

# Energy Efficient Transmission of Image over DWT-OFDM System

Lakshmi Pujitha Dachuri, Nalini Uppala

**Abstract**—In many applications retransmissions of lost packets are not permitted. OFDM is a multi-carrier modulation scheme having excellent performance which allows overlapping in frequency domain. With OFDM there is a simple way of dealing with multipath relatively simple DSP algorithms.

In this paper, an image frame is compressed using DWT, and the compressed data is arranged in data vectors, each with equal number of coefficients. These vectors are quantized and binary coded to get the bit streams, which are then packetized and intelligently mapped to the OFDM system. Based on one-bit channel state information at the transmitter, the descriptions in order of descending priority are assigned to the currently good channels such that poorer sub-channels can only affect the lesser important data vectors. We consider only one-bit channel state information available at the transmitter, informing only about the sub-channels to be good or bad. For a good sub-channel, instantaneous received power should be greater than a threshold  $P_{th}$ . Otherwise, the sub-channel is in fading state and considered bad for that batch of coefficients. In order to reduce the system power consumption, the mapped descriptions onto the bad sub-channels are dropped at the transmitter. The binary channel state information gives an opportunity to map the bit streams intelligently and to save a reasonable amount of power. By using MATLAB simulation we can analyze the performance of our proposed scheme, in terms of system energy saving without compromising the received quality in terms of peak signal-noise ratio.

**Keywords**—Binary channel state, Channel state feedback, DWT-OFDM system, Energy saving, Fading broadcast channel.

## I. INTRODUCTION

ORTHOGONAL Frequency Division Multiplexing (OFDM) [1] is becoming a very common multi-carrier modulation technique for transmission of signals over wireless channels in diverse environments. Orthogonal Frequency division Multiplexing (OFDM) is an efficient type of parallel transmission scheme that is based on the basic Frequency Division Multiplexing (FDM) transmission scheme. Where FDM divides a channel into many non-overlapping sub-channels to transmit information, OFDM makes use of the available bandwidth by allowing these sub-channels to overlap by modulating the information on orthogonal carriers that can easily be discriminated between at the receiver. OFDM divides the high-rate stream into parallel lower rate data and hence prolongs the symbol duration, thus helping to eliminate Inter Symbol Interference (ISI). In an OFDM system the sub-

channels overlap with each other to a certain extent which leads to the reduced use of bandwidth and since these carriers are orthogonal to each other Inter Carrier Interference (ICI) is also reduced [2]. The input data sequence is mapped into symbols, which are distributed and sent over the  $N$  parallel sub-channels, one symbol per channel. To permit dense packing and still guarantee that a minimum of interference between the sub-channels is encountered, the carrier frequencies must be chosen carefully. By using orthogonal carriers which in the Frequency domain can be viewed so as the frequency distance between two sub-carriers is given by the distance to the first spectral null. Wavelet transformation has recently emerged as a strong candidate for digital communications [3].

A key observation is that, the unequal importance level of the compressed image coefficients can be combined intelligently with the binary channel state feedback to achieve an improved transmission performance in delay-sensitive applications. This feedback can also be used further for energy saving in the transmission process with little or no trade-off in transmission performance.

In DWT, the most prominent information in the signal appears in high amplitudes and the less prominent information appears in very low amplitudes. Data compression can be achieved by discarding these low amplitudes. The wavelet transform enables high compression ratios with good quality of reconstruction. At present, the application of wavelets for image compression is one of the hottest areas of research. Recently, the Wavelet Transforms have been chosen for the JPEG 2000 compression standard.

JPEG2000 [4] standards provides a set of features that are of importance to many high-end and emerging applications by taking advantages of new technology. It addresses where current standards fail to produce the best quality or performance and provides. Recently, the Joint Photographic Expert Group (JPEG2000) has developed a new discrete wavelet-based image compression standard, commonly referred to as JPEG2000. Our preliminary study on discrete wavelet-based image compression (using JPEG2000) says that the wavelet transform step consumes more than 60 % of the CPU time during image compression process. By optimizing algorithmic features of the transform step, performance and energy requirements of the entire image compression process can be significantly improved. For this reason, we target the wavelet transform step to minimize the energy consumption.

