Improved Image Transmission over Wireless Channels

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Abstract — **An improved technique for image transmission over wireless channel with flat Rayleigh fading is considered in this paper. The proposed scheme minimizes the mean-square error in image transmission rather than the bit error rate. The minimization is done by optimizing the power allocated to each bit according to its importance to the image quality along with the use of channel coding. An algorithm that works iteratively to achieve this goal is presented and analyzed in this paper. It is shown that the proposed technique provides significant gain compared to conventional schemes that send the same power for all bits. It also provides better performance compared to the case were power allocation alone or coding alone is used, with a gain of 2 to 3 dB. It also provides a good performance in terms of reducing the peak-to-average power ratio compared to the case of power allocation alone.**

Index Terms — **Coding, Image transmission, MMSE , power allocation.**

I. INTRODUCTION

Image transmission is a key service to be offered by third generation mobile radio systems [1] [2] as well as future generations. This is to meet the increasing demand for multimedia services fueled by the surge in Internet use and the need for accessing all types of information while on the move. However, sending images and video signals require a communication system capable of sending data at high speeds while keeping the average probability of bit error at an acceptable level. This is deemed to be very challenging in mobile radio systems due to the harsh nature of the wireless medium caused by multipath propagation and mobility of users. To meet these requirements, wireless communication systems that efficiently utilize the system resources are sought. These resources include transmission bandwidth and transmitted power.

Power control has been an effective approach to mitigating the effect of fading channels in the quality of signal transmission over wireless channels [3] [4]. The system typically involves a mechanism of measuring the quality of the channel seen by the receiver and providing such information to the transmitter to adjust the amount of transmitted power. For instance, if the channel is good then less power is used while if the channel is bad then more power is used. Few modifications to this strategy have been proposed such as to send higher data rates rather than reducing the power if the channel is good or not to send at all if the channel is bad. The main issues for these systems are the need for a feedback link fast enough to track the time variation of the channel and not utilizing the message structure of the image or video signal to be transmitted in power allocation.

The other effective approach to improve the quality of signal transmission over wireless channels is the use of channel coding techniques. Channel coding is considered as a main component of any digital communications system operating over wireless channels. However, there is an increase in the required bandwidth (or reduction in the data rate) due to channel coding. Thus, we would like to provide better performance while minimizing the amount of bandwidth used by the coding scheme. A common problem with coding schemes is their degraded performance at low signal-to-noise ratio. Variable rate channel coding schemes have been proposed to take advantage of knowledge of the channel status [5]. In some systems, like second generation GSM mobile radio system, channel coding is used selectively for message bits that carry more information while no coding is used for less important bits [6].

Recently, a new algorithm for power allocation to information bits according to their importance was proposed and proved to provide a gain of 3 to 4 dB in image transmission over AWGN channel, without any increase in the bandwidth [7]. The proposed scheme was based on adjusting the amount of power transmitted for each bit according to its importance in the image quality as measured by the mean-square error. However, the system suffered from an increase in the peak-to-average power ratio.

In this paper, we propose a new algorithm for combining power allocation with coding to improve the quality of image transmission over fading channels. The intention is to utilize the advantages and minimize the drawbacks of both schemes. For example, coding doesn't perform well at low SNR while power allocation provides considerable gain in such a condition. Moreover, coding will help in decreasing the peak-to-average power ratio. The combined scheme is well suited for transmission of image and video signals, where different bits carry different amount of information. The combined scheme is specifically optimized for minimizing the mean square error (MSE) of the image or video signal rather than the bit error rate (BER) since it is more indicative of the image quality, as was shown in [7].

The paper is organized as follows. Section II presents the signal model. The proposed combined power optimization and coding algorithm is presented in section III. Section IV presents the simulation results. Finally, conclusions are drawn in section V.

II. PROPOSED SYSTEM DESCRIPTION

As mentioned earlier, the proposed scheme is in this paper will perform joint power allocation and coding for individual bits that are used to represent a pixel in an image. More power and coding will be allocated to bits that carry more information while bits with less significance are allocated less power and may be coded or not. The objective is to obtain a better quality of image transmission.

