International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249 – 8958, Volume-2, Issue-3, February 2013

ICI Cancellation Schemes and Selection Criteria in Orthogonal Frequency Division Multiplexing System: A Review

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Abstract— ***Orthogonal Frequency Division Multiplexing (OFDM) is considered as a digital multi carrier modulation technique. This technique will use a large number of closely spaced orthogonal subcarriers to avoid cross-talk. It provides high data rates with sufficient robustness to radio channel damages. A major problem in OFDM is carrier frequency offset error between the transmitted and received signals. Due to this the orthogonality of the subcarriers is no longer maintained which results in ICI (Inter carrier Interference). As a result the power leakage among the subcarriers which results in reduction in the system performance. In this paper, different ICI cancellation techniques such as frequency domain equalization, time domain windowing, pulse shaping and ICI self-cancellation are studied and our main concentration is on the ICI self-cancellation scheme.***

Index Terms— Carrier frequency offset (CFO), crosstalk, Inerter Carrier Interference, frequency domain equalization, pulse shaping, self-cancellation, multicarrier modulation.

I. INTRODUCTION

With the evolution of internet the need for wireless technology that can deliver data at high speeds in a spectrally efficient manner is increased. For supporting such high data rates with sufficient robustness to radio channel damages a careful selection of modulation or multiple access techniques are required. By the usage of FDM, FDMA, TDMA and CDMA we are facing certain problems. By the usage of FDM there could be a loss in bandwidth and by the usage of FDMA and TDMA there could be a chance of occurring the problems like multipath fading, time dispersion which leads to ISI, lower bit rate capacity, requirement of large transmit power for high bit rates and less spectral efficiency. For this reason most of the wireless technologies use CDMA and OFDM. But CDMA has more multipath fading and complexity than the OFDM. So, OFDM appears to be most suitable than all the remaining technologies. OFDM is considered as a digital multicarrier modulation technique that provides high data rates and now it is used in many communication systems.

Manuscript received on February, 2013.

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IEEE802.11, IEEE802.16, DVB-T and DAB are some of the examples of OFDM which provides high data rates for wireless LANS and it is also used in ADHOC networks. The wireless LAN standard of OFDM supports a bit rate of 6 to 54 Mbps.

Frequency selective fading can be effectively reduced by using serial-to-parallel converter and inter-symbol interference (ISI) can be efficiently reduced by adding cyclic prefix in OFDM system. In this paper a brief description of OFDM system is given. But one of the main drawbacks of OFDM system is its sensitivity to frequency offset error and Doppler shift which causes Inter-carrier Interference (ICI). Different methods are implemented for reducing this ICI and those methods are frequency domain equalization, time domain windowing, pulse shaping and ICI self-cancellation. The rest of this paper is organized as follows. A brief description of OFDM is given in section 2. Different methods for ICI cancellation are discussed in section 3. Finally, section 4 concludes the paper.

II. ORTHOGONAL FREQUENCY DIVISION MULTIPLEXING

A. Orthogonality

If two signals are said to be orthogonal then their dot product is zero. As the subcarriers are orthogonal then the spectrum of each subcarrier has a null at the center frequency of the other subcarriers in the system. It is as shown in the figure.

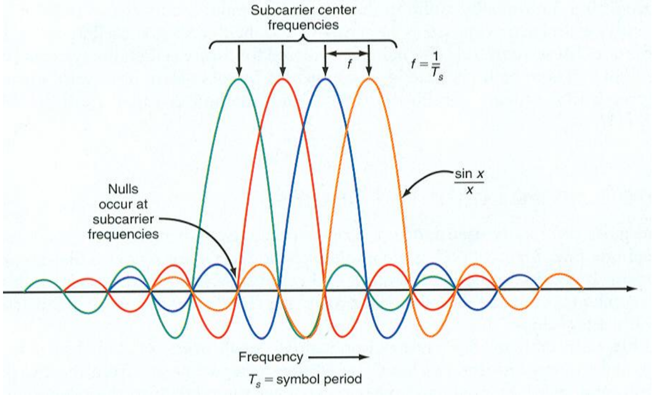

FIGURE1: ORTHOGONALITY OF SIGNALS

B. OFDM Generation And Reception

The block diagram of a typical OFDM transceiver is as shown. 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) performs the same operations as an IDFT, but IFFT requires fewer computations when compared to IDFT 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.

Therefore the OFDM symbol can be expressed as

$$x(n) = \frac{1}{N}\sum_{m=0}^{N-1} X(m)\, e^{\frac{j2\pi nm}{N}}$$

Where x(n) denotes the sample of the OFDM signal, X(m) denotes the modulated symbol within subcarrier and N is the number of subcarriers.

On receiving side this symbols are converted back to parallel stream and mapped with FFT then with demodulation scheme and converted to serial data as output data.