DWT-OFDM [5] system is studied the transmission of DWT compressed still image over OFDM multipath channels. The image sample goes first through a transform, which

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generates a set of frequency coefficients. The transformed coefficients are then quantized (or divided by a certain fixed value) to reduce the volume of encoded data. The output of this step is a stream of integers, each of which corresponds to an index of a particular quantized binary. Encoding is the final step, where the stream of quantized data is converted to a sequence of binary symbols in which shorter binary symbols are used to encode integers that occur with relatively high probability. This helps reduce the number of bits transmitted. In that approach, the high pass coefficients were simply discarded before transmission. In contrast, in our approach, we consider the possibility of transmitting the low pass as well as high pass coefficients. We also explore the possibility of energy saving in transmission process over fading channel environment by discarding the coefficients of lower importance level through an informed decision process. In our proof of concept study, we generate four coefficients, after the first level DWT. Each coefficient in the form of a data vector is mapped on to a sub-channel. We compare the energy saving and reception quality performance, by sending all coefficients over the mapped sub-channels versus discarding the ones that are mapped on to the bad channels. Our results show that, up to 60% energy saving is possible at the low fading margins with a considerably high gain in the quality (PSNR) of the received image.

This paper is organized as follows: The system model is given in Section II, formulation and analysis in Section III, results analysis in Section IV and finally conclusions in Section V.

## II. SYSTEM MODEL

In our system model, an image frame is compressed using DWT, and the compressed data is arranged in data vectors, for each data vector gives equal number of coefficients. These vectors are packetized and mapped to the OFDM system and then quantized and binary coded to get the bit streams. At each time only one bit channel state information is available at the transmitter, because it checks the each bit individually either good or bad by threshold  $P_{th}$ . For a good sub-channel, instantaneous received power should be greater than a threshold  $P_{th}$ . Otherwise, the sub-channel is in fading state and considered bad for that batch of coefficients. The less power data will be discarded at receiver when it transmitted through deeply faded sub-channels. Thus, the power saving is achieved in image transmission. Below clearly explains each section of the DWT-OFDM block diagram.

### A. DWT-OFDM System

This section discusses the conventional OFDM using DWT [6].

