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Performance Assessment of OFDM Utilizing FFT/ DWT over Rician Channel Effected by CFO

Aanchal Jhingan and Lavish Kansal*

Department of Electronics and Communication Engineering, Lovely Professional University, Punjab, India; aanchaljhingan@yahoo.co.in, lavish.15911@lpu.co.in

Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a popular kind of multi-carrier based transmission technique that has found its applications in some wireless and wireline systems. But this system suffers from several facts that degrade its performance resulting in the interference of sub-carriers. Carrier Frequency Offset (CFO) is considered as one of the factor that causes interference in the system, leading to an Inter-Carrier Interference (ICI) between the carriers that results in a degradation in the performance factor of the system. In this research work, a comparative estimation is done on the Bit Error Rate (BER) performance of Discrete Wavelet Transform (DWT) OFDM and Fourier Transform (FFT) OFDM in the presence of CFO in both of the given systems. The research focuses mainly on the improvement of the BER in the system. The complete analysis is done by considering the channel to be Rician and the systems performance is estimated for some practical values of CFO. The complete simulation is done in the MATLAB. As the CFO increases the error in the system also increases, but still in that situation, DWT shows better improvement than the conventional system. The BER performance of OFDM systems shows improvement for all the diverse PSK modulation.

Keywords: BER, CFO, DWT, FFT, ICI, IDWT, IFFT, ISI, OFDM

1. Introduction

OFDM is a multi-carrier technique that has been adopted as a standard in wireless broadband communications that offers high data rates for 4G wireless systems. In this, high data rates are transmitted by sending some orthogonal and overlapped to each other sub-carriers. The sub carriers on the sub-channels are closely spaced and are divided in the narrow bands. For the improvement of the spectral efficiency, an orthogonal relationship is required to be maintained among the sub-carriers that make the recovery of data from each carrier an easier process as long as the orthogonality is maintained between them. In this scheme, the main principle is to divide high rate stream of data into some low rate that are further taken for transmission in parallel. Each low rate stream is then taken for modulation which can be done by any modulation scheme. These modulation process and its reverse makes the calculation more proficient with FFT at the reception side and its inverse on the transmitter side. The insertion of guard interval helps in mitigating the interferences caused in the symbol and channel, also the extension of the symbol period helps in the code synchronization. Due to the usage of the orthogonal carriers at the transmitter side a reduction in the cross-talk among the sub-channels is achieved that eradicates the need of the inter-carrier bands. The bandwidth which is available is divided among the sub-carriers. Each sub-carrier is modulated at a low bit rate and the carriers are separated in such a way that helps in the compact utilization of the offered bandwidth[1]. OFDM is a very renowned transmission technique that shows great efficiency in the spectra's and also provides robustness to the fading caused due to multi-paths and the impulsive noise for the functioning of high data-rate wireless based communication systems. The sensitivity of the system to the frequency offset and the phase noise results in a loss of orthogonality in the carriers resulting in interferences. The Fourier Transform procedures help in the maintenance of the orthogonality between the carriers by defining the signal in its own domain. OFDM is the only modulation scheme that can handle data with limited bandwidth.

* *Author for correspondence*

In the recent trends, it is established that an improved performance is achieved by replacing IFFT block by IDWT and FFT block by DWT[2]. The performance of OFDM system has been evaluated for both the FFT and DWT in the presence of CFO and Doppler Effects[3]. WHT offers a better alternative for FFT in case of UWB system implementation[4]. WHT efficiently reduces the BER as well as the requirement of incorporating the guard band in comparison to FFT[5,6]. In addition to reducing the BER the use of wavelet also reduces the effect the ICI and ISI[7,8]. Diverse discrete transforms like DCT, DWT offers significant improvement in the basic OFDM system performance in comparison to OFDM system incorporated with FFT[9]. In this paper, a comparative analysis on the DWT based system to the simple conventional OFDM system is prepared, and the performance of both of the systems is estimated on the base of the BER curve drawn. The simulated results are obtained for different modulations i.e for N-PSK (N=2,4,8,16,32) under the Rician channel with the CFO present in the system ranging from 0 to 0.2. Simulations conclude that as the value of CFO increases the bit error rate also rises up in the system.

