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Analysis of ICI Self Cancellation Techniques Used In Wireless Lan Systems

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Abstract—Wireless communications has been emerged out as the mostly investigated and recent technical field since last several years. The increase in demand for the tremendous data rate and to support enormous number of users simultaneously that too reliably have come out with the methods of achieving huge capacity wireless systems. Earlier Wireless LAN networks currently used the IEEE802.11b standard, can facilitate data rate of 10Mbps.Today Wi-Fi standard IEEE802.11n is able to provide data rate of around 150 Mbps. The 4G (LTE-A) systems are providing the services of higher data rate and flexibility to have simultaneous voice communications, video-conferencing and other multi-media applications. The 5G systems are focused to provide these facilities in a more power and bandwidth efficient way. The underlying technology used in 4G and 5G systems is multi-carrier modulation techniques i.e. MIMO-OFDM.Besides the usefulness of OFDM, there are some shortcomings of this technology too which include high maximum-to-mean power, sensitivity to frequency offset and Inter Carrier Interference (ICI). This paper presents techniques for improving the performance of orthogonal frequency-division multiplexing (OFDM) systems by improving Inter-Carrier-Interference.

Keywords: Inter Carrier Interference, LAN, MIMO, OFDM, Wireless Communication, Self-Cancellation

I. INTRODUCTION

Chang in 1966 presented idea of OFDM concept and achieved a patent of it in 1970. OFDM is a modulation and multiplexing technique for sending data through multiple parallel paths by assigning different frequencies to different sub-carriers.The difference in frequencies are of order of 1/(symbol period) which ensures their orthogonality. Then, researchers identified a new OFDM system[1,2] that used DFT to decrease the complexity. With the advances in VLSI and DSP, todays OFDM systems are using FFT and IFFT blocks. Cyclic prefix (CP) or guard interval (feature of OFDM) was discovered by Ruiz in 1980 for OFDM systems. With cyclic prefix, energy efficiency has been trade off but there is a noticeable enhancement in (Inter Symbol Interference) reduction.. That’s the reason that this feature has been introduced in the present IEEE standards[3,4]. But there are some drawbacks of OFDM too. One of the major hindrance is ICI (Inter-Carrier-Interference).In frequency domain, the orthogonality of two subcarriers may be disoriented if one subcarrier is having some finite value in other’s sub-carrier’s spectra[5]. In time domain, ICI exists if the fading channel characteristics changes during one symbol period.There can be several reasons of this loss in orthogonality which include phase noise and frequency offset**.**

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II. ICI REDUCTION METHODS

Several authors has suggested their ways to reduce ICI. Some of these algorithms have been listed and discussed below:

a) Frequency domain equalization:- As the ICI interference arrangement keep changing in every frame But its pattern is invariable from symbol-to-symbol with in each frame. So, estimation of equalization coefficients has been done by utilizing pilot sub-carriers in between data sub-carriers shown in **Fig.1**.But it has several drawbacks. The ICI reduction due to fading distortion has been reduced which doesnot cause significant ICI [1]. Main cause of ICI occurrence has not been considered. Also, the estimation algorithms are very complicated. So, this method is not used in [5].

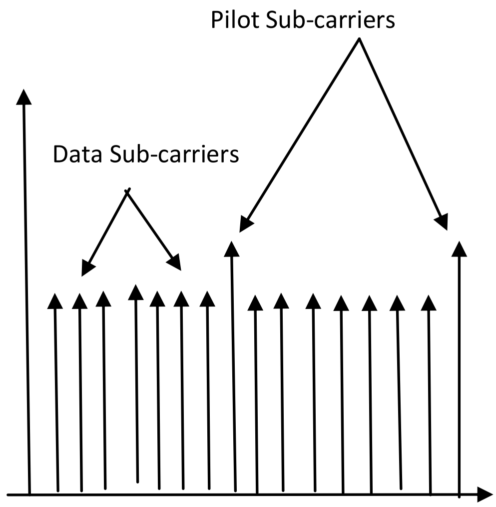

Fig.1: Pilot sub-carriers arrangement

b) Windowing method:-Seyedi invented ICI scheme that is executed through windowing at the sender and reception side. Windowing is the procedure which multiplies an appropriate function with the transmitting signal. The same function is utilized at the detector side to recover the original signal back. During his implementations, he proved that other self-cancellation schemes can be implemented from this windowing method. Using simulations, he demonstrated that this method worked well in the time-varying channels too [6].

