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Variable Power Distribution Based JPEG2000 Image Transmission Using OFDM System

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Abstract:
This paper proposes a novel approach for robust transmission of JPEG2000 (JP2) images over wireless channels. It relies on using a wavelet transform that allows for a proper unequal distribution of the transmission power among JP2 coding units according to their contribution to the decoded image quality. In the proposed system, the JP2 stream is divided into a certain number of packet groups and each group is transmitted through a separate sub-channel at a different rate and power.
By using an Unequal Power Allocation (UPA) scheme and Orthogonal Frequency Division Multiplexing (OFDM) technique a transmission of JPEG2000 images over a block fading - frequency selective channel is presented. Power is assigned to each bit in the JPEG2000 bit stream using instantaneous and average channel state information based on its contribution to the decoded image quality. More over measured and compared the total power and consumed power for transmission. When the UPA scheme is used results show an improvement of up to10. 5 dB in the decoded image quality.

Key words: *JPEG2000, OFDM, Wireless Image Transmission, Unequal power Allocation*

1.Introduction

Wireless transmission of still images and video streams over fading and noisy channels is a challenging task which has been under enormous developments in recent years. Fading, interference, shadowing, path loss and multipath are sources of disturbance in wireless channels, which introduce error to a transmitted data bit stream. The challenge in transmission of a scalable bit stream is to ensure high reliability of the received signal, while maintaining high data rate during transmission.

MOBILE applications are expected to significantly intensify the transmission of visual data over wireless channels in the next future, due to the widespread use of multimedia mobile communications for both personal and business purposes. This will soon generate a strong demand for wireless devices able to efficiently transmit multimedia data and the transmission of images is probably the most desired features. A crucial point for the overall performance of these applications is the quality of the data delivered to the end user. In this context, compression techniques are usually adopted to reduce the needs in terms of bandwidth, while ensuring acceptable reconstruction quality. Nevertheless, due to the extensive use of predictive and variable length codes, a compressed stream is in general more vulnerable to data losses and transmission errors, which can desynchronize the decoder causing spatial and temporal error propagation.

1.1.Related Work And Contributions

Among available techniques for image transmission which use JPEG2000 source coder, [2] proposes UEP by jointly optimizing source rate and channel rate using the Viterbi algorithm. In [3], UEP is achieved by using the error-resilient feature of JPEG2000 images and employing product coded streams which consist of Turbo-codes and Reed- Solomon codes. In [4], the authors obtain UEP uses Reed Solomon (RS) channel coding for the header and convolutional coding for the body of the image bitstream. In [5], Houas *et al.* utilize Rate Compatible Punctured Convolutional (RCPC) codes to enable UEP for transmission of JPEG2000 images in OFDM systems. In [6], Sabir *et al.* propose to transmit JPEG compressed images using an UPA scheme over MIMO systems. An optimized UPA scheme is proposed in [7] based on increasing image quality as well as RS channel coding to protect coded bitstream. Most of these strategies make use of product channel codes which increase complexity and lower the data rate. Unlike recently published researches, in [8], we proposed an optimized UPA scheme based on minimizing the total image distortion which proved its effectiveness for frequency flat (non-selective) fading channels. Using our previous approach, in this paper, we propose an optimized UPA scheme suitable for transmission of JPEG2000 images in frequency selective channels, an issue which arises at high transmission rates associated with multimedia communications. Our proposal offers several advantages: maintains a low complexity, does not lower data rate and does not require a dedicated source decoder.

Our contributions can be summarized as follow:

• Following [8], we propose a UPA scheme for frequency selective block fading channels, where the power allocation algorithm is combined with Orthogonal Frequency Division Multiplexing (OFDM).

• We further provide an in-depth analysis of the actual
power consumed by the coding passes, and verify that the summation of these power values match the total power constraint considered for the whole bitstream.

• Finally, a comprehensive Monte Carlo simulation study is presented to demonstrate the efficiency of the proposed UPA algorithm in an OFDM system.

