

Robust Image Transmission with OFDM over an AWGN Channel

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Abstract— In this paper a new scheme is proposed for progressive image transmission over coded Orthogonal Frequency Division Multiplexing (OFDM) system with Low Density Parity Check Coding (LDPC). Trigonometric transforms are used in this scheme for improving the performance of the OFDM systems and reducing the Peak-to-Average Power Ratio (PAPR) of OFDM signal. It improves the error resilience ability and transmission efficiency for progressive image transmission over Additive White Gaussian Noise (AWGN) channel. The Set Partitioning In Hierarchical Trees (SPIHT) algorithm is used for source coding of the images to be transmitted. In the proposed scheme the transmit data sequence of the OFDM signal after Inverse Fast Fourier Transform (IFFT) is grouped into in-phase and in-quadrature components, then each component is transformed using either the Discrete Cosine Transform (DCT) or the Discrete Sine Transform (DST). The simulation results show that adding the DST to the system improves the visual quality of reconstructed images and reduces the PAPR of OFDM signal more than the DCT.

Index Terms--LDPC, OFDM, PAPR, SPIHT, TRIGONOMETRIC TRANSFORMS.

1. INTRODUCTION

OFDM modulation has been adopted by several wireless multimedia transmission standards, such as Digital Audio Broadcasting (DAB) and Digital Video Broadcasting (DVB-T), because it provides a high degree of immunity to multipath fading and impulsive noise. High spectral efficiency and efficient modulation and demodulation by IFFT/FFT are also advantages of OFDM. In the frequency selective retransmission channel, all fading and Inter-Symbol Interference (ISI) result in severe losses of transmitted image quality. OFDM divides frequency-selective channel into several parallel narrow frequency selective narrow-band channels, and modulates signal into different frequencies. It can significantly improve the channel transmission performance without employing complex equalization schemes. It also has broad application prospect in wireless image and video communications [1, 2]. There are still some challenging issues, which remain unresolved in the design of OFDM systems. One of the major problems is high PAPR of transmitted OFDM signals. Therefore, the OFDM receiver detection efficiency is very sensitive to the nonlinear devices used in its signal processing loop, such as Digital-to-Analog Converter (DAC) and High Power Amplifier (HPA), which may severely impair system performance due to induced spectral regrowth and detection efficiency degradation. There are several developed techniques to reduce the PAPR in OFDM systems [3, 4] such as clipping [5], companding [6, 7], Partial Transmit Sequence (PTS) [8], Selected Mapping (SLM) [9] and coding [10]. The clipping technique is the simplest one that can be used in OFDM systems, but it causes additional clipping noise which degrades the system performance. An alternative technique to mitigate the PAPR problem is based on signal transformations. This technique involves a signal transformation prior to amplification, then an inverse transformation at the receiver prior to demodulation. In [11] trigonometric

transforms were suggested as alternatives for the FFT to reduce the PAPR. The authors in [11] concluded that OFDM systems with trigonometric transforms provide higher PAPR reduction than the standard FFT based system. However, modified the OFDM symbols before transmission using the PTS. Their results reveal that without PTS, the distribution of PAPR is the same for that conventional one such that the reduction depends on PTS, which makes redundancy in the system. The SPIHT algorithm has been introduced by Said and Pearlman [12]. It is an algorithm based on the wavelet transform, and restricts the necessity of random access to the whole image to small sub images. The principle of the SPIHT is partial ordering by magnitude with a set partitioning sorting algorithm, ordered bit plane transmission, and exploitation of self-similarity across different scales of an image wavelet transform. The success of this algorithm in compression efficiency and simplicity makes it well known as a benchmark for embedded wavelet image coding. The SPIHT is used for image transmission over the OFDM system in several research works [13, 14] because the SPIHT has a good rate-distortion performance for still images with comparatively low complexity and it is scalable or completely embeddable. To improve the BER performance of the OFDM system, several error correcting codes have been applied to OFDM. LDPC codes have attracted much attention particularly in the field of coding theory. LDPC codes are a class of linear block codes which provide a reliable transmission for coding performance that is very close to the Shannon's limit and can outperform Turbo codes at long block length but with relatively low decoding complexity. LDPC has been adopted as the DVB-S2 standard. A (N, K) LDPC code can be represented by a very sparse parity-check matrix having M rows, N columns and code rate $R=K/N$, where $K=N-M$. It was originally invented by Gallager in 1963 [15] and rediscovered by Mackay and Neal recently [16]. The combination of the high spectral efficiency OFDM modulation technique and LDPC coding will be a good