c) *Extended Kalman Filtering (EKF):-* This method doesn’t work well for small frequency offsets. Despite for large values of frequency offset, this method performs well. The Maximum Likelihood method adds some additional bits but error performance is improved. Further EKF method improves further BER but adds complexity to the system.

d) *Total ICI Cancellation*:-Xue Li described a ICI reduction technique named as total ICI Cancellation. It does not provide reduction in data rate or bandwidth. Moreover, it utilizes the orthogonality .Total ICI Cancellation scheme worked well in the time varying channels and also in the channels affected by frequency offset [7,8].

e) ICI self-cancellation scheme:- The method worked in two stages. On sender side, one data symbol is send on tomultiple sub-carriers with a designed set of coefficients[2,10]. The set of these coefficients are constructed in such a way so as to reduce frequency distortions. On the reception side, received signals are summed together with proposed coefficients to have reduction in ICI [9]. The method performs well in

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severely distorted multipath environment and under doppler spread conditions too. As it eliminates the need of equalizers, so it is less complex also. This method suffers from a drawback of degradation of spectral efficiency as the two sub-carriers are allocated on to one symbol[11-13].

III. SYSTEM MODEL AND ANALYSIS

The OFDM block diagram is shown as below in Fig.2.

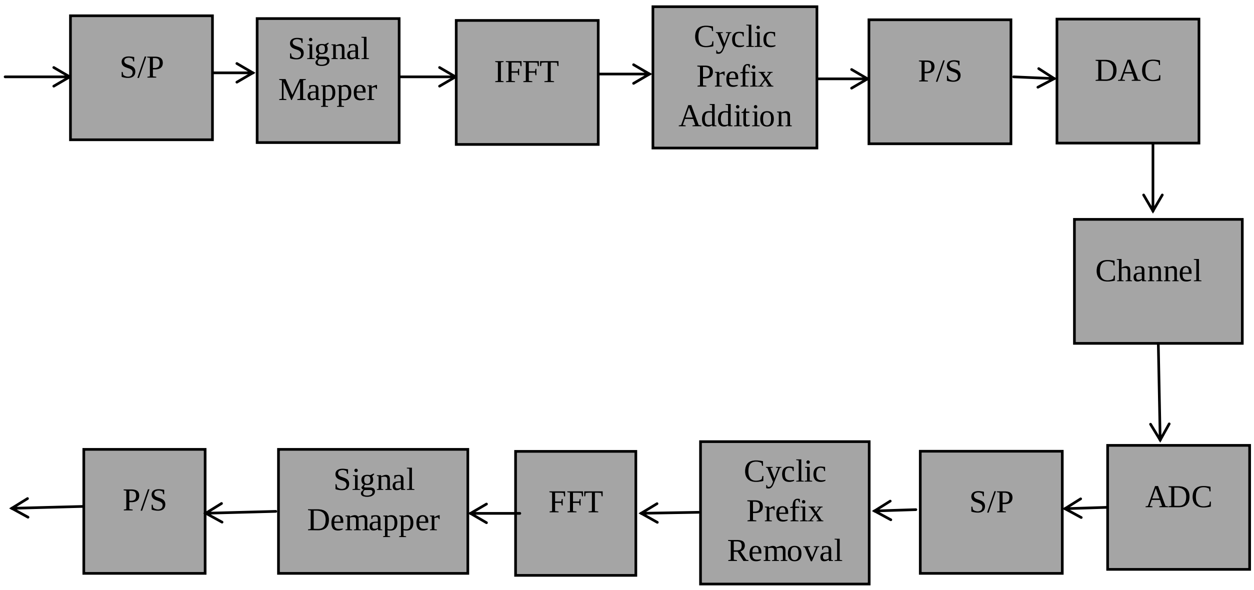
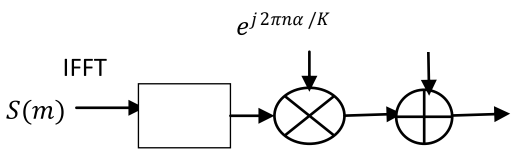


