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Analysis of BER Performance of OFDM System by Adaptive Modulation

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Abstract*— *Orthogonal Frequency Division Multiplexing is an emerging broadband multi-carrier modulation scheme. The robust high-bandwidth capabilities of orthogonal frequency division multiplexing confer immediate advantages on wireless products that systems are doing so. OFDM is also being considered for use in 4G cellular systems. A well-known problem of OFDM is its sensitivity to frequency offset between the transmitted and received carrier frequencies. This frequency offset introduces inter-carrier interference in the OFDM symbol. This project investigates adaptive modulation & ICI self-cancellation methods for combating the effects of channel fading & ICI respectively. These methods are compared in terms of bit error rate performance, bandwidth efficiency, and computational complexity. We propose an adaptive modulation method in order to combat channel with deep fading through simulations, it is shown that this technique is effective in mitigating the effects of ICI.

Index Terms*—*OFDM, 4G, ICI.

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) is special form of multi-carrier transmission technique in which a single high rate data stream is divided into multiple low rate data streams. These data streams are then modulated using subcarriers which are orthogonal to each other. In this way the symbol rate on each sub channel is greatly reduced, and hence the effect of inter symbol interference (ISI) due to channel dispersion in time caused by multipath delay spread is reduced. Guard interval can also be inserted between OFDM symbol to reduce ISI further. The orthogonality between subcarriers can be maintained, even though the signal passes through a time-dispersive channel by cyclically extending the OFDM symbols into guard interval. In an OFDM transmission system, each subcarrier is attenuated individually under the frequency-selective and fast fading channel. The channel performance may be highly fluctuating across the subcarriers and varies from symbol to symbol [1]. If the same fixed transmission scheme is used for all OFDM subcarriers, the error probability is dominated by the OFDM subcarriers with highest attenuation resulting in a poor performance. Therefore, in case of frequency selective fading the error probability decreases very slowly with increasing average signal-to-noise ratio (SNR) [2].This problem can be mitigated if different modulation schemes are employed for the individual OFDM subcarriers. Unlike adaptive serial systems, which employ the same set of parameters for all data symbols in a transmission frame, adaptive OFDM schemes have to be adapted to the SNR of the individual subcarriers. This will substantially improve the performance and data throughput of an OFDM system. For example if the subcarriers that will exhibit high bit error probabilities in the OFDM symbol to be transmitted can be identified and excluded from data transmission, the overall BER can be improved in exchange for a slight loss of system throughput OFDM also has some drawbacks. Because OFDM divides a given spectral allotment into many narrow subcarriers each with inherently small carrier spacing, it is sensitive to carrier frequency errors. which may be caused by Doppler shift in the channel, or by the difference between the transmitter and receiver local oscillator frequencies. This frequency offset introduces inter-carrier interference in the OFDM symbol. We propose an adaptive modulation method in order to combat channel with deep fading. Bits are allocated on each subcarrier so that the overall transmit power is minimized under a fixed bit error rate (BER). This project investigates adaptive modulation & ICI self-cancellation methods for combating the effects of channel fading & ICI respectively.

This paper is organized as follows: The system model is described in section II. The ICI canceling modulation and demodulation used in the simulations are presented next. Section III gives the idea about the adaptive modulation technique used. Section IV discusses the simulation results. Finally conclusions are made in section V.

II. SYSTEM MODEL

A. *Analysis of Inter-Carrier Interference*

In this project, the frequency offset is modeled as a multiplicative factor introduced in the channel

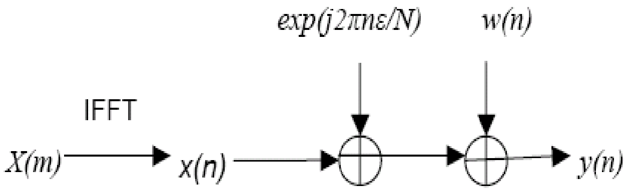

Figure 1 Frequency Offset Model

The received signal is given by,

$$y(n) = x(n)\ e^{\frac{j2\pi n\varepsilon}{N}} + w(n) \tag{1}$$

Where ε is the normalized frequency offset, and is given by $\Delta f N T_s$. Δf is the frequency difference between the transmitted and received carrier frequencies and T_s is the sub-carrier symbol period. $w(n)$ is the AWGN introduced in the channel. The effect of this

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frequency offset on the received symbol stream can be understood by considering the received symbol $Y(k)$ on the k^{th} sub-carrier.

