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Analysis of OFDM and WPOFDM Systems in Different Wireless Multipath Channels

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Abstract
In this paper, the performance analysis for orthogonal frequency division multiplexing (OFDM) and wavelet packet based OFDM (WPOFDM) systems over different wireless multipath channels has been investigated. The bit error rate (BER) performance for both systems is shown to be comparable and even at times better for OFDM especially in frequency selective fading channel at high values of S/N. Simulation results also show a significant enhancement for WPOFDM in terms of spectral efficiency and side-lobes suppression comparing to OFDM.
Keywords: OFDM, WPOFDM, PSD, BER performance, wavelet filters, fading channels.

1. Introduction

OFDM based on the discrete Fourier transform is a powerful multi-carrier modulation (MCM) scheme for high data rate transmission over fading channels [1, 2]. OFDM adopts wavelet packet function as carriers which have the characteristic of good orthogonality and time-frequency localization. WPOFDM systems have overall the same capabilities as OFDM systems with some improved features. For efficient implementation of OFDM systems, inverse fast Fourier transform (IFFT) and FFT are employed in modulation and demodulation, respectively. In addition, cyclic prefix is added in each symbol of OFDM in order to improve the robustness against multipath interference. OFDM has been proposed for digital mobile radio and wireless multimedia communication [3].

WPOFDM is a multiplexing method that uses orthogonal waveforms derived from a wavelet packet transform to combine a collection of parallel signals into a single composite signal. WPM was first proposed by Lindsey [4] in 1997 as an alternative to OFDM. The fundamental theories of OFDM and WPM have many similarities in their way of functioning and performance but there are some significant differences which give the two systems distinctive characteristics [5-8]. OFDM signals only overlap in the frequency domain while the wavelet packet signals overlap in both, time and frequency. Due to time overlap WPM systems cannot use cyclic prefix (CP) or any kind of guard interval (GI) that is commonly used in OFDM systems. OFDM utilizes CP to overcome interference caused by dispersive channels [9]. The greatest motivation for pursuing WPM systems lies in the freedom they provide to communication systems designers. Unlike the Fourier bases which are static sines/cosines, WPM uses wavelets which offer flexibility and adaptation that can be tailored to satisfy an engineering demand [10].

The purpose of this paper is to perform a simulation study to investigate the BER performance of OFDM and WPOFDM systems under the influence of flat fading and frequency selective fading channels. This paper is divided in to five main sections: section II will briefly explain the OFDM system model; section III describes the WPOFDM system model. The experimental results obtained by computer simulations are presented in section IV, and finally section V concludes the paper.

2. OFDM System Model

In OFDM System the IFFT and FFT are applied at the transmitter and receiver sides, respectively. The output of the IFFT in discrete time domain with N subcarriers is [1]:

$$x(n) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} X(k) e^{j2\pi nk/N} \tag{1}$$

The output of the FFT in frequency domain is:

$$X(k) = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} x(n) e^{-j2\pi nk/N} \tag{2}$$

Figure 1. shows the OFDM system model, in which the transmitter first converts the input data from a serial stream to parallel sets. Each set of data contains one symbol. For each subcarrier before performing the IFFT data set is modulated by DPSK modulation technique and then the parallel to serial block creates the OFDM signal. Flat and frequency selective fading channels are used to determine the performance of the system. The receiver performs the inverse of the transmitter.

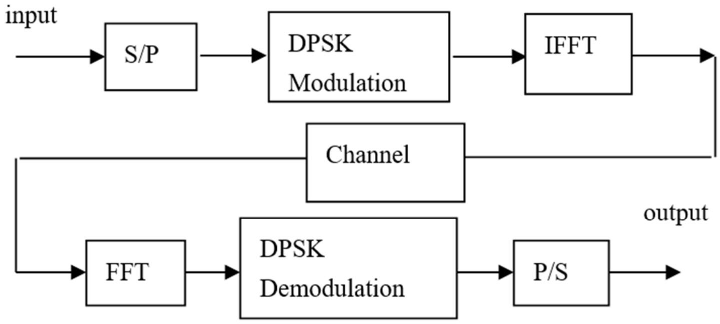

Figure 1. OFDM system model

3. Wavelet Packet Based OFDM System Model (WPOFDM)

The method of WPOFDM is similar to OFDM mentioned before, but the subcarrier waveforms are obtained through the WPT. The IWPT is used to build the transmitted symbol while the WPT allows retrieving the data symbol transmitted. Since wavelet theory has part of its origin in filter bank theory, the processing of a signal through WPT is usually referred as decomposition (i.e. into wavelet packet coefficients), while the reverse operations is called reconstruction (i. e. from wavelet packet coefficients) or synthesis.