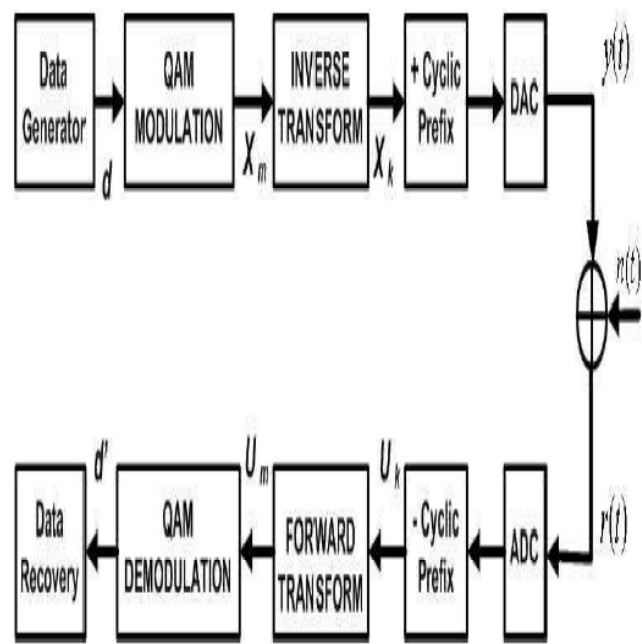


Fig. 1 An OFDM transceiver with inverse and forward transform blocks of DWT OFDM

The DWT-OFDM implementation model and follow with the discussion that this platform satisfies the orthonormal bases and perfect reconstruction properties. The transceiver of DWT-OFDM is shown in Fig. 1. In the top part, the transmitter first uses a digital modulator (i.e. 16 ; QAM) which maps the serial bits into symbols converting  $dk$  into  $X_m$ , within  $N$  parallel data stream  $X_{m(i)}$  where  $X_{m(i)}$ ;  $0 \leq i \leq N-1$ . The main task of the transmitter is to perform the discrete wavelet modulation by constructing orthonormal wavelets. Each  $X_{m(i)}$  is first converted to serial representation having a vector  $XX$  which will next be transposed into  $CA$ . This means that  $CA$  not only its imaginary part has inverting signs but also its form is changed to a parallel matrix. Then, the signal is up-sampled and filtered by the LPF coefficients or namely as approximated coefficients. Since our aim is to have low frequency signals, the modulated signals  $XX$  perform circular convolution with LPF filter whereas the HPF filter also perform the convolution with zeroes padding signals  $CD$  respectively. Note that the HPF filter contains detailed coefficients or wavelet coefficients. Different wavelet families have different filter length and values of approximated and detailed coefficients. Both of these filters have to satisfy orthonormal bases in order to operate as wavelet transform. In the transmitter part, this signal is simulated using MATLAB command  $[Xk] = \text{idwt}(CA; CD; wv)$  where  $wv$  is the type of wavelet family. On the other hand, the reverse process is simulated using  $[ca; cd] = \text{dwt}(Uk; wv)$  in the receiver. The  $ca$  signal will be processed to the QAM demodulator for data recovery. However, the  $cd$  signal is discarded because it does not contain any useful information.

### B. Packetizing and Mapping onto the OFDM System

As mentioned in Fig. 3 bit streams are packetized by chopping them into vectors of size N-bits each packet containing four vectors for each vector have to add one training bit to estimate the sub-channel at the receiver [7]. For this paper taking an example of OFDM with IFFT size 128, system has 32 packets are arranged in parallel to get 128 bit streams (see Fig. 2). Each bit vector in a packet is m-array modulated, and 32 packets are simultaneously transmitted through different sub-channels set. By the feedback from system decides the sub-channel condition either it is good or bad, and accordingly rearrange the data vectors to map them to the IFFT module. For quality reception and energy saving implement a new mapping scheme. The reverse process is done at the receiver with suitable treatments due to the discarded or lost data vectors.

