Compressive Sensing over OFDM Systems

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Abstract— *Communications development is the fastest-growing Nowadays, so the need and the constant demand for faster and more reliable communication methods have increased. Here, the compressive sensing appeared to meet this need. Compressive sensing is a new method of sampling that is not rendered to the Shannon-Nyquist law. In this thesis, we studied the effects of orthogonal (Fourier and wavelet) modulation with compressive sensing modeling on the characteristics of the signal that are used for medical and security applications. The compressed image performance has been tested in three ways and transmitted via the FFT-OFDM system and the DWT-OFDM system, under various baseband modulation schemes with the effect of white Gaussian noise. Then we compared the transmission performance via FFT-OFDM versus DWT-OFDM. From the simulation is observed that the wave-based OFDM system is better than the Fourier-based OFDM system Furthermore, the wavelets better than Fourier in the utilization of Bandwidth, Unlike FFT that allocates part of Bandwidth of the cyclic prefix (CP), and thus part of it is wasted.*

Keyword: Compressive Sensing, wavelet, DWT, Fourier, OFDM ,DCT.

I. INTRODUCTION

With the increasing demand for the rapid transfer of data, especially video, he recently started using Fourier modulation used worldwide in fourth-generation telecommunications systems; This may extend to the fifth generation, but wavelets can also be used for orthogonal modulation. In addition, to support rapid transit, compression modeling emerged in 2007, as data compression occurs during modeling, not beyond. There are many transmission techniques used to transmit digital signals with different environments. One of the most significant techniques, which proved to be efficient, is the Orthogonal Frequency Division Multiplexing system (OFDM). The OFDM has represented a special form of multi-carrier transmission, . The OFDM is an efficient and flexible modulation technique that is greatly used in wired communication and wireless systems. The OFDM is the basic transmission scheme in fourth-generation (4G) and five-generation (5G) [1], [2], [3]. There are many methods of data compression. In this thesis, we will study the effects of orthogonal (Fourier and wavelet) modulation with compression modeling on the characteristics of signals that are used for medical and security applications, for example, the perception of the speaker or portrait in airports and military applications, in preparation for the fifth generation who is expected to use compression modeling [4][5].

1.1 LITERATURE REVIEW

Abdullah & Hussain in (2009) studied the comparison of DWT-OFDM to replace FFT-OFDM with their BER results, showing that DWT-OFDM was better than FFT-OFDM [5]. Abdullah & Hussain in (2011) discussed BER output in DWT-OFDM, The DWT-OFDM features zero padding and transpose vector when transmitting the signal, with impulsive noise effects by varying the Poisson recurrence parameter from small to high, and results show that the impact of impulsive noise on the device is restricted when the value is massive [6].

II. BACKGROUND

A. OFDM:

Chang has proposed the first system called OFDM in 1966 [1]. To be transmitted the data over the orthogonal carriers will be originating as a stream. This serial data after parallel transformation OFDM is a modulation technique mainly suited for transmitting signals over which dispersive medium. In OFDM, the signals are orthogonal to each other; it means that they are very independent of one another. Hence, there are many advantages to using OFDM[6]. Though there are some disadvantages like errors in frequency caused by a local oscillator at the transmitting end and the receiving end, it will avoid the ISI effect, the efficiency of the bandwidth is high, it will reduce burst errors and frequency selective fading. The wavelet transforms are considered along with the OFDM [7][8]. In OFDM wideband fading channels are divided into narrowband sub-channels, it means that OFDM divides the complete spectrum into many sub-channels, the Figure 1 below shows Fourier-based OFDM (FFT-OFDM) and wavelet-based OFDM (DWT-OFDM) with three type of compression.

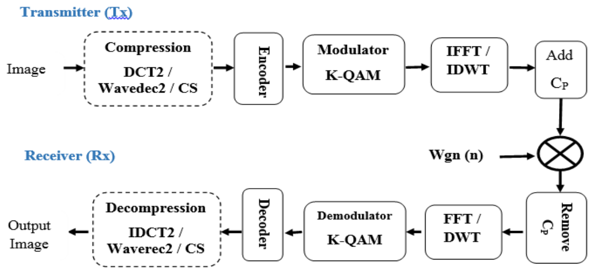


Fig. 1. FFT/DWT-OFDM Transmission System with three Type of Compression

B. Compressed sensing

Compressed sensing is an exciting, fast-growing field that has attracted considerable interest in signal processing, statistics, and computer science, as well as in the wider scientific community.