The continuous wavelet transform of the signal *x(t)* can be defined as [11]:

$$\Psi_x^{\psi}(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} x(t) \psi^* \left(\frac{t-\tau}{s} \right) dt \tag{3}$$

Where $\Psi(t)$ is the mother wavelet, τ represents the translation parameter which is corresponding to the time information in the signal and S represents the scale parameter.

A discrete wavelet transform (DWT) is a wavelet transforms where the wavelets are samples discretely in which the scaling parameter S is discretized by 2^m and the translation parameter τ by $2^m n$, where m and n are integers. The DWT and IDWT representation of a signal *x(t)* is given by (4) and (5), respectively [11]:

$$X_n^m = 2^{-m/2} \int x(t) \psi\left(2^{-m} t - n\right) dt \tag{4}$$

$$x(t) = \sum_{m \in M} \sum_{n} X_n^m \psi_{m,n}(t) \tag{5}$$

Where X_n^m represents the DWT coefficients at different scale and translation parameters, $\psi_{m,n}(t)$ is the mother wavelet and represents the basis wavelet functions (subcarriers) with compressed factor m times and shifted n times for each subcarrier. The WPOFDM system model is shown in Figure 2.

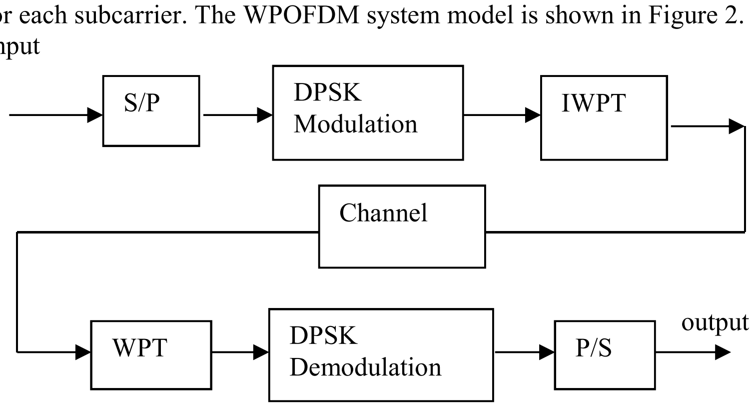

Figure 2. WPOFDM system model

WPOFDM provides a signal diversity which is similar to spread spectrum systems to some extent. Such diversity is in fact making joint use of time and frequency space. Practically, using two different generating waveforms allows us to produce two modulated signals that can transmitted on the same frequency band and suffer from reduced interference only. The amount of cross-correlation between the signals is directly dependent on the generating wavelets chosen. This particular feature could be exploited for instance in a cellular communication system, where different wavelets are used in adjacent cells in order to minimize inter-cell interference.

4. Simulation Results

4.1 OFDM Performance

The performance of OFDM over flat fading and frequency selective fading channels for different values of FFT size is shown in Figures 3, 4 and 5.