$$Y(k) = X(k)S(0) + \sum_{l=0, l\neq k}^{N-1} X(l)S(l-k) + n_k$$

$$k = 0,1.........N-1 \qquad (2)$$

Where N is the total number of sub-carriers, $X(k)$ is the transmitted symbol for the k^{th} sub-carrier, is the FFT of $w(n)$, and $S(l-k)$ are the complex coefficients for the ICI components in the received signal. The ICI components are the interfering signals transmitted on sub-carriers other than the k^{th} sub-carrier. The complex coefficients are given by

$$S(l-k) = \frac{\sin(\pi(l+\varepsilon-k))}{N\sin(\pi(l+\varepsilon-k)/N)} \exp(j\pi(1-\frac{1}{N})(l+\varepsilon-k)) \qquad (3)$$

The carrier-to-interference ratio (CIR) is the ratio of the signal power to the power in the interference components. It serves as a good indication of signal quality. It has been derived from (3.2) and is given below. The derivation assumes that the standard transmitted data has zero mean and the symbols transmitted on the different sub-carriers are statistically independent [6].

$$CIR = \frac{|S(k|^2}{\sum_{\substack{l=0\\l=k}}^{N-1} |S(l-k)|^2} = \frac{|S(0)|^2}{\sum_{l=0}^{N-1} |S(l)|^2} \qquad (4)$$

B. Block diagram

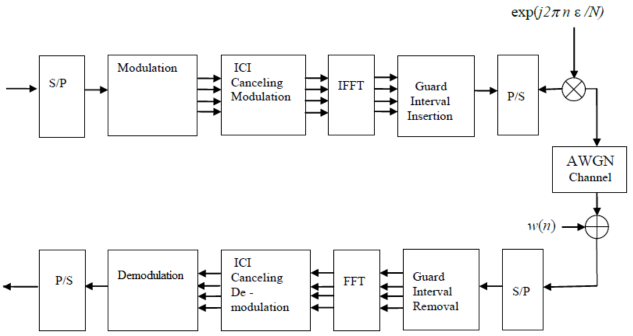

Figure 2. Block diagram

The high data rate serial input bit stream is fed into serial to parallel converter to get low data rate output parallel bit stream. Input bit stream is taken as binary data. The low data rate parallel bit stream is modulated in Signal Mapper. Modulation can be BPSK, QPSK, etc.

The modulated data are served as input to ICI canceling modulation. ICI coefficients can be found in this. The OFDM symbols are fed to Inverse Fast Fourier transform so that each subcarrier is assigned with a specific frequency. In this block, orthogonality in subcarriers is introduced.

In IFFT, the frequency domain OFDM symbols are converted into time domain OFDM symbols. After this, Guard interval is inserted in each OFDM symbol to eliminate inter symbol interference (ISI). All the OFDM symbols are taken as input to parallel to serial block. This OFDM signal is allowed to pass through digital to analog converter (DAC). In DAC the OFDM signal is fed to RF power amplifier for transmission. If there is frequency mismatch between transmitter and receiver local oscillators frequency offset occurs. Then the signal is allowed to pass through additive white Gaussian noise channel (AWGN channel).

C. ICI canceling modulation

The ICI self-cancellation scheme requires that the transmitted signals be constrained such that

$$X(1) = -X(0), X(3) = -X(2),......X(N-1) = -X(N-2) \qquad (5)$$

Using (3.3), this assignment of transmitted symbols allows the received signal on subcarriers k and $k + 1$ to be written as [6,18].

$$Y'(k) = \sum_{\substack{l=0\\l=even}}^{N-2} X(l)[S(l-k) - S(l+1-k)] + n_k \qquad (6)$$

$$Y'(k+1) = \sum_{\substack{l=0\\l=even}}^{N-2} X(l)[S(l-k-1) - S(l-k)] + n_{k+1} \qquad (7)$$

and the ICI coefficient $S'(l-k)$ is denoted as

$$S'(l-k) = S(l-k) - S(l+1-k) \qquad (8)$$

D. ICI canceling demodulation

ICI modulation introduces redundancy in the received signal since each pair of subcarriers transmit only one data symbol. This redundancy can be exploited to improve the system power performance,. To take advantage of this redundancy, the received signal at the $(k + 1)^{th}$ sub carrier, where k is even, is subtracted from the k^{th} sub carrier. This is expressed mathematically as

$$Y''(k) = Y'(k) - Y'(k+1) \qquad (9)$$

$$\sum_{\substack{l=0\\l=even}}^{N-2} X(l)[-S(l-k-1) + 2S(l-k) - S(l-k+1)] + n_k - n_{k+1}$$

