ISSN 2320-9984
Volume 2 Issue 4 | December 2014
ISSN: 2320-9984 (Online)

International Journal of Modern Engineering & Management Research
Website: www.ijmemr.org

Analysing BER Performance of CE-OFDM by Using Discrete Wavelet Transform

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***Abstract**—In this paper Constant Envelope - Orthogonal Frequency Division Multiplexing (CE-OFDM) system using wavelet transform is proposed. This system shows a better performance than OFDM system. OFDM suffers from PAPR problem and the problem is mitigates by CE-OFDM by including phase modulation at transmitter and phase demodulation at receiver. In this paper, simulation result for FFT and wavelet on CE-OFDM is discussed. The system performance is described in Bit Error Rate (BER). It proves that wavelet performs better than FFT. Finally, it is shown that CE-OFDM can be used as a PAPR reduction scheme with reasonable acceptable BER.*

***Keywords:**—CE-OFDM, PAPR, BER, wavelet*

1. INTRODUCTION

In an OFDM system, the transmitted signals have high peak values in time domain as many subcarrier components are added. Thus, OFDM systems are known to have high peak to average power ratio (PAPR) when compare with single carrier system. The high PAPR is problem in an OFDM system as signal to noise ratio (SNR) is decreases. PAPR of a signal can be expressed as [1]

$$PAPR_{dB} = 10\log\left(\frac{\max[x(t)x^*(t)]}{E[x(t)x^*(t)]}\right) \qquad \text{……….(1)}$$

where ()* is conjugate operator. An OFDM symbol can be expressed as sum of complex tones which is equally spaced in frequency, let first calculate the PAPR of single complex tone. Consider a complex tone signal $x(t) = e^{j2\pi ft}$ with period T. The peak value of signal is given by:

$$\max[x(t)x^*(t)] = \max[e^{j2\pi ft}.e^{-j2\pi ft}] = 1 \qquad \text{……….(2)}$$

The mean square value of signal is given by:

$$E[x(t)x^*(t)] = E[e^{j2\pi ft}.e^{-j2\pi ft}] = 1 \qquad \text{……….(3)}$$

This gives PAPR of zero dB. An OFDM time signal is made of *K* complex tones (called subcarriers). Signal can be represented by following formula:

$$x(t) = \sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}} \qquad \text{……….(4)}$$

Let us assume $a_k = 1$ for any *k*. In this the peak value of signal is:

$$\max[x(t)x^*(t)] = \max\left[\sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}} \sum_{0}^{K-1} a_k^* e^{\frac{-j2\pi kt}{T}}\right] = K^2 \qquad \text{.(5)}$$

The mean square value of signal is given by:

$$E[x(t)x^*(t)] = E\left[\sum_{0}^{K-1} a_k e^{\frac{j2\pi kt}{T}} \sum_{0}^{K-1} a_k^* e^{\frac{-j2\pi kt}{T}}\right] = K \qquad \ldots(6)$$

The PAPR of OFDM symbol with K subcarriers with each subcarrier having same modulation is simply K.

2. CONSTANT ENVELOPE OFDM

CE-OFDM uses a completely different technique of signal transformation with reduced PAPR. This technique includes phase modulation at the transmitter and phase demodulation at the receiver. Phase modulation transforms the amplitude variations in OFDM signal into a constant amplitude signal thereby reducing the vast difference between the peak power and average power. This generates a signal with a constant envelope.

CE-OFDM Transmitter:

The transmitter of the CE-OFDM scheme is shown in the Figure 1. The input data is firstly mapped with a digital modulator and then converted from a serial stream to parallel sets. Every set of data contains one symbol, S_i , for each subcarrier. During each *T*-second block interval, an *N*-DFT point IDFT (Inverse Discrete Fourier Transform) generates sum of orthogonal sub carriers $x[n]$ [2].

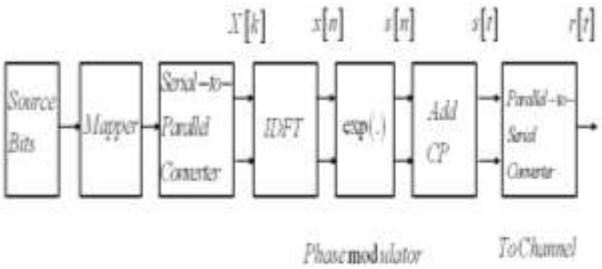

Figure.1. CE-OFDM system –Transmitter

Then, $x[n]$ which is a high PAPR OFDM sequence is passed through a phase modulator, indicated as $\exp(.)$ in figure 1, to obtain the *0* dB PAPR sequence. The cyclic prefix (CP) is appended to $s[n]$ before transmission of the signal. Cyclic prefix is a special feature which reduce Inter-Channel-Interference (ICI) and Inter-Symbol-Interference (ISI) through the channel through which signal is propagated [3]. The basic idea is to replicate part of OFDM symbol from the back-to-the-front in order to create a guard period.

CE-OFDM Receiver:

At the receiver end as shown in the Figure 2, the cyclic prefix samples are discarded firstly and the remaining samples $r[n]$ are processed [4].

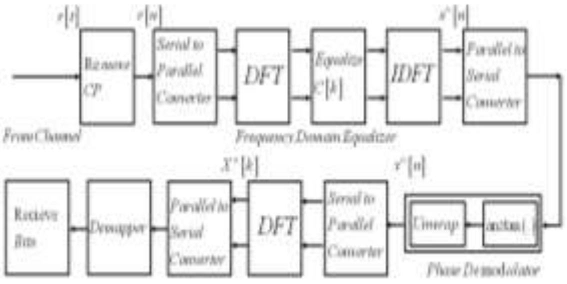

Figure.2. CEOFDM system model –Receiver

At the phase demodulator block, the phase is extracted by taking the inverse tangent of the quadrature baseband components using the $\arctan(.)$ block. Now, this is followed by a phase unwrapper to obtain the phase demodulated signal $x^\wedge[n]$. The phase estimate from the phase demodulator is confined to the 2π range from $(-\pi \text{ to } +\pi)$. The original transmit phase that deviates outside the $-\pi$ to $+\pi$ range is wrapped to within this mentioned range. Phase wrapping is more frequent for larger modulation indices whereby the large OFDM signal peaks result in large fluctuations in the CE-OFDM transmit phase.