candidate for high speed broadband wireless applications. The BER performance of the Low Density Parity Check Coding- Coded Orthogonal Frequency Division Multiplexing system (LDPC-COFDM) is influenced by the sub channels which have deep fade due to frequency selective fading. According to this combination, several algorithms were introduced into LDPC-COFDM system to improve the BER by adaptive bit loading and power allocation of each subcarrier [17], [18]. The paper concentrates on two targets reducing the PAPR of the OFDM signal and improving the quality of the reconstructed images. It considers the trigonometric transforms as a way for reducing the PAPR by using the character of the DCT/DST energy focused in the low component. The data of OFDM signal is modulated by IFFT then using DCT/DST, which can reduce the PAPR. Compared with the means of SLM-OFDM and PTS-OFDM, OFDM system modified by DCT/DST maintain the system orthogonal properties, which will not result in additional noise and need not transmit side information. At the same time, the proposed method reduces the PAPR greatly and the system has character of low complexity hardware. The rest of this paper is organized as follows. Section 2, presents the SPIHT compression algorithm. The proposed system description with modification is explained in section 3. Section 4, introduces the simulation results. Finally, the conclusions followed by the relevant references are included in section 5.

2. THE SPIHT ALGORITHM

The SPIHT algorithm defines and partitions sets in the wavelet decomposed image using a special data structure called a spatial orientation tree. A spatial orientation tree is a group of wavelet coefficients organized in to a tree rooted in the lowest frequency (coarsest scale) subband with offspring in several generations along the same spatial orientation in the higher frequency subband. Fig.1, shows a spatial orientation tree and the parent children dependency defined by the SPIHT algorithm across subband in the wavelet image. The tree is defined in such a way that each node has either no offspring (the leaves) or four offspring at the same spatial location in the next finer subband level. The pixels in the lowest frequency subband-tree roots are grouped into blocks of 2x2 adjacent pixels, and in each block one of them; marked by star as shown in Fig. 1; has no descendants. SPIHT describes this collocation with one to four parent-children relationships,

$$\text{parent} = (i,j)$$

$$\text{children} = [(2i,2j),(2i + 1,2j),(2i,2j + 1),(2i + 1,2j + 1)]$$

The SPIHT algorithm consists of three stages: initialization, sorting and refinement. It sorts the wavelet coefficients into three ordered lists: the list of insignificant sets (LIS), the List of Insignificant Pixels (LIP), and the List of Significant Pixels

(LSP). At the initialization stage the SPIHT algorithm first defines a start threshold based on the maximum value in the wavelet pyramid, then sets the LSP as an empty list and puts the coordinates of all coefficients in the coarsest level of the wavelet pyramid (i.e. the lowest frequency band; LL band) into the LIP and those which have descendants also into the LIS. In the sorting pass, the algorithm first sorts the elements of the LIP and then the sets with roots in the LIS. For each pixel in the LIP it performs a significance test against the current threshold and outputs the test result to the output bit stream. All test results are encoded as either 0 or 1, depending on the test outcome, so that the SPIHT algorithm directly produces a binary bit stream. If a coefficient is significant, its sign is coded and its coordinate is moved to the LSP. During the sorting pass of LIS, the SPIHT encoder carries out the significance test for each set in the LIS and outputs the significance information. If a set is significant, it is partitioned into its offspring and leaves. Sorting and partitioning are carried out until all significant coefficients have been found and stored in the LSP.