Subsequently, the ICI coefficients for this received signal becomes

$$S''(l-k) = -S(l-k-1) + 2S(l-k) - S(l-k+1) \qquad (10)$$

When compared to the two previous ICI coefficients $|S(l-k)|$ for the standard OFDM system and $|S'(l-k)|$ for the ICI canceling modulation, $|S''(l-k)|$ has the smallest ICI coefficients, for the majority of $l-k$ values, followed by $|S'(l-k)|$ and $|S(l-k)|$. This is shown in Figure 4 for $N = 64$ and $\varepsilon = 0.4$. The combined modulation and demodulation method is called the ICI self-cancellation scheme. The reduction of the ICI signal levels in the ICI self-cancellation scheme leads to a higher CIR. From formula given below, the theoretical CIR can be derived as

$$CIR = \frac{\left|-S(-1)+2S(0)-S(1)\right|^2}{\sum_{l=2,4,6....}^{N-1}\left|-S(l-1)+2S(l)-S(l+1)\right|^2} \quad (11)$$

Using the theoretical results for the improvement of the CIR should increase the power efficiency in the system and gives better results for the BER. Hence, there is a tradeoff between bandwidth and power tradeoff in the ICI self-cancellation scheme.

III. ANALYSIS BY ADAPTIVE MODULATION

OFDM using a low symbol rate and the use of a guard period minimize multipath. Potential for a high SNR means that high modulation schemes can be used in OFDM systems, allowing for improved system spectral efficiency. Additionally each subcarrier can be allocated a different modulation scheme based on the measured channel conditions.

These measurements can be easily obtained as part of the channel equalization step, allowing subcarriers to be dynamically allocated modulation schemes based on the SNR of each subcarrier. These variations in SNR arise due to interference, transmission distance, frequency selective fading, etc. This technique is known as adaptive modulation. Those subcarriers with a low SNR can be allocated to use BPSK (1 b/s/Hz) or to transmit no data at all. Subcarriers with a high SNR can transmit higher modulation schemes such as 256-QAM (8 b/s/Hz) allowing a higher system throughput. The modulation allocation is flexible in OFDM systems allowing them to be optimized to local current conditions, rather than having to always use a low modulation scheme just to ensure the system operates during worst-case conditions. Once each subcarrier has been allocated bits for transmission, they are mapped using a modulation scheme to a subcarrier amplitude and phase, which is represented by a complex In-phase and Quadrature-phase (IQ) vector. Figure 3 shows an example of subcarrier modulation mapping. This example shows 16-QAM, which maps 4 bits for each symbol. Each combination of the 4 bits of data corresponds to a unique IQ vector, shown as a dot on the figure. A large number of modulation schemes are available allowing the number of bits transmitted per carrier per symbol to be varied.

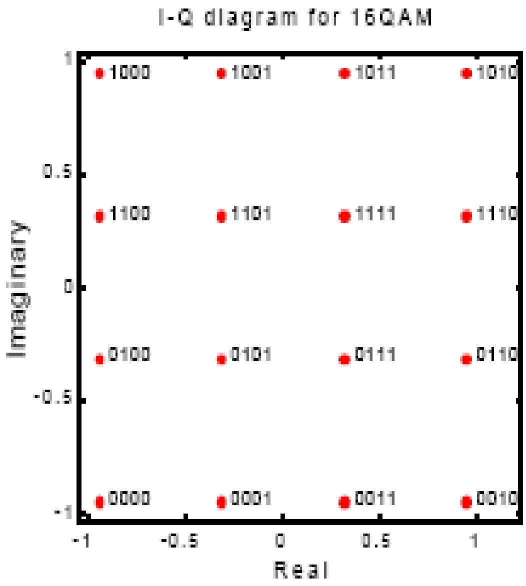

Figure 3. Example IQ modulation constellations. 16-QAM, with gray coding of the data to each location

IV. SIMULATION RESULTS AND DISCUSSION

The simulation parameters used for the above model is as given below

Table 1.Simulation parameters

Parameters	Specification
IFFT size	512
No. of Carriers	250
Channel	AWGN
Frequency Offset	0.2,0.4
Modulation	BPSK,QPSK,QAM
No. of Symbols	1000

A. Effect of frequency offset on ICI components

To analyze the effect of ICI and Adaptive Modulation on the received signal, we consider a system with Parameters:

N=16
Frequency offset=0.2 & 0.4
l=0

We are analyzing the signal received at the sub-carrier with index 0. The complex ICI coefficients $S(l-k)$ are plotted for all sub-carrier indices in Figure

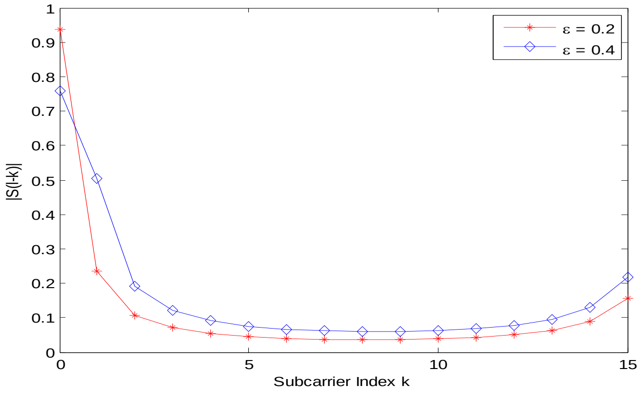

Figure 4. Coefficients for N=16 Carriers

This figure shows that for a larger ε, the weight of the desired signal component, $S(0)$, decreases, while the weights of the ICI components increases. The authors also notice that the adjacent carrier has the maximum contribution to the ICI. This fact is used in the ICI self-cancellation technique described.

