult} + \varepsilon_{gfadd}) / codeword, \qquad (5)$$

where m represents the number of bits per symbol, t stands for the error protection level, ε_{gfadd} and ε_{gfmult} respectively denote the energies consumed for adder and multiplier blocks over Galois Field [10].

After applying an *RS(n, k)* code, the failure probability of a block is described as

$$P_{fail}(t) = \sum_{j=t+1}^{n} \binom{n}{j} {b_{sym}}^{j} (1 - b_{sym})^{n-j} , \tag{6}$$

where b_{sym} is the symbol error rate that can be represented as

$$b_{sym} = 1 - (1 - b_{cur})^{m} \tag{7}$$

in which b_{cur} is the channel bit error rate.

In a bitstream, the header bits are much more important than the texture bits. If the header bits are lost, the texture bits become useless. On the contrary, if the header bits are successfully transmitted, the errors in the texture bits can be compensated by inter-prediction or intra-prediction enabled by the contents of header bits. Thus, re-organizing the video bitstream, we put a group of macroblocks' header bits together into the MSP (Most Significant Portion) class and put the texture bits of those macroblocks into the LSP (Least Significant Portion) class. Then, different channel protections are applied to different classes of data. More specifically, higher protection is applied to the MSP class. In order to decrease the overhead of side information, we packetize the compressed bitstream as in [11].

It can be seen from (6) that the power consumption of the channel coding is a function of the error correction capability. Suppose the MSP has bit rate $R_{s,m}$ with error protection level t_m; while the LSP has bit rate $R_{s,l}$ with error protection level t_l, the consumed power in the channel can then be represented as

$$\begin{aligned} P_c &= P_{c,MSP}(R_{s,m}, t_m) + P_{c,LSP}(R_{s,l}, t_l) \\ &= \frac{R_{s,m}}{(n - 2t_m) \times m} \times \varepsilon_{rsenc}(t_m) + \frac{R_{s,l}}{(n - 2t_l) \times m} \times \varepsilon_{rsenc}(t_l) \cdot \end{aligned} \tag{8}$$

3.3 Transmission power consumption

Energy consumption of the power amplifier is characterized by its power-aided-efficiency (PAE), η, defined as the ratio of the output power P_t to the power drawn from the supply. Power amplifiers are typically designed to maximize η at the maximum output power $P_{t,max}$. The use of power control in a power-optimized CDMA system requires amplifiers with good efficiency over a wide range of output power, especially for lower output power. The linearized wide-band CDMA handset's power amplifier based on predistortion in the specific bias-control scheme discussed in [12] can achieve a high PAE of over 40% for a 20dB output power range. The efficiency $\eta(P_t)$ of this power amplifier can be obtained from [12]. .

For a given transmission bit energy (ε_b), the power consumed for transmitting bits with rate R_t can be represented as

$$P_t = \varepsilon_b \times R_t = \varepsilon_b \times (R_s + R_c) \, . \tag{9}$$

Then, the power consumption of the power amplifier is given by

$$\varepsilon_t(P_t) = {P_t}/{\eta(P_t)} \, \cdot \tag{10}$$

IV. MINIMIZATION OF THE POWER CONSUMPTION FOR THE MOBILE STATIONS

Having analyzed the power consumed in each individual component, now we adjust the power control step size, target SIR, source rate and protection levels to minimize the total power consumption while satisfying the QoS requirements for each mobile. As mentioned above, the total power consumption is composed of source coding power, channel coding power and transmission power. Hence, the power-optimized rate allocation problem can be formulated as

$$\begin{aligned} \min_{\{{R_s}^i, {R_c}^i, \gamma^i\}} \sum_{i=1}^{N} (& {P_s}^i (S_1^i, n_1^i, S_2^i, n_2^i, {R_s}^i) + {P_c}^i ({R_c}^i) \\ & + {\varepsilon_t}^i ({P_t}^i, \gamma^i)) \\ s.t. \quad & {D_u}^i \le D_0^i \ , \end{aligned} \tag{11}$$

where N is the number of users in the system and the superscript i represents the i^{th} user, γ^i denotes the target E_b/N_0, ${D_u}^i$ and D_0^i respectively represent the expected uplink distortion and maximal tolerable distortion, which can be derived from the QoS requirements. ${R_s}^i$ and ${R_c}^i$ are the source rate and channel coding rate, respectively. P_s^i, P_c^i, and P_t^i are the power consumption for video source encoding, channel UEP, and data transmission, respectively.

