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A Survey on Carrier Frequency Offset and Inter Carrier Interference Cancellation in MIMO OFDM Systems

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Abstract

In recent days most important communication scheme is multiple input and multiple output orthogonal frequency division multiplexing (MIMO-OFDM) with a multi carrier modulation (MCM). There is a high reliable rate of data transmission when MIMO is combined with OFDM in broadband wireless channels.The Carrier Frequency Offset (CFO) effect is believed to make OFDM-based systems sensitive to mistakes caused by frequency mismatch which leads to inter carrier interference (ICI). The frequencies inconsistency of the local oscillators is the major cause of ICI near transmitting and the receiving end. Many methods and algorithms are developed for reducing the CFO effect and also for estimating and correction of CFO. One more issue in MIMO-OFDM systems is ICI that occurs due to the mismatch in the orthogonality function among the sub-carriers used for transmission of signal and the signal that is transmitted.

In this work we investigate numerous strategies which have been examined for calculation of CFO and ICI cancellation. ICI self-cancellation is one of the most effective and efficient reduction strategies to minimise the ICI influence in the signal. The cause for the formation of the CFO and its impacts are demonstrated, and the system's performance is investigated. The key CFO estimation and correction algorithms and methodologies are examined and discussed.

Keywords:

OFDM, MIMO System, CFO, ICI

1. Introduction

For upcoming 5G mobile networks many academics believe that multiple input multiple output (MIMO) technology is a viable option. Antennas transmit (TX) separate data streams simultaneously using spatial multiplexing to boost system throughput [1-2]. The introducing of overlapping in OFDM is to turn a frequency-selective fading channel into a group of frequency-flat fading channels for simpler equalization, with a property of orthogonality in sub-channels [3].The adding of samples of cyclic prefix (CP) in front of samples of OFDM, so that OFDM may withstand inter-symbol interference (ISI).

Three factors should be addressed in OFDM systems with single antenna or other multicarrier systems: frequency synchronization, time synchronization, and estimation of channel. MIMO-OFDM is much very sensitive to frequency synchronization and estimating of channel problems [4].Mismatches in local oscillators between transmitting and receiving, along with Doppler shifts, causes carrier frequency offsets (CFOs) [5]. The orthogonality of the subcarriers disrupts by CFOs, resulting in inter-carrier interference and potential system performance reduction [6]. Timing synchronisation is less essential than frequency synchronisation and channel estimation because CP insertion tolerates timing mistakes [7]. We expect that the timing offsets are equivalent to focus in this studyand concentrate on frequency synchronisation and estimation of channel.

A frequency offset must be measured and adjusted at the receiver to provide excellent transmission quality [8]. Due to the large number of unknown factors, the simultaneous estimate of the channel and the frequency offset poses difficult issues in MIMO-OFDM systems. Some estimate techniques consider CFO and channel estimations independently by employing distinct training sequences [9].Channel estimation is accomplished in these methods on the assumption of zero CFO or frequency synchronisation. However, in the presence of noise, such assumptions are rarely valid.

A key issue with the MIMO OFDM paradigm is distortions like as carrier frequency offset and phase noise, which disrupt orthogonality and induce ICI. Many solutions have been presented in the literature to address the constraints of the OFDM paradigm, which are inter carrier interference and peak to average power ratio. In the year 2000, the first symmetric self-cancellation mechanism was invented, in which data is delivered over two carriers that are symmetric to each other.This resulted in progress in lowering ICI. The self-cancellation strategies that yield excellent results in overcoming ICI include neighbouring self-cancellation [10], neighbouring data conjugate [11], and symmetric data conjugate [12]. Many more strategies and processes based on wavelet transform, hybrid approach, and CP reuse method have been presented in recent literature to achieve considerable increases in overall system performance [13].Alternative solutions for mitigating frequency offset problems include frequency domain equalisation and time domain windowing [14]. A study of several inter carrier interference cancellation methods utilised in MIMO-OFDM in the downlink of Long Term Evolution (LTE) provides a clear knowledge of the benefits and uses of the many available systems [15]. The simplest approach has been proven to be self-cancellation. This article is a study of several strategies used for CFO estimate and ICI cancellation.

