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# Dynamic Power Allocation For Transmission of 2-D Signals Over Wireless Channels

**M Padmaja[1] P Satyanarayana[2] & K.Prasuna[3]**

[1]Department of Electronics and Communication Engineering, VR Siddhartha Vijayawada-7, AP.
[2]Head of Electrical and Electronics Engineering, Sri Venkateswara University, Tirupati, AP.
[3]Department of Electronics and Communication Engineering, Vijaya Institute of Technology for Women, Vijayawada,AP.
[1]padmaja19m@gmail.com, [2]satyamp1@yahoo.com, [3]prasuna.k@rediffmail.com

ABSTRACT

A power allocation technique is based on the transmitted bits according to their significance on the message quality. The proposed scheme is based on optimizing the power allocation to minimize the mean square error rather than the bit error probability of image signals transmitted over fading wireless channels. An analytical framework for the power allocation technique is developed. Two techniques of power allocation: fixed and dynamic, are investigated in the paper. Simulation results show that the proposed scheme provides a gain in $E_b/N_0$ in AWGN channels and also in flat fading channels over conventional equal-power allocation system. This gain is achieved without any increase in bandwidth, as opposed to that achieved with channel coding. The gains achieved with this algorithm come at the expense of slight increase in the peak-to-average power ratio of the transmitted signal.

*Keywords:* Dynamic Power Allocation, Mean Square Error, Rayleigh Fading Channels.

## 1. INTRODUCTION

Transmission of images and video signals over wireless links is considered as one of the prime applications of future mobile radio communication systems. However, such applications require the use of relatively high data rates (in the Mbps range) compared to voice applications. With such requirement, it is very challenging to provide acceptable quality of services as measured by the bit error rate (BER) due to the limitations imposed by the wireless communication channels such as fading and multipath propagation. Furthermore, the user mobility makes such a task more difficult because of the time varying nature of the channel. The main resources available to communications systems designers are power and bandwidth as well as system complexity. Thus, it is imperative to use techniques that are both power and bandwidth efficient for proper utilization of the communication resources.

Power control has been an effective approach to mitigating the effect of fading channels in the quality of signal transmission over wireless channels. 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. These systems are considered as opportunistic systems since they take advantage of the information about the channel to optimize the communications process. 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. For instance, if a data rate of 2 Mbps is available for video transmission; this rate would be reduced to 1 Mbps if 1/2 rate channel coding is used. Thus, we would like to provide better performance while minimizing the amount of bandwidth used by the coding scheme. Variable rate channel coding schemes have been proposed to take advantage of knowledge of the channel status. 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.

In this paper, we propose an algorithm for power allocation to information bits according to their importance. This scheme is well suited for transmission of image and video signals, where different bits carry different amount of information. The power allocation scheme is specifically optimized for minimizing the mean square error (MSE) of the image or video signal and not the BER. There is no increase in the bandwidth requirement of the proposed system. It is also possible to combine the proposed algorithm with channel coding to obtain a balance between power and bandwidth utilization.

## 2. SYSTEM MODEL

The system considered is a typical binary phase shift keying (BPSK) digital communication system for image transmission. Initially, the image 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. The transmitted signal is represented as

$$S(t) = \sum_{k=0}^{\infty} \sum_{i=0}^{M-1} \sqrt{w_i} b_{ki} g(t-(kM+i)T_b) \tag{1}$$

where $w_i$ is the transmitted power and $b_{Ki}$ is the information data (±1) of the $i^{th}$ bit in the $k_i$ block of the $M$ bits representing one of the samples, $g(t)$ is a rectangular pulse shape of the transmitted signal, and $T_b$ is the bit duration. Index $i$ represents the location of a bit within the $M$ bits belonging to the same sample with $M$-1 representing the most significant bit (MSB) and index 0 representing the least significant bits (LSB).

The wireless channel is modeled as a flat Rayleigh fading channel [3] with received signal given by

$$r(t) = \alpha s(t-\tau) + n(t) \tag{2}$$

Where α represents the complex channel coefficient with amplitude following the Rayleigh distribution and uniform phase over [0, 2π] and $r$ 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 No /2.

The received signal is processed using a matched filter to minimize the BER. Perfect knowledge of the channel coefficient is assumed to allow for coherent detection. Once the decision about the information bits is made; digital to analog conversion is used to reconstruct the original image.