The demodulated symbol stream is given by

$$y(m) = \sum_{n=0}^{N-1} Y(n)\, e^{\frac{-j2\pi nm}{N}} + w(m)$$

Where w (m) corresponding to the FFT of the samples of the w (n).

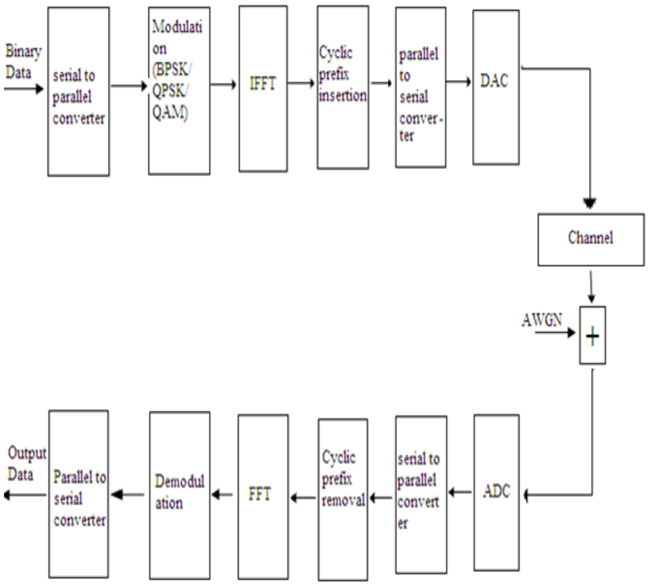

Figure 2:OFDM generation and reception block diagram

III. ICI CANCELLATION METHODS

Several methods are suggested for ICI cancellation. Those are frequency domain equalization, time domain windowing, pulse shaping and ICI self cancellation.

A. FREQUENCY DOMAIN EQUALIZATION

The fading distortion in the channel causes ICI in the OFDM demodulator. Compensation for fading distortion in the time domain introduces the problem of noise enhancement. So frequency domain equalization process is used for reduction of ICI by using suitable equalization techniques. We can estimate the ICI for each frame by inserting frequency domain pilot symbols in each frame as shown.

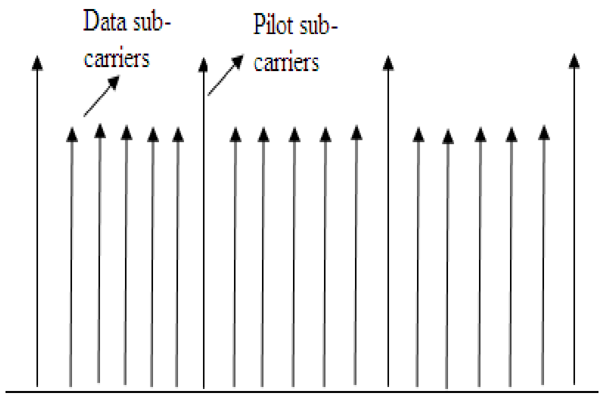

Figure3.Pilot Subcarriers arrangement

The equalizer co-efficient for eliminating ICI in the frequency domain can be derived from the pattern of the pilot symbol & hence a suitable equalizer can be constructed. It can only reduce the ICI caused by fading distortion but it does not deal the problems of frequency mismatch between transmitter and receiver and doppler shift which is the main source of ICI. Again it is only suitable for flat fading channels, but in mobile communication the channels are frequency selective fading in nature because of multipath components. Here also the channel needs to be estimated for every frame. Estimation of channel is complex, expensive & time consuming. Hence this method is not effective one.

B. TIME DOMAIN WINDOWING

We know that OFDM signal has widely spread power spectrum. So if this kind of signal is transmitted in a band limited channel, certain portion of the signal spectrum will be cut off, which will lead to inter carrier interference (ICI). To reduce the interference, the spectrum of the signal wave form need to be more concentrated. This is achieved by windowing the signal. Basically windowing is the process of multiplying the transmitted signal wave form with a suitable function (i.e. with window function). The same window is used in the receiver side to get back the original signal. It can only reduce the ICI caused by band limited channel and it also does not deal with the frequency mismatch between the transmitter and receiver, and the Doppler shift. Windowing is done frame by frame & hence it reduces the spectral efficiency to a large extent. Hence this method is also not an effective one.

C. PULSE SHAPING

The purpose of pulse shaping is to reduce the side lobes. If we can reduce the side lobe significantly then the ICI power will also be reduced significantly. But the drawback is complexity in implementation.