2. Carrier Frequency Offset

OFDM is a popular approach for wireless systems that require high data rates for transmission. This approach is said to be extremely sensitive to frequency offset as well as time synchronisation. Furthermore, its responsiveness to the CFO, which is a frequency difference at both the transmitter and receiver sides leads to the ICI in the signal and the performance of system is reduced. If the modulation of the signal carrier at the receiver end is equal with the initial carrier frequency, which allows the baseband signal to pass band signal and then again it reverts to baseband level. There are two significant concerns with the carrier signal that is utilized for modulation. In which one important concern is the phase offset caused by the instabilities of the carrier signal generators utilized in both parts.

The other is the CFO, which happens as a result of a Doppler shift, which is essentially a frequency mismatch between the local oscillators present at the sections. This impact intensifies, destroying the orthogonality of the sub-carriers. As a result, synchronisation is required for the system.Carrier frequency offset is divided into two types one is integral carrier frequency offset (IFO) and the other one is fractional carrier frequency offset (FFO). IFO is denoted as $\boldsymbol{\xi}_i$ and FFO is denoted by $\boldsymbol{\xi}_f$. The IFO causes a factor of $\boldsymbol{\xi}_i$ as a cyclic shiftat the receptor section regarding each sub carrier, but it has no effect on the orthogonality between the components of carrier frequency, whereas the FFO destroys the orthogonality between the sub carriers. The estimation of CFO is observed in two domains one is time domain and other is frequency domain and is defined as:

Time: In a time domain, there are two approaches defined. The Cyclic Prefix (CP) is one, while the training sequence is another. The signal is estimated using the CP approach by assuming a little influence of the channel. The phase offset which is present between the cyclic prefix and which is available in its subsequent portion of the symbol are used to retrieve the CFO from the signal, but in case of training based technique, the sequence of training is expected to add up to the front of the MIMO signals to facilitate normalized CFO estimate.

Frequency: The frequency domain approaches outlined primarily entail a comparative study of the phase of each sub-carrier to its respective consecutive symbol, and the phase shift achieved in the symbol after this comparison happens only due to the CFO. For the pilot technique, two distinct modes are defined for estimating the CFO in this particular domain.The first is the mode of acquisition, and the second is the mode of tracking. In the primary mode, i.e. mode of acquisition, the CFO is estimated on a greater specified range of CFO, but in the other tracking mode, only the fine CFO is estimated.

The CFO also causes subcarrier orthogonality to be lost. The loss of orthogonality between the carriers as a result of frequency offset is seen in below Figure 1. The occurrence of ICI is seen when the reference point of frequency near the receiver is offset with regard to the reference point frequency of the transmitter due to a frequency mistake.

