Energy Efficient JPEG 2000 Image Transmission over Point-to-Point Wireless Networks

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Abstract

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***Abstract*— In this paper, we propose an energy efficient JPEG 2000 image transmission system over point-to-point wireless networks. The objective is to minimize the overall processing and transmission energy consumption with the expected end-to-end QoS guarantee, which is achieved by jointly adjusting the source coding schemes, channel coding rates, and transmitter power levels in an optimal way. The advantages of the proposed system lie in three aspects: adaptivity, optimality, and low complexity. Based on the characteristics of the image content, the estimated channel conditions, and the distortion constraint, the proposed low-complexity joint source channel coding and power control algorithm adjusts the coding and transmission strategies adaptively, which can approximate the optimal solution with a tight bound.**

I. INTRODUCTION

With the rapid growth of mobile wireless communication systems, wireless multimedia has recently undergone enormous development. However, to design an efficient multimedia communication system over wireless channels, there still exist many challenges, of which some are caused by severe wireless channel conditions, some due to the special characteristics of the compressed multimedia data, and some from resource limitation, such as power supply.

Due to severe wireless channel conditions, such as path loss, fading, co-channel interference, and noise disturbances, the capacity of the wireless channels is much lower than the wired channels, and the bit error rate (BER) is much higher [1]. Meanwhile, the throughput may fluctuate due to time-varying characteristics of the wireless channels. The severe channel conditions have placed major obstruction for designing efficient multimedia communication systems over wireless environments.

Since multimedia data contains a lot of redundancy, to efficiently utilize limited resources, source compression is always necessary. Compared with the general data, the compressed multimedia data has some special characteristics, such as *unequal importance*, *error tolerance*, and *constrained error propagation* [2]. *Unequal importance* denotes that different part of the compressed bitstream exhibits different perceptual and structural importance. *Error tolerance* means that even if errors are introduced, the original information may still be reconstructed with some tolerable degradation. *Constrained error propagation* denotes the phenomenon that if some bits are corrupted, the neighboring bits are likely to become useless as well, especially in the case when variable-length coding is applied. Meanwhile, the affected bits can be restricted inside a certain range by applying error resilient coding schemes. These special characteristics differentiate the multimedia transmission from the general reliable data communication.

In wireless multimedia communications, another important design consideration is energy efficiency [3], [4]. Since most users of a wireless network are mobile, which rely on a battery with a limited energy supply, minimizing the energy consumption can extend the battery lifetime, and subsequently extend the life of the network.

In a wireless multimedia transmission system, the energy consumption mainly occurs during transmission and processing. The transmission energy consumption is determined by the transmitter power level, the transmission duration, as well as the efficiency of the power amplifier. Sentence should be divided. The total consumption of processing energy is dominated by source coding, channel coding, and baseband processing. The actual consumption depends on a number of factors including IC technology, coding complexity, desired throughput, etc [5]. In general, maintaining a good quality of service (QoS) and minimizing average energy consumption are contradictory. In wireless multimedia communications, the contradiction becomes more salient due to design challenges. To address this contradiction, besides reducing power consumption at circuit design stage [5], schemes based on joint source channel coding (JSCC) principle can be applied to utilize the limited energy in more efficient ways as in [3], [4], [6].

In this paper, we focus on the point-to-point image transmission over wireless channels, and propose an energy efficient system to minimize the overall processing-and-transmission energy consumption, given the expected end-to-end distortion constraint. In the proposed system, an image is first encoded as a scalable bitstream with multiple quality layers that is optimal in the R-D sense. Given the estimated channel condition, the characteristics of the image content, and the end-to-end distortion constraint, the proposed system can adaptively determine the number of layers to be transmitted and adjust the source coding rate, the source level error resilience scheme, the channel coding rate, and the transmitter power level for each layer through the proposed low-complexity joint source channel coding and power control (JSCCPC) algorithm.