The system considered in this paper is a typical binary phase shift keying (BPSK) digital communication system for image or video transmission. Initially, the image or video signal is converted from analog to digital using any of the conventional source coding schemes. For example, the signal is sampled, quantized, and then coded into binary bits for transmission by the BPSK system. Each sample is coded into *M* bits.

These bits will be processed at the transmitter by the coding block followed by the power allocation algorithm as shown in Figure 1. First a frame of data is formed by buffering *N* bits at a time. Typical frame duration is 20 ms, however smaller values could be used to reduce the delay. The data is first de-multiplexed into *M* parallel streams, with each stream having the bits of similar importance. In other words, most significant bits for consecutive samples (pixels) are placed together, then the next most significant bits, and so on. Each stream of bits will be either fed into a channel encoder or passed without encoding according to the energy per bit-to-noise power spectral density (E_b / N_o) of the system.

Although convolution coding is used in this paper, other encoding schemes may be used. The outputs of the encoders are multiplexed together followed by interleaving to resist the effect of channel fading. The interleaving is done such that all the bits that correspond to the same sample (pixel) of the original signal are gathered back again to insure that the channel conditions will be the same for all of them. In other words, the interleaving block will not only improve the performance of the decoder but also allow the power allocation to be feasible; since we can assume that the channel conditions will stay the same for the same pixel and hence the value of E_b / N_o used to set the power allocated to each bit is the same. This E_b / N_o will be the input for the power allocation algorithm to adjust the energy for each symbol according to its importance as will be descried later on.

The transmitted BPSK signal is represented as

$$s(t) = \sum_{k=0}^{M-1} \sum_{i=0}^{L/R_{ck}-1} \sqrt{w_k}\, c_{ki}\, g(t-(kM+i)T_s) \quad (1)$$

where w_k is the transmitted power for the symbols in the k^{th} stream, c_{ki} is the i^{th} code symbol (± 1) or the k^{th} data bit depending whether coding is used or not, $g(t)$ is a rectangular pulse shape of the transmitted signal, T_s is the symbol duration, R_{ck} is the either the code rate or one depending if coding is used or not, and $L = N / M$ is the number of bits per stream.

The wireless channel is modeled as a flat Rayleigh fading channel with received signal given by

$$r(t) = \alpha s(t-\tau) + n(t) \quad (2)$$

where α represents the complex channel coefficient with amplitude following the Rayleigh distribution and uniform phase over $[0, 2\pi)$ and τ is the propagation delay. The additive white Gaussian noise (AWGN) is represented by $n(t)$ with zero-mean and two sided power spectral density of $N_0 / 2$.

The received signal is processed using a matched filter followed by the de-interleaver and then convolutional decoding using the Viterbi algorithm. The decoder output bits are regrouped so that bits belonging to one sample are placed in their proper order. Finally, digital to analog conversion is used to reconstruct the original image.

Let us define the power vector as $\underline{w} = [w_0 w_1 ... w_{M-1}]$. In the conventional scheme of power allocation, all bits carry the same amount of power regardless of their significance. Thus, $\underline{w}$ is simply a vector of all ones; i.e. $w_i = 1$ for $i = 0, 1, ..., M-1$. Such allocation is shown to be suboptimal and we propose to optimize the allocated amount of power to each symbol, i.e. optimize $\underline{w}$, such that more power is allocated to the most important bits under the constraint that the average energy per bit is kept the same as for the conventional scheme. We remark that there is no increase in the transmission bandwidth of the signal due to this power allocation scheme and the only increase is due to the coding. However, the peak-to-average power ratio (PAPR) will be increased slightly. In the proposed iterative scheme in the following section, we will keep the PAPR under a specified value such that there is no significant degradation in the efficiency of the power amplifier use to amplify the signal.