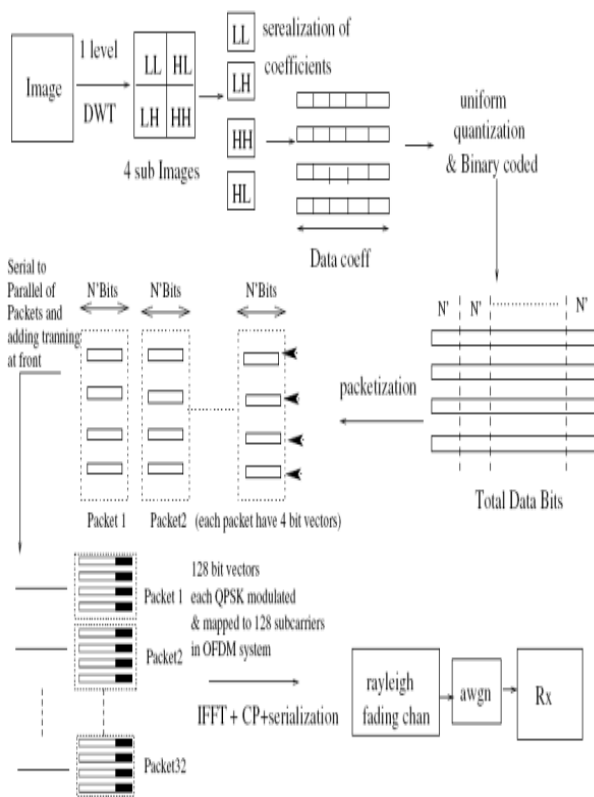


Fig. 2 DWT-OFDM SYSTEM

#### 1. Proposed Mapping Scheme

For intelligent mapping of the data vectors [8], sub-channel states are fed back to the transmitter in binary form (i.e., one-bit per subcarrier: good (1) or Bad (0)). This simple feedback approach also has very less complexity, as it involves only comparison of received signal power with a predefined threshold  $P_{th}$ . In a slow fading scenario, a Bad channel feedback implies the data sent through that sub-channel would have been below an acceptable quality. Accordingly, in our energy saving transmission policy, those data mapped on to the bad sub-channels are discarded at the transmitter.

Additionally, at the receiver, to discard a data vector, the receiver checks if the received power of a data vector is below an acceptable threshold. Retransmission of discarded coefficients is avoided. Instead, the discarded coefficients at the receiver are replaced by the average coefficient values of their respective sub-images, which introduce some distortion. To reduce the distortion due to discarding some data, propose a mapping scheme which takes care of the importance level of the mapped data such that the less important data (i.e., in general for DWT image, low pass filtered components are more important:

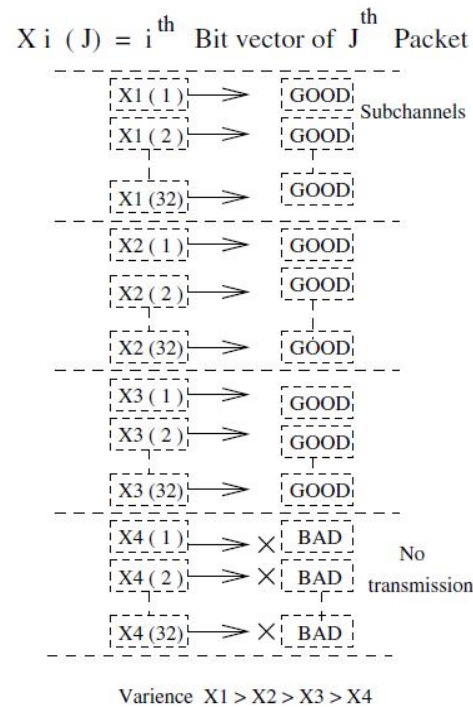


Fig. 3 Packet mapping based on channel state DWT-OFDM system

The ones with lower variance levels) are mapped to the bad sub-channels. As described in Fig. 3, arrange the bit vectors from all 32 packets such that they are spaced as apart as possible in frequency domain. The sub-channels are grouped in to good and bad categories, as depicted in Fig. 3. For this group formation we scan all the sub-channels and collect the bad sub-channels in order, while maintaining the order of the good ones. The average distortion per coefficient in a packet produced by this scheme is denoted by  $D$  for the analysis purpose. The chosen threshold value  $P_{th}$  affects the selection of data vectors that are to be discarded at the transmitter. Thus, the quality of reception and the amount of power saved are also changed. It may be mentioned here that the chosen  $P_{th}$  corresponds to a particular fading margin.

### C. Channel Model

In this study we use block fading channel model [9] as in. The channel model is illustrated in Fig. 3, where  $M$  is the coherence bandwidth in terms of number of sub-channels. In a

block fading environment,  $M$  consecutive sub-channels will simultaneously be either bad or good. Each such set consisting  $M$  sub-channels is called a sub-band. We denote total number of such sub-bands in the OFDM system as  $N$ . Thus, the total number of sub-channels in the system is  $N \times M$ . All sub-bands are independently faded with Rayleigh-distributed envelop, which corresponds to the block fading approximation in frequency domain [10]. Our proposed mapping scheme generates a situation of subcarrier assignment for each data vector in a packet. Analysis of this environment is presented in Section III.