In the proposed system, JPEG 2000 [7] is adopted as the source coding standard; it has the following desirable properties: state-of-the-art compression performance, quality scalability, and strong error resilience [8], [9]. These three properties are of importance for image transmission over error-prone channels, where high compression performance can be used to save limited resources, quality scalability to facilitate the unequal error protection (UEP), and error resilient coding to restrict the error propagation range [2]. In our work, rate-compatible punctured convolutional (RCPC) codes [10] are used as the channel encoder to combat the channel errors, since it can provide variable degree of protection using the same codec with manageable coding complexity, which is very suitable for hardware implementation. To further improve the system performance, transmitter power can be adaptively adjusted by the system across several levels.

The superiority of the proposed system to the existing systems, as well as the contribution of the paper, lies in the following properties: adaptivity, optimality, and low complexity. These are the key properties for efficient multimedia transmission systems. Adaptivity indicates that the proposed system is adaptive to the channel condition, the characteristics of the image content, and the QoS constraint. Optimality means that it can approximate the optimal solution with a tight bound. Low complexity lies in that the JSCCPC algorithms can be executed with negligible time, which is very suitable for online processing. Another advantage of the proposed system is that it exploits the error resilient coding schemes at the source coding stage. Currently, no existing energy efficient image or video transmission system has incorporated all these properties at the same time. Most existing systems focus on reducing the channel BER, while this paper shows that restricting the error propagation range by applying source error resilient coding schemes can improve the system performance dramatically in many situations.

The rest of this paper is organized as follows. Section II gives a brief introduction to JPEG 2000 and the available error resilient coding schemes. Section III describes the proposed system and the interaction among its components. Section IV analyzes and formulates the processing and transmission energy consumption for the proposed system. The proposed low-complexity JSCCPC algorithm is presented in Section V. Simulation results and performance comparison are presented in Section VI. Finally, Section VII concludes this paper and suggests the future work.

II. JPEG 2000 AND ERROR RESILIENT CODING

JPEG 2000 is a wavelet-based still image compression standard using the embedded block coding with optimized truncation algorithm [8], [11]. After color space conversion, the wavelet transform decomposes each component into several *resolution levels*, each containing a series of *subbands*. After quantization, the coefficients in each wavelet subband are partitioned into regular arrays of *code blocks* for entropy coding.

Each code block is entropy-coded independently using context adaptive arithmetic coding [8]. Each bit-plane is coded with three passes, and each pass generates an embedded bitstream, called a *coding pass*, to provide a variable quality contribution to the reconstructed image. Following entropy coding, a post compression rate allocation procedure selects coding passes from each code block in such a way that the reconstructed image distortion is minimized under a given bit-rate constraint. The selected coding passes are packetized into data packets. These packets are then assembled into the final coding stream. Each packet consists of packet header and packet body.

The packetization procedure imposes a particular organization on the selected coding passes to facilitate many of the desired coding stream features, such as *quality scalability*, where the bitstream contains embedded subsets, and each represents an efficient compression of the original image at increased distortion [9]. In this paper, we let n_l denote the number of bits in layer l, and w_l denote the average distortion reduction (gain) per bit for layer l, which is defined as the ratio of the distortion reduction to the total number of bits in this layer. Since the bitstream is generated in a RD optimal sense, we always have $w_k > w_j$ for $j > k$.

To combat the error propagation, JPEG 2000 provides many error resilient coding schemes [12]. The code block size can be adjusted to trade the coding efficiency with error propagation range, since the error propagation can be restricted inside each code block due to the independent entropy coding. The resynchronization markers can be inserted periodically to synchronize the decoder against error occurrence. Extra structural redundancy can be added to protect headers, since usually the headers play a more important role than the body. Fixed length entropy coding can employed to eliminate the error propagation, which is especially suitable for very adverse channels. At the decoder end, error concealment can be applied to further alleviate the error effects.