III. CODING AND POWER ALLOCATION ALGORITHM

Minimizing the average probability of bit error during transmission is commonly the main objective in designing a communication system. The rational is that minimizing the probability of error will result in better quality of signal transmission. However, this is not always the case. For instance, in voice, image, and video transmission, what is important is the quality of the message after detection. A better performance measure in such cases is the root-mean square error (RMSE) rather than the BER because bits transmitted by the system do not carry the same amount of information about the message. Thus, it is important to establish a relationship between the RMSE and BER for those applications.

For a system with M bits per sample, there are 2^M different samples to be transmitted. The binary representation of sample x_j is given by the j^{th} row of the following $2^M \times M$ matrix,

$$H = \begin{bmatrix} 0\,0\,0\,...........0 \\ 0\,0\,0\,...........1 \\ .... \\ .... \\ 111\,...........1 \end{bmatrix} \qquad (3)$$

with elements h_{jk}. The mean square error (MSE) is given by

$$MSE = \sum_{j=0}^{2^M-1} (x_j - \hat{x}_j)^2 P(x_j) \qquad (4)$$

where $\hat{x}_j$ is the estimate of the j^{th} sample reconstructed after detection of the M bits and $P(x_j)$ is the a priori probability that the j^{th} sample is transmitted. Without loss of generality, let us consider the transmission of the sample with a value of zero and a binary representation of all zero (j = 0). The possible received sequence of M bits will be one of the other $2^M - 1$ combinations. The probability that i^{th} sample with a decimal value of (i) is reconstructed is given by

$$PS_i = \prod_{k=0}^{M-1} [P_k \gamma_{i0}(k) + (1-P_k)\overline{\gamma}_{i0}(k)] \qquad (5)$$

where P_k is the probability that the k^{th} bit is in error and $\gamma_{i0}(k)$ is

$$\gamma_{i0}(k) = \begin{cases} 0 & if \quad h_{0k} = h_{ik} \\ 1 & if \quad h_{0k} \neq h_{ik} \end{cases}. \qquad (6)$$

with the notation $\overline{\gamma}_{i0}(k)$ representing the binary inversion of $\gamma_{i0}(k)$.

The MSE for the above case is calculated as

$$MSE_0 = \frac{1}{2^M - 1} \sum_{j=1}^{2^M-1} i^2 \prod_{k=0}^{M-1} [P_k \gamma_{i0}(k) + (1-P_k)\overline{\gamma}_{i0}(k)] \qquad (7)$$

The MSE for other samples can be obtained following a similar procedure and the average MSE can be calculated by averaging over all possible samples. It is possible to show that, on average, all MSE values are approximately the same and hence equation (7) will be average MSE. The root mean-square error (RMSE) is obtained by taking the square root of (7). Note that the probability of the k^{th} bit to be in error for the AWGN case, without coding is given by

$$P_k = Q(\sqrt{2E_b(k)/N_0}) \qquad (8)$$

If coding is used, then it can be approximated by the upper bound formula [8]

$$P_k < \sum_{d=d_{free}}^{\infty} \beta_d Q(\sqrt{2\frac{E_b(k)}{N_0} R_c d}) \qquad (9)$$

where $E_b(k) = w_k T_b$ is the energy for the k^{th} bit.

Power Allocation Algorithm

The problem at hand can be stated as follows. We would like to find the optimum power distribution such that the RMSE is minimized subject to the constraints that the average energy per bit is kept constant and the PAPR is kept below a certain limit. The above optimization is done for RMSE regardless of the average probability of bit error. The proposed iterative power allocation algorithm is as follows:

1. *Initialization*:
   i. initialize the power distribution vector to all ones (assume the energy is the same for all bits with $w_i = 1$ for i = 0, 1, …, M - 1)
   ii. initialize the coding flag vector, F, to all zeros (assume that no coding will be done for any of the bits, i.e. $F_i = 0$ for i = 0, 1, …, M - 1)
   iii. calculate MSE using (7) and (8) for a given E_b / N_0
   iv. define two bits, B is borrowing power and D is donating power
   v. Set the maximum limit of the PAPR to $PAPR_{max}$ and set the energy step size to ΔE_b