2.Objective Description

2.1.Jpeg2000 Image Coder

The transformation technique used in JPEG2000 is the Discrete Wavelet Transform (DWT). The first operation is to (optionally) partition a source image into a number of rectangular non-overlapping blocks called tiles. Then DWT is applied to each tile which essentially analyses an image by decomposing it into subbands at different levels of resolution. The first level of decomposition consists of four subbands LL1, LH1, HL1, HH1 [9]. The LL1 subband is the lowest resolution of the tile. The LL1 subband can be further decomposed by applying DWT. This process can be repeated to obtain different resolution levels. Then, each resolution of each tile component is further partitioned into precincts. Within every sub band, each precinct contributes one packet to the code-stream of the image. Entropy encoding is used to further subdivide the precincts into code-blocks. Each code-block is then decomposed into a number of bit-planes. Finally the coder scans through the bit planes within three coding passes. Each of the coding passes collects the relevant information about the bit-plane data. Fig.1 illustrates a 3 layer decomposition of a source image using DWT and its partitioning into four resolution levels, sub bands, precincts, and code-blocks.

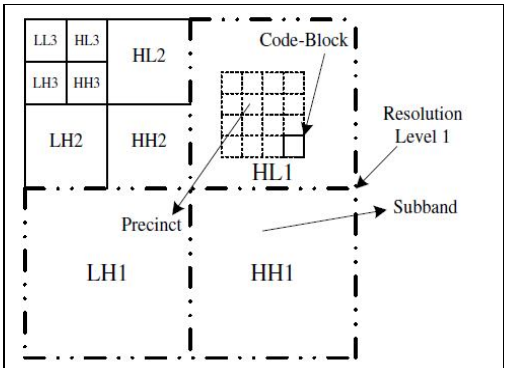

Fig. 1: Components of a JPEG2000 transformed image

Figure 1

2.2.Orthogonal Frequency Division Multiplexing

In some respects, OFDM is similar to conventional frequency-division multiplexing (FDM). The difference lies in the way in which the signals are modulated and demodulated. Priority is given to minimizing the interference, or crosstalk, among the channels and symbols comprising the data stream. Less importance is placed on perfecting individual channels. In OFDM, the subcarrier frequencies are chosen so that the subcarriers are orthogonal to each other, meaning that crosstalk between the sub channels is eliminated and inter carrier guard bands are not required. This greatly simplifies the design of both the transmitter and the receiver. Unlike in conventional FDM, a separate filter for each sub channel is not required.

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication, whether wireless or over copper wires, used in applications such as digital television and audio broadcasting, DSL broadband internet access, wireless networks, and 4G (4^{th} generation) mobile communications.

3.Design Approach

This chapter gives the complete illustration about the proposed method including block diagram and its operation.

The below fig denotes the overall block diagram of the proposed approach. It is divided into two sections named as OFDM transmitter at which the preprocessing (JPEG2000 encoding) takes place and OFDM receiver at which post processing (JPEG2000 decoding) takes place. Once the Structural Information Retrieval unit recovers the required information from the source code such as the number of code-blocks and the number of coding passes within each code-block, the UPA optimization algorithm is applied on the coded bit stream of the JPEG2000 image. In the UPA optimization block, an optimal power is allocated to each bit in order to minimize the total distortion of the received image. The vector e'_{ij} contains the optimized power of each bit of the code stream.

This vector is divided into several blocks using a serial to parallel buffer, and each block is diagonalised into a matrix, $\mathbf{E'}_n$ of size N × N, where N is the number of subcarriers in the OFDM transmitter. Then, the Instantaneous Power Adjustment unit uses the instantaneous Channel State Information (CSI) to calculate the actual power of each bit in the north transmission block, and forms the diagonal matrix **E**n. In the OFDM transmitter, a serial to parallel buffer is used to divide the bit stream obtained from the JPEG2000 encoder into N_B number of parallel blocks, x_n, each of size N×1. The power profile and data corresponding to each block are multiplied to form the vector