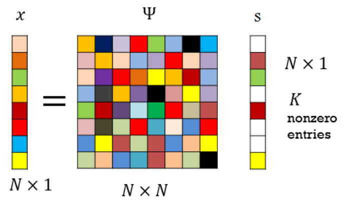
The new theory called compressive sensing assumes that there are many areas in the frequency representation of the signal that are, i.e., empty areas exist that should not be sampled. In 2008, a new approach in CS was invented based on chaos filters [10]. Compressed sensing (CS), recently been introduced by Candes and Tao [11] and Donoho [12] as a type of random undersampling, allows for the acquisition and reconstruction of sparse/compressible signals at a rate lower than that of Nyquist. First, random linear projection is used to acquire efficient representations of the signals directly. Then, nonlinear techniques are used to The structure of the optimization equation (finding the best value for the vector under certain conditions) is using one of the aggregate (norm) formulas for the vector elements.

a) Sparse Signal Acquisition

The signal (input image), represented as a column vector, this signal Considers a real, finite, one-dimensional, can represent signal x as SPARES vector by expressed as

$$x = \sum_{i=1}^{N} \psi i \; si \; = \; \Psi s \qquad (1)$$

Where x: Signal expressed in the time domain.
s: The vector of coefficients.
Ψ: Discrete cosine transform matrix.



-a-

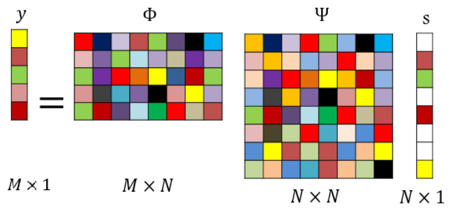
A measurement vector y consisting of m < n linear vector x projections. This can be described compactly through the

$$\boldsymbol{y}=\boldsymbol{\Phi x} \qquad (2)$$

Then y can be written, by substitution equation 2 in above as shown

$$\boldsymbol{y}= \boldsymbol{\Phi}\ \boldsymbol{\psi}\ \mathbf{s}=\boldsymbol{\Theta}\ \mathbf{s} \qquad (3)$$

Where **Φ**: is defined as the random matrix with Gaussian i.i.d. element.
y: is the measurement vector.



-b-

Fig. 2. a,b Diagram shown the Process of Compressive Sensing

b) Reconstruction Signal

The signal reconstruction algorithm must take the measurements of *M* in the vector *y*, the random matrix as well as the basis and reconstruct equivalently the signal x or its sparse coefficient vector s. Equation (4) can be solved by the structure of the optimization equation is using one of the aggregate (norm) formulas for the vector elements.

- **Restoration of the minimum L0 norm:** The sum of the elements whose value is not equal to zero.

  $$\hat{\mathbf{s}} = \operatorname{argmin} \parallel \mathbf{s}' \parallel_0 \qquad \mathbf{(4)}$$

  Can recover a correct sparse signal but needs an exhaustive listing of all possible positions of non-zero inputs in s, hence that numerically unstable and non-complete reconstruction.
- **Reconstruction of the minimum L1 norm :**The sum of the absolute values

  $$\hat{\mathbf{s}} = \operatorname{argmin} \parallel \mathbf{s}' \parallel_1 \qquad \mathbf{(5)}$$

  Luckily, the optimization is based on the norm L1 and can exactly recover K-sparse signals and closely approximate compressible signals with high probability.
- **Reconstruction of minimum L2 norm:** The square of values as shown down

  $$\hat{\mathbf{s}} = \operatorname{argmin} \parallel \mathbf{s}' \parallel_2 \qquad \mathbf{(6)}$$

The L2 norm, tests signals energy and does not signal sparsity, therefore, this norm never finds a sparse solution.

C. Classical Compression

The term compression refers to reducing the quantity of data used to represent (image, sound, and video) without far reducing the quality of the original data. Therefore, the required storage size will reduce, so big size images can be stored and it can transfer in a faster way to save time, transmission bandwidth [13].

a) Discreet Cosine Transfer:

Proposed the DCT by Ahmed et al. [14]. Discrete Cosine Transform used to process single or two-dimensional data. It is a widely used unitary transform for video and image applications. DCT, such as DFT provides information of the signal in the frequency domain [15]. The DCT represents the transformation of the original image x(n,m) pixels to their DCT coefficients; the coefficients equal the original image pixels in number and, for 2D image can be defined as mathematical form [4]:

$$X(r,k) = \frac{pr\ pk}{N} \sum_{n=0}^{N-1} \sum_{m=0}^{N-1} x(n,m) cos\frac{\pi(2n+1)r}{2N} cos\frac{\pi(2m+1)k}{2N} \quad (7)$$

