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Comparative Study of ICI Cancellation Methods in OFDM System

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Abstract: Now-a-days, wireless communication is increasingly in demand for high data rate applications. The orthogonal frequency division multiplexing (OFDM) is one of the digitalize modulation utilized in a wide area of communications framework. It is a successful modulation and multiplexing technique that is utilized in various systems like IEEE 802.11a, IEEE802.16e (or WiMAX), hiperlan/2, DAB, DVB, DSL. OFDM uses the multi sub-carriers within the single channel and these sub-carriers are closely spaced orthogonal signals, transferred in parallel scheme. OFDM is the way to slow down the symbol rate without slowing down the data rate. However, there are some problems with OFDM like Carrier Frequency Offset (CFO), Bit error rate (BER) & Inter Carrier Interference (ICI). Due to the different carrier frequency offsets, orthogonality of sub-carriers is degraded and even the small change in carrier can lead to ICI. This paper focuses on the technique of improving the performance of OFDM for wireless communication by reducing the ICI caused by Carrier Frequency Offset (CFO). This paper delivers the number of wireless communication standards and numerous applications where OFDM systems are referred and can be used in the future techniques.

Key Words: OFDM, Carrier Frequency Offset (CFO), Inter Carrier Interference (ICI), Bit Error Ratio (BER), Cyclic prefix.

1. Introduction

The development in digitalized communication has been witnessed in later a long time which increases the high-speed information transmission.

The new technologies have been used in new applications like audio conferencing, video conferencing, 3D television, web access etc[1]. Latest and future mobile communication system 4G and 5G, respectively are expected to give high speed performances such as multimedia, video and audio. However, current 4G system endures from a few basic issues for instance attenuation, multi-path fading, delay spread & self-jamming etc[1,2]. New methods and arrangements are required to be inserted in 4G and 5G communication systems so as to take care of the issues and improving the performance of the communication system. Orthogonal frequency division multiplexing (OFDM) is the promising modulation technique to give high-speed rate service areas for 4G and 5G communication scheme. OFDM is the multi-carrier modulation scheme that uses the multiple subcarriers within the same single channel to transmit the data. Input signals are splitted into multi signals over one frequency using Multi-Carrier Modulation and then these multi signals are transmitted after modulation & demodulated at the receiver side over the channel [1]. On receiver side, these multi signals are combined together. The orthogonality of received signal should be maintained. Orthogonality means closely spaced and overlapped sub-carriers or received multi signals without Inter-Carrier-Interference (ICI). It is utilized in the wireless communication schemes due to the enormous bandwidth efficiency, invulnerability to frequency selective fading channels and multipath distortion tolerance[3]. However, OFDM lacks in giving the expected performance due to sensitivity to synchronization errors and high-peak-to-average power ratio (PAPR). These error synchronizations at receiver end leads to ICI due to carrier frequency offset (CFO) and Inter Symbol Interference (ISI)[4]. This can be worsen by motion-including Doppler shift[5]. "Large CFO can be separated into two portions- fractional frequency offset (FFO) & integer frequency offset (IFO) for estimation"[6-10]. Circular shift of the sub-carrier in the frequency domain is generated by IFO while Orthogonality between sub-carriers can be lost because of the FFO. The OFDM signal spectrum is shown in Figure 1.

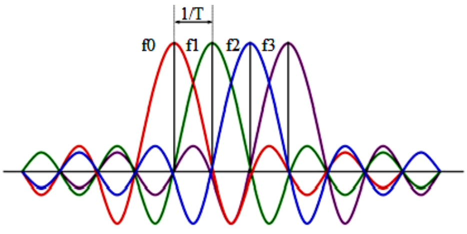

Figure1: OFDM signal spectrum

In direction to advance the performance of synchronization of the system in both time and frequency domain is required by eliminating the interference caused by CFO and ISI caused by timing errors. “Cyclic prefix (CP) centered techniques were presented to govern the frequency offset & symbol timing”. The cyclic prefix prolongs the guard time cyclically between the symbols of the signal. Cyclic extension means tail of the symbol is copied and pasted in the start of the symbol to avoid the ISI and CFO as well. How cyclic prefix is used in symbol shown in Figure 2

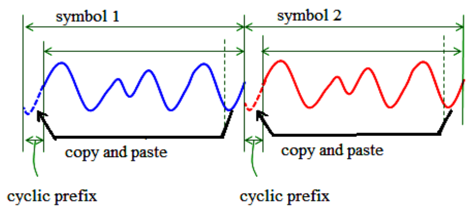

Figure 2: extension of guard interval using cyclic prefix

2. System Model

Simple concept of the OFDM is to break the bulky data/signal into multiple small data/signals and transmit the whole data/signal over different carrier signals in parallel scheme. OFDM works in both time and frequency domain. The IFFT (Inverse Fast Fourier Transform) & the FFT (Fast Fourier Transform) are utilized for modulation & demodulation to make OFDM systems more efficient. Figure 3 illustrates the system module of the OFDM.