To quantify the effect of error propagation, we borrow the concept of *average error propagation length* (AEPL) from [2]. The AEPL is used to denote the average number of affected bits for every bit error that is introduced. In general, the AEPL varies according to the applied error resilient coding schemes as well as the error position. We assume the error resilient schemes can be applied layer by layer, and each layer has a corresponding AEPL, which is determined by the characteristics of that layer and the applied error resilient coding schemes. We also assume that the overall distortion caused by channel errors is the sum of the distortion introduced at each layer. We call this as *layer independence* assumption. Although this assumption of *layer dependence* is not precise, it can simplify the system analysis. Furthermore, we have found that the distortion of each layer can be approximated quite accurately by the the number of bits in error multiplied by the average error propagation length and the average gain

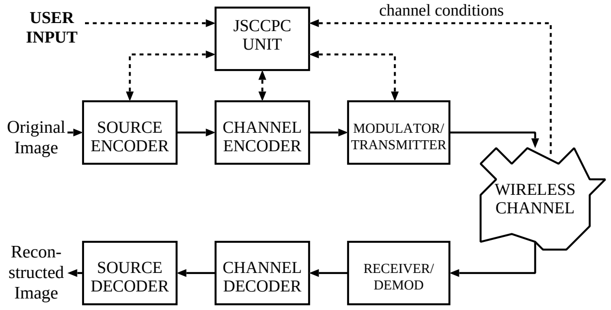

Fig. 1. Block diagram of the proposed system

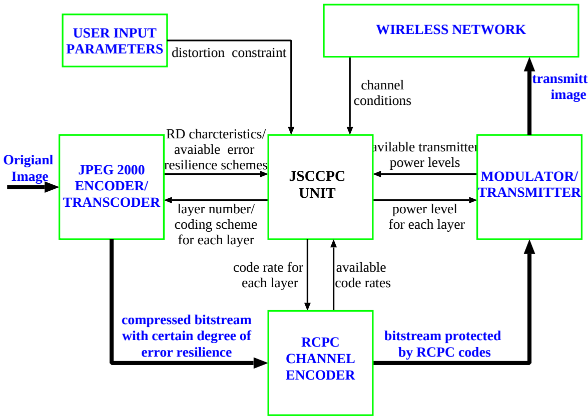

Fig. 2. Interaction among different components

III. SYSTEM DESCRIPTION AND PROBLEM FORMULATION

Before describing the system, we need to specify the underlying channel models. In theory, an additive white Gaussian noise (AWGN) channel model is often used. However, the wireless channel suffers from path loss, shadowing, multipath, Doppler shift, and so on [1]. Hence, to design a real system, fading channel models have to be considered. The JSCCPC system can work both on AWGN channel and on fading channel, with the only assumption that the transmitter can know the estimated channel conditions. In the following, we first present the block diagram of the JSCCPC system as well as the interactions among its components. Then we introduce the notations to be used and formulate the optimization problem.

A. System Description

As illustrated in Fig. 1, the transmitter in the JSCCPC system is composed of four parts: source encoder, channel encoder, wireless transmitter, and JSCCPC unit. The interaction among these components is illustrated in Fig 2. The JPEG 2000 source encoder generates quality scalable bitstreams, which are then protected using RCPC channel codes with different rates, and transmitted by the wireless transmitter with specified power levels. Given the estimated channel condition, the characteristics of the image content, and the set of available coding and transmission strategies, the JSCCPC unit tries to find the optimal number of layers to be transmitted and the optimal strategies for each layer, such that the overall energy consumption is minimized given the expected end-to-end distortion constraint. Currently, the coding and transmission strategy is a combination of the source error resilient coding schemes, the channel coding rate and the transmitter power level. At the receiver end, the received bitstreams are then decoded and reconstructed.

In the JSCCPC system, the source encoder can work in the two modes: compression and transcoding. In the compression mode, it generates a quality scalable bitstream with multiple quality layers in a RD optimal sense. In the transcoding mode, the goal is to make the bitstream more robust by applying various forms of error resilient coding schemes. Currently, four types of error resilient coding schemes are considered: header protection, packet level synchronization marker, coding passes level synchronization marker, and RAW coding, as in [2]. The RAW coding implies that no entropy coding is applied. We use Reed Solomon (RS) codes [13] to protect the header information.

For the channel coder, RCPC codes are used. The RCPC codes are obtained by puncturing a low rate $1/N$ convolutional code (mother code) periodically with period P to obtain a family of codes with rate $P/(P+l)$. The l can be varied between 1 and $(N-1)P$, with the restriction on the puncturing tables to ensure that all code bits of high rate codes are used by the lower rate codes [10]. Currently, the family of RCPC codes with mother code rate $1/3$ is adopted from [10], with period $P=8$ and memory size $M=6$.