2. System Model of OFDM

The OFDM system simulation is done using MATLAB. Figure 1 represents the general block diagram of the basic model of the system, in which a serial data stream is transformed into some N number of parallel streams and after appropriate modulation (QPSK or BPSK or M-PSK) the relative sum of sub carriers approached the IFFT/IDWT block[10]. The rician channel model is considered for comparing the BER of the FFT and the DWT system. For the conventional system, the FFT and its inverse is achieved and the necessitate conversion of frequency to the time domain is done. The system becomes DWT wavelet-based system by swapping IFFT and FFT modules with the relative modules that are the IDWT and the DWT module. In the same way, the FFT based OFDM system is also represented with the IFFT and the FFT modules[11]. The Cyclic Prefix (CP) is added up at the output part of the IFFT in such a way to keep the signal away from the IC and IS interferences which is done by using the extension of the symbol with its repetitive to be applied at the end of the symbol[12]. The resultant of which is then taken for the transmission of the signal. The addition of CP increases the complexity in the system. For the DWT based system, it doesn't need the CP to be applied in the system, that makes it a less complexed system to be implemented. CP is considered as the redundant data that provides restrictions towards the useful date. By ignoring this, the data rate and the efficiency can be enhanced which helps in motivating the DWT technique to be used in the system that does not make use of CP.

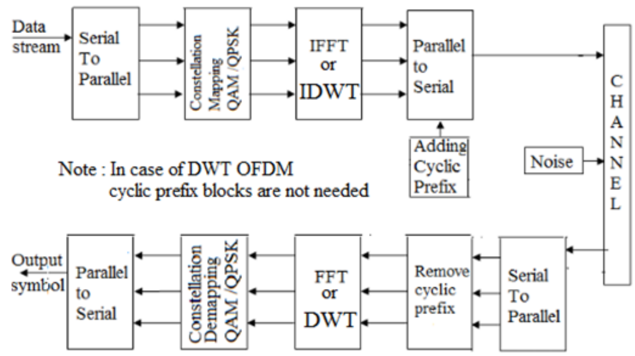


Figure 1. Block Diagram of OFDM System.

The OFDM symbol demonstrated is shown as:

$$x(n) = \frac{1}{N\sum_{m=0}^{N-1}\left(X_m e^{\frac{j2\pi mn}{N}}\right)};0 \le n \le N-1 \quad (1)$$

Here, X_m defines the baseband data which is available on each of the carrier. The D/A (digital to analog) conversion procedure creates a time-domain signal that is analog in nature under the Rician channel. In Rician channel, when a signal is taken for transmission, the Line of Sight (LOS) and non LOS, two paths are present between the transmitter and receiver part due to which the received signal is imposed on both the direct from LOS path and the scattered multipath waves from non-LOS path. The presence of dominant and a stationary signal component like LOS results in the small scale fading that is rician's envelope distribution. In that case, when random components from multi-paths that arrive at different angles are superimposed on a single stationery placed dominant signal. Fading in this channel occurs when one of the signals, basically from LOS signal is stronger than the other signals the amplitude gain of which is regarded by the rician distribution. The relative signal of each carrier is taken for the conversion process in a form of a discrete sequence represented by the y(n). At the receptor section, the received signal is taken further for the demodulation by using the FFT operation on the sequence[13]. The demodulated signal stream is expressed in a form:

$$y(m)=\sum_{n=0}^{N-1} y(n)e^{-\frac{j2\pi mn}{N}};0\leq m\leq N-1 \quad (2)$$

DWT OFDM is assumed as a proficient approach towards the conventional OFDM system in order to replace the FFT process in that basic system. The conventional OFDM system was preferred for wireless transmission due to its great performance from a long time. In the Fourier system, the signal taken is brokeup into an infinite set of signals that is a sum of the sines and cosines for destroying the orthogonal relationship among the carriers[14]. Whereas in the wavelet technique, the signal is break down in two parts by the filters i.e., a Low-Pass (LPF) and a High-Pass (HPF) Filters. At this breakdown by the filters, the signal is assumed to be down-sampled at the output of the filters, as it is said that at the output of the filters the half of the frequency components are filtered out. The application of the Wavelet transform is done in a way to eliminate the add up of the CP in the symbols that further leads to a less bandwidth wastage in the system and also increases the efficiency of the system by the 25%and also it helps in reducing the power required in the transmission. The spectra's model of the systems under different parameters shows that the DWT system is much more an improved version of the basic FFT OFDM system.

In the Wavelet transformation, the signal to be transformed is taken for the decomposition into a basis set of the waveform functions which are named as the Wavelets, which further helps in giving abetter improved way for making the analysis of the signals by constructing an investigation based on the coefficients of the transformed functions i.e. the Wavelets. The usage of the wavelet transformation is very admired among the engineers, mathematicians and the technologists and also very interestingly used among various applications. The basis functions of the transforms make it a useful function by localizing in the both of the domains i.e. in the time and the frequency and by owning unlike resolutions in their respective assigned domains.

A LPF and HPF, these two filters are used in the system to work as a QMF that satisfies a perfect and proper reconstruction of the signal with the orthonormal properties in it. In the wavelet system, the signals u after the modulation process are required to be sent for the transmission by making the use of the zero padding in the signals and also by the application of the vector transpose on the same. This is a very flexible technique and provides an efficient way to be used for decomposition of the signals in the system. The wavelet based LPF provides the approximation coefficients in the system, whereas the HPF presents the detailed coefficients in the same. The different wavelet families are said to have different filters that are available and that satisfies the Orthogonality Principle in them. The output transformed by the IDWT output is shown in the Figure 2 can be represented as the following:

$$x_i(n)=\sum_{k=0}^{\infty}\sum_{m=0}^{\infty} D_k^m 2^{\frac{k}{2}}\varphi\left(2^k n-m\right) \quad (3)$$

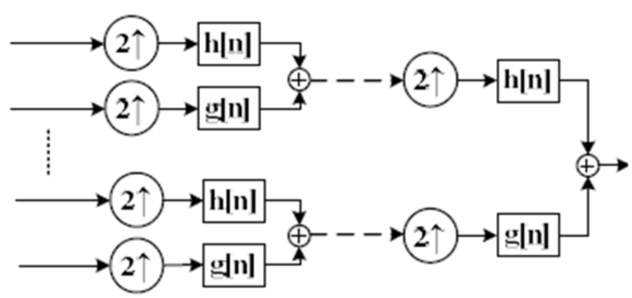


Figure 2. Block Diagram for IDWT Transform.

Where D_k^m are the wavelet defined coefficients and *ψ(t)* is the basis function for the wavelet with a compression factor of *k* and which is shifted by a factor of *m* for each of the sub-carrier. At the reception, the DWT and the demodulation process helps in the recovery of the input data back by discarding the zeros that were adding up at the transmission part as shown in the Figure 3. The output transformed by the DWT is given as follows:

$$D_k^m=\sum_{n=0}^{N-1} x_i(k)2^{\frac{k}{2}}[\varphi\left(2\right]^k n-m\right) \quad (4)$$

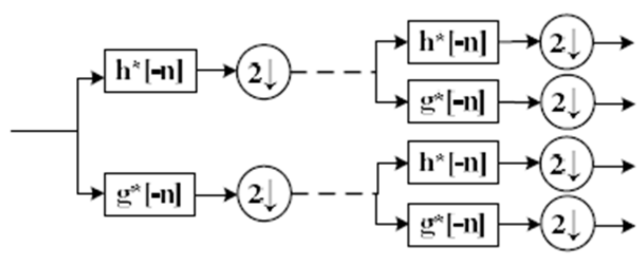


Figure 3. Block Diagram for DWT Transform.