After the sorting pass for all elements in the LIP and LIS, SPIHT does a refinement pass with the current threshold for all entries in the LSP, except those which have been moved to the LSP during the last sorting pass. Then the current threshold is divided by two and the sorting and refinement stages are continued until a predefined bit-budget is exhausted. Details of SPIHT algorithms are presented in [12].

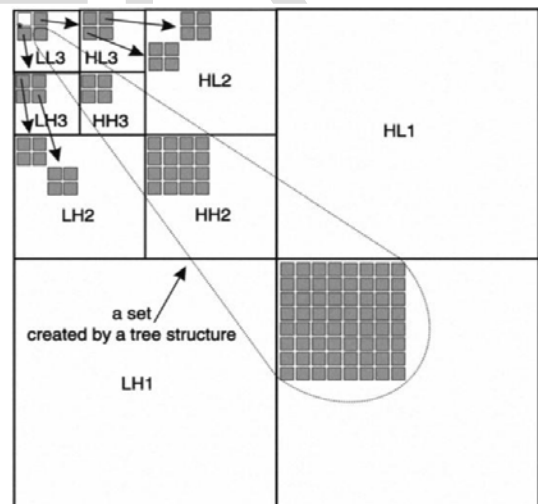


Fig. 1: Parent-children dependency and spatial orientation trees across wavelet subbands in SPIHT.

3. OFDM SYSTEM DESCRIPTIONS WITH PROPOSED MODIFICATION

The block diagram of the proposed LDPC-COFDM system is illustrated in Fig. 2. As will be shown in the next sections,

the proposed modifications will be in the transform and replacement block. The SPIHT coder is chosen as the source coding technique due to its flexibility of code rate and simplicity of designing optimal system. The SPIHT divides the image stream into several layers according to the importance of progressive image stream. Then the image stream is converted to a binary format. Afterwards the information bits are LDPC encoded at the LDPC encoder. The OFDM considered in this paper utilizes N frequency tones (number of subcarriers) hence the baseband data is first converted into parallel data of N subchannels so that each bit of a codeword is on different subcarrier. The N subcarriers are chosen to be orthogonal, Then, the transmitted data of each parallel subchannel is modulated by Binary phase Shift Keying (BPSK) modulation because it provides high throughput and best performance when combined with the OFDM. Finally, the modulated data are fed into an IFFT circuit, such that the OFDM signal is generated. The resulting OFDM signal can be expressed as follows:

where X_n is a discrete time sample.

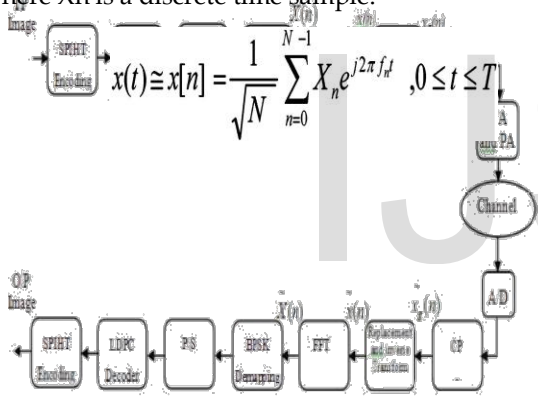


Fig. 2: The LDPC COFDM system model with trigonometric transforms

The output of IFFT is split into two components; in-phase and in-quadrature. Then, either the DCT or the DST is applied to both components, separately. The first half of samples of the in-phase component after the transform (L_i) is concatenated with the first half of samples of the in-quadrature component after the transform (L_q) to form the new in-phase component. Similarly, the second half of samples of the in-phase component after the transform (H_i) is concatenated with the second half of samples of the in-quadrature component after the transform (H_q) to form the new in-quadrature component. Finally, the new components are added to produce the OFDM signal as shown in Fig. 3. This sequence after this process can be called $x(n)$ with the subscript d referring to the trigonometric transformation process. Each data block is padded with a cyclic prefix (CP) of a length longer than channel impulse response to mitigate the Inter-Block Interference (IBI). The continuous COFDM signal $x_c(t)$ is generated at the output of the digital to analog (D/A) converter. According to [1], the PAPR of transmitted analog signal can be expressed as follows:

$$PAPR = \frac{\max |x_g(t)|^2}{E[|x_g(t)|^2]}$$

where $E[.]$ is the average power. Generally, the PAPR is considered for a single OFDM symbol, which has a time duration T . This duration comprises a number of samples equal to $(N_f + N_g)$, where N_g is the guard interval length. At the receiver, the guard interval is removed and the time interval $[0, T]$ is evaluated. The replacement and inverse transform are then applied to the received samples. Afterwards, the OFDM sub channel demodulation is implemented by using a FFT then the Parallel-to-Serial (P/S) conversion is implemented. This received OFDM symbols are demodulated at the demodulator. The demodulated bits are decoded with each LDPC encoded block and data bits are restored. These data are converted into image format, such that SPIHT decoder can be obtained.

4. SIMULATION RESULTS

In this section, simulation experiments are carried out to study the transmission of SPIHT coded images on LDPC COFDM modified by Trigonometric transforms over AWGN channel. The parameters used in the simulation are: the number of subcarriers of a LDPC coded OFDM system (N) is considered to be 256, Cyclic Prefix is 64, Rate of the SPIHT (r) = 0 to 1. LDPC code of $R = 1/2$ is employed with sum-product decoding, where R denotes the code rate and a (512, 1024) parity check matrix is used. The maximum number of iterations in sum-product decoding is set to 10. The input

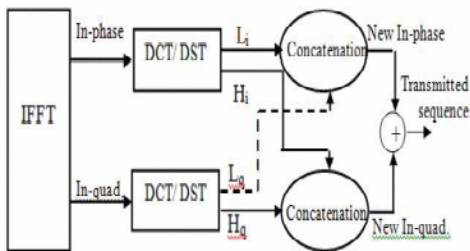


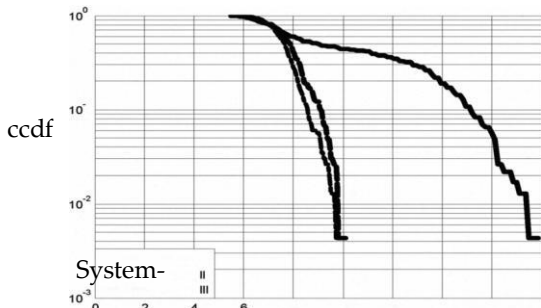
Fig. 3: The trigonometric transform and replacement process.

image is 8 bits per pixel, grayscale test image, 'Cameraman' from MATLAB toolbox is utilized in the simulation has a resolution 256x256 pixels. The fidelity of it was measured by the Peak Signal-to-Noise Ratio, PSNR, which usually expressed in terms of the logarithmic scale. MSE is the mean squared error between the original and the reconstructed image, and Peak is the maximum possible magnitude for a pixel inside the image. The peak value is 255 for an 8 bits/pixel of original image. To verify the effectiveness of the proposed method; adding Trigonometric transforms to the OFDM system to reduce the PAPR, the analysis is divided into two methods one with DCT and another with DST and compare them with COFDM and set SPIHT coder as source coding. The three transmission schemes were designed as follows:

- Scheme I** : The system which consists of coded OFDM
- Scheme II** : The system I with the DCT transforms for the transmitted signal.
- Scheme III**: The system I with the DST transform for the transmitted signal.