B. Problem Formulation

In this paper, we assume the channel conditions do not change during the transmission of one image. For each quality layer l, let S_l^s, S_l^r, S_l^c, and S_l^p denote the set of available source error resilient coding schemes excluding header protection, the set of available RS code rates for header protection, the set of available RCPC code rates, and the set of available transmitter power levels, respectively, and let $s_l = \langle s_l^s, s_l^c, s_l^r, s_l^p \rangle$ denote the coding and transmission strategy for this layer, where $s_l^s \in S_l^s$, $s_l^r \in S_l^r$, $s_l^c \in S_l^c$, and $s_l^p \in S_l^p$. Let s_l^0 denote that the layer l is not transmitted, and $\bar{s} = \langle s_1, s_2, \ldots, s_L \rangle$ the coding and transmission strategy for the whole image.

Let D_{total} denote the overall distortion if no layers are received, and $G_l(s_l)$ the expected gain (distortion reduction) when strategy s_l is applied on layer l. Assuming the distortion metric is additive, the overall expected gain $G(\bar{s})$ can be calculated as

$$G(\bar{s}) = \sum_{l=1}^{L} G_l(s_l) \tag{1}$$

and the overall expected distortion $D(\bar{s})$ becomes

$$D(\bar{s}) = D_{total} - G(\bar{s}) \tag{2}$$

Given w_l, n_l, and the AEPL $L_l^{aepl}(s_l)$, $G_l(s_l)$ can be approximated as

$$G_l(s_l) = w_l n_l (1 - P_e(s_l) L_l^{aepl}(s_l)) \tag{3}$$

where $P_e(s_l)$ denotes the average BER by applying strategy s_l on layer l under the latest channel SNR.

Let $R_l(s_l)$ and $E_l(s_l)$ denote the total number of bits and the total amount of energy consumed by applying strategy s_l on layer l, then the overall rate usage $R(\bar{s})$ and energy consumption $E(\bar{s})$ can be calculated as

$$R(\bar{s}) = \sum_{l=1}^{L} R_l(s_l) \tag{4}$$

$$E(\bar{s}) = \sum_{l=1}^{L} E_l(s_l) \tag{5}$$

The joint source channel rate allocation and power control problem can be formulated as a constrained discrete optimization problem as in (6):

$$\arg\min_{\bar{s}} E(\bar{s}) \quad \text{s.t.} \quad D(\bar{s}) \le D_{max} \tag{6}$$

where D_{max} is the maximum tolerable end-to-end distortion in expectation. To find the optimal solution, dynamic programming techniques can be applied. However, the complexity can increase exponentially with L and the size of the strategy set. In Section V, we propose a greedy-like algorithm to approximate the optimal solution.

IV. ENERGY CONSUMPTION ANALYSIS

A. Transmitting Energy Consumption Analysis

Let η denote the power-aided-efficiency (PAE) of the transmitter amplifier, which is defined as the ratio of the output power to the power drawn from the supply. Given the transmitter power level $P_t \in S_l^p$, the PAE $\eta(P_t)$, and the system transmit rate B, the transmission energy consumption per bit $\varepsilon_b(P_t)$ becomes

$$\varepsilon_b(P_t) = \frac{P_t}{\eta(P_t)B} \tag{7}$$

Now, the total transmission energy consumption for layer l by applying strategy s_l can be calculated as

$$E_l^t(s_l) = R_l(s_l)\varepsilon_b(s_l) \tag{8}$$

B. Processing Energy Consumption Analysis

The processing energy consumption mainly takes place in three parts: source coding, channel coding, and baseband processing. In the JSCCPC system, we assume the power dissipation P_{base} for the baseband processing is fixed during transmission and the energy consumed by the baseband processor is only determined by the transmission time. For simplicity, we also assume that the source coding in the compression mode consumes a fixed amount of energy E_{com}.