### III. FORMULATION AND ANALYSIS

We now formulate the average distortion and energy savings in our proposed transmission scheme. We measure the system performance by probabilistic analysis of the average distortion in a block fading environment. Distortion involved for various loss events. As described in Section II B 1, in the proposed scheme we arrange the data vectors and sub-channels in such a way that only the specific loss events can take place. For example, it is unlikely to happen that the data vector with higher importance is transmitted through a bad sub-channel, resulting in a loss, while the lesser important data is mapped to a good sub-channel and received correctly. Thus, the proposed mapping scheme gives an opportunity to reduce the distortion as much as possible for a given channel condition. Observe that, only a few loss events can take place. Let  $x_1, x_2, x_3$ , and  $x_4$  are the data vectors corresponding to the four sub-images obtained from original frame using DWT compression. Also, let  $\sigma_{x_1}^2, \sigma_{x_2}^2, \sigma_{x_3}^2$ , and  $\sigma_{x_4}^2$  are the respective variances. Without any loss of generality, assume that the variances  $\sigma_{x_1}^2$  to  $\sigma_{x_4}^2$  are in descending order of magnitude. Thus, the corresponding importance levels are also in descending order. These data vectors are mapped over different sub-channels in such a way that only a few specific loss events are possible. The corresponding likelihood of loss events would be: only  $x_4$  is lost;  $x_3$  and  $x_4$  are lost;  $x_2, x_3$ , and  $x_4$  are lost; and all  $x_1, x_2, x_3$ , and  $x_4$  are lost. Thus, according to our mapping strategy only four combinations of the loss events are possible. The respective distortion associated would be as follows.

The distortion when no data coefficients are lost or discarded is given by:

$$D_{1111} \equiv D_4 = \frac{4\Delta^2}{12}$$

where  $\Delta$  is the step size of the quantizer and  $\frac{4\Delta^2}{12}$  is the total quantization noise. The distortion when only  $x_4$  is lost or discarded is given by:

$$D_{1110} \equiv D_3 = \sigma_{x_4}^2 + \frac{3\Delta^2}{12}$$

Similarly, the distortion when  $x_3$ , and  $x_4$  are lost or discarded is given by:

$$D_{1100} \equiv D_2 = \sigma_{x_4}^2 + \sigma_{x_3}^2 + \frac{3\Delta^2}{12}$$

The distortion when  $x_2, x_3$ , and  $x_4$  are lost or discarded is given by:

$$D_{1000} \equiv D_1 = \sigma_{x_4}^2 + \sigma_{x_3}^2 + \sigma_{x_2}^2 + \frac{\Delta^2}{12}$$

and, the distortion when  $x_1, x_2, x_3$ , and  $x_4$  are lost or discarded is given by:

$$D_{0000} \equiv D_0 = \sigma_{x_4}^2 + \sigma_{x_3}^2 + \sigma_{x_2}^2 + \sigma_{x_1}^2$$

where  $D_i$  = distortion when only  $i$  number of data vectors out of the four are received in a packet ( $i = 0, 1, 2, 3, 4$ ). In general, we can write:

$$D_i = \begin{cases} \frac{i\Delta^2}{12}, & \text{if } i = 4, \\ \sum_{i+1}^4 \sigma_{x_i}^2 + \frac{i\Delta^2}{12}, & \text{otherwise.} \end{cases} \quad (1)$$

#### A. AWGN Channel

For the Additional White Gaussian Noise (AWGN) [11] channel the received signal is equal to the transmitted signal with some portion of white Gaussian white noise added. This channel is particularly important for discrete models operating on a restricted number space, because this allows one to optimize the circuits in terms of their noise performance.

$$\hat{S}(t) = s(t) + n(t)$$

where  $n(t)$  is a sample function of a Gaussian random process. This represents white Gaussian noise.