The output of the phase demodulator is in serial form which is converted to parallel and then processed by the OFDM demodulator which consists of the *N* correlators, one corresponding to each subcarrier. This correlator bank is implemented in practice with the Discrete Fourier Transform resulting in $X[k]$. The data in serial from is demodulated by a symbol de-mapper that yields the received bits.

Thus, the transmitter achieves reduction in PAPR, by modulating the phase of the signal, to nearly 0 dB after conventional OFDM modulation. Also, at the receiver side, phase demodulation is done first followed by the conventional OFDM demodulation. Hence, the signal transformation technique for PAPR reduction works.

The output of the phase demodulator is processed by the OFDM demodulator which consists of the N correlators, one corresponding to each subcarrier. This correlator bank is implemented in practice with the Fast Fourier Transform (FFT). The symbol de-mapper yields the received bits. The performance of the receiver becomes better if a finite impulse response filter is placed before the arctangent calculator [7, 8]. The performance is also dependent on the modulation index. The Symbol error rate is given by

$$SER \approx 2\left(\frac{M-1}{M}\right)Q\left(2\pi h\sqrt{\frac{6\log_2 M}{M^2-1}\frac{E_b}{N_0}}\right) \quad \text{...... (7)}$$

where, Q is the Gaussian *Q*-function, E_b is the energy per bit of the transmitted band pass CE-OFDM signal and N_0 is the one sided power spectral density (PSD) of additive white Gaussian noise. The Bit Error Rate (BER) can be calculated as

$$BER \approx SER/\log_2 M.$$

$$BER \approx \frac{2}{\log_2 M}\left(\frac{M-1}{M}\right)Q\left(2\pi h\sqrt{\frac{6\log_2 M}{M^2-1}\frac{E_b}{N_0}}\right) \quad \text{......(8)}$$

3. WAVELET BASED OFDM

In Wavelet based OFDM (DWT-OFDM), the time-windowed complex exponentials are replaced by wavelet “carriers", at different scales (*j*) and positions on the time axis (*k*). These functions are generated by the translation and dilation of a unique function, called "wavelets mother" and denoted by ψ (*t*):

$$\psi_{J.K}(t) = 2^{-j/2}\psi\left(2^{-j}t-k\right) \quad \text{.................(9)}$$

The orthogonality of these carriers relies on time location *(k)* and scale index *(j)*. Wavelet carriers exhibit better time-frequency localization than complex exponentials while DWT-OFDM implementation complexity is comparable to that of FFT- OFDM. The key point ‘orthogonality’ is achieved by generating members of a wavelet family, according to equation

$$\left\langle \psi_{jk}(t),\psi_{m.n}(t)\right\rangle = \begin{cases}1, j=m \,\&\, k=n\\ 0, otherwise\end{cases} \quad \text{...............(10)}$$

These functions have orthonormal basis of $L^2(R)$, if infinite number of scales $j \in Z_j$ are considered. To obtain finite number of scales, scaling function $\phi(t)$ is used. DWT-OFDM symbol now can be considered as weighted sum of wavelet and scale carriers, as expressed in equation (11). This is close to the Inverse Wavelet Transform (IDWT).

$$s(t) = \sum_{j\le J}\sum_{k} w_{jk}(t)\psi_{jk}(t) + \sum_{k} a_{j.k}\Phi_{j.k}(t) \quad \text{..........(11)}$$

The properties of wavelets make it as a better choice for different applications such as biomedical engineering, nuclear engineering, pure mathematics, computer graphics and animation, acoustics and seismology, image synthesis, magnetic resonance imaging, data compression, astronomy, music, optics, human vision, radar etc. In this paper, wavelet based CE-OFDM is implemented and comparision is done with FFT in MATLAB software.

4. RESULT

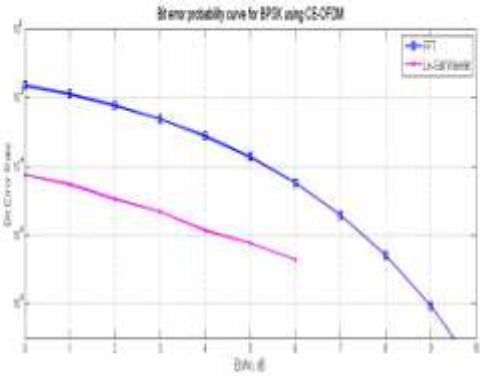

Figure.3. Bit error probability is presented for BPSK using CE-OFDM with FFT and Le-Gall wavelets.

In Figure 3, Bit error probability is presented for BPSK using CE-OFDM with FFT, and wavelet while considering $2\pi h = 1$.

5. CONCLUSION

In this paper CE-OFDM technique is described, though the OFDM is good but it suffers from the PAPR problem. This PAPR problem is reduced by using the CE-OFDM and it is concluded that wavelet gives better result than FFT in term of BER in CE-OFDM.

6. ACKNOWLEDGMENT

I would like to thank my guide Asst. Prof. Raj Tiwari for his encouragement, guidance and support. Also I would like to thank Department of Electronics and Communication, Gyan Ganga Institute of Technology and Sciences, Jabalpur for their encouragement to publish this paper.

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