In the transcoding mode, some operations are negligible, while others are required to be accounted for. For instance, sync marker insertion requires little computation, so the energy consumption is negligible. However, for the RAW coding, the energy is calculated as the product of the number of raw bits and the energy consumption per bit ε_{raw}. For header protection, the energy consumption is determined by the code type and code rate, as well as the number of code words to be coded.

Assume $RS(n,k)$ code over Galois field $GF(2^m)$ [13] is used to protect headers. Let $2t = n - k$ be the number of check symbols in the n-symbol codeword. Let ε_{add}^{gf}, ε_{mul}^{gf}, and ε_{inv}^{gf} denote the energy consumption of m-bit addition, $m \times m$-bit multiplication, and m-bit inversion over $GF(2^m)$, respectively. According to [14], the energy consumed per codeword generation is given by

$$\begin{aligned} &\varepsilon^{RS}(n,t,m) = \\ &(6tn + 14t^2)\varepsilon_{mul}^{gf} + (6tn + 10t^2)\varepsilon_{add}^{gf} + 3t\varepsilon_{inv}^{gf} \end{aligned} \tag{9}$$

Now we address the energy consumed at the channel coding stage. For a specific family of RCPC codes, assume the mother code rate is $1/N$, the puncturing period is P, and the memory size is M. Due to the characteristics of the encoding procedure, the energy consumption per input bit by the encoder can be approximated as

$$\varepsilon_{enc}^{RCPC} = N\varepsilon_{xor}^{M} \tag{10}$$

where ε_{xor}^{M} denotes the energy consumed per M-bit XOR operation.

We use a register-exchange based Viterbi algorithm (VA) for decoding [15], [16]. In this case, the energy consumption mainly results from the following operations: *branch metric computation*, *state metric update*, and *survivor path recording*, where only branch metric computation energy consumption depends on the RCPC code rate. The state metric update can be implemented using a add-compare-select (ACS) module. Let ε_{add} denote the energy consumption per add operation with given quantization level, and assume that the energy consumed per ACS operation is ε_{acs}, and the energy consumed per register exchange is ε_{reg}. Then the overall energy consumption of the decoder per output bit becomes

$$\varepsilon_{dec}^{VA} = 2^M \left(\frac{P+l}{P}\varepsilon_{add} + \varepsilon_{acs} + \varepsilon_{reg} \right) \tag{11}$$

Now the total processing energy consumption $E_l^p(s_l)$ becomes

$$\begin{aligned} &E_l^p(s_l) = \\ &E_{com} + R_l(s_l)\left(\frac{P_{base}}{B} + \varepsilon_{enc}^{RCPC} + \varepsilon_{dec}^{VA} + \varepsilon^{RS} \right) \end{aligned} \tag{12}$$

V. JSCCPC ALGORITHM FOR SINGLE-HOP TRANSMISSION

The proposed JSCCPC algorithm presented in this section is similar with the scheme proposed in [2], where they have proposed an efficient joint source channel coding and rate control scheme to minimize the end-to-end distortion given the rate constraint. The basic idea is to allocate the energy step by step. At each step, it assigns some amount of energy to certain layer which can be utilized in the most efficient way, that is, it can achieve the largest distortion reduction. Before describing the algorithm, we first introduce some notations.

For each layer l, let $\Delta G_l(s_l, s_l')$ be the *relative distortion reduction* by changing the schemes from s_l to s_l', that is:

$$\Delta G_l(s_l, s_l') = G_l(s_l') - G_l(s_l) \tag{13}$$

and let $\Delta E_l(s_l, s_l')$ be the *relative energy consumption increase* by changing the schemes from s_l to s_l':

$$\Delta E_l(s_l, s_l') = E_l(s_l') - E_l(s_l) \tag{14}$$

Now, we define the *normalized gain* as

$$g_l(s_l, s_l') = \frac{\Delta G_l(s_l, s_l')}{\Delta E_l(s_l, s_l')} \tag{15}$$