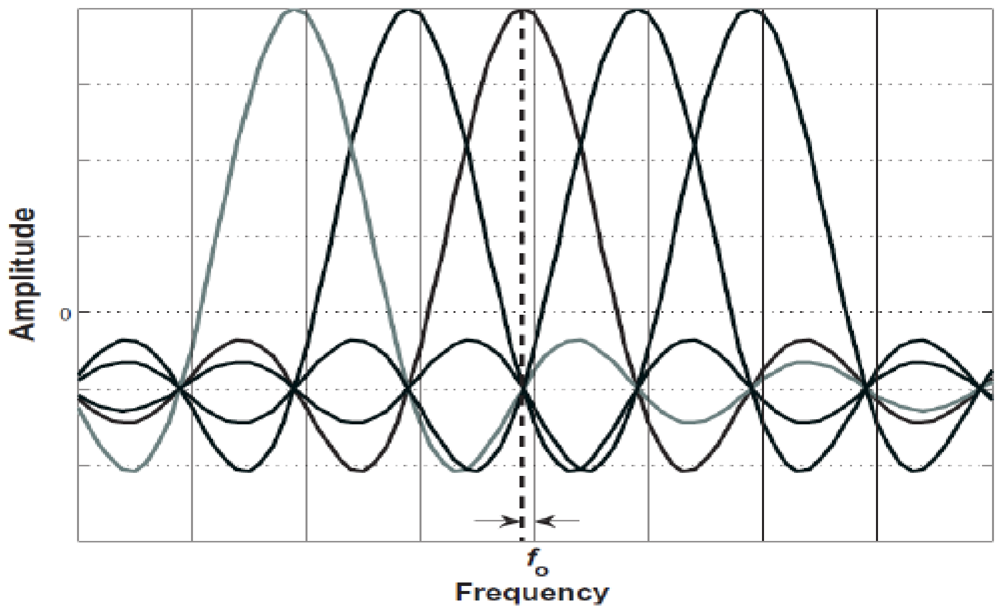

Figure 1: Carrier Frequency Offset

3. Inter Carrier Interference

The basic concept is to reproduce the data samples that are similar on several subcarriers with varying weighting coefficients, and then combine these samples linearly with predetermined weighting factors at the receiver end. As interference is cancelled out, the residual intercarrier interference in the signal received is reduced to a level of significant. To reduce the influence of carrier frequency offset on the subcarriers the weighting coefficients are used.

The ICI self-cancellation approach [10] refers to the combined approach for modulation and demodulation of ICI cancelling. In a MIMO-OFDM system the offset of normalized channel frequency is assumed, the signal received on subcarrier k in a frequency domain is evaluated and shown :

$$y(k) = x(k)S(0) + \sum_{l=0,l\neq k}^{N-1} x(l)s(l-k) + w(k) \quad (1)$$

The total number of subcarriers represented as N and the white Gaussian noise is represented as w(k).

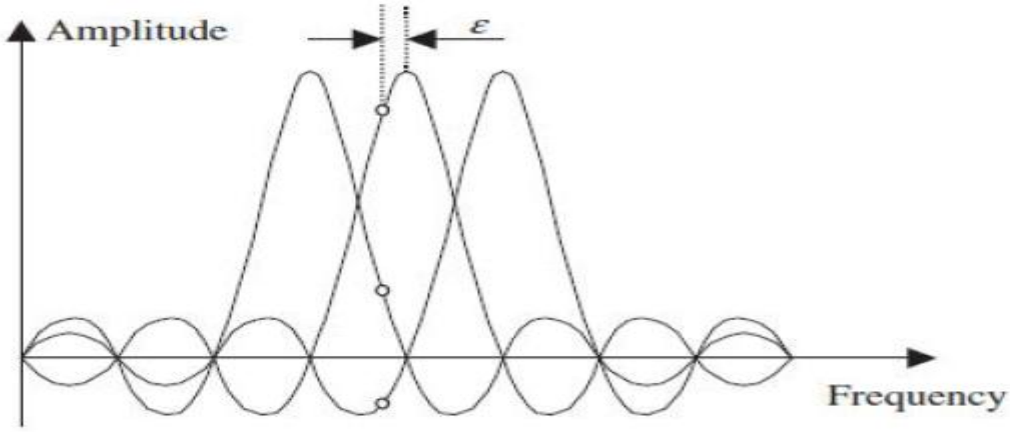

Figure 2: Inter-carrier interference (ICI) subject to CFO

ICI cancellation is made up of two blocks: ICI cancellation modulation and ICI cancellation demodulation.

