Reduction of Inter Carrier Interference using Extended Kalman Filter in OFDM Systems for Different Channel Models

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Abstract: ***Orthogonal Frequency Division Multiplexing (OFDM) is a multirate data transmission technique. The main drawback of OFDM is, its sensitivity to frequency offset in the channel, which may be caused by Doppler shift in the channel. This introduces loss of Orthogonality of Carrier Signals. Intercarrier Interference (ICI) occurs due to the loss of Orthogonality. The bit error rate (BER) increases rapidly with increasing frequency offsets. This is a main restriction in OFDM systems. The existing approaches to reduce ICI can be categorized as frequency-domain equalization, time –windowing and the ICI self cancellation scheme. To reduce ICI Self cancellation method is easy to implement and gives better results for lower modulation. For higher modulation schemes, it does not offer much increase in performance .So we propose Extended Kalman filter (EKF) method to overcome the drawback of self cancellation method. Then, different Modulation Schemes are adopted for the analysis along with EKF.***

Keywords: Orthogonal Frequency Division Multiplexing (OFDM), InterCarrier interference (ICI), Self cancellation scheme (SC), Extended Kalman filter (EKF)

1. Introduction

The demand for high data rate services has been increasing very rapidly and there is no slow down in sight. Almost every existing physical medium capable of supporting broadband data transmission to our homes, offices and schools have been or will be used in the future. This includes both wired (Digital Subscriber Lines, Cable Modems, Power Lines) and wireless media. Often, these services require very reliable data transmission over very crude environments. Most of these transmission systems experience many degradations, such as large attenuation, noise, multipath, interference, time variation, non-linearity's, and must meet many constraints, such as finite transmit power and most importantly finite cost. One physical-layer technique that has recently gained much popularity due to its robustness in dealing with these impairments is multi-carrier modulation. High capacity and variable bit rate information transmission with high bandwidth efficiency are just some of the requirements that the modern transceivers have to meet in order for a variety of new high quality services to be delivered to the customers. Because in the wireless environment signals are usually impaired by fading and multipath delay spread phenomenon, traditional single carrier mobile communication systems do not perform well.

Orthogonal Frequency Division Multiplexing (OFDM) [8] is simply defined as a form of multi- carrier modulation where the carrier spacing is carefully selected so that each sub-carrier is orthogonal to the other sub-carriers. Orthogonality can be achieved by carefully selecting the sub-carrier frequencies. One of the ways is to select sub-carrier frequencies such that they are harmonics to each other. The

Inter-carrier interference (ICI) is the main disadvantage of OFDM, however, is its susceptibility to small differences in frequency at the transmitter and receiver, normally referred to as frequency offset. This frequency offset [4] can be caused by Doppler shift due to relative motion between the transmitter and receiver, or by differences between the frequencies of the local oscillators at the transmitter and receiver.

In FDM [1], each of the several low rate user signals is modulated with a separate carrier and transmitted in parallel. Thus the separation of the users is in the frequency domain. In order to be able to easily demodulate each user signal, the carriers are spaced sufficiently apart from each other. Moreover, guard band has to be provided between 2 adjacent carriers so that realizable filters can be designed. Hence the spectral efficiency is very low.

A Fading Channel is known as communications channel which has to face different fading phenomenon's, during signal transmission. Due to multiple signal propagation paths [6], multiple signals will be received by receiver and the actual received signal level is the vector sum of the all signals. In real world environment, the radio propagation effects combine together and multipath is generated by these fading channels these signals incident from any direction or angle of arrival. In multipath, some signals aid the direct path and some others subtract it.

2. OFDM System Block Diagram

Figure1 shows the block diagram of a typical OFDM transceiver. The transmitter section converts digital data to be transmitted, into a mapping of subcarrier amplitude and phase. It then transforms this spectral representation of the data into the time domain using an Inverse Discrete Fourier Transform (IDFT). The Inverse Fast Fourier Transform (IFFT) [3] performs the same operations as an IDFT, except that it is much more computationally efficiency, and so is used in all practical systems. In order to transmit the OFDM signal the calculated time domain signal is then mixed up to the required frequency. The receiver performs the reverse operation of the transmitter, mixing the RF signal to base band for processing, then using a Fast Fourier Transform