Let $s^0, s^1, s^2, \ldots, s^{|S|} \in S$ be the set of all available schemes in the increasing order according to their energy consumption for a certain layer. Now we define the *feasible strategy set*, S_l, for each layer l, as the subset of S where the necessary and sufficient condition that $s^i \in S$ belongs to S_l are

$$\min_{k<i} g_l(s^k, s^i) > 0 \tag{16}$$

and

$$\min_{k<i} g_l(s^k, s^i) > \max_{j>i} g_l(s^i, s^j) \tag{17}$$

In other words, all the feasible strategies should reside on the convex hull of the energy-gain curve for that layer. Consequently, for all $s_l^1, s_l^2, \ldots, s_l^{|S_l|} \in S_l$, we have the following properties:

$$0 = E_l(s_l^0) < E_l(s_l^1) < \cdots < E_l(s_l^{|S_l|}) \tag{18}$$

$$0 = G_l(s_l^0) < G_l(s_l^1) < \cdots < G_l(s_l^{|S_l|}) \tag{19}$$

$$(\forall j > i) : g_l(s_l^i, s_l^{i+1}) > g_l(s_l^j, s_l^{j+1}) \tag{20}$$

For each layer l, the feasible strategy set can be obtained using a conventional convex hull analysis, as in Alg. 1.

Algorithm 1 feasible strategy set search

```
Let $S_l$ be the set of all available schemes for layer $l$;
for ($\forall s \in S_l$) do
    Calculate $G_l(s)$ and $E_l(s)$;
end for
Arrange the elements $s$'s of $S_l$ in increasing order according to $E_l(s)$;
Delete all the $s$'s from $S_l$ if there exists an $s'$ such that $G_l(s') > G_l(s)$ and $E_l(s') \le E_l(s)$;
Perform convex hull analysis on $S_l$ such that the elements of $S_l$ satisfy the inequalities (16) and (17);
Return $S_l$;
```

After finding the feasible strategy sets for all the layers, the JSCCPC algorithm given in Alg. 2 can be applied to approximate the optimal solution for (6). By adjusting the length of the last transmitted layer to be transmitted, the optimal solution can be approximated very well.

The computation complexity of the proposed algorithm is analyzed below. Assume the total number of quality layer is L, the total number of available strategies is N_s, and the number of marked strategies is N_m. Let the time for calculating $G_l(s_l)$ and $E_l(s_l)$ be T_g. By using quick sort, the computation complexity of the feasible strategy set search for each layer becomes $O(N_sT_g + N_s log_2 N_s + 2N_s)$, where N_sT_g results from the gain and rate calculation, $N_s log_2 N_s$ from the quick sort, and $2N_s$ from convex hull analysis. Then the overall computation complexity becomes $O(LN_sT_g + LN_s log_2 N_s + 2N_sL + N_m log_2 L)$. If $L = 10$, $N_s = 100$, $N_s = 50$, then the bound becomes $1000T_g + 10000$.

Algorithm 2 JSCCPC algorithm for single-hop

```
$G = 0; G_{min} = D_{total} - D_{max}$;
for ($1 \le l \le L$) do
    Find $S_l$ using Alg. 1;
    Let $s_l = s_l^0$ and mark $s_l^0$;
end for
while ($G < G_{min}$) do
    Find the layer $l$ and the strategy $s_l'$ such that $g_l(s_l, s_l')$ is maximized among all layers and all unmarked strategies in this layer ;
    $G = G + \Delta G_l(s_l, s_l')$;
    Mark $s_l'$ and let $s_l = s_l'$;
end while
if ($G > G_{min}$) then
    Let $l$ be the last layer with $s_l \ne s_l^0$, adjust the length of this layer to be $n_l - n_l(G - G_{min})/G_l(s_l)$;
end if
Return $\bar{s}$ and $\{n_l\}$.
```

VI. SIMULATION RESULTS

In our simulations, we assume that 0.18μ CMOS circuits are used, with the input voltage $V_{dd} = 2.5V$. The target system throughput is 1Mbps. The modulation scheme is BPSK. A family of RCPC codes with code rates varying from $8/9$ to $1/3$ is used, where the mother rate is $1/3$, period is 8, and memory size is 6 [10] . Four transmitter power levels are assumed to be available: 10dBm, 11dBm, 12dBm, 13dBm. Four types of source error resilient coding schemes can be applied by the source transcoder, which are header protection using RS codes, packet level sync. marker insertion, coding pass level marker insertion, and RAW coding. Two channel models are considered: AWGN channel and Rayleigh flat fading channel. For Rayleigh flat fading channel, the Doppler frequency is set to be $80Hz$. We assume the receiver can perfectly estimate the channel state information (CSI). To calculate the transmission power consumption, we assume the PAE is 40%. The power consumption of RS coding and RCPC coding are estimated using the power estimation tool MED [17]. In our simulation, P_{base} = 10mW. Since the energy consumption of source compression is independent of the optimization, its value is not factored in.