At the transmitter, OFDM includes the high-speed input stream, digital modulation and multiplexing scheme, serial-to-parallel converter, IFFT, parallel-to-serial converter, addition of the cyclic prefix and digital to analog converter (DAC). User information input stream is modulated to lessen the possibility of errors at receiver end11,12. For mapping the bit stream into the symbols of carrier signal either 16-QAM or QPSK is used. IFFT converts the time domain signals into frequency domain signals. Guard interval is added between OFDM symbols using cyclic prefix extension. To make the OFDM signals steeper and smoother edged, windowing is applied. Then after converting the digital signal into analog, whole data/signal is passed on to transmitter stage for the transmission to the receiver. At receiver, first of all ADC is used to get the digital signal from analog one.

For time and frequency synchronization, equalizer is used. Then cyclic prefix is removed, serial signals are converted into parallel signal, FFT modulation is implemented to convert the frequency domain signal into time domain signal. Serialization of output signal is followed by symbol de-mapping and after that channel demodulation is performed to get the sent user information.

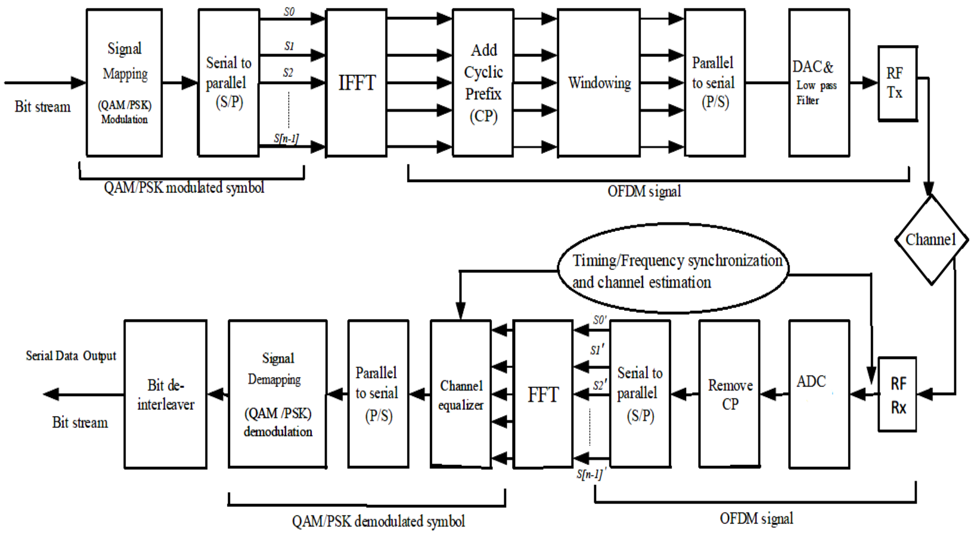

Figure 3: OFDM System Model

3. Applications of OFDM System

OFDM system is most prominent technology which is widely adopted in wireless communications. This technology gives the efficiency of bandwidth and robustness of the channels. Some applications of the OFDM are as following-

3.1 **DAB**: Digital Audio Broadcasting spots the advanced technology which offers the significant points of interest over the present FM radio for both audio and broadcasting. DAB's adaptability likewise gives more extensive selection of the programs which may not be accessible on FM. A single station may offer its audience members a decision of mono voice commentaries on three or four brandishing events in the meantime and after that bit-streams are combined to give excellent sound for the show which takes after.

3.2 **HDTV (High Definition TV):** commercial TV channel was first distributed by England.

3.3 **HIPERLAN2:** it is wireless LAN developed by European institute ETSI which is alternative of IEEE standard 802.11. it can give 54Mbps of data rate over OFDM.

3.4 **IEEE 802.11a/g:** This standard working in 2.4 and 5 GHz group indicates the per-stream rates extending from 6 to 54 Mbps. 802.11a system which communicates on 5GHz band, supports the 12 concurrent channels. Maximum speed of one channel of the 802.11a can be 54 Mbps.