The DWT based OFDM provides some of the advantages over the conventional OFDM system:

- Requires less overhead because of the absence of CP.
- No requirement of the pilot tones that maintains the bandwidth usage.
- Provides robustness against the ICI and the ISI.

3. Effect of CFO over OFDM

OFDM is a widely used transmission technique to be used in the wireless based communication systems that uses higher data rates. The orthogonality between the subcarriers, less degradation in the performance of the system is achieved as well as the efficiency in the bandwidth that results in a good performance parameters. However, there is one major limitation in the OFDM system which is the sensitivity of this system to the CFO effect that occurs due to the comparative motion among the transmitter and the receptor section that results in a loss of the Orthogonality among the carriers that in a result leads to a degradation in the performance of the system or by the mismatch in the frequencies of the oscillators placed at both of the ends. This OFDM system is said to be capable of utilizing more effectively the frequency spectrum by making the use of overlapped sub-carriers in the system. These type of carriers are assumed to be partially overlapped with each other with the absence of any kind of interference among the neighbouring sub-carriers of the system. This system is very sensitive to the offsets in the frequencies, so this system is supposed to offer an ease of the equalization of the channel at the frequency domain. CFO which is caused due to this frequency offset results in a great absence of the Orthogonality among the carriers that results in the ICI which further degrades the performance of the system significantly. So, its estimation and correction is very much required for the performance of the system. As already mentioned over, one of the main roots for the CFO effect in the OFDM systems is the Doppler's frequency shift denoted by f_D and the mismatch in the frequency mismatch between sender and receiver denoted by f_m. So, if the normalized CFO denoted by ε is defined as a ratio of a sum represented as $f_D + f_m$ to the spacing in the carriers denoted byDf, the received signal represented byr(n) for the transmission signal denoted by the s(n) is shown as follows:

$$r(n) = e^{j}\frac{2\pi N(f_D + f_m)}{B_s}s(n) = e^{\frac{j2\pi n\varepsilon}{N_{FFT}}}s(n) \qquad (5)$$

The bandwidth of the OFDM signal is represented by B_s which is expressed as $B_s = N_{FFT}Df$. In the ideal cases, the signal which is received at the front end of the system's receiver is supposed to be given as in the expression 2. But this is assumed to be true and a valid one only when there is no Doppler or CFO effect and that kind of the ideal conditions are practically not supposed to exist. The CFO presence in the system rules out the main ideal conditions. So, the main expression for the received and the modulated signal denoted by R(k) can be deduced as follows:

$$R_{\varepsilon}(k) = FFT[e^{\frac{j2\pi n\varepsilon}{N_{FFT}}}s(n) = S(k-\varepsilon) \qquad (6)$$

The ICI which is added up in the system due to the mismatch in the frequencies results in an absence of the orthogonality among the carriers and in a result introduces high performance degradation in the system. In this work, the performance of the system in terms of BER is simulated with the presence of the CFO in both of the systems i.e. the conventional FFT-OFDM system and the DWT-OFDM system.

4. Simulation Parameters and Procedure

The simulation for both the systems i.e the conventional and the DWT based OFDM is achieved in the using MATLAB. In the DWT based system, the filter banks to be used are chosen in a way that the resultant output of which satisfies the ideal condition with the perfect reconstruction of the signal and helps in rendering needed Orthogonality among the carriers. The complete simulation is done on the basis of the parameters which are defined in the Table 1 for the conventional model with a comparison of that to the wavelet model. The research study for is done for both of the systems under the scope of the different modulation techniques with some practical values of the CFO. A comparative analytical study is done for the two systems and an analytical approach is made on the basis of the BER curves drawn by them. The complete simulation for the systems is done under the Rician channel.