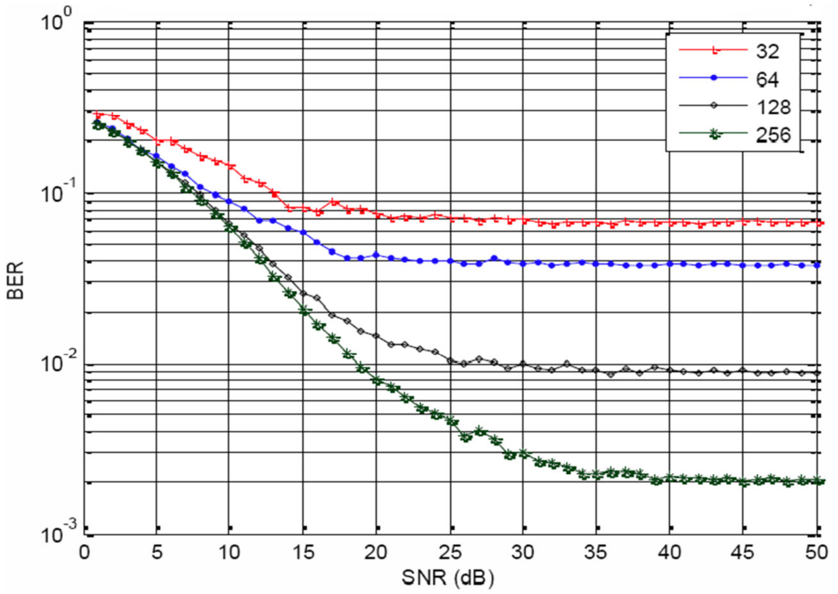

Figure 3. OFDM over flat fading channel using different number of subcarriers

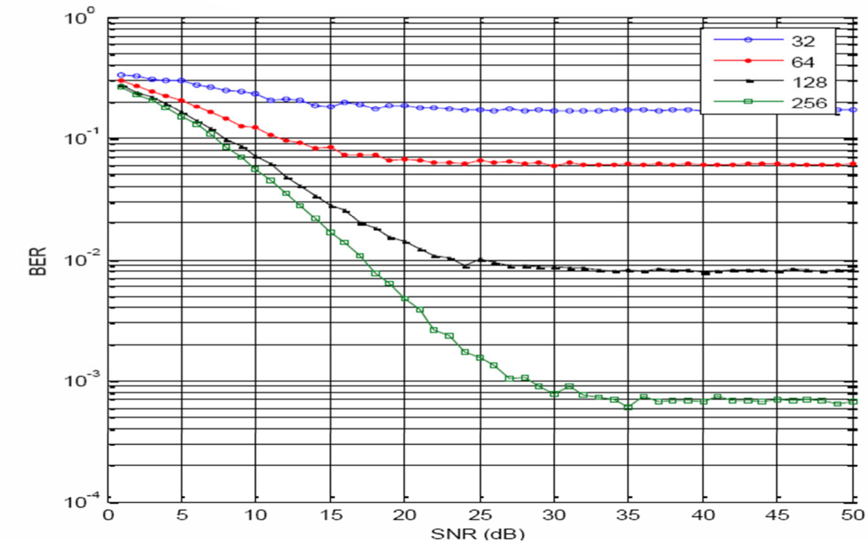

Figure 4. OFDM over frequency selective fading channel using different number of subcarriers

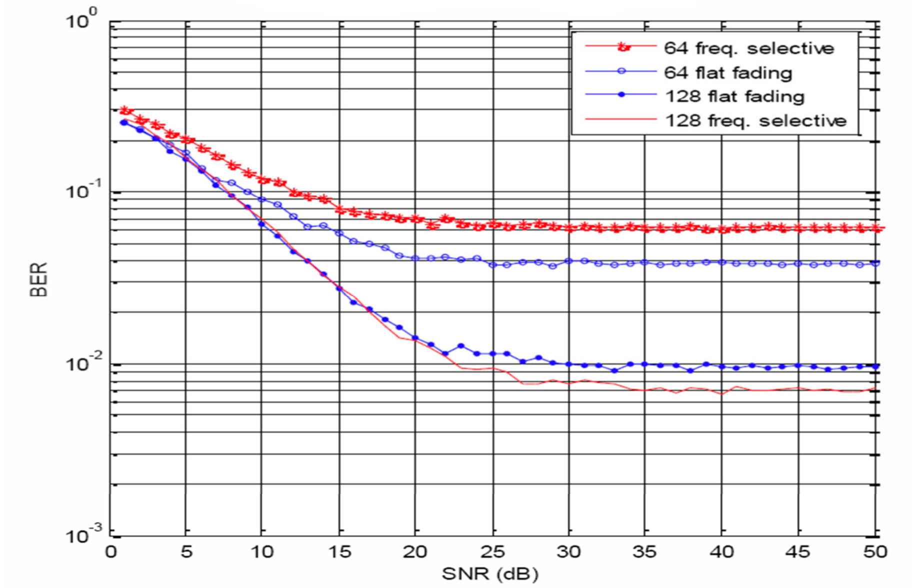

Figure 5. OFDM over different types of fading channels using different number of subcarriers

According to the assumption of OFDM effect on the signal, where it expands the duration of symbol period to be larger than the delay of the channel, then the performance in frequency selective channel will be similar to it in flat fading channel and this effect is obvious in Figure 5, specially when the number of subcarriers increase (the expansion of symbol duration increase) this will lead to improve the performance.