$$S_n = \sqrt{E_n x_n}$$

Where **E**n is an N × N diagonal matrix whose diagonal elements (defined later in (4)) are the actual power of the bits in the vector x_n. To modulate the N subcarriers by the bit stream, elements of s_n are transformed by the Inverse Fast Fourier Transform (IFFT) to form $y_n = Q^H s_n$. The adjacent subcarriers in y_n are apart exactly by one cycle. This property ensures the orthogonality between the subcarriers. The lower rate parallel subcarriers provide higher symbol duration which lessens the relative amount of dispersion in time caused by multipath delay spread. This, in addition to introducing a guard time in every OFDM symbol, eliminates Inter Symbol Interference (ISI) [10].In the guard time, a cyclic prefix is appended to the beginning of each OFDM symbol (y_n), to form the transmitting sequence, z_n, with a size of (N +m) × 1, as shown in Fig. 3. The cyclic prefix consists of the last m samples of every OFDM symbol (m < N). The size of the cyclic prefix, m, is equal to the memory of the channel or the number of taps in the multipath channel. The wireless communication channel is considered to be block fading frequency selective where the terminals are equipped with single transmit and receive antennas. The channel impulse responses for the nth transmission block are given by $h_n = [h_0, h_1 \ldots h_{m-1}]^T$ where m is the channel memory length and n = 1, 2, ...,N_B. The random vectors, h_n, are assumed to be independent zero-mean complex Gaussian, remain constant over a single block of data and vary independently for every block. The received signal at the destination terminal is given by:

$$r_n = H_n Q^H \sqrt{E_n x_n} + v_n \quad n = 1, 2, \ldots, N_B$$

where $\mathbf{r}_n$ is the nth received block of data, H_n is an N × N Circulant matrix for the nth transmission block with entries $[H_n]_{ik} = [h_n]_{(i-k) \bmod N}$ and $[h_n]_i = 0$ for $i > m - 1$. The vector vis the Additive White Gaussian Noise (AWGN) with a size of N × 1, zero mean and variance of 1/2 per dimension.

The OFDM receiver transforms the received samples to the frequency domain by applying the Fast Fourier Transform (FFT), i.e. multiplying by the Q matrix.

$$Qr_n = \lambda_n \sqrt{E_n x_n} + QV_n \qquad n = 1, 2, \ldots\ldots N_B$$

Where $\lambda_n = QH_nQ^H$ is a diagonal matrix of size N × N for the nth transmission block, in which the elements of diagonal are [11]:

$$[\lambda_n]_{ii} = \sqrt{N} q_i^H (h_n, \overbrace{0, 0 \ldots . 0}^{N-m})^T \quad i = 1, 2, \ldots \ldots N$$

where q_i is the i^{th} column of matrix Q. Due to the different realizations of the channel impulse responses for each block of data, the diagonal elements of change for every block n of the received signal, and they can be looked upon as the gains of a slow fading non-frequency selective channel equivalent to the m-tap channel. Moreover, these elements are in fact the eigen values of the channel matrix (H).