B. Effect of frequency offset on CIR

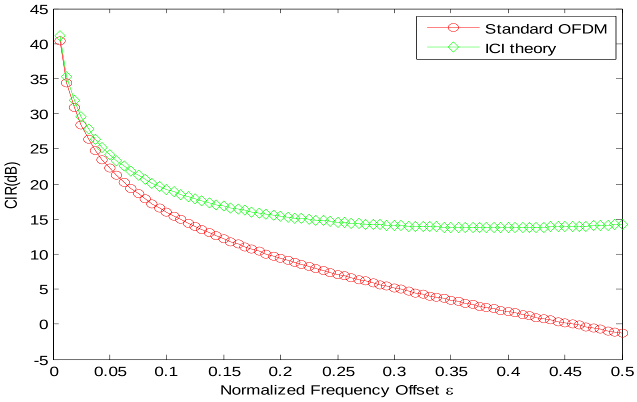

Figure 5. CIR vs. ε for System/Proposed System

Fig 5. shows the comparison of the theoretical CIR curve of the ICI self-cancellation scheme calculated by (10). As expected, the CIR is greatly improved using the ICI self-cancellation scheme. The improvement can be greater than 15 dB for $0 < \varepsilon < 0.5$. Using the theoretical results for the improvement of the CIR should increase the power efficiency in the system and gives better results for the BER.

C. Reduction of BER by adaptive modulation

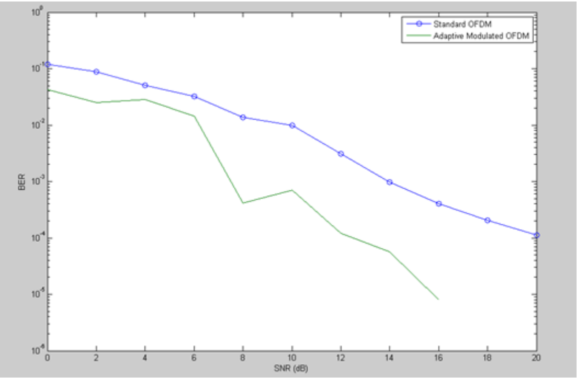

Figure 6.BER vs SNR for OFDM/Adaptive modulation

BER is improved for OFDM by adaptive modulation technique, this can be seen in fig 5.6 but it is not smooth, it can further be made linear by ICI self-cancellation. Using ICIself cancellation technique we can get greatly improved and linear results.

D. Effect of ICI self-cancellation scheme on BER

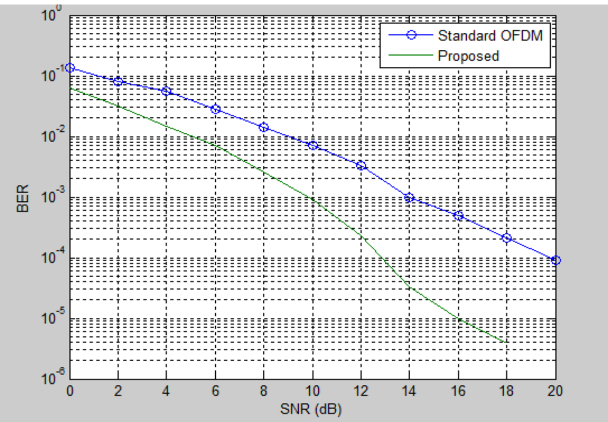

Figure 7. BER vs SNR for OFDM System/Proposed Approach

Here the plot shows BER vs SNR with self cancellation scheme. As SNR increases BER curve leans downward this indicates reduction in bit error rate very smoothly as compared to by adaptive modulation.

V. CONCLUSION

In this paper, the performance of OFDM systems in the presence of frequency offset between the transmitter and the receiver has been studied in terms of the Carrier-to-Interference ratio (CIR) and the bit error rate (BER) performance. Inter-carrier interference (ICI), which results from the frequency offset, degrades the performance of the OFDM system.

1. CIR is greatly improved using the ICI SC scheme; this improvement will increase the power efficiency in the system & hence better results for BER.
2. Adaptive modulation allocates bits dynamically, hence this method is used to combat channel with deep fading.

By using these methods the BER is improved in comparison to simple OFDM system.

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