4.2 WPOFDM Performance

Now the performance of WPOFDM will be investigated over flat and frequency selective fading channels using different number of subcarriers, as shown in Figures 6, 7 and 8.

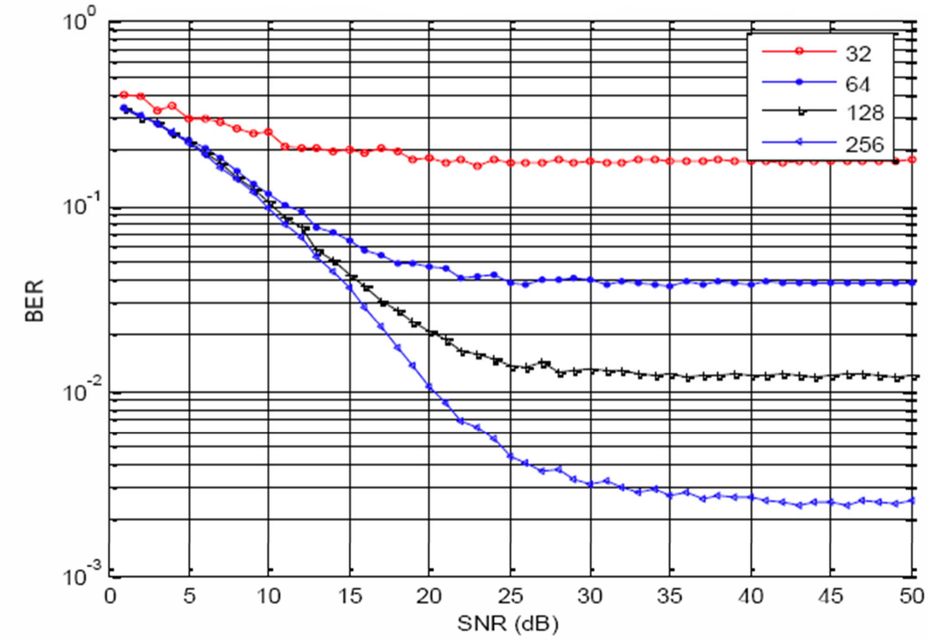

Figure 6. WPOFDM over flat fading channel using different number of subcarriers

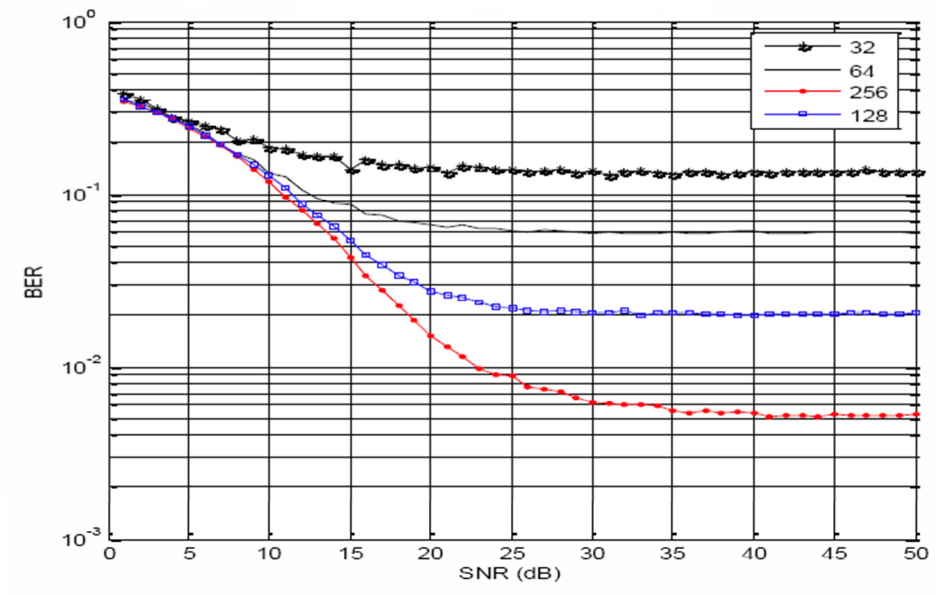

Figure 7. WPOFDM over frequency selective fading channel using different number of subcarriers