The power vector is defined as $w = [w_0 w_1 w_2 ... w_{M-1}]$. In the conventional scheme of power allocation, all bits carry the same amount of power regardless of their significance. Thus, $w$ is simply a vector of all ones; i.e. $w_i = 1$ for $i = 0, 1... M-1$. Such allocation is suboptimal and proposes to optimize the allocated amount of power to each block of data, i.e. optimize $w$, 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 BPSK signal.

## 3. POWER ALLOCATION ALGORITHM

In digital communications, minimizing the average probability of bit error during transmission is of more interest. 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 we care about 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 $xj$ is given by the $jth$ row of the following $2^M \times M$ Matrix,

$$PSNR = 10\log_{10}\left(\frac{255^2}{MSE}\right) \tag{3}$$

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

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

where $x_i$ 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, we consider the transmission of the sample with a value of zero and a binary representation of all zero ($i = 0$). 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

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

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

$$\gamma_{i0}(k) = 0 \quad if \quad h_{0k} = h_{ik}$$
$$= 1 \quad if \quad h_{0k} \neq h_{ik} \tag{6}$$

The notation $\overline{\gamma_{io}(k)}$ represents the binary inversion of $\gamma_{io}(k)$. The MSE for the above case is calculated as

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

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. hence equation (7) will be average MSE.

The wavelet transform decomposes the 2-D signal into a set of sub signals called shapes with different resolutions corresponding to different frequency bands. Hence, different allocations are tested, assuming that details at high resolution and diagonal directions are less visible to the human eye. Haar wavelets are used for image decomposition to calculate MSE and PSNR.

Unequal error protection was restricted to a single or at most two parameters. For example, UEP was provided only by unequally assigning different amounts of FECs, and only unequal power allocation was considered. Moreover in although an unequal allocation of source coding, channel coding, and synchronization error tolerances was made to the different sub bands of a wavelet compressed image, no optimization was performed. Other previous works had only prioritized ARQ requests. Furthermore, a hybrid FEC/ARQ scheme was used, UEP was provided solely by different amounts of FECs and there was no prioritization of ARQ requests.

## 4. NUMERICAL RESULTS

The simulation results for the RMSE and PSNR obtained using the conventional fixed power and proposed dynamic power allocation algorithms. The results obtained via equations via simulation on AWGN channel with Rayleigh fading were presented in tabular forms. The results shown in Fig. I indicate the performance of fixed power allocation and dynamic power allocation in terms of MSE and PSNR using BPSK and QPSK at $E_b/N_o$ of 1db for the 2-D test signal Lena.gif with resolution 256 × 256.Table 2 shows the same for cameraman.tif.

The performance comparison between fixed power allocation and dynamic power allocation is plotted for BER with $E_b/N_o$ varying from 0*db* to 10*db* for lena.gif using BPSK as shown in Fig I. The original 2-D signals are shown in Fig II and Fig IV. 2-D signals transmitted over AWGN channel with Rayleigh fading are reconstructed using the proposed algorithm are shown in Fig. III and Fig. V respectively.

**Table1**
**Performance of Fixed and Dynamic Power Allocation for Bpsk and Qpsk (Lena.gif)**

| *BPSK* | *LEVEL* | *MSE* | *PSNR* |
|---|---|---|---|
| | Level 1 | 1.830 | 45.490 |
| Equal Power | Level 2 | 0.630 | 50.130 |
| Allocation | Level 3 | 0.170 | 55.610 |
| | Level 4 | 0.045 | 61.520 |
| | *LEVEL* | *MSE* | *PSNR* |
| Dynamic | Level 1 | 1.827 | 45.490 |
| Power Allocation | Level 2 | 0.628 | 50.120 |
| | Level 3 | 0.168 | 55.600 |
| | Level 4 | 0.040 | 61. 490 |
| *QPSK* | *LEVEL* | *MSE* | *PSNR* |
| | Level 1 | 1.831 | 45.5 |
| Equal | Level 2 | 0.628 | 50.14 |
| Power Allocation | Level 3 | 0.170 | 55.61 |
| | Level 4 | 0.046 | 61.50 |
| | *LEVEL* | *MSE* | *PSNR* |
| | Level 1 | 1.830 | 45.49 |
| Dynamic | Level 2 | 0.627 | 50.14 |
| Power Allocation | Level 3 | 0.168 | 55.61 |
| | Level 4 | 0.045 | 61.54 |