2. *Iteration*:
   i. set B = $M-1$, most significant bit (MSB) as borrower; and D = 0, least significant bit (LSB) as donor
   ii. reduce the energy for the D bit by ΔE_b and increase the energy of B bit by the same amount such that during the n^{th} iteration we have

$$E_{bD}(n) = E_{bD}(n-1) - \Delta E_b$$
$$E_{bB}(n) = E_{bB}(n-1) + \Delta E_b$$

Note that within a block of M bits, the minimum energy per bit is zero and the maximum energy per bit is ME_b, where E_b is the average energy per bit

iii. Calculate the MSE by using (7) and (8) for the uncoded bits and by using (7) and (9) for the coded bits for the following cases (note that the coding flag vector determines the bits to be coded)

    (a) Both the borrower and the donor are coded.
    (b) The borrower is coded while the donor is not.
    (c) The donor is coded while the borrower is not.
    (d) Both of the borrower and the donor are not coded.

    According to the minimum value of the MSE calculated previously, update the coding flag vector such that

    1. F_B =1 and F_D=1 if case (a) gave the minimum MSE.
    2. F_B =1 and F_D =0 if case (b) gave the minimum MSE.
    3. F_B =0 and F_D =1 if case (c) gave the minimum MSE.
    4. F_B =0 and F_D =0 if case (d) gave the minimum MSE.

    We keep changing the energy of the two bits until we find the minimum value of MSE while the PAPR is kept less than $PAPR_{max}$

iv. Repeat the same procedure (ii) and (iii) above but with the donor bit D is incremented by one until all least significant bits are used.

v. Next reduce the borrower bit by one to optimize the second most significant bit ($B = M - 2$) and repeat steps (ii) till (iv)

vi. The above steps are repeated until all bits are optimized; i.e. $B = 0$

vii. Every time the minimum MSE is searched for and PAPR is ensured to be within the limit of $PAPR_{max}$

IV. NUMERICAL RESULTS

Simulation and analytical results for the RMSE obtained using the conventional equal-power, power allocation alone, coding alone, and combined coding and power allocation algorithms are presented. An image transmitted using each of these schemes is shown in Fig. 2. The image was transmitted at an average E_b / N_0 of 7 dB over a flat Rayleigh fading channel. As we see, the combined approach provides and excellent reproduction of the image compared to others. Coding alone provide a better picture but still falls short of the quality of the combined approach. Power allocation alone and the conventional algorithms did not provide acceptable quality.

Figure 3 shows the RMSE performance as a function of E_b / N_0 for the four schemes over a flat Rayleigh fading channel. There was no limit imposed on the PAPR, so this shows the ultimate gain we can achieve with power allocation. As we can see, coding alone is good for high E_b / N_0 while power allocation alone is good for low E_b / N_0. The combined approach shows excellent performance over the whole range of E_b / N_0 since it works to optimize the performance according to the operating E_b / N_0. Specifically, it shows about 2 to 3 dB gain over the coding alone or the power allocation alone cases at low E_b / N_0. The gain over the power allocation alone and conventional schemes is quite significant.

As noted in [7], the power allocation algorithm achieves good performance but at the expense of increasing the PAPR. It was shown that allowing the PAPR to increase by 3 to 4 dB would get most of the gain. However, this is relatively a high price to pay since it reduces the efficiency of the power amplifier significantly. With the combined coding and power allocation technique proposed in this paper, a good reduction in the PAPR is achieved, though. This is illustrated in Fig. 4, where the RMSE is plotted against the limit imposed in PAPR at a given value of E_b / N_0. To achieve the same RMSE, there is a reduction in PAPR of about 2 dB compared to the power allocation alone.

V. CONCLUSION

In this paper, combined coding and power allocation is proposed to improve the quality of image transmission over wireless channels. The criterion for optimization is minimizing the mean-square error of the transmitted image rather then the average probability of bit error. This criterion is used to exploit the difference in importance among bits representing image pixels. Numerical and simulation results of the proposed scheme show that the mean-square error performance is significantly improved compared to the case of coding alone, power allocation alone, or conventional equal-power scheme; with a gain of about 3 dB in E_b / N_0. While achieving this gain, the proposed scheme also reduces the peak-to-average power ratio compared to the case of power allocation alone. A typical reduction is about 2 dB in PAPR.