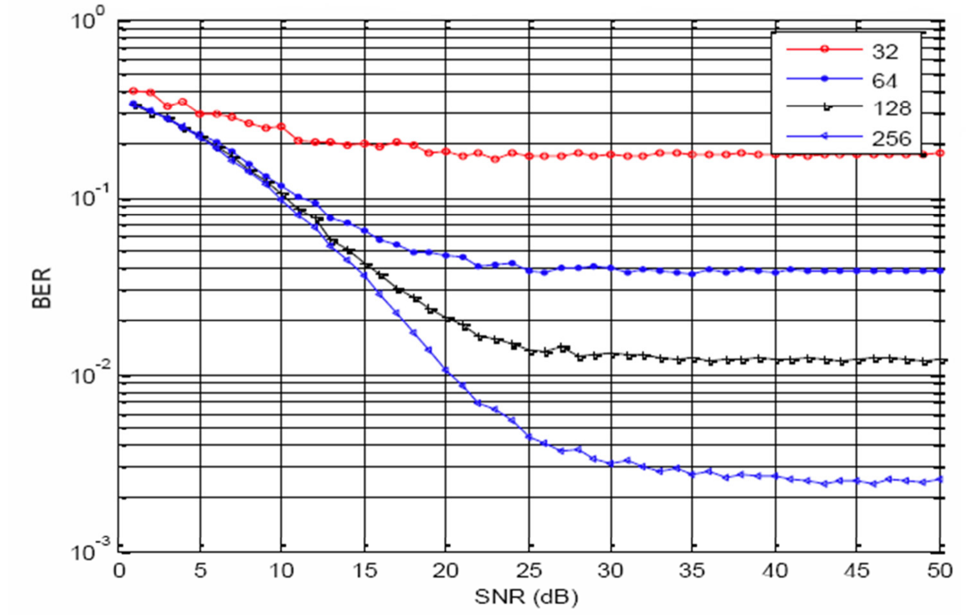

Figure 8. WPOFDM over different types of fading channels using different number of subcarriers

Exactly as the case of OFDM, WPOFDM will have the same effect on the improving the performance of the transmission over frequency selective channel and this is clearly shown in Figure 8.

4.3 Comparison between OFDM and WPOFDM

Many orthogonal wavelet filters are used to test their effect on the WPOFDM. Figure 9 shows the comparable effect of these filters, 'db2' filter will be used in this paper.