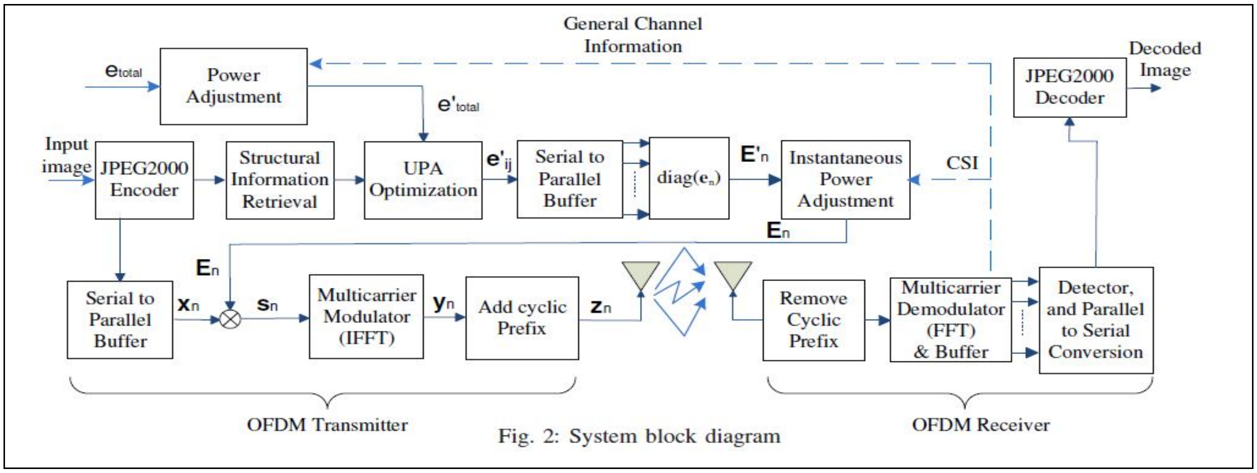

Figure 2

Overall, it can be noticed that addition and removing of the cyclic prefix, along with the cyclic convolution of the OFDM symbols with the channel impulse response, convert an m-tap channel (frequency selective) to m path slow fading non-frequency selective channels [11].
At the receiver side, once the coefficient realizations of the slow fading paths are identified, the OFDM receiver feeds back the instantaneous CSI to the Instantaneous Power Adjustment unit. Moreover, data can be recovered using a simple zero forcing equalizer and can be sent to the JPEG2000 decoder to produce the output image.
One of the advantages of our proposed system is that the recovered data does not need a dedicated source decoder and can be decoded by any standard JPEG2000 decoder. Another advantage of our proposed UPA-OFDM algorithm lies in its capability to be extended to other application beyond JPEG2000Image standard.

4.Unequal Power Allocation

An UPA scheme is driven by the fact that different parts of the JPEG2000 bit stream have different impact on the quality of the decoded image and consequently, are of different importance to us. The UPA scheme exploits the hierarchical structure of the JPEG2000 coded bit stream in order to assign higher power to the more important parts. First evaluate the total distortion of the received image in terms of the bit error probability, and consequently, in terms of the power assigned to different segments of the bit stream. The UPA algorithm then aims at minimizing the expected distortion of the decoded image.
It is widely assumed that the total distortion of the JPEG2000 decoded bit stream is the summation of the distortions due to each code block in the JPEG2000 coded bit stream.

$$D_{Total} = D_0 + \sum_{i=1}^{N} D_{CB_i}$$

Where D_{CBi} is the distortion due to the i^{th} code block (CB_i) and N is the number of code blocks in the bit stream. D_0 is the inevitable distortion due to quantization in source coding.
Under the assumption, and using the D_{ij} evaluated by the "structural information retrieval" block, the expected value of D_{CBi} is

$$E[D_{CB_i}] = \sum_{j=1}^{N_i} p_{ij} D_{ij} \prod_{k=1}^{j-1} (1 - p_{ik})$$

Where N_i is the number of coding passes in CB_i ,and p_{ij} is the probability that there is at least one bit error in CP_{ij} . Therefore:

$$[D_{Total}] = D_0 + \sum_{i=1}^{N} p_{ij} \sum_{j=1}^{N_i} D_{ij} \prod_{k=1}^{j-1} (1 - p_{ik})$$

Since a bit error at any position within the same coding pass, has the same effect on the resulting image distortion, the UPA algorithm assumes the same amount of power for all bits of a given coding pass, thus, resulting in the same probability of error for all bits within the same coding pass.
Defining $p_{eb}(i, j)$ as the bit error rate (BER) of CP_{ij} , and $N_b(i, j)$ as the number of bits in CP_{ij} , p_{ij} can be written as:

$$p_{ij} = 1 - (1 - p_{eb}(i,j))^{N_b(i,j)}$$

For example, for additive white Gaussian noise (AWGN) channel we have:

$$p_{eb}(i,j) = Q(\sqrt{\frac{2P_{ij}}{N_0}})$$

in which, N_0 is the noise power. Total distortion relates the expected value of the total distortion of the received image, to the powers assigned to each coding pass of the bit stream.

The UPA unit aims at minimizing the total distortion at the receiver, by dividing the total power available to it unequally among coding passes.

$$P'_{Total} = \sum_{i=1}^{N} P_{ij} \sum_{j=1}^{N} N_b(i,j)$$

The role of the "power adjustment" unit in calculating P'_{Total}.After the optimization algorithm calculates the transmission powers for each coding pass, P_{ij} , the UPA unit uses the CSI, namely the fading factor h, to adjust the final power assigned to each bit of CP_{ij} as follows:

$$P^f{}_{ij} = \frac{P_{ij}}{h^2 + \alpha}$$

Division by h^2 compensates for the effect of fading, however, for practical purposes and to suppress very large powers resulting from very small and near zero fading factors, a constant α is added to the denominator.