Where:

$$0 \le r\,, k\,, n\,, m\ \le N$$

$$p_v = \{\begin{matrix} 1 & v=0 \\ \sqrt{2} & v \neq 0 \end{matrix}\}$$

b) Discrete Wavelet Transform:

Wavelets are useful for compressing signals. Wavelets can be used to process, compress and improve signals, in fields such as medical imaging where image Smashing when is not bear. It can be used to remove noise from an image [16]. The wavelet transform provides a representation of the time and frequency of the signal [17]. The way to compress data using wavelet is to assume a threshold then cut all coefficients below this threshold, coefficients It is given by [4].

$$\mathbf{C(l,j)} = \sum \mathbf{x(n).\,\psi l,j(n)} \qquad (\mathbf{8})$$

Where : C(l, j) represent the coefficients ,

$\Psi_{l,j}$ (n) : The wavelet.

III. PROPOSED WORK

At the transmitter, the data signals (image) that were compressed in three ways classical compression (DCT, WAV) and compressive sensing to be transmit using FFT-OFDM and DFT-OFDM techniques. After modulation by rectangular modulation with different degrees, data are converted from serial to parallel then converted from the frequency domain to the time domain by using IFFT if used FFT-OFDM and IDWT when used DWT-OFDM. A cyclic prefix (CP) is inserted into each symbol to prevent the inter symbol interference (ISI) but this step is not needed for dealing with DWT-OFDM, because it does not require the addition of a periodic prefix, and then converted from parallel to serial. The OFDM signal is ready for transmission. At the receiver, all stages of the transmitter will be reversed, which include analog to digital converter, converting from serial to parallel, cyclic prefix removal, converting the data from the time domain to the frequency domain by using FFT and DWT, applying demodulation of rectangular modulation, and converting from parallel to serial. After these stages, Mean squared error (MSE) measures are applied to know which properties of signals have been affected of the transmission process through the noisy OFDM system and the comparison between two systems is, FFT-OFDM and DWT-OFDM to know which is better in the transmission.

IV. EXPERIMENTAL RESULTS

Using MATLAB, we implemented FFT-OFDM and DWT-OFDM with (BPSK, QPSK,16QAM, 64QAM) modulation, on the compressed image in three methods (Discrete Cosine Transform, Discrete Wavelet Transform, and Compressive Sensing), where the signal to noise ratio,(SNR) ranges from -40 dB to 40 dB; assuming wired communication system, the compressed signal passed on only via one path. After compressed signals are receiving from FFT/DWT-OFDM, The mean squared error (MSE) of the sent and received image is calculated. Figures 1-2 show the DCT-Compressed Image Transmission over FFT-OFDM.

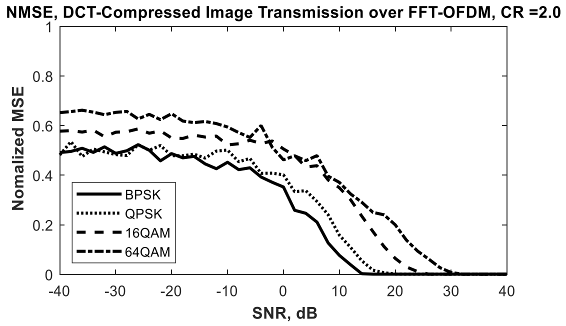


Fig. 3. DCT-Compressed Image Transmission over FFT-OFDM

The compressed image by DCT when sending over FFT-OFDM with different QAM modulation shown in the figure below

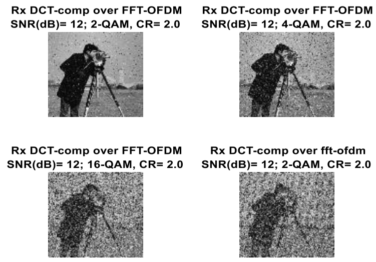


Fig. 4.DCT-Image over FFT-OFDM with different QAM modulation

Through the above Figure, it was found that when using different degrees of QAM while sending compressed images via FFT-OFDM, the higher the QAM degree, the faster the speed of transmission with the greater the error rate.