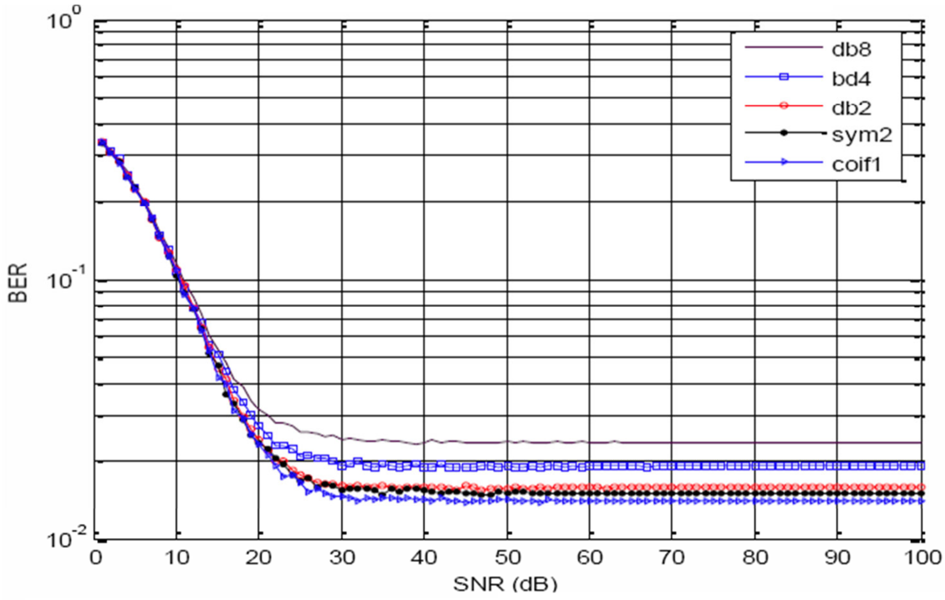

Figure 9. Various Wavelet filters over Rayleigh fading channel

A comparison between OFDM and WPOFDM is the core issue in this paper, and this section illustrates the simulation results of MATLAB code which compare the performance of both schemes in flat fading and frequency selective fading channels using different number of subcarriers as shown in Figures 10 and 11.