To take this fact into account, the "power adjustment" unit, adjusts the total power assigned for the transmission of the image (P_{Total}) to the power assigned to the UPA unit, P'_{total} as follows:

$$P_{Total} = P'_{Total} E\left[\frac{1}{h^2 + \alpha}\right]$$

where E

$$\left[\frac{1}{h^2+\alpha}\right] = \int_{0^+}^{\infty} \frac{1}{h^2+\alpha} \frac{h}{\sigma^2} e^{-\frac{h^2}{2\sigma^2}} dh = e^{\alpha} \int_{\alpha}^{\infty} \frac{e^{-h}}{h} dh$$

It should be noted that if CSI is not available at the transmitter, we have to find the optimal power assignments based on the average fading factor of the channel.

The actual power values of all coding passes have to sum up to the total available power (e_{total}). That is:

$$e_{total} = \sum_{n=1}^{N_B} \sum_{i=1}^{N} [E_n]_{ii}$$

5.Performance Evaluation

This chapter gives the complete details about the performance evaluation of the proposed approach. Three gray scale test images of the Lena and peppers of each of size 512 × 512 pixels have been taken for simulation in order to compare the performance of UPA and UEP schemes. To obtain simulation results, mat lab software is used as the JPEG2000 image coder to encode Lena and Peppers images of size 512 × 512 at a rate of 0.25 bit per pixel (bpp). The settings for the JPEG2000 codec are 64 × 64 code-blocks,128×128 precincts, and one level of decomposition. The header information is assumed to be transmitted error-free. Binary Phase Shift Keying is used to modulate the bit stream produced by theJPEG2000 codec.

The results are compared using the image quality in terms of average PSNR and MSE total image of transmitted and reconstructed image at the receiver end. The performance of EPA and UPA over both the Gaussian and a Rayleigh fading channel is plotted against SNR of the system.

The PSNR is defined as the ratio of maximum power of a signal to the noise power. It is often denoted in decibels (dB) and can be expressed as given below

$$MSE = \frac{1}{mn}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}\|I(i,j) - K(i,j)\|^2$$

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

Where m = 512, n = 512, $I(i, j)$ and $K(i, j)$ are the transmitted and reconstructed image at the receiver respectively. 8 bits represent each pixel of a gray scale image, which leads to2^8 quantization levels for each component with maximum quantized amplitude of 2^8-1 that equals to 255. The qualitative and quantitative performance results of all the test images with UPA and UEP schemes are discussed in the following sections. We summarize these results in this chapter based on SNR values.

Figure 3 Original Lena Image & Figure 4: Retrieved Lena Image At 0.25bpp

The performance of the system is analyzed by comparing the average PSNR and the average BER profile of the received image transmitted through the following channel scenarios:

- Block fading and non-frequency selective
- Block fading and 2-tap frequency selective
- Block fading and 3-tap frequency selective

Each tap of the frequency selective channel is assumed to have a Rayleigh fading distribution with AWGN, and is independent of the other taps. Images are transmitted over the first channel scenario with both the UPA algorithm as well as Equal Power Allocation (EPA) technique. For the second and the third channel scenarios OFDM technique is applied, to eliminate the effect of ISI and Inter Carrier Interference (ICI), together with UPA.

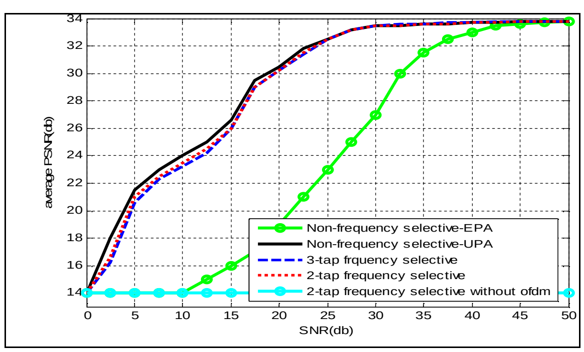

Figure 5: Comparison Of PSNR Of The Received Lena (512 × 512, 0.25 Bpp) Image Transmitted Through Different Channel Scenarios

The number of subcarriers (N) used in the OFDM transmitter is 16. For the second channel scenario, we also simulate the transmission without OFDM to show the disastrous effect of frequency selectivity of the channel in the absence of OFDM.