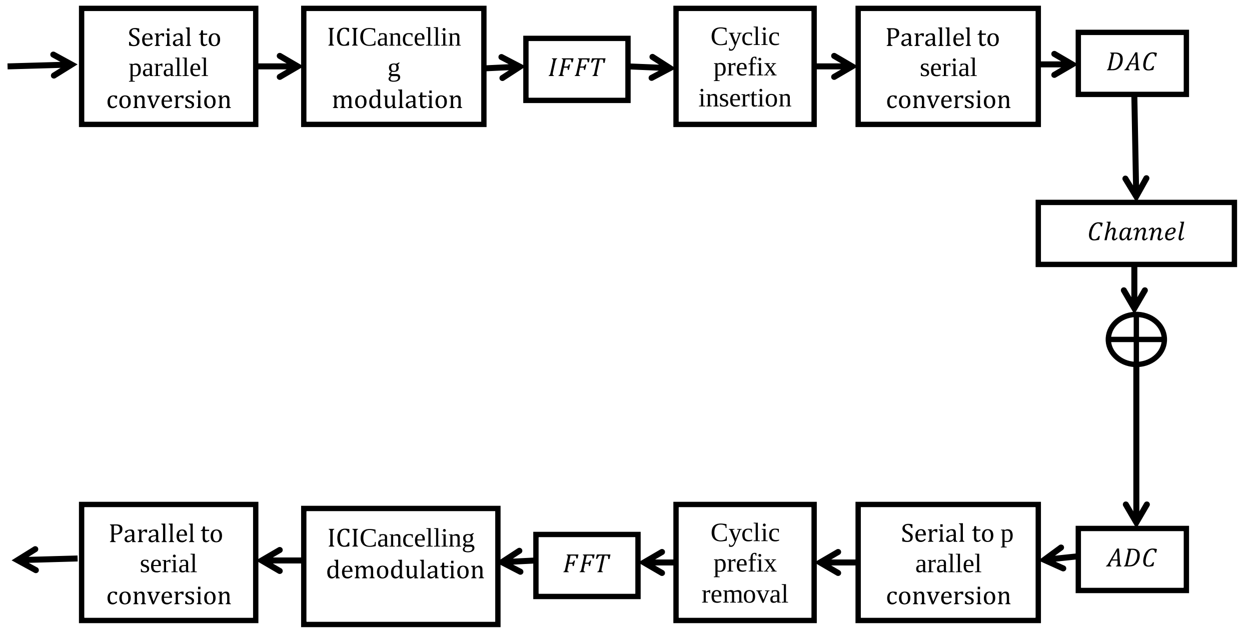

Figure 3: Schematic View of ICI Cancellation block

The MIMO-OFDM block with ICI Cancellation is depicted in Figure 3. Data is inserted on neighbouring or symmetric sub-carriers in the ICI cancelling modulation block using various self-cancellation algorithms. The effect of carrier frequency offset is cancelled at the receiver end by the ICI demodulation block (CFO).

4. Review on CFO

The author of [16] proposed a unique strategy that employs the joint maximum a posteriori (JMAP) methodology for the CFO evaluation and OFDM channel by utilizing the channels past sum-up data. A modified joint maximum a posteriori technique with no grid explorations was devised to reduce the difficulty of the Estimating Carrier frequency offset JMAP estimator. The estimated procedures were tested using mathematical simulations, and the results validated the enhanced performance of the suggested methodology while differentiating it from the existing schemes.

The author presented a strategy in [17] that addresses the issue of blind synchronisation for OFDM based on the system of OFDM/OQAM with no prior knowledge of the response of channel. In the case of multipath fading channels, an innovative NDA combined estimation methodology of CFO and symbol timing offset (STO) was examined. Finally, several thorough experiments were carried out to evaluate the suggested scheme's great efficiency and efficacy.

In [18], author presented a novel methodology based on the CFO's blind estimator and imbalance of I/Q in an OFDM system that do not require any prior knowledge of channel side information or training symbols. The most major rationale for this technique was the presence of null subcarriers in many OFDM systems. Finally, execution results were provided to support the efficacy of the proposed model, and using the standard schemes the performance of the system is evaluated.

In [19], a novel methodology to examining the performance of an OFDM amplify-and-forward (AF) system in the presence of a CFO is presented. Despite the fact that SCM was thoroughly investigated in OFDM systems, the BER of the system with CFO was not achieved in the usual research. Finally, its durability was assessed by extensive testing.In [20], a new scheme has been established, which includes two novel methodologies for DSC estimates and combined CFO systems. In this case, two novel strategies were afterwards devised based on SKF. For each user, the initial strategy employs Schmidt– Kalman filtering to estimate block element modifier (BEM) and CFO coefficients. The following methods use Gaussian particle filtering in conjunction with SKF to estimate each user's BEM and CFO coefficients. As a result, the suggested model was found to produce good results in the investigational study.

The author developed a unique blind estimator of CFO for uplink OFDMA systems in [21]. The CFO has been redesigned as a sparse recuperation optimization problem with improved resolution by using the sparsity embedded in the OFDMA data. Furthermore, the behavior of the developed approach in comparison to other conventional estimators was examined, and the mathematical results show that the developed methodology outperformed the conventional estimators in terms of consistency.