(FFT) to analyze the signal in the frequency domain. The amplitude and phase of the subcarriers is then picked out and converted back to digital data. The IFFT and the FFT are complementary function and the most appropriate term depends on whether the signal is being received or generated. In cases where the signal is independent of this distinction then the term FFT and IFFT is used interchangeably the binary data sent at the transmitter side is compared with the binary data received at the receiver. Bit error rate is calculated by comparing both the transmitted binary data and received binary data. Systems using a number of different types of modulation of subcarriers within OFDM [2], such as Binary phase shift keying (BPSK), quadrature phase shift keying (QPSK) and quadrature amplitude modulation (QAM)

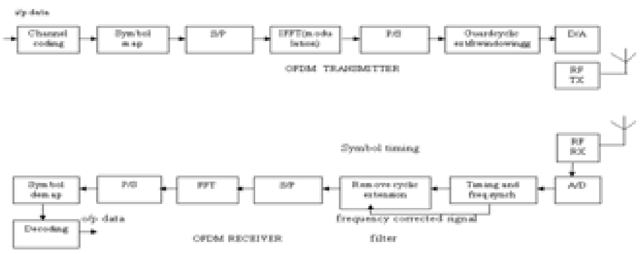

Figure 1: OFDM system block diagram

3. 1CI Self Cancellation scheme

ICI self cancellation is a scheme that was introduced by Zhao and Sven-Gustav in 2001 to combat and suppress ICI in OFDM. Succinctly, the main idea of this scheme is to modulate the input data symbol onto a group of subcarriers with predefined coefficients[3] such that the generated ICI signals within that group cancel each other, hence the name self- cancellation. It is seen that the difference between the ICI co-efficient of two consecutive sub-carriers are very small. This makes the basis of ICI self cancellation.

Here one data symbol is not modulated in to one sub-carrier, rather at least in to two consecutive sub-carriers. If the data symbol +a' is modulated in to the 1st sub- carrier then -a' is modulated in to the 2nd sub-carrier. Hence the ICI generated between the two sub-carriers almost mutually cancels each other. This method is suitable for multipath fading channels as here no channel estimation is required, because in multipath case channel estimation fails as the channel changes randomly. This method is also suitable for flat channels. The method is simple, less complex & effective. The major drawback of this method is the reduction in band width efficiency as same symbol occupies two sub carriers.

3.1 ICI Cancelling Modulation

In an OFDM communication system[7], assuming the channel frequency offset normalized by the subcarrier separation is ε , then the received signal on subcarrier *k* can be written as

$$y(k) = x(k)s(0) + \sum_{l=0,k}^{N-1} x(l)s(l-k) + nk \qquad (1)$$

$$k = 0,1,\ldots.\ N-1$$

Where N is the total number of the sub carriers, *X (k)* denotes the transmitted symbol for the *k*th subcarrier and *nk is* an additive noise sample. The first term in the right-hand side of (1.1) represents the desired signal. The second term is the ICI component. The sequence *S (l - k)* is defined as the ICI coefficient between *l*th and *k*th subcarriers, which can be expressed as

$$s(l-k) = \frac{\sin(\pi(l+\varepsilon-k))}{N\sin\left(\frac{\pi}{N}(l+\varepsilon-k)\right)} \cdot \exp\left\{j\pi\left(1-\frac{1}{N}\right)(l+\varepsilon-k)\right. \qquad (2)$$

It is seen that the difference of ICI coefficient between two consecutive subcarrier {(S (*l*-*k*) and S (*l*+1-*k*)} is very small. Therefore, if a data pair (a, -a) is modulated onto two adjacent subcarriers (*l* , *l*+1), where *a* is a complex data, then the ICI signals generated by the subcarrier *l* will be cancelled out significantly by the ICI generated by subcarrier *l*+1 Assuming the transmitted symbols are such that X(1) = -X(0), X(3) = -X(2),…….., X(N-1) = -X(N-2), then the received signal on subcarrier *k* becomes

$$y'(k+1) = \sum_{l=0,even}^{N=2} x(l)[s(l-k-1) - s(l-k)]) + nk + 1 \qquad (3)$$

Similarly the received signal on subcarrier *k*+1 becomes

$$y'(k+1) = \sum_{l=0,even}^{N-2} x(l)[s(l-k-1) - s(l-k)] + nk + 1 \qquad (4)$$

In such a case, the ICI coefficient is denoted as

$$s'(l-k) = s(l-k) - s(l+1-k) \qquad (5)$$

3.2 ICI Cancelling Demodulation

To further reduce ICI, ICI cancelling demodulation is done. The demodulation is suggested to work in such a way that each signal at the *k*+1th subcarrier (now *k* denotes even number) is multiplied by ― -1‖ and then summed with the one at the *k*th subcarrier. Then the resultant data sequence is used for making symbol decision. It can be represented as