3.5 **WiMAX (Worldwide Interoperability for Microwave Access):** It is a mobile broadband wireless access technology which works in 2to 11 GHz of spectrum band with IEEE 802.16 standard.

4. Factors Causing ICI

Reasons causing ICI or equivalently CFO could be the Doppler shift and it is so as of the relative motion of the receiver or/and transmitter or difference between the local oscillator's frequencies of the transmitter and receiver[13].

4.1 Doppler Effect:

When transmitter or/and receiver are in motion then due to relative motion there can be apparent shift in frequency of the received signal. This shift in frequency of the signal can be defined as Doppler Effect. This happens only in narrow band communications. For example, when any vehicle is moving then quality of the audio call can be affected by Doppler Effect.

4.2 Synchronization Error:

With practical transmitter and receiver, it is very hard to achieve the perfect synchronization of transmitter and receiver because of the instability of the practical oscillators which includes the offset frequency. OFDM is excessively sensitive even for very slight frequency offset that's why small change could be negligible for other applications but not for OFDM.

4.3 Multipath Fading:

Multipath fading implies that more than one replica of the wanted signal achieved by the receiver. Multipath fading causes the ISI and also makes the ICI worse by shifting the phases. Where ISI can be reduced by Cyclic Prefix but ICI still needs the little more attention.

5. ICI Cancellation Methods

5.1 Time Domain Windowing

To reduce the side lobes of the OFDM and make it more steeper, windowing could to be used. Power spectrum of OFDM is widely spread. The definite percentage of the OFDM signal can be cut-off if it happens to pass though band limited channel which can lead to ICI. The spectrum of the signal can be multiplied to make it more concentrated using the time windowing method. The same windowing is used at the receiver end. However, this reduces the ICI only for band limited channels. The product of window function needs to meet the Nyquist vestigial symmetry criterion to remove the ICI. Conventional orthogonal multi-carrier signal is as

$$S(tx)=\sum_{k=-\infty}^{\infty}\sum_{n=0}^{N-1} w(t-kT)a_{nk}(\exp(jnw_{\Delta}(t-kT))) \tag{5.1}$$

where, $\{a_{n.k}\}$ is the complex sequence, nw_{Δ} $\{n=0,1,\ldots,N-1\}$ are carrier frequency. T is the length of window function which modifies the signal at every frame. ICI can be given as

$$a_{nk}a_{nk}^{*}\int_{-T/2}^{T/2} w^2(t)\exp(-jw_{\Delta}(n-m)t)dt=0, \quad \text{for } m\neq n\ . \tag{5.2}$$

If $w^2(t)$ meets the Nyquist vestigial symmetry then condition will be fulfilled.

5.2 Pulse Shaping

Each carrier signal of OFDM system consists of one main lobe with many side lobes of decreased amplitude. When at the peak of the distinct carrier, some power of side lobes takes places, it induces the ICI. Primary motivation, behind the pulse shaping method is to diminish the amplitude of the side lobes. Some methods of pulse shaping are rectangular pulse (REC),

raised cosine (RC), better than raised cosine pulse (BTRC) sinc power pulse (SP) & improved sinc power pulse (ISP), etc. The functions are
Rectangular Pulse,

(5.3) $$P_{REC}(f)=\sin c(fT)$$

Raised Cosine Pulse

(5.4) $$P_{RC}(f)=\frac{\sin c(fT)\cos(\pi\alpha fT)}{1-(2\alpha fT)}$$

Better than raised Cosine Pulse,

(5.5) $$P_{BTRC}(f)=\frac{\sin c(fT).2\beta fT\sin\pi\alpha fT+\cos(\pi\alpha fT)-1}{1+(2\beta fT)^2}$$

Sinc Power Pulse

(5.6) $$P_{P_{SP}}(f)=\sin c^n(fT)$$

Improved Sinc Power Pulse,

(5.7) $$P_{ISP}(f)=\left\{-\alpha(fT)^2\right\}\sin c^n(fT)$$

5.3 Maximum Likelihood (ML) Estimation

In Maximum Likelihood Estimation which was suggested by the Moose, first frequency offset is predicted statistically and cancelled at the receiver end. In this method, replication of OFDM signal is done and phases of every subcarriers in-between the consecutive symbols are compared before transmission. This technique reduces the ICI in signals.