Fig. 2: OFDM block diagram

The detected signal is given by the equation (Eq. (1))

$$b(n) = \mathrm{s(n)}\exp\left(\frac{\mathrm{j}2\pi\mathrm{n}\alpha}{\mathrm{K}}\right) + w(n) \tag{1}$$

where α represents the normalized frequency offset, and is given by $\Delta \mathrm{x} KT_s$, Δx indicates the deviation between sender and receiver frequencies, T_s is the symbol duration of sub-carrier and w(n) is white the noise. .The distortion occurred due to frequency offset on the detected data can be elaborated by assuming the detected symbol B(k) on the kth sub-carrier (Eq. (2)) [15].



$$B(k) = S(\mathrm{k})\mathrm{I}(0) + \sum_{l=0, l\neq k}^{K-1} \mathrm{S(l)I(l-k)} + \mathrm{w(n)}$$

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$$\text{where} \qquad k = 0,1,2, \ldots \ldots K-1 \tag{2}$$

where K denotes the subcarrier's number, S(k) is the data symbol send for the ksubcarrier, and I(l-k) are ICI coefficients in the detected signal.

Assuming B(k)is the DFT of b(n) (Eq. (3)-Eq. (8)). Hence

$$B(k) = \sum_{n=0}^{K-1} s(n) \exp(\frac{j2\pi n\alpha}{K}) \exp\left(\frac{-j2\pi nk}{K}\right) \tag{3}$$

$$B(k) = \sum_{n=0}^{K-1} \frac{1}{K} (S(l)(\exp(\frac{j2\pi nl}{K}) \exp(\frac{-j2\pi n(\alpha-k)}{K}) \tag{4}$$

$$B(k) = \frac{1}{K} \sum_{m=0}^{K-1} S(l) \sum_{n=0}^{K-1} exp(j2\pi n \left(\frac{l+\alpha-k}{K}\right))$$

Expanding, $\frac{1}{K} \sum_{n=0}^{K-1} \exp(j2\pi n(l+\alpha-\frac{k}{K}))$ using geometric series as,

$$= \frac{1}{K} \sum_{n=0}^{K-1} \exp(j2\pi n(l+\alpha-\frac{k}{K}))$$

$$= \frac{1}{K} \left(\frac{1-\exp\left(j2\pi(l+\alpha-k)\right)}{1-\exp(j2\pi(l+\alpha-k/K}\right.$$

$$= \frac{1}{K} \frac{\exp(j2\pi(l+\alpha-k)[\exp\left(-\frac{j2\pi(l+\alpha-k)}{2}\right) - \exp\left(\frac{j2\pi(l+\alpha-k)}{2}\right)]}{\exp(j2\pi(l+\alpha-k)/2K[\exp\left(-\frac{j2\pi(l+\varepsilon-k)}{2K}\right) - \exp\left(\frac{j2\pi(l+\varepsilon-k)}{2K}\right)]}$$

$$= \frac{1}{K} \frac{\exp(j2\pi(l+\alpha-k)\left(1-\frac{1}{K}\right) \sin(\pi(l+\alpha-k))}{\sin(\pi(l+\alpha-k)/K} \tag{5}$$

Substituting Eq. (4) in Eq. (5), we get

$$B(\mathrm{k}) = \sum_{m=0}^{N-1} S(l)\, \mathrm{I}(\mathrm{l}-\mathrm{k}) \tag{6}$$

Where

$$\mathrm{I}(\mathrm{l}-\mathrm{k}) = \frac{\exp(j2\pi(l+\varepsilon-k)\left(1-\frac{1}{N}\right) \sin(\pi(l+\varepsilon-k))}{\sin(\pi(l+\varepsilon-k)/N} \tag{7}$$

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which are the appropriate ICI coefficients. The carrier-to-interference ratio (CIR) is the proportion of the transmitted signal power to the interference power. [14]

$$\mathrm{CIR} = \frac{|\,I(k)|^2}{\sum_{\substack{i=0 \\ l\neq k}}^{K-1} |I(l-k)|^2} = \frac{|\,I(0)|^2}{\sum_{l=0}^{K-1} I(l)|^2} \tag{8}$$