Table 1. Simulation Parameters

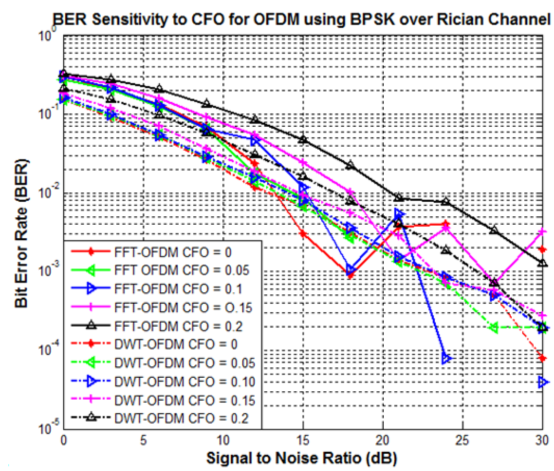
Simulation parameters	Values for FFT-OFDM	Values for DWT-OFDM
Number of Data sub-carriers	256	256
Number of sub-carriers in cyclic prefix	16	16
Modulation	BPSK, QPSK, 8-PSK, 16-PSK, 32-PSK	BPSK, QPSK, 8-PSK, 16-PSK, 32-PSK
Channel	Rician	Rician
CFO values	0, 0.05, 0.1, 0.15, 0.2	0, 0.05, 0.1, 0.15, 0.2
Wavelet used	N/A	Haar/ biorthogonal

A comparative study for the systems analysed a better performance in the terms of BER in the wavelet system in comparison to the conventional system. A gain is obtained over the FFT system by the DWT system in the terms of the SNR. The FFT model suffers from bandwidth wastage due to the addition of CP, that it inferior in front of the wavelet system that doesn't requires the usage of the CP in its system. All the simulation parameters are given in the Table1. BER versus Eb/No curve simulation is carried out.

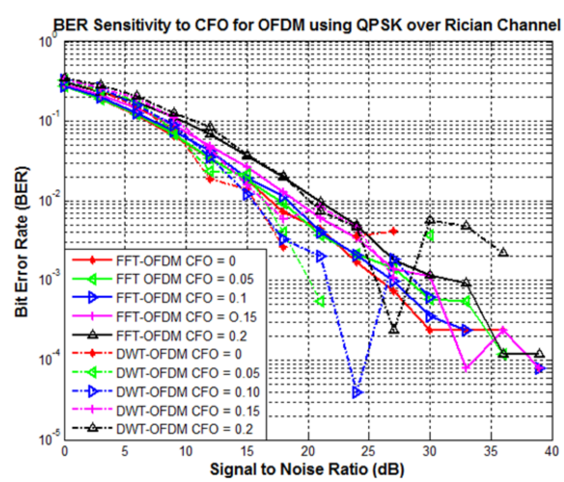
5. Results and Discussions

The results are simulated for the FFT system and the DWT in the MATLAB software. The analysis is made on the basis of the BER versus Eb/No curve which is drawn for both the systems with the CFO effect present in them for different ε values lying in a range of 0 to 0.2 with a step difference of about 0.05. The comparative study for both the systems is presented for different modulation techniques, i.e., for N-PSK (where N=2,4,8,16,32). From results it is analysed that as the CFO value rises up in the system, the chances of the error in the system also increases. So, its elimination from the system is a much required factor for the effective system's performance. The performance is measured for both the systems under Rician channel for various modulation techniques.