Let $r_i' = R_t^i \gamma^i$, we can obtain P_t^i from the following equation [1]

$$\left(\frac{W}{r_i'} + 1\right) h_i P_t^i \left[1 - \sum_{j=1}^{N} \frac{1}{\left(\frac{W}{r_j'} + 1\right)}\right] = \eta_0 W \qquad i = 1,2,\ldots,N \, , \tag{12}$$

where W and h_i are respectively the total bandwidth for all users and the channel gain of the i^{th} user. It can be seen from (12) that it is necessary to be aware of r_i's of other users when calculating the transmission power of the current user. Moreover, if every user's r_i' is minimized, the transmission power of each user reaches the minimum simultaneously.

In general, it is difficult to minimize the total power consumption of all users at the same time. To solve this problem, we develop an iterative solution as follows.

Step 1: Find the initial value, $r_{i,0}'$.

Since minimizing r_i' of each user achieves the minimal transmission power and requires no information of other users, we can set the minimal r_i' as the initial value, which can be computed from

$$\min_{\{R_t^i,\gamma^i\}} r_i^{'}$$

$$s.t.\ \ D_u^i \le D_0^i \qquad i = 1,2,\ldots,N \ . \tag{13}$$

For the i^{th} user, the expected uplink distortion, D_u^{i}, is composed of the source distortion (D_s^{i}) and the channel distortion (D_c^{i}). The source distortion is caused by the searching range in the ME algorithm and video rate control; while the channel distortion results from the channel transmission error. Mathematically,

$$D_u^i = D_s^i(R_s) + \sum_{m=1}^{N_{msp}} P_{fail}(m) \times D_c^i(m) + \sum_{n=1}^{N_{lsp}} P_{fail}(n) \times D_c^i(n) \ , \tag{14}$$

where N_{msp} is the number of blocks in MSP, N_{lsp} is the number of blocks in LSP, $P_{fail}(m)$ is the failure probability of the m^{th} block, and $D_c(m)$ is the channel distortion caused by the failure of the m^{th} block.

Step 2: Update $r_{i,t}^{'}$.

We update $r_{i,t}^{'}$ to minimize the power consumption of all users by minimizing each user's total power consumption. Mathematically, it can be formulated as follows:

$$\min_{\{R_s^{\,i},R_c^{\,i},\gamma^i\}} P_s^{\,i}(S_1^i, n_1^i, S_2^i, n_2^i, R_s^{\,i}) + P_c^{\,i}(R_c^{\,i}) + \varepsilon_t^{\,i}(P_t^{\,i}(\gamma^i))$$

$$s.t. \qquad D_u^{\,i} \le D_0^i \qquad i = 1,2,\ldots,N \ , \tag{15}$$

Then, the optimal set of (R_s^i, R_c^i, γ^i) is obtained by solving (15) as in [13] to update $r_{i,t}^{'}$. Notice that influences from different users on the capacity of the system are different. Considering the capacity constraint of a power-control system with transmission power constraint, p_i, at t^{th} iteration, we define a weight for each user to represent its influence on the capacity in the following [1]:

$$w_i = \frac{p_i h_i}{r_{i,t}^{'}} \qquad i = 1,2,\ldots,N. \tag{16}$$

When w_i is large, the increase of $r_{i,t}^{'}$ will consume more capacity of the system. In order to satisfy the capacity constraint more efficiently, the MS with the larger w_i will update its $r_{i,t}^{'}$ using Equation (15) prior to the MS with the smaller one. Moreover, the updated $r_{i,t}^{'}$ of the previous user should be used for the next user to speed up the convergence.

Step 3: Stop criterion.

If $\left|P_{M,t+1}^i - P_{M,t}^i\right| \le \varepsilon \cdot P_{M,t+1}^i$,

exit for the i^{th} user

and goto *Step 2* for the next user;

Otherwise $t=t+1$

and goto *Step 2* for the next user.

Note that $\varepsilon < 1$ and $P_{M,t}^i$ is the minimized power consumption for the i^{th} user at t^{th} iteration.