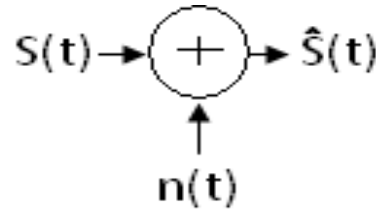


Fig. 4 Block diagram of the AWGN channel

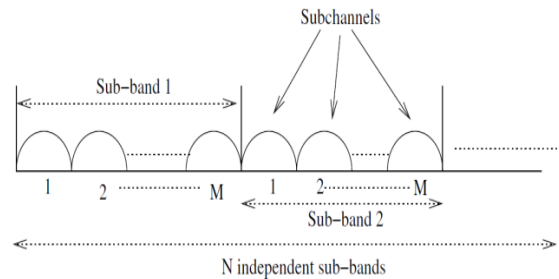


Fig. 5 The concept of block fading channels in OFDM system

### B. Block Fading Channel Behavior

The performance of the proposed scheme depends on probability of the loss events [12]. In this section, the probabilities of loss events are determined with respect to the channel fading parameter. As mentioned in section II.B, the packets are mapped in such a way that the channel fading can be considered independent for all the four data vectors in any packet. For Rayleigh fading channel, the received power  $P$  is exponentially distributed with probability density function (pdf) given by:

$$fP(a) = \frac{1}{P} \exp\left(-\frac{a}{P}\right) \quad (2)$$

where  $P$  be the average received power. If  $F$  is the fading margin, it is related to the receiver threshold sensitivity  $P_{th}$  as:

$$F = \frac{\bar{P}}{P_{th}}, \quad (3)$$

Let  $P$  be the probability that a sub-band is deeply faded. Using (2),  $P$  can be expressed as:

$$P = \int_0^{P_{th}} fP(a) da = 1 - \exp\left(-\frac{1}{F}\right) \quad (4)$$

In our interleaved coefficient mapping scheme, all the four sub-channels per group of four coefficients are from different sub-bands. Thus,  $p$  will also be the probability of a sub-channel to be bad. Let  $P_i$  = probability associated with the loss event  $i$ , for  $i = 0, 1, 2, 3, 4$ , which produces distortion  $D_i$ . Thus, for an arbitrary received packet we can write:

$$P_i = \binom{4}{i} p^{4-i} (1-p)^i. \quad (5)$$

Then, the average distortion of the proposed scheme can be written as:

$$\bar{D} = \sum_{i=0}^4 D_i P_i, \quad (6)$$

where  $D_i$ ,  $P_i$  can be determined by (1), (5) respectively.

### C. Energy Saving Measure

In the proposed scheme the less important data vectors are discarded at the transmitter to save power if corresponding sub-channel is in fading state. Denoting the percentage of data not transmitted in a packet as a measure of the percentage of energy saving, using (5) we can write energy saving expression as:

$$\% \text{ energy saved} = 100 \times \sum_{i=0}^4 i P_i / 4. \quad (7)$$

## IV. RESULT

The formulas are mentioned in Section III, as per the formulas, we have present analysis of formulas and simulated results in this section. For simulations we transmitted standard Lena image of size  $256 \times 256$  pixels. At here we have taken

OFDM system with  $N \times M = 128$  subcarriers. By these subcarriers 32 packets are transmitted in simulation process. In this packets are distributed in frequency domain and time domain. The packets are transmitted back to back; data will be corrupted due to time delay in process. So, we had give time interval for each packet while transmitting through subcarriers. We simulated block fading channel with number of sub-bands  $N = 4$  and the coherence bandwidth equivalent to 32 subcarriers ( $M = 32$ ). QPSK modulation scheme is used. Thus,  $128 \times 2$  bits per OFDM symbols are transmitted through a sub-channel.

The variances of data vectors obtained for 'Lena' image provide the conditional distortion values associated with different loss events given by (1). The conditional distortions are plotted against the loss events in Fig. 6. We can observe the effective distortion variation according to the importance of the data vectors. Analytically obtained distortion measure and percentage energy saving, given by (6) and (7), respectively, are plotted against the  $P_{th}$  in Fig. 8, where the analyzed results are supported by simulated values. From Fig. 7, it can be concluded that the distortion in reception process increases with power threshold  $P_{th}$ . The figure that the energy saving is also increasing by restricting lesser important data from transmission through bad sub-channels. In the worst case, it follows that we can save more than 60 percent power. Transmission of Lena image through the OFDM system provides simulation data, showing PSNR and energy saving variations (quality) in Fig. 8. The receiver rejects a coefficient for which the instantaneous SNR is below an acceptable threshold. It can be noted from Fig. 6.