IV. RESULTSAND DISCUSSIONS

Simulated Analysis has been made for various methods for ICI self-cancellation . In data inversion method, data ‘ s’ is modulated on odd sub carriers and data ‘-s’ is modulated on even sub carriers.In data conjugate method, data ‘s’ is modulated on odd sequenced sub-carriers and ‘-s*’ on even sequenced sub-carriers. In improved method, data ‘s’ is modulated on first half of the sub carriers and ‘-s*’ on the second half of the sub carriers. In improved method, it has been observed that interference between a sub-carrier and its symmetric sub-carrier i.e. I(l-k)-I(K-1-l-k), is very small. Hence a pair of data symbols (s,-s*) is transmitted onto two sub-carriers (m, K-1- l), where s is the complex information and –s* is the negative conjugate of s. **Table1** describes the system design parameters.

Table 1: System Design Parameters

Parameter	Specifications
Number of OFDM symbols	1000
Frequency offset	0, 0.3, 0.35, 0.4
Modulation	BPSK
Channel	AWGN

Case 1: BER of BPSK OFDM system at frequency offset = 0

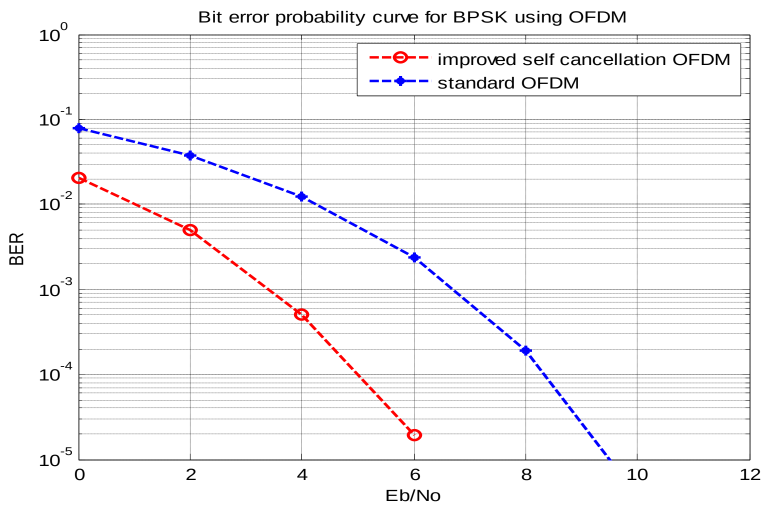

Fig. 3: Bit-error-rate comparison of basic OFDM system and improved OFDM system augmented with ICI cancellation scheme

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From**Fig.3** and **Fig.4**, it can be concluded that the proposed method has less BER as compared to standard OFDM system. BER improvementis shown in **Table 2** and **Table 3** for different values of frequency offsets. **Fig. 5** shows that CIR has been improved for improved method.

Table 2: Improvement in bit error rate between improved OFDM system and basic OFDM system

E_b/N_0 (dB)	BER (Standard OFDM System)	BER (Self-cancellation data conjugate system)	Improvement (in times)
0	0.0786	0.0204	0.74
2	0.0375	0.0052	0.86
4	0.0125	0.0006	0.92
6	0.0024	0	1