$$y(k) = y'(k) - y'(k+1) = \sum_{i=0}^{N=2} x(l)[-s(l-k-1) \qquad (6)$$

$$+ 2s(l-k) - s(l-k+1)] + nk - nk + 1$$

The corresponding ICI coefficient then becomes

$$s(l-k-1) + 2s(l-k) - s(l-k+1) \qquad (7)$$

4. Extended Kalman Filter

Kalman filters are common in communications and signal processing literature. The Kalman filter[7] is a remarkably versatile and powerful recursive estimation algorithm that has found various applications in communications, such as adaptive equalization of telephone channels, adaptive equalization of fading dispersive channels, and adaptive antenna arrays. As a recursive filter, it is particularly applicable to non-stationary processes such as signals transmitted in a time-variant radio channel. In estimating non-stationary processes, the Kalman filter computes estimates of its own performance as part of the recursion and use this information to update the estimate at each step. Therefore, the estimation procedure is adjusted to the time-variant statistical characteristics of the random process.

4.1 ICI Cancellation

There are two stages in the EKF scheme [5] to mitigate the ICI effect: the offset estimation scheme and the offset correction scheme.

Offset Estimation Scheme:

To estimate the quantity $\varepsilon(n)$as using an EKF in each OFDM frame, the state equation is i.e., in this case we are estimating an unknown constant ε This constant is distorted by non-stationary process x(n) an observation of which is the preamble symbols preceding the data symbols in the frame.

The observation equation is

$$y(n) = x(n)e^{\frac{j2\pi n'\varepsilon}{N}} \quad (8)$$

Where y(n) denotes the received preamble symbols distorted in the channel(n) the AWGN and x(n) the IFFT of the preambles X(k) that are transmitted ,which are known at the receiver. Assume there are N_p preambles preceding the data symbols in each frame are used as a training sequence and the variance $\sigma 2$ the AWGN w (n) is stationary. The computation procedure is described as follows.

1. Initialize the estimate $\hat{\varepsilon}(0)$ and corresponding state error $P(0)$
2. Compute then $H(n)$, the derivative of $y(n)$ with respect to $\varepsilon(n)$ at $\hat{\varepsilon}(n-1)$, the estimate obtained in the previous iteration.
3. Compute the time-varying Kalman gain $K(n)$ using the error variance $P(n-1)$, H(n) and $\sigma 2$.
4. Compute the estimate $\hat{y}(n)$ using $x(n)$ and $\hat{\varepsilon}(n-1)$, i.e. based on the observations up to time $n-1$, Compute the error between the true observation $y(n)$ and $\hat{y}(n)$.
5. Update the estimate $\hat{\varepsilon}(n)$ by adding the $K(n)$ -weighted error between the observation $y(n)$ and $\hat{y}(n)$ to the previous estimation $\hat{\varepsilon}(n-1)$.
6. Compute the state error $P(n)$ with the Kalman gain $K(n)$, (n) , and the previous error $P(n-1)$.
7. If n is less than N_p increment n by 1 and go to step 2; otherwise stop.

It is observed that the actual errors of the estimation $\hat{\varepsilon}(n)$ from the ideal value $\varepsilon(n)$ are computed in each step and are used for adjustment of estimation in the next step.

Offset Correction Scheme:

The ICI distortion in the data symbols $x(n)$ that follow the training sequence can then be mitigated by multiplying the received data symbols y(n) with a complex conjugate of the estimated frequency offset and applying FFT, i.e.

$$\overline{x\wedge(n)} = FFT\{y(n)e^{-}j2\Pi\varepsilon^{\wedge}n'/N\} \quad (9)$$

As the estimation of the frequency offset by the EKF scheme is pretty efficient and accurate, it is expected that the performance will be mainly influenced by the variation of the AWGN.