A unique computationally competent blind CFO estimator for MIMO-OFDM systems was proposed in [22]. Furthermore, a cost function was meticulously modeled, and it could be accurately articulated as the superposition of particular cosine waves with the influence of noise. Finally, numerical data as well as hypothetical functionality were supplied to support the built system.Furthermore, the performance of the recommended methodology was investigated and compared with three standard procedures in order to study the methodology's performance.

The author of [23] used an innovative adept detecting technique to relieve the effect of the CFO in SM-OFDM systems. The adopted methodology in particular, applies a unique Similar to SM-OFDM models with multiple CFOs, with zero symbols used as OFDM symbols. Furthermore, based on the outcomes of a range of traditional algorithms, the selected method was determined to provide better results.

To improve the performance of OFDM communication system, a new hybrid swarm algorithm is developed in [24]. This hybrid swarm algorithm is combined with SVM classifier to address the issue of allocation of resources in OFDM system. In addition to hybrid swarm algorithm and SVM, an interference probability condition is generating using HPSO –SVM to address the issue regarding allocation of resources. The author in [25] presented a discrete wavelet transform (DWT) technique using a typical MIMO–OFDM radio over fibre system to achieve the threshold bit error rate. The suggested model was additionally combined with an Alamouti-Space–time Block Codes (A-STBC) MIMO–OFDM based Radio over Fibre (RoF) system, and the resulting signal was sent over a 10 km RoF connection when there is a non-linearity. In the presence of additive white Gaussian noise (AWGN) and phase offset owing to insufficient carrier phase estimation, the RF received signals are transferred across a Rayleigh fading wireless channel at the radio access point (RAP).

5. Techniques used for ICI Cancellation

The cause of ICI is the presence of offsets between the transmitter and receiver frequency references, which reduces the performance of the OFDM system. To lessen this ICI, many researchers proposed the following approaches to attenuate frequency offsets:

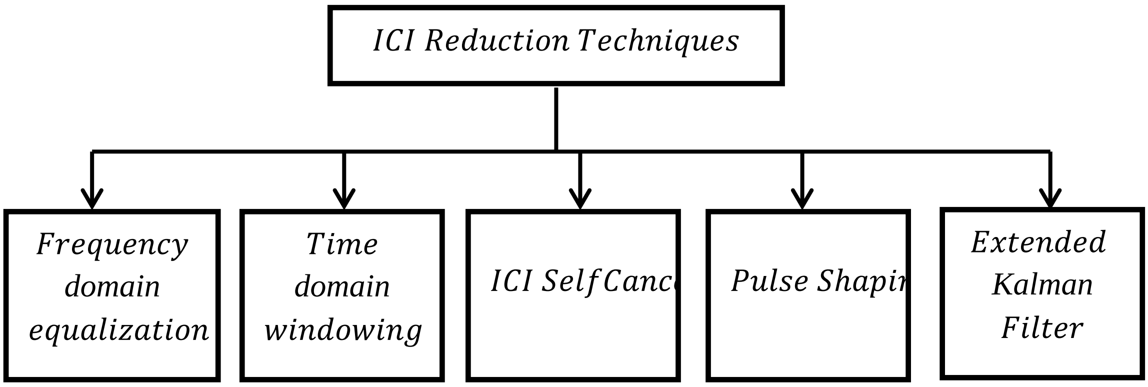

Figure 4: Different ICI Cancellation techniques

A. Frequency domain equalization

Frequency domain equalization methods eliminate the effects of distortion. In general, the pattern of ICI fluctuates from one frame to other frame but holds constant across all symbols in a frame that is been demodulated. The ICI is evaluated with the help of pilot symbols which are generated in frequency domain, these pilot symbols are inserted into the frames and the equalization coefficients are calculated.

However, it merely lessens ICI due to fading distortion, whereas frequency offset and Doppler shift are the principal sources of ICI. Furthermore, it is only suited for flat fading channels, but in case of mobile communicationthe channel fading mainly is frequency selective. These factors restrict the use of this approach for ICI reduction.