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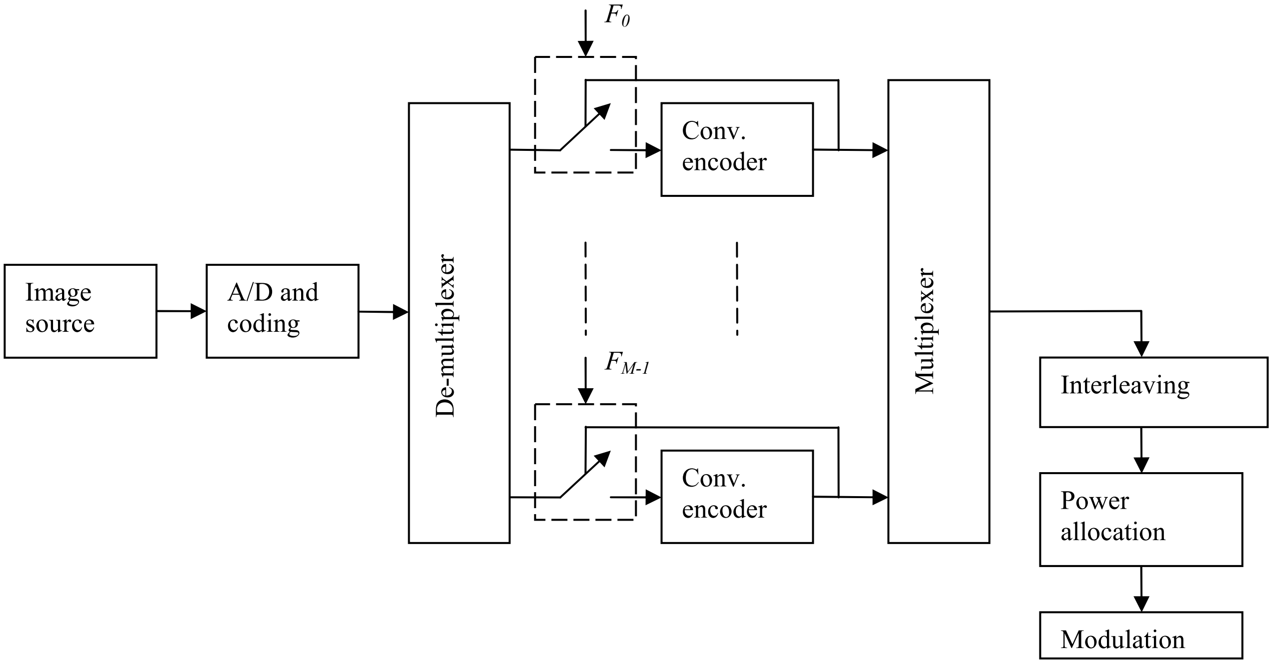
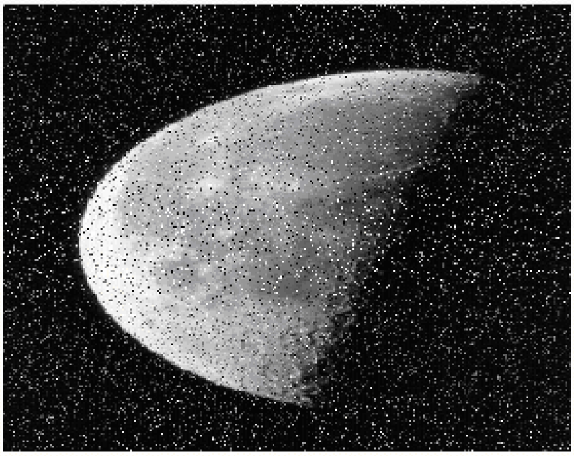
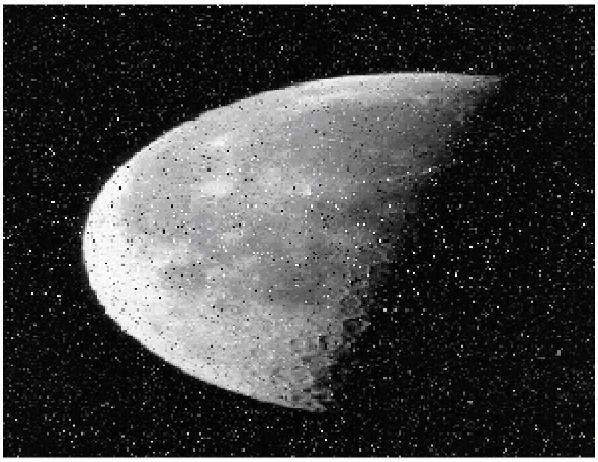