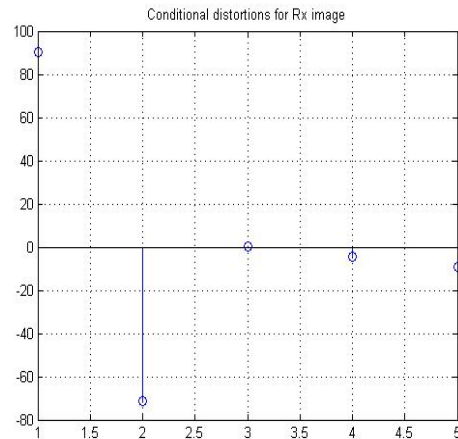


Fig. 6 Conditional distortions for Lena image



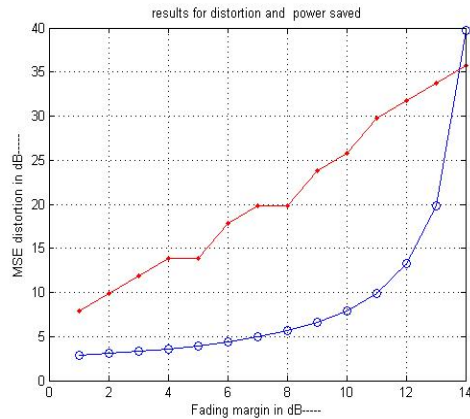


Fig. 7 Simulation and analytical results for distortion and % power saving

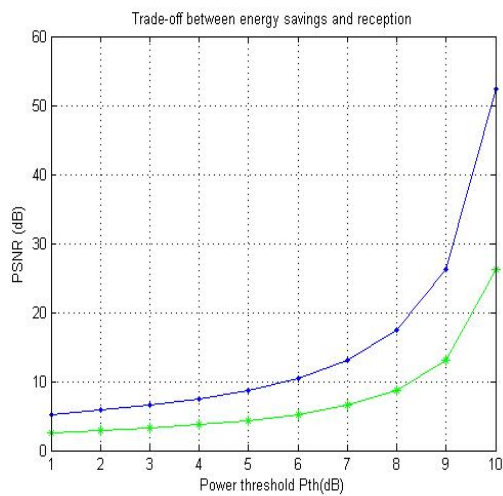


Fig. 8 Trade-off between energy saving and reception

It can be further noted that, we restrict the transmission depending upon the instantaneous received power of the sub-channels, and a decision is made based on the value  $P_{th}$ . Thus, the amount of power saved and the corresponding degradation in quality for a higher  $P_{th}$  can be controlled. It would be user dependent to choose between the reception quality and energy saving, as both are controlled by the parameter  $P_{th}$ .

Fig. 9 shows the received Lena images with different PSNR. Note that, PSNR = 18 dB corresponds to a reasonably poor image quality. Thus, at a given channel SNR, an arbitrary choice of  $P_{th}$  may lead to an unacceptably poor reception quality.



(a) source image (b) decomposed image



(c) PSNR 15 dB (d) PSNR 21 dB



(e) PSNR 30 dB (f) PSNR 38 dB

Fig. 9 Transmitted Lena image and its received version at different PSNRs

## V. CONCLUSION

In this paper present an energy saving approach to transmission of discrete wavelet transformation based compressed image frames over the OFDM channels. We propose an energy saving approach, where the compressed coefficients are arranged in descending order of priority and mapped over the channels starting with the good ones. The coefficients with lower importance level, which are likely mapped over the bad channels, are discarded at the transmitter to save power without significant loss of reception quality. By using MAT LAB simulation analyze the performance of our proposed scheme, in terms of system energy saving without compromising the received quality in terms of peak signal-noise ratio.

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