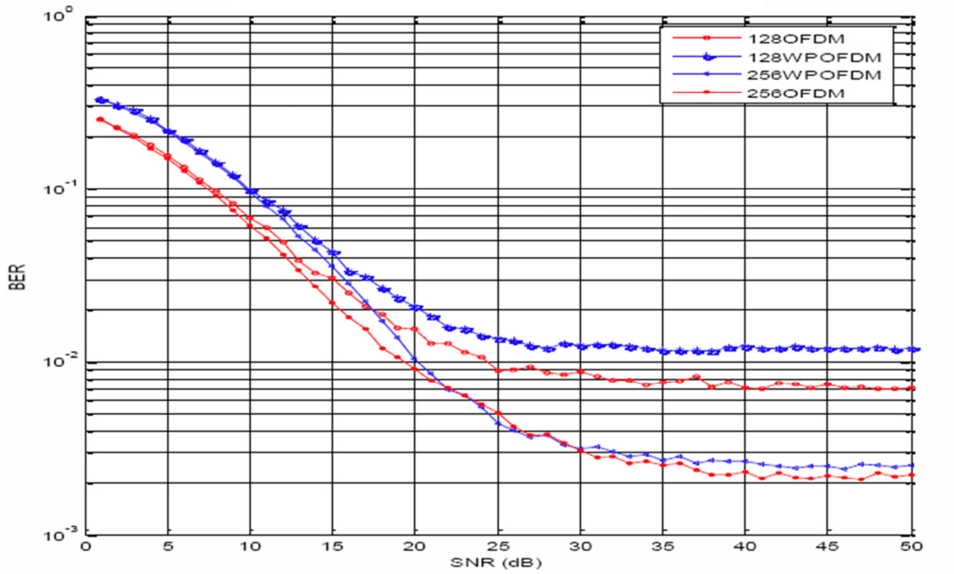

Figure 10. OFDM vs WPOFDM over flat fading channel

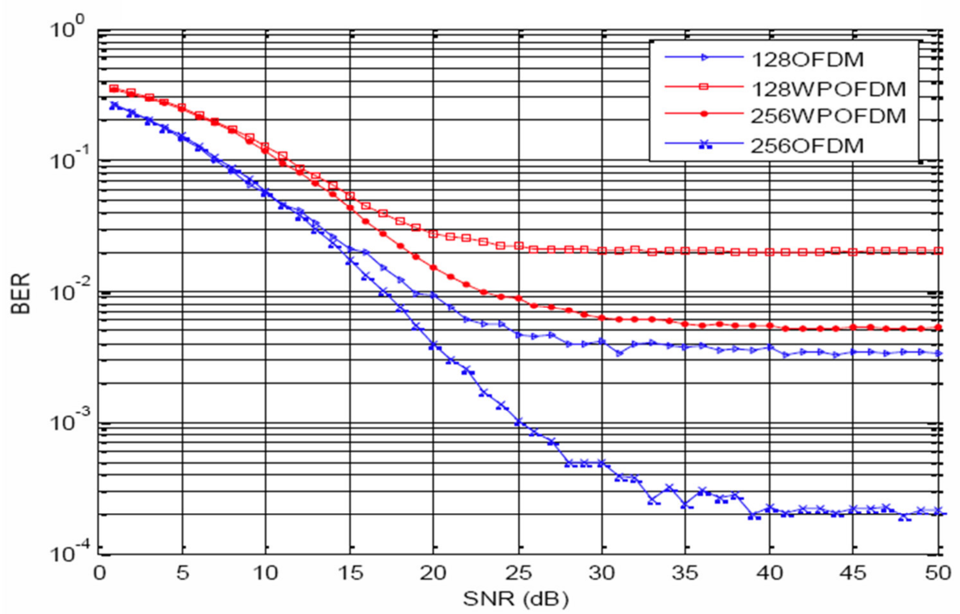

Figure 11. OFDM vs WPOFDM over frequency selective fading channel

Figure 10 shows the BER performance of OFDM with guard interval and WPOFDM in flat fading channel. It is noticed that the BER for WPOFDM is approximately the same as OFDM, especially when large number of subcarrier is used. WPOFDM outperforms OFDM under the absence of guard interval [12]. While in Figure 11, when frequency fading channel is used, the OFDM gives interesting results in terms of BER compared to WPOFDM, especially at high values of S/N. Yet, OFDM is less sensitive than WPOFDM in a frequency fading channel transmission.

4.4 Power Spectral Density

Power spectral density (PSD) for both schemes is shown in Figure 6.

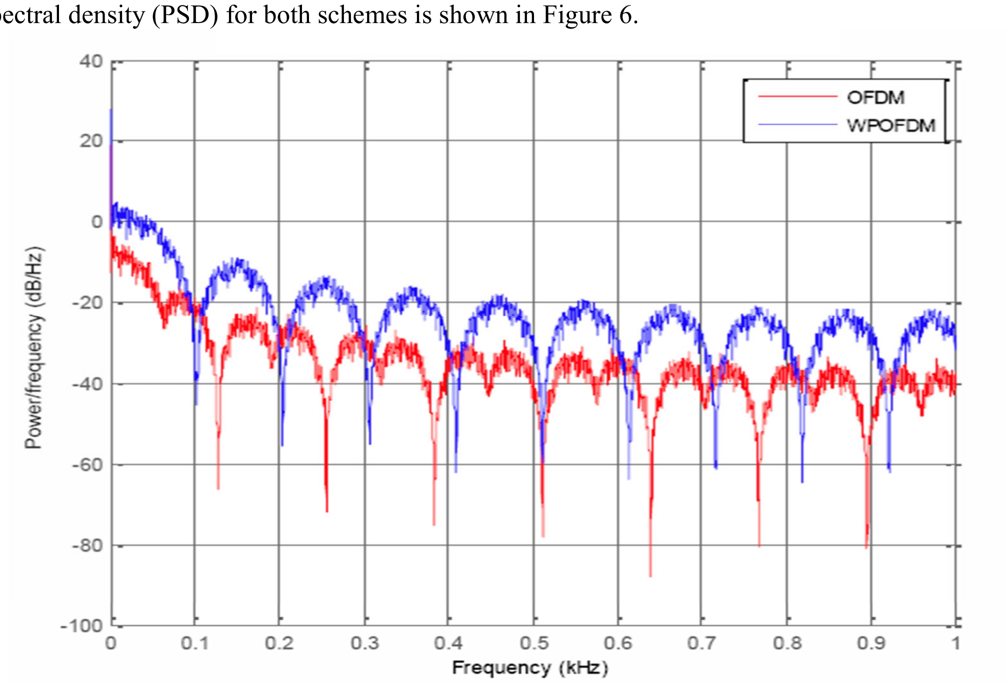

Figure 12. Power spectral density estimate via Welch

As shown in Figure 12 OFDM has lower side lobes than WPOFDM. The main lobe of OFDM is wider than that of WPOFDM and hence WPOFDM improves the spectral efficiency due to the extension of cyclic prefix at the start of each OFDM symbol.

5. Conclusion

The performance comparison of OFDM system with WPOFDM system has been carried out in flat fading and frequency selective fading channels using different number of subcarriers and 'db2' wavelet filter. In a flat fading channel it is observed that the BER performance for the two systems is almost the same. OFDM system is less sensitive than WPOFDM in a frequency selective fading channel, and hence performs better than WPOFDM in terms of BER especially at high values of S/N. It is also observed that the WPOFDM system improves the spectral efficiency due to the exclusion of cyclic prefix at the start of each symbol unlike the OFDM system.

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