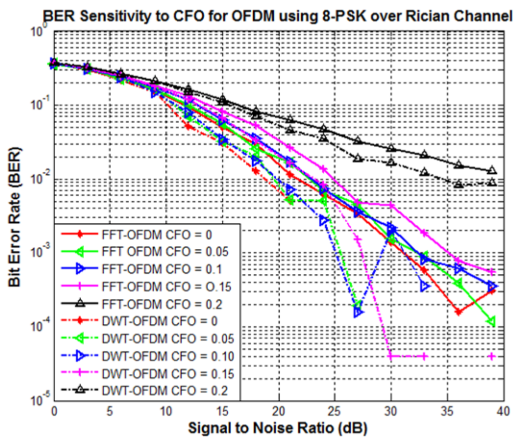
In the Figure 4(a-e), a representation of the BER performance of DWT and FFT system is shown over the different levels of the CFO present in them. In the Figure 4(a), the BER performance for both the systems is compared under the BPSK modulation scheme with the CFO effect present in that and the graph clearly depicts an enhancement in the performance which is achieved by making the use of wavelet transform in the system. In the Figure 4(b), QPSK is employed as a modulation scheme for the comparison of both the systems and the observations obtained are also same as that of previous one in this case also. In Figure 4(c), the systems are simulated for 8-PSK technique and the wavelet system is seen performing better than the Fourier system. In the Figure 4(d), the level of modulation to be used is the 16-PSK and in this scenario also the BER performance is improved using the wavelet scheme. Similarly, the same observations are made from the Figure 4(e), where the modulation level is 32-PSK. The channel for transmission is considered to be Rician, where one of the path (LOS) is larger than the other ones.



(a)



(b)



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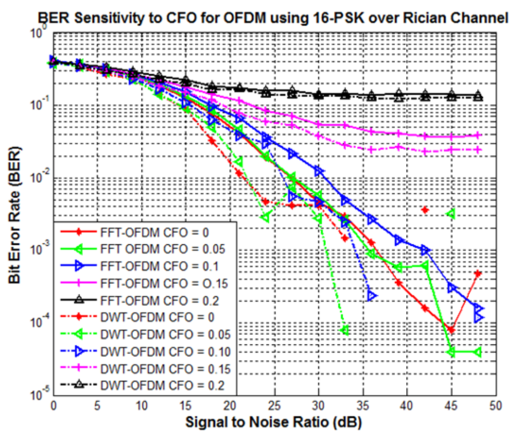
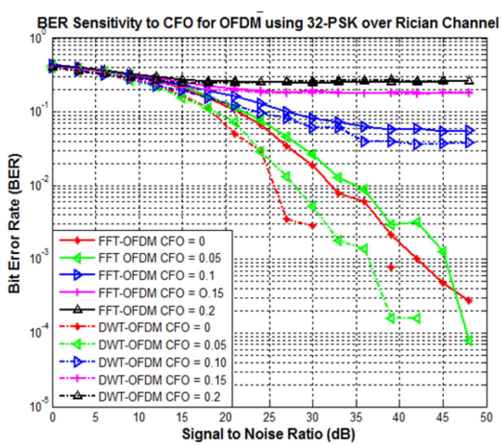


(d)



(e)

Figure 4. (**a**) Performance comparison of DWT-OFDM and FFT-OFDM for BPSK. (**b**) Performance comparison of DWT-OFDM and FFT-OFDM for QPSK. (**c**) Performance comparison of DWT-OFDM and FFT-OFDM for 8-PSK. (**d**) Performance comparison of DWT-OFDM and FFT-OFDM for 16-PSK. (**e**) Performance comparison of DWT-OFDM and FFT-OFDM for 32-PSK.

6. Conclusion

The complete simulation is performed on the root simulation parameters for both the systems defined in the table. From the simulations, it is concluded that with the increase in the CFO level the error rate in the system relative to that also take a rise. From the graphs, it is concluded that the error rate variation in terms of the BER is less between the wavelet and the conventional system, but it is the nature of the wavelet technique that is highlighting its performance in a better and enhanced way and also providing less overhead in comparison to the conventional system. In the end, it is concluded that the DWT system performs better and an improved one over the conventional system with the CFO effect presence. For future, this research work can be extended for different environments and the simulation parameters. Along with them, different CFO mitigating techniques can also be adopted in the system for better performance.

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