D. ICI SELF CANCELLATION

It is seen that the difference between the ICI co-efficient of the two consecutive sub-carriers is 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.

a. ICI Cancelling Modulation

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

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

Where N is the total number of the subcarriers, 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 the above equation represents the desired signal. The second term is the ICI components. The sequence S(*l*-*k*) is defined as the ICI coefficient between *l*th and *k*th subcarriers, which can be expressed as

$$S(l-k) = \frac{\sin(\pi(l+\varepsilon-k))}{N\,\sin(\frac{\pi}{N}(l+\varepsilon-k))}\, e^{(j\pi\left[1-\left(\frac{1}{N}\right)\right](l+\varepsilon-k))}$$

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

$$Y'(k) = \sum_{l=0, l=even}^{N-2} X(l)\left[S(l-k) - S(l+1-k)\right] + nk$$

Similarly the received signal on subcarrier k+1 becomes

$$Y'(k+1) = \sum_{l=0, l=even}^{N-2} X(l)\left[S(l-k-1) - S(l-k)\right] + nk+1$$

In such a case, the ICI coefficient is denoted as S'(l-k) = S(l-k) – S(l+1-k)

It is found that S'(l-k) << S(l-k), which is as shown in the figure 4

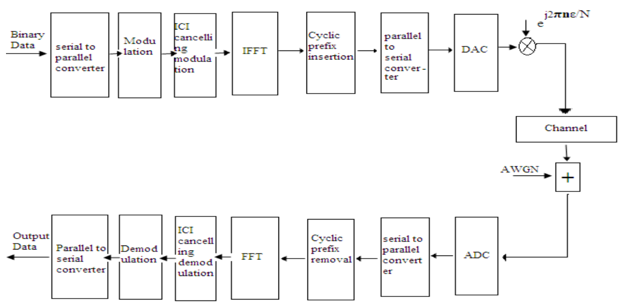

Figure 4. Block Biagram of ICI Self Cancellation Scheme

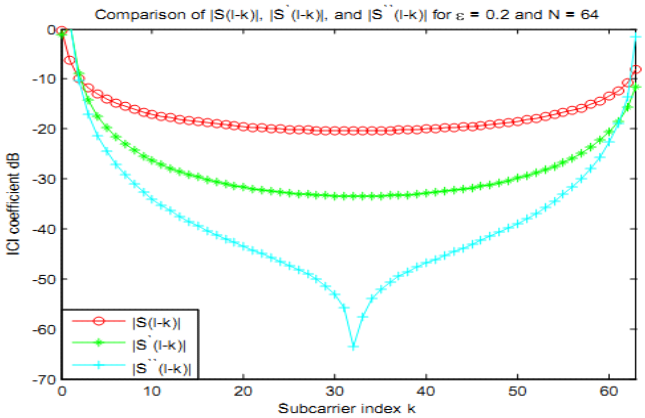

Figure 5. Comparison between |S (l-k)|, |S'(l-k)| and |S"(l-k)|

b. 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

$$Y''(k) = Y'(k) - Y'(k+1$$

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

The corresponding ICI coefficient then becomes

S"(l-k) = - S(l-k-1) + 2S(l-k) – S(l-k+1)

The above figure shows that the amplitude comparison of |S(l-k)| , | *S'* (*l*- *k*) | and | *S"* (*l*- *k*) | for N = 64 and ε= 0.3. For the majority of (*l*-*k*) values, | *S'*(*l*-*k*) | is much smaller than | *S*(*l*-*k*) | , and the | *S"*(*l*-*k*) | is even smaller than | *S'*(*l*-*k*) | .

Thus, the ICI signals become smaller when applying ICI cancelling modulation. On the other hand, the ICI canceling demodulation can further reduce the residual ICI in the received signals. The combined ICI cancelling modulation and demodulation method is called the ICI self-cancellation scheme. The major drawback of this method is the reduction in band width efficiency as same symbol occupies two sub-carriers.

IV. CONCLUSION

From the literature survey ICI self cancellation will prove to be the best method because ICI self cancellation is suitable for both multipath fading & flat fading channels where as frequency domain equalization is only suitable for flat fading channels. Frequency domain equalization needs channel estimation for every frame and the estimation of channel is complex, expensive & time consuming but whereas ICI self cancellation does not require channel estimation and equalization. Frequency domain equalization reduces the ICI caused by fading distortion and time domain windowing reduces the ICI caused by band limited channel but they do not deal with the major cause for ICI i.e. ICI caused by the frequency mismatch between transmitter and receiver and due to doppler shift which is dealt by ICI self cancellation. Simple in implementation i.e. less complexity and effective when compared to frequency domain equalization, time domain windowing and pulse shaping.

ACKNOWLEDGMENT

Authors are thankful to the Dr. P.V. SUBBAIAH principal of AMRITASAI INSTITUTE OF SCIENCE AND TECHNOLOGY for creating research environment in the department, are also extends their sincere thanks to the management of the institute for providing such an environment in the organization.

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