After all users obtain the optimal sets of (R_s^i, R_c^i, γ^i), the optimal (R_s^i, R_c^i, γ^i) are passed to the BS for updating the desired SIR targets and spreading factors through the pilot channel from MS to BS.

V. SIMULATION RESULTS

The simulations are to demonstrate effectiveness of our proposed joint power control and JSCC video communication scheme. In this simulation, we tested (1) *Scheme A*: our joint power control and JSCC scheme with adaptive source complexity, adaptive power control step size and adaptive target E_b/N_0; (2) *Scheme B*: a power-control system with fixed source complexity, fixed power control step size and fixed target E_b/N_0.

5.1 Simulation setup

We consider a single cell CDMA system with ten mobile stations operating in a wireless flat fading channel. The testing video sequence Foreman is coded in QCIF at a temporal resolution of 15 fps. In every 15 frames, the first frame is intra-coded and the remaining frames are inter-coded. The desired video quality (PSNR) is set to 30dB. The radio transmission parameters and propagation models from outdoor to indoor and pedestrian environment are adopted and can be obtained from the IMT-2000 evaluation methodology [14]. The large-scale path loss and small-scale fading are considered simultaneously in the proposed system. The Jakes model is used to simulate the fading channel. The simulation parameters are tabulated in Table 1.

Table 1. Simulation parameters

Chip Rate	11.0593 Mchips/sec						
Transmit Power adjust step size	0.25dB – 1.5dB						
Power Amplifier	Noise figure = 5dB						
Cell range	50m – 300m						
Moving speed	3km/h						
Source and channel codec	0.18μ, 2.5V CMOS Technology						
ME parameters	S_1	16	16	32	32	64	64
	n_1	15	10	12	8	20	15
	S_2	2	4	2	2	4	4
	n_2	2	2	2	2	4	2

5.2 Simulation results

Figure 3 shows comparison results of the total power consumption for the above two schemes with different cell range. It can be seen from Figure 3 that our proposed scheme saves more power compared to the fixed power-control system given the same PSNR requirement. Figure 4 shows the power saving ratio of our proposed scheme compared with the fixed system. We can see from Figure 4 that the power saving ratio decreases smoothly with the increasing cell range. This is because the ratio of the processing power to the total power consumption decreases when the distance is increased, as the transmission power consumption must be enlarged to deal with the path loss and fading. As a result, the optimization of processing-and-transmission power consumption by adaptive rate allocation yields smaller power saving gain.

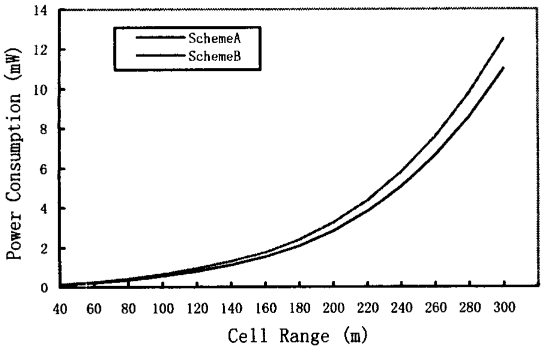

Figure 3. Comparisons of power consumption for *Scheme A* and *Scheme B*.

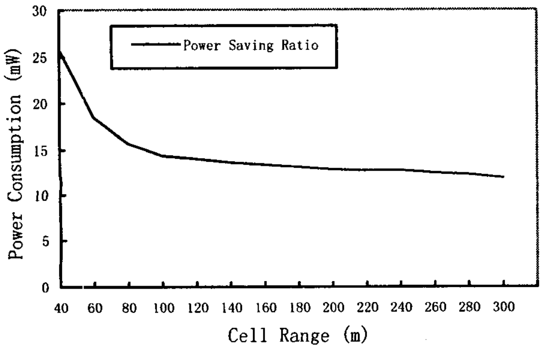

Figure 4. Power saving ratio of our proposed scheme.

VI. CONCLUSIONS

In this paper, we propose a power-optimized architecture for video communication in a cellular CDMA system. Joint power control and JSCC are presented in our scheme to minimize the total power consumption at all mobile stations. Simulation results show that our proposed scheme achieves significant power saving compared to the fixed one.

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