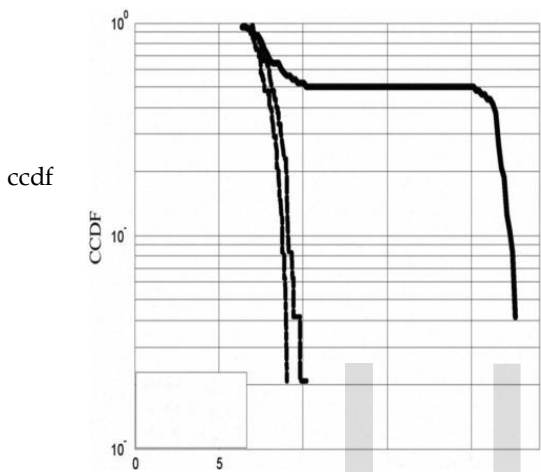
Simulation were carried out respectively according to the above three schemes. Firstly, we present the simulation of the complementary cumulative distribution function (CCDF) curves for the proposed SPIHT LDPC COFDM with Trigonometric transforms. The CCDF is a useful statistical indication about the signal power distribution. It is defined as the probability that the signal is at or higher than a given amplitude PAPR Fig. 4 (a, b) shows the CCDFs of the PAPR for the three proposed schemes at different SPIHT rates: 0.5 and 1 respectively. Clearly, the PAPR performance of the proposed systems II and III outperforms the system I without each other. The figure reveals that system with the DST has a better reduction in the PAPR than that with the DCT nearly up to 0.25dB (Fig. 4(b)). It is also noted that the PAPR can be achieved by increasing the value of SPIHT rate as the data increased and the statistical distribution is clearer. On the other side, the effect of the SPIHT compression ratios on the PSNR of the received image results in the three schemes and compare with the OFDM system without LDPC are shown in Fig.5. For the lower SNR values (5dB), the PSNR performance deteriorates for all schemes except that with the DST however at higher SNR values (10 dB or greater) all the schemes have the ideal performance which is equal to the output of SPIHT Compression. It can be noticed from this figure, for system III at low SNR and all systems at higher SNR, as the SPIHT rate increases the PSNR also increases. This is due to the fact of injecting more information about the image to the receiver and thus it will have more capability to reproduce a better reconstructed image. Finally, the impact of the number of

subcarriers on the performance of the three schemes is studied and shown in at lower SPIHT rate $r = 0.2$ to save the bandwidth on the channel. It is clear that, the Scheme III provides a significant PAPR reduction, especially for a large number of subcarriers.



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papr Sphit=0.5



5. CONCLUSION

In this paper, an efficient LDPC coded OFDM system with trigonometric transforms supporting image transmission using SPIHT compression technique is presented and studied. The effectiveness of the proposed system is investigated through simulations over AWGN channel. It is found that the proposed system must be designed carefully in order to achieve a reduction in the PAPR without degrading the PSNR performance. For LDPC COFDM with rate ($R=0.5$) and rate of SPIHT rate ($r = 1$) the OFDM signal can be reduced by nearly 7dB or 7.25dB by adding the DCT or DST respectively. We also showed the PSNR for the received image at different rates. This work shows the performance of the system model using 256x256 grayscale images.

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Fig. 4: CCDF of the PAPR for the LDPC COFDM (system I) that with DCT (system II) and finally that with DCT

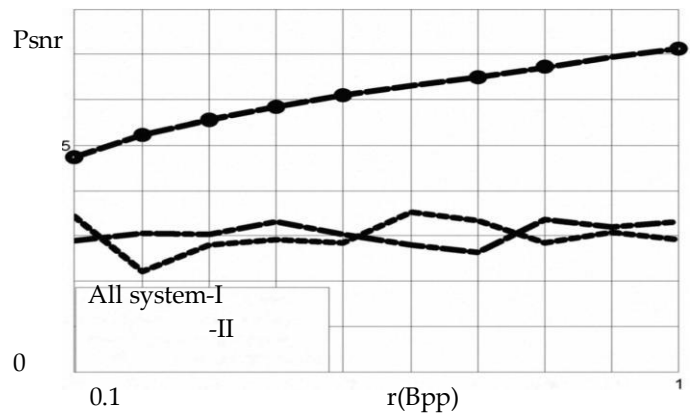


Fig. 5: The relation between the PSNR and the rate of SPIHT compression ratio on AWGN channel.

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