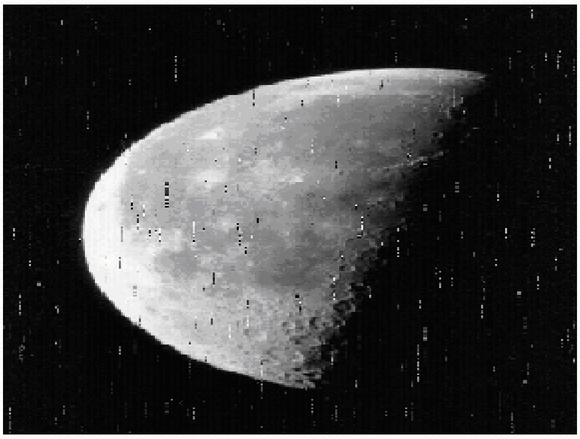
Fig. 1. Combined power allocation and coding system block diagram.



(a) conventional



(b) power allocation



(c) coding alone

(d) combined power allocation and coding

Fig. 2. Image transmission over flat Rayleigh fading with E_b / N_0 of 7 dB; (a) conventional equal-power; (b) power allocation; (c) coding alone; (d) combined power allocation and coding.

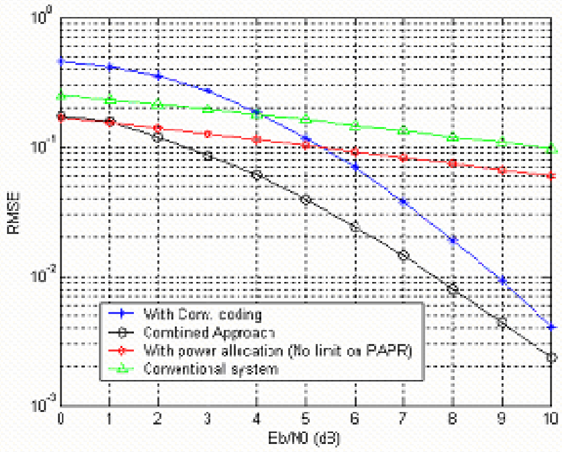


Fig. 3. Mean square error performance of image transmission with no peak-to-average power ratio limits over flat Rayleigh fading with E_b / N_0 of 7 dB.

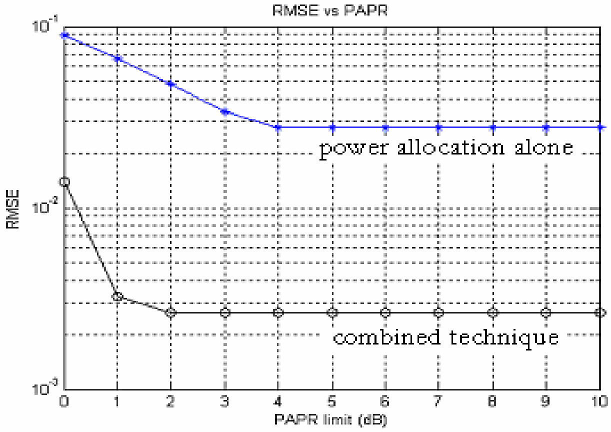


Fig. 4. Effect of allowed increase in PAPR on the mean square error performance in AWGN with E_b / N_0 of 3 dB