5. Simulation Results

In order to compare the two different cancellation schemes, BER curves were used to evaluate the performance of each scheme. The OFDM transceiver system was implemented as specified by Figure (1) . Modulation schemes of binary phase shift keying (BPSK) and quadrature phase shift keying (QPSK) were chosen as they are used in many standards such as 802.11a

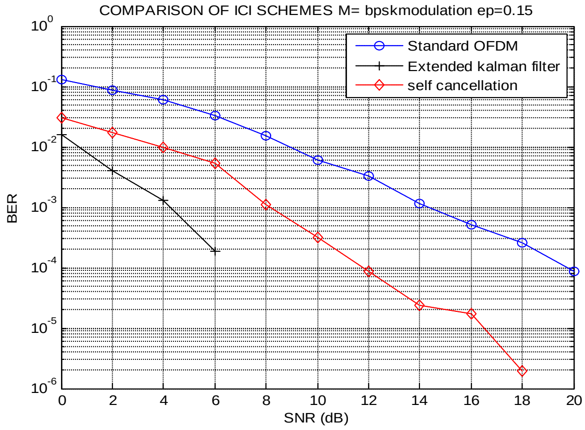

Figure 2: BER performance using BPSK modulation for N=512, M=2, $\varepsilon = 0.15$

Here an Endeavour has been made to analyze the performance of OFDM with standard OFDM, Self cancellation scheme and Extended Kalman filter scheme 512 bits, frequency offset 0.15,are initialized for different schemes viz(OFDM,SC,EKF).From this analysis, for an SNR value of 6dB ,the observed BER is as follows(OFDM=0.00015,SC=0.0014,EKF=0.00011).

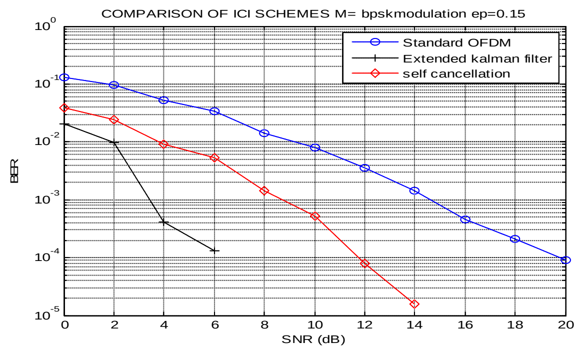

Figure 3: BER performance using BPSK modulation for N=1024, M=2, $\varepsilon = 0.15$

Here an Endeavour has been made to analyze the performance of OFDM with standard OFDM, Self cancellation scheme and Extended Kalman filter scheme 1024 bits, frequency offset 0.15,are initialized for different schemes viz(OFDM,SC,EKF).From this analysis, SNR value of 6dB,the observed value is as follows (OFDM=0.012,SC=0.0014,EKF=0.000105).

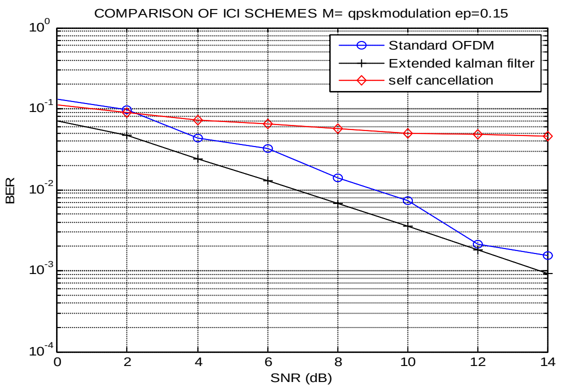

Figure 4: BER performance using QPSK modulation for N=512, M=4, $\varepsilon = 0.15$

To Evaluate the performance of OFDM with standard OFDM, Self cancellation scheme and Extended Kalman filter scheme 512 bits, frequency offset 0.15,are initialized for different Schemes viz(OFDM,SC,EKF).From this analysis, for SNR value of 14dB,the observed BER is as follows(OFDM=0.001,SC=0.014,EKF=0.001).