B. Time domain windowing

To minimize sensitivity to distortions and frequency offsets, the time domain windowing approach is applied. There is a display of strong side lobes for the entire frequency range due to the frequency response attained by the DFT filter in OFDM system. As a result, the OFDM signal is extremely susceptible to the disturbances caused by the frequency and phase of the system. To improve the signal to interference ration (SIR) a second order polynomial nyquist windows function is suggested in [26]. This is known as the second order continuity window (SOCW), and the unity roll of factor is taken into account. It outperforms the increased cosine window and functions as an anti-frequency offset for systems with tiny frequency offsets. In [27], authorinvestigates the impact of several Nyquist windows such as increased cosine window, BTRC, SOCW, Frank's window, and double jump window on the bit error rate (BER) and SIR measures.

C. ICI Self Cancellation

The basic principle is to modulate one data symbol onto a group of subcarriers, resulting in a 10dB rise in CIR value. In [28] author examines this strategy with linear and cubic differences in weighting coefficients over a set of three neighbouring components. As a result, ICI signals created inside a group can self-cancel with one another. To reduce the ICI induced by CFO, ICI self-cancellation techniques with various ICI cancelling modulation and demodulation approaches are proposed.

Although ICI self-cancellation reduces ICI more effectively, it has a significant downside in terms of spectral efficiency. This scheme's bandwidth efficiency concern can be mitigated by increasing the number of subcarriers or utilizing a bigger signal alphabet size [29].Similarly, the author of presented a differential grouping weighted symmetry data-conjugate mapping strategy in [30] to reduce the influence of ICI in rapid time-varying channels. This mapping approach increases bandwidth efficiency and performs better in terms of carrier to interference ratio.

D. Pulse shaping

Because of CFO, orthogonality between carriers is compromised, and some power of side lobes exists in the center of individual carriers, which is referred to as ICI power. As the CFO's influence grows, so does the ICI's. The power of ICI increases as the amplitude of side-lobes is lower with the help of pulse shaping. The following is the author's representation of the complex envelope of the transmitted symbol in OFDM with shaping of pulse in [31]:

$$x(t) = e^{j2\pi f_c t} \sum_{k=0}^{N-1} D_k \sqrt{p(t)} e^{j\pi f_k t}$$

Where $k = 0, \dots, \dots, N-1$

To minimize the side lobes, a number of pulse shaping functions are suggested. In [32] author proposes an optimised "better than" raised cosine (BTRC) pulse. It will makes use of an extra free parameter (FP) whose ideal value is proportional to the filter's roll of factor. Higher values for the roll of factor result in better ICI suppression. This pulse improves performance for low and moderate NFOs by reducing ICI power and increasing SIR.

E. Extended Kalman filtering

The Kalman filtering technique is a strong recursive estimating technique that has several uses in communications. The performance of the CFO estimate of an OFDM communication system employing Extended Kalman filtering (EKF) is demonstrated in [33]. EKF refers to the Kalman filter that linearizes regarding the current mean and covariance. Later, to mitigate the ICI effects, a planar extended kalman filtering (PEKF) is developed [34].The received signal is separated into two parts: real and fictitious. The PEKF is used to estimate frequency offsets based on the connection between the imaginary and real parts. Without knowing the original phase error information, the estimated CFO is compensated. In [35], explains the EKF for estimating CFO and correcting such estimates.

6. Conclusion

Over the last decade, there has been a fast increase in the need for high data rate wireless communication. MIMO-OFDM is emerging as a new communication technique that uses Multiple Carrier Modulation to enable effective communication. The basic principle underlying MIMO-OFDM and the various strategies for predicting CFO and removing the ICI in OFDM are discussed in this work.One of the major problems identified in MIMO-OFDM system is the effect of CFO, due to which there is a loss in subcarriers orthogonality which results in ICI in the symbols**,** causing performance degradation in the system, disrupting its robustness for multipath fading and also efficiency of the spectrum is affected.As a result, a thorough evaluation of this effectand its correction is required for the communication system to function more efficiently.ICI self-cancellation is a useful strategy for dealing with numerous Doppler frequency discrepancies since the ICI signals are enabled to cancel each other. To solve the problems in the field of CFO and to satisfy customer requests, new concepts must be developed.

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