When replication of sequence length N of OFDM signal is done then in the non-existence of the noise, 2N sequence {r(n)} is given as |S'(1-p)|, where {x(p)} = (2p+1) complex modulation values utilized to modulate (2p+1) sub-carriers, H(p) is channel transfer function for p^{th} carrier signal and ε is frequency offset of the channel.

The demodulation of first set of N-symbol is done using N-point FFT to generate the sequence $R_1(p)$ and demodulation of second set of symbol is done utilizing the another N-point FFT to generate the sequence $R_2(p)$, that is

(5.8) $$R_2(p)=R_1(p)e^{j2\pi\varepsilon}$$

Adding the AWGN (Additive White Gaussian Noise) generates

(5.9) $$Y_1(p)=R_1(p)+W_1(p)$$

(5.10) $$Y_2(p)=R_2(p)e^{j2\pi\varepsilon}+W_2(p),$$ where p= 0,1,…..,N-1

ML estimation method is an unbiased estimation of the frequency offset. After knowing the frequency offset, ICI can be lessened by multiplying the received frames with a conjugated shift in the frequency and by using the FFT as

(5.11) $$X(n)=FFTY(N)^{-j2\pi\varepsilon/N}$$

5.4 ICI Self-Cancellation Technique

In self-cancellation technique of the ICI, one data symbol is modulated onto the bunch of the sub-carriers utilizing the predefined weighting coefficients so that generated bunch of ICI cancels out each other. If 1st subcarrier 'm' is modulated with data X and 2nd subcarrier 'm+1' is modulated with –X then the ICI generated between two subcarriers cancels out each other. This method is better than methods mentioned above. Performance improvement of the OFDM system is possible by data signal redundancy.

For further reduction in ICI, demodulation scheme is utilized. In this scheme, "-1" is multiplied with signal at "p+1" sub-carrier and addition of it is done to the p sub-carrier. In ICI modulation, if the transmitted data is constrained as X (1) = -X (0), X (3) = -X (2),…..,X (N-1) = -X (N-2) then received signal can be written on "n" and "n+1"

(5.12) $$Y(p)=\sum_{m=0,2,4,6...}^{N-2}X(m)(S(m-p)-S(m+1-p)_n+n_k)$$

(5.13) $$Y'(p)=\sum_{m=0,2,4,6...}^{N-2}X(m)(S(m-p-1)-S(m-p)_n+n_{k+1})$$

and the ICI coefficient S'(m-n) referred as

(5.14) $$S'(m-p)=S(m-p)-S(m+1-p)$$

When only even sub-carriers are taken for summation then number of total interfered signals can halve. For most of the m-n values, |S' (m-p)|<<| S(m-p)| condition is observed in ICI cancellation modulation.

In ICI modulation, every couple of sub-carrier transmits only one data symbol only which exploits the bandwidth efficiency. Therefore, to make redundancy method more effective, sub-carriers are subtracted instead of adding that can be expressed as…

(5.15) $$Y''(p)=Y'(p)-Y'(p+1)=\sum_{m=0}^{N-2} X(m)(-S(m-p-1)+2S(m-p+1)_n+n_k-n_{k+1})$$

and ICI coefficient for this received signal can be

(5.16) $$S''(m-p)=S(m-p-1)+2S(m-p)-S(m-p+1)$$

This method is known as demodulation of ICI cancellation.

The combination of modulation and demodulation is called Self Cancellation of ICI. This method does the much better work than the standard OFDM systems.

6. Conclusion and Future Work

In this paper, we have briefly portrayed OFDM for wireless communications with some application, ICI causing factor and different elimination methods of ICI. We have compared some ICI suppression techniques for improvement of the multi-carrier OFDM signal. Time domain windowing and Maximum Likelihood elimination methods are found not very effective for reduction of ICI. Windowing method does not address much with causing of ICI like frequency synchronization between transmitter & receiver, and Doppler Effect. Since Maximum likelihood method provide better performance for BER but it is very complex as compare to self-cancellation and pulse shaping method. However, self-cancellation is also not very efficient as compare to the pulse shaping as self-cancellation method decreases the bandwidth efficiency by modulating the same data onto more than two carriers. Hence pulse shaping methods are more effective than the other methods for reducing the ICI power. OFDM system has entranced significant enthusiasm for the future gigabit broadband, wireless and wired correspondence. Our future focus will be on simulation of the OFDM signal to remove/ minimize the limitations such as CFO (carrier frequency offset), BER (bit error rate) using the simulation tool MATLAB and give the results in next paper.

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