In this section, three schemes are compared: joint source channel matching (JSCM), joint source channel matching with power control (JSCMPC), and JSCCPC. In these schemes, the multi-layer quality scalable bitstream is first generated using JPEG 2000 under the compression mode. JSCM means that only channel code rates can be adaptively adjusted, while source error resilient coding schemes and transmitter power levels are kept fixed. JSCMPC means that both channel code rates and transmitter power levels can be adaptively adjusted, while source error resilient coding schemes are fixed. JSCCPC means that all the three parameters can be adaptively adjusted.

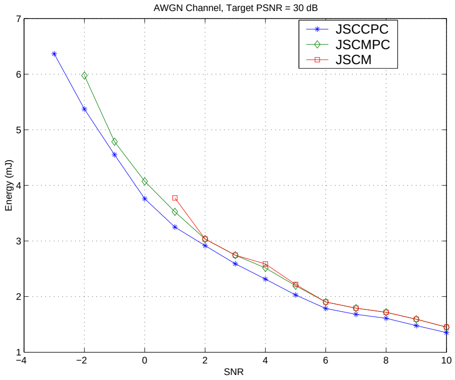

Fig. 3. Simulation results for AWGN channels

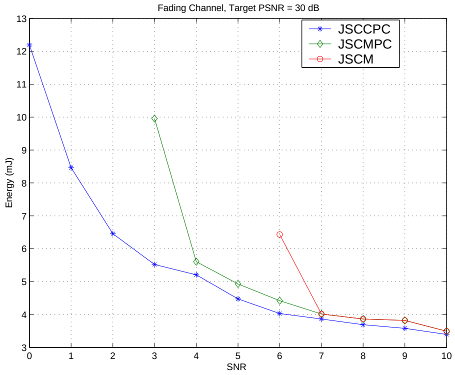

Fig. 4. Simulation results for Fading channels

Fig. 3 shows the simulation results for the AWGN channel with target PSNR equal to 30dB. The channel SNR varies from -3dB to 10dB with the reference transmitter power level 10dBm. If the target QoS constraint is not achieved, no point is drawn in the figure. From the simulation results we can see that the JSCCPC scheme performs slightly better than the other two schemes in all situations, and the JSCMPC scheme outperforms the JSCM scheme when the SNR is low.

Fig. 4 shows the simulation results for Rayleigh fading channels. Compared with Fig. 3, we can see that under the same channel SNR and QoS constraint, fading channel causes more energy consumption. The key observation is that the energy efficiency of JSCCPC scheme becomes more salient, especially when the SNR is relatively low. For example, at 6dB, the JSCCPC consumes 9% less energy than the JSCMPC, and 37% less than the JSCM. At 3dB, the JSCCPC consumes 45% less energy than JSCMPC. Under these conditions, the JSCM scheme cannot even achieve the target PSNR. For channel conditions in which the SNR is less than 3dB, the target PSNR can only be achieved by the JSCCPC.

VII. CONCLUSION AND FUTURE WORK

In this paper, we propose an energy efficient image transmission system for point-to-point wireless networks. The proposed algorithm is adaptable, optimal and has low-complexity, which overcomes the drawbacks of previous approaches. Simulations have been conducted with AWGN and fading channel models and illustrate that up to 45% less energy consumption could be achieved under relatively severe channel conditions.

Currently, the system only considers the case that the transmitter can directly communicate with the receiver. In some cases, the transmitted signals may have to be relayed by some intermediate nodes. One direction of our future work is to extend the system to relay networks. Another direction is to extend the system to multi-cast transmissions.

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