Superior PSNR performance of the system using UPA in contrast with EPA is apparent. For example, at a channel SNR value of 20 dB, using the UPA algorithm improves the PSNR of the received image by about 10.5 dB. To obtain the average PSNR values in Fig. 5.5, it is assumed that the total available power to transmit an image, e_{total}, is fixed. Since employing OFDM increases the amount of the required power(due to addition of the cyclic prefix), essentially less power will be available to distribute among data bits. In Fig. 5.3, it is shown that the reduction in the amount of power available to data bits in a multi-tap channel reduces slightly the PSNR performance at SNR values less than 20 dB. This reduction in the PSNR performance can also be explained theoretically by recognizing that the amount of extra power required for the cyclic prefix in2-tap and 3-tap channels is equal to 10 log(18/16) = 0.5 dB and 10 log(19/16) = 0.75 dB, respectively. However, at SNR values of greater than 20 dB, the PSNR performance of the 2-tap and 3-tap channels start to converge, and eventually reach the performance of the non-frequency selective channel.

This figure also suggests that at very high SNR values (50 dB), the average PSNR values of the UPA and EPA algorithms approach to each other. This behavior is expected since at high SNR values the bit error rate is very low, regardless of the power allocation algorithm. As expected, if the OFDM technique is not applied to an image transmitted through a frequency selective channel, the average PSNR performance of the received image will have a poor value of about 14.5 dB.

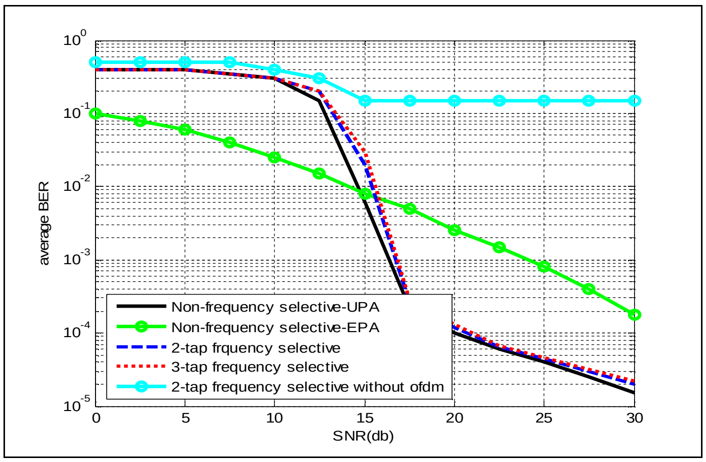

Figure 6: Comparison Of BER Of The Received Lena (512×512, 0.25 Bpp) Image Transmitted Through Different Channel Scenarios

Fig shows the BER performance of the received bit stream of the image. The impact of having less power available to assign to data bits in a multi-tap channel, due to addition of cyclic prefix, can be seen here as well. An interesting observation made from Fig.5.6 is that for SNR values less than 15 dB the EPA scheme has a lower BER than the UPA algorithm. However, as shown in Fig. 5.5,the PSNR performance when employing the UPA algorithm is much higher in comparison with the EPA technique. Moreover, although the 2nd scenario without OFDM demonstrates a low PSNR value of 14.5 dB regardless of the SNR value, yet its BER performance shows an improving trend as SNR increases up to16 dB, and beyond that, an error flow occurs. The explanation lies in the fact that the BER curves show the average probability of an information bit being received with error, regardless of its location in the JPEG2000 bit stream and its impact on the distortion (equivalently the PSNR) of the received image. For the UPA algorithm, bits with low impact in the distortion are protected much less than the bits with high impact. This results in a high overall BER for this scenario; however, the distortion in the received image is lower compared to the EPA case, simply because bits with higher impact in the distortion are received at much lower error rate.

6.Conclusion

In this project, JPEG2000 images are transmitted through frequency selective block fading channels using an UPA algorithm and OFDM technique. The proposed algorithm allocates unequal power to each coding pass based on its contribution to the quality of the received image. The simulation results for the Lena and Peppers images confirm superior PSNR performance of the UPA algorithm over EPA technique for non-frequency selective channels. To maintain this superior performance for frequency selective channels, we use the OFDM technique along with the UPA algorithm. This method helps in removing the negative effects of ISI and ICI in frequency selective channels; however, slight degradation in the PSNR performance is noticeable. More over the BER performance of the received images is analyzed for different scenarios where UPA, EPA and OFDM are applied. In addition, the actual amount of power consumed for transmission is measured and showed to match the total available power at the transmitter, with a close precision.

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