**Table2**
**Performance of Fixed and Dynamic Power Allocation for Bpsk and Qpsk (Cameraman.tif)**

| *BPSK* | *LEVEL* | *MSE* | *PSNR* |
|---|---|---|---|
| | Level 1 | 1.920 | 45.28 |
| Equal | Level 2 | 0.590 | 50.36 |
| Power Allocation | Level 3 | 0.174 | 55.71 |
| | Level 4 | 0.045 | 61.59 |
| | LEVEL | MSE | PSNR |
| | Level 1 | 1.910 | 45.27 |
| Dynamic | Level 2 | 0.580 | 50.33 |
| Power Allocation | Level 3 | 0.172 | 55.71 |
| | Level 4 | 0.044 | 61. 64 |
| *QPSK* | *LEVEL* | *MSE* | *PSNR* |
| | Level 1 | 1.910 | 45.29 |
| Equal | Level 2 | 0.600 | 50.34 |
| Power Allocation | Level 3 | 0.170 | 55.72 |
| | Level 4 | 0.045 | 61.58 |
| | *LEVEL* | *MSE* | *PSNR* |
| | Level 1 | 1.904 | 45.28 |
| Dynamic | Level 2 | 0.595 | 50.38 |
| Power Allocation | Level 3 | 0.168 | 55.76 |
| | Level 4 | 0.040 | 61.61 |

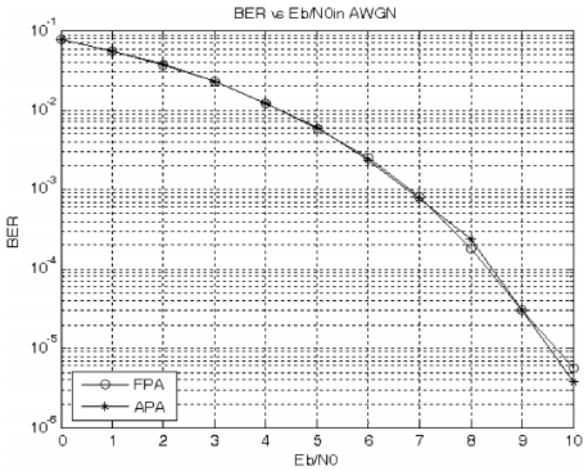


**Fig 1: Performance of Fixed and Dynamic Power Allocation**

**Fig 2: Original 2-D Signal (Lena)**

**Fig 3: Received 2-D Signal (Lena)**

**Fig 4: Original 2-D Signal (Cameraman)**

**Fig 5: Received 2-D Signal (Cameraman)**

**Fig 6 (a) Level 1 Decomposition**

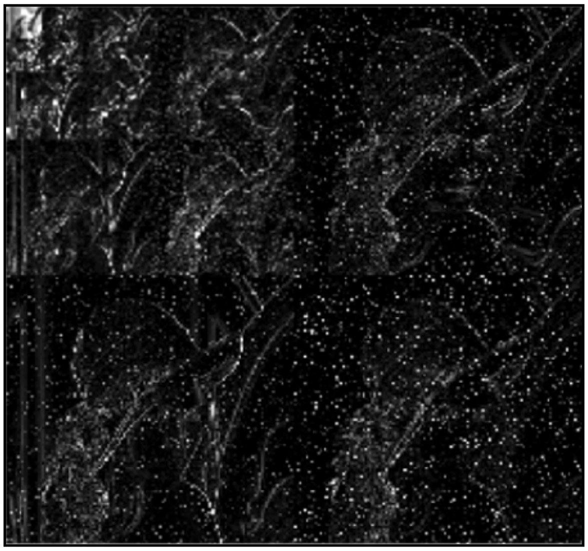

**Fig 6(b): Level 4 Decomposition**

## 5. CONCLUSION

A new algorithm for power allocation in 2-D signal transmission over wireless channels is presented. The proposed algorithm optimizes the bit power allocation based on minimizing the MSE rather than the average BER. It is shown that the proposed scheme provides a significant performance gain compared to the conventional fixed power scheme over Rayleigh fading channels. The proposed technique can be implemented easily since it does not require real time processing and can be computed off-line.

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