While Figures 7 show the DCT-Compressed Image Transmission over DWT-OFDM

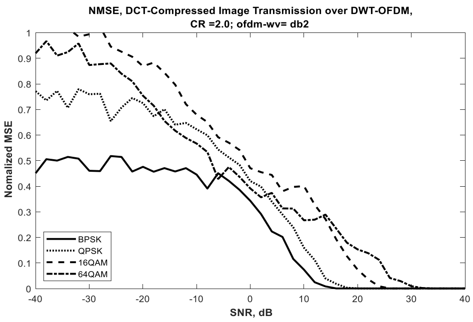


Fig. 5. DCT-Compressed Image Transmission over DWT-OFDM

We observe from the previous results, DWT advanced on FFT when compressing and sending images through the FFT-OFDM and DWT-OFDM systems, especially at high QAM and SNR.

Now the following figures show compressing the image by wavelet and sending it through the FFT-OFDM system

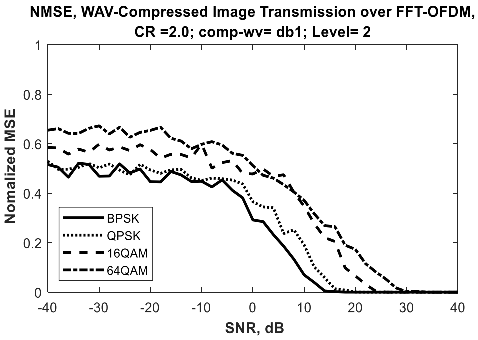


Fig. 6. WAV-Compressed Image Transmission over FFT-OFDM

Figures below show compressing the image by wavelet and sending it through the DWT-OFDM system

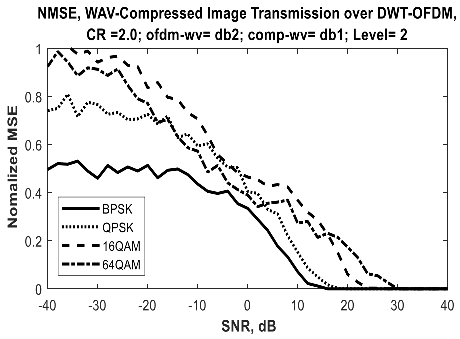


Fig. 7.WAV-Compressed Image Transmission over DWT-OFDM

We used the classic compression that includes DCT and WAV. Now we will compress the image using the compressive sensing method, which is a modern method.

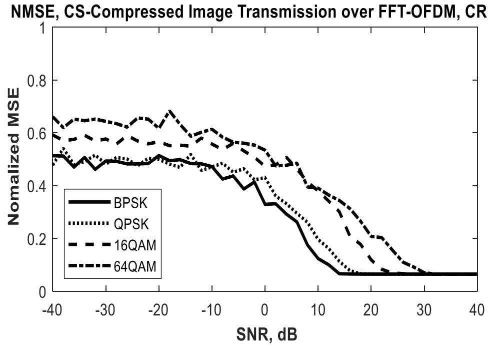


Fig. 8. CS over FFT-OFDM

Now shown CS over DWT-OFDM

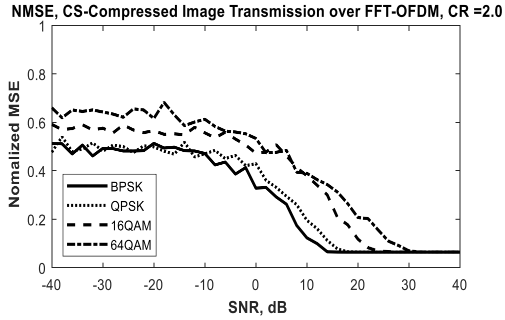


Fig.9. CS over DWT-OFDM

V. CONCLUSIONS

In this paper, we used OFDM system with FFT-OFDM and DWT-OFDM types to transfer compressed images in three ways (DCT, WAV, and Compressive Sensing) under White Gaussian Noise with BPSK, QPSK, 16QAM, and 64QAM modulation and show the following:

DWT-OFDM performs better than FFT-OFDM because of DWT-OFDM the cyclic prefix avoidance, which leads to the utilization of Bandwidth, Unlike FFT-OFDM, and it observed that with the same SNR dB and compression ratio, DWT-OFDM provides low Mean Square Error (MSE) as compared to FFT-OFDM. Therefore The Wavelet-based OFDM system is better than Fourier based OFDM when the Quarter Amplitude Modulation is 16QAM and 64QAM and the signal ratio ranges from 20 to 40. Finally, the performance of the methods that implement the wavelet has overcome the performance of the methods that implement the Fourier of the same signal (image).

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