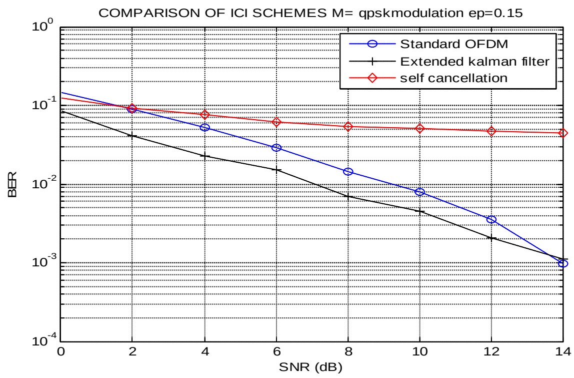

Figure 5: BER performance using QPSK modulation N=1024, M=4, $\varepsilon = 0.15$

To analyze the performance of OFDM with standard OFDM, Self cancellation scheme and Extended Kalman filter scheme 1024 bits, frequency offset 0.15,are initialized for different schemes viz(OFDM,SC,EKF).From this analysis, for an SNR value of 14dB,the observed BER is as follows (OFDM=0.00105,SC=0.014,EKF=0.001).

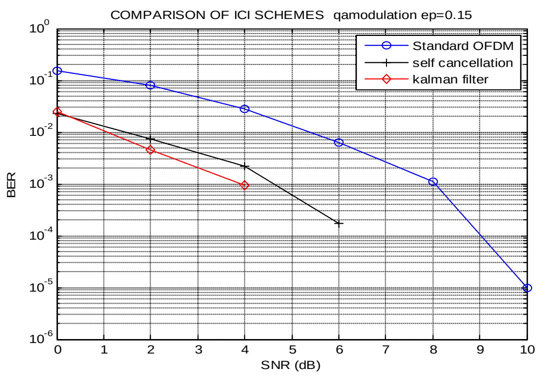

Figure 6: BER performance in AWGN using 4 QAM modulations

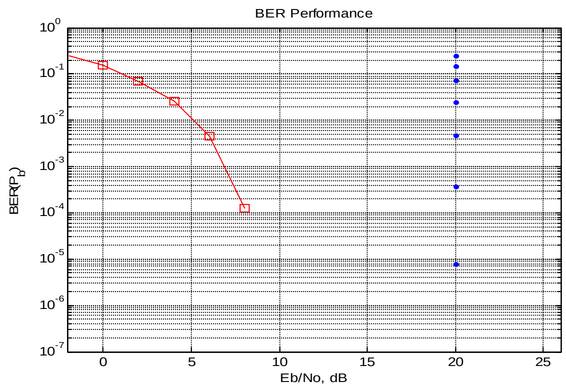

Figure 7: BER performance using 16 QAM modulations Rayleigh fading

Table 1: BER in AWGN Channel using BPSK Modulation

Method	*BER Rate for M=BPSK*		
	64	512	1024
OFDM	0.012	0.00015	0.012
Self Cancellation	0.014	0.0014	0.0014
Extended kalman filter	0.00017	0.00011	0.000105

Table 2: BER Performance in AWGN Channel Using QPSK Modulation Scheme

Method	*BER Rate for M=QPSK*		
	64	512	1024
OFDM	0.00107	0.001	0.00105
Self Cancellation	0.0135	0.014	0.014
Extended kalman filter	0.00105	0.001	0.001

Table 3: BER in AWGN Channel Using QAM Modulation

Modulation	*BER In Rayleigh*
4 QAM	0.000104
16QAM	0.000101
32QAM	0.000101
64 QAM	0.000104

Table 4: BER in RAYLEIGH using QAM Modulation

Method	*4 QAM Modulation*	*16 QAM Modulation*	*32 QAM Modulation*
OFDM	0.0102	0.6309	1.99
Self cancellation	0.00101	0.501103	0.701
Extended kalman filter	0.001	0.6309	0.6301

6. Conclusion

In this analysis, the performance of OFDM systems in the presence of frequency offset between the transmitter and the receiver has been analyzed in terms of the bit error rate (BER) performance. Inter-carrier interference (ICI) which results from the frequency offset degrades the performance of the OFDM system. Two methods were explored in this project for mitigation of the Inter Carrier Interference (ICI). The Extended Kalman filter (EKF) method for estimation and cancellation of the frequency offset has been investigated in this project. The simulations were performed in an AWGN and RAYLEIGH fading. For BPSK Modulation 1024 bits transmitted, Extended Kalman filter performs better when compared to Self Cancellation scheme. It is observed that the BER is minimum for AWGN in BPSK modulation scheme. But in the case of QPSK modulation 512 bits transmitted the bit error rate should be minimum. When higher order modulation scheme such as QAM is used, 1024 bits transmitted the bit error rate should be minimum than BPSK, QPSK Modulation schemes. Above table shows comparison of Modulation schemes. Rayleigh Fading performs better than AWGN (16 QAM).

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