Case2: BER of BPSK OFDM system at frequency offset = 0.3

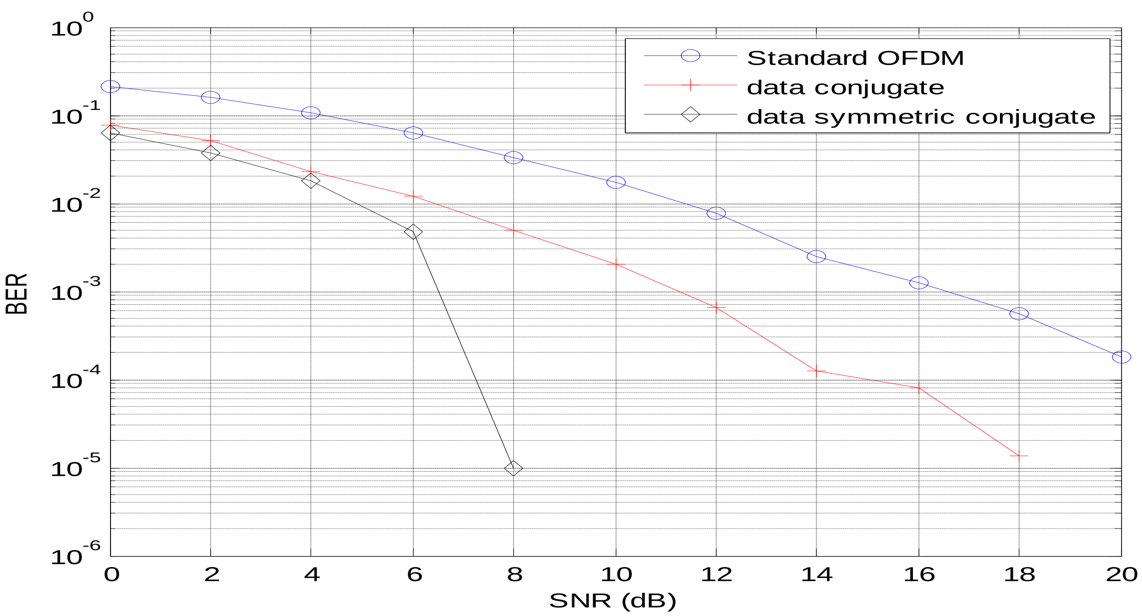

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Fig. 4:BER comparison of basic OFDM and improved OFDM augmented with different ICI self-cancellation schemes

Table3: Improvement in bit error rate between improved OFDM systems and standard OFDM system at frequency offset = 0.3

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SNR (in dB)	BER (standard)	BER Data inversion/data conjugate	BER Data Symmetric conjugate	Improvement using data conjugate as compared with standard OFDM System (in times)	Improvement using data symmetric conjugate as compared with standard OFDM System (in times)
0	0.1887	0.0586	0.0555	0.68	0.70
2	0.1711	0.0524	0.0407	0.69	0.76
4	0.1043	0.0265	0.0135	0.74	0.87
6	0.0639	0.0115	0.0053	0.82	0.91
8	0.0343	0.0048	0	0.86	1

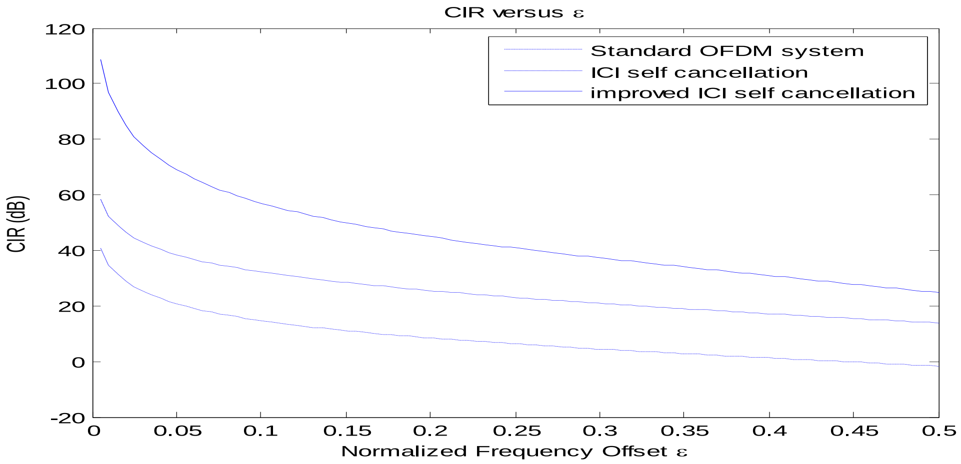

Fig. 5: CIR(Carrier-to-interference Ratio) (in dB) versus frequency offset

V. **CONCLUSION**

This paper focuses on techniques to eliminate the main shortcoming of OFDM system i.e. ICI (Inter-Carrier-Interference). Simulations are carried out on MATLAB software and the results are carried out for several ICI self-cancellation techniques. Using Simulations, it has been concluded that the improved self-cancellation scheme improves carrier to interference ratio. Also, it has been noticed that bit error rate of improved method is less as compared to other methods. Also, it has been perceived that at frequency offset=0.3, the performance of the improved ICI self-cancellation method has been augmented up to 0.91 times as compared with the basic OFDM system.

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