Frequency Synchronization in OFDM

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Abstract - **This paper focuses on performance analysis of BPSK based MIMO & MIMO-OFDM system. Nowadays, there is a requirement of higher data rate for wireless communication systems. In this paper we are going to compare MIMO & MIMO-OFDM system & how MIMO-OFDM is used to overcome high data rate problem is shown. MIMO is a multiple antenna technology. MIMO systems employ multiple antennas at both the transmitter & receiver to improve the range & performance of communication system. OFDM is a category of multicarrier modulation technique. In OFDM sub-carrier frequencies are orthogonal to each other i.e. they cannot interfere with each other (cross-talk between the sub-channels is eliminated). To reduce inter symbol interference (ISI) & to enhance system capacity OFDM for MIMO channels is considered. For transmission of signals over wireless channels OFDM is a very popular modulation technique. MIMO & MIMO-OFDM module is carried out through Matlab simulation. Our analysis and simulations indicate that oversampling and nulling of subcarriers can speed up the acquisition further. When pilot and (incomplete) channel information is available, it can be successfully included via priors to significantly improve the synchronization performance.**

Index Terms **-Carrier Frequency Offset (CFO), Cyclic Prefix (CP), Intercarrier Interference (ICI), Orthogonal Frequency Division Multiplexing (OFDM)**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has gained a great deal of popularity lately due to its high spectral efficiency and robustness to multipath. In the last few years, OFDM has been employed in various commercial applications that include wireless local area networks (IEEE 802.11a and HIPERLAN/2), terrestrial Digital Audio Broadcasting (DABT) and terrestrial digital video broadcasting (DVB-T) (Yi-Hao *et al*., 2007). It is well known, however, that the performance of OFDM systems is very sensitive to frequency synchronization errors (Jungwon *et al*., 2004; Pollet *et al*., 1998). The local oscillators at the transmitter and receiver may not be synchronized and that results in residual Carrier Frequency Offset (CFO) at the receiver after down-conversion. Doppler spread, which is

present in mobile environments due to changing channel conditions between the transmitter and the receiver, also contributes to the carrier offset. The CFO introduces Inter-Carrier Interference (ICI), which destroys the orthogonally among the subcarriers and attenuates the desired signal, reducing the effective Signal-to-Noise Ratio (SNR) (Pollet *et al*., 1998). This results in degraded system performance.[12]

To maintain the orthogonality of sub carriers, CFOs and timing errors must be estimated and adequately compensated for. Many methods have been proposed in the literature to estimate and compensate for the CFO. Most of the conventional methods are based on a Frequency-Domain (FD) approach then time domain, where, CFO is estimated with the phase difference between two successive symbols (Kapoor *et al*., 1998; Xu and Manoakis, 2010). Several schemes (Morelli and Mengali, 1972, 1999). have been investigated for the CFO estimation in OFDM/OFDMA systems. The methods of CFO estimation can be classified into two groups, i.e., time domain CFO estimation and frequency domain CFO estimation. Frequency domain CFO estimation schemes can be further classified into two groups ie the training symbol based approache such as (Kapoor *et al*., 1998) and blind estimation such as Van de Beek *et al*. (1997). Moose (1994) proposed a pilot based CFO estimation scheme by detecting the phase shifts between several successive identical pilot blocks. Schmidl and Cox (1997) presented a robust synchronization scheme for OFDM using one unique OFDM symbol which has a repetition format within half a symbol period and the acquisition is achieved in two separate steps through the use of a two-symbol training sequence.

This research assesses the effects of CFO upon Signal to Noise Ratio (SNR) of OFDM system and orthoganality of subcarriers. Accordingly research focus on techniques to compensate for carrier frequency offset in OFDM system. Two CFO estimation schemes are analyzed in this regard: The time domain CP based scheme and frequency domain based Moose scheme. Both schemes are analyzed under Doppler fading.

II. SYSTEM MODEL AND ASSUMPTIONS

Schematic diagram of Fig. 1 is a baseband equivalent representation of an OFDM system. The input binary data is first fed into a Serial to Parallel (S/P) converter. Each data stream then modulates the corresponding subcarrier by QPSK or MQAM. Modulations can vary from one subcarrier to another in order to achieve the maximum capacity or the minimum Bit Error Rate (BER) under various constraints. In this study we use, for simplicity, only QPSK in all the subcarriers and *N* to denote the number of subcarriers in the OFDM system.

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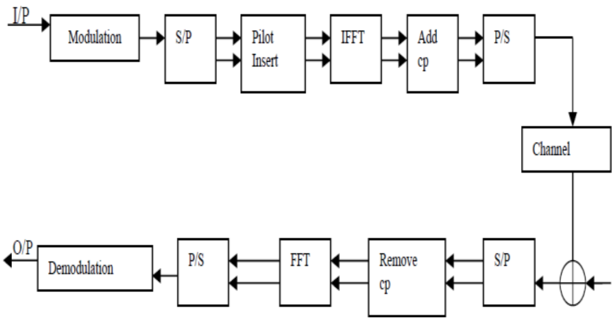

Fig. 1: OFDM baseband model

The modulated data symbols, represented by complex variables $X(0)$,….., X (N-1), are then transformed by the inverse fast Fourier transform (IFFT). The output symbols are denoted as $x(0)$,…., $x(N$-1). In order to avoid Inter-Symbol Interference (ISI), Cyclic Prefix (CP) symbols, which replicate the rear part of the IFFT output symbols, are added in front of each OFDM symbol. The parallel data are then converted back to a serial data stream before being transmitted over the multipath fading channel. The received data y (0), …… , y (N-1) corrupted by multipath fading and AWGN are converted back to Y (0),……., Y (N- 1) after discarding the prefix and applying FFT and demodulation.

The channel model we adopt in the present study is a multipath slowly time varying fading channel, which can be described by:

$$y(k)=\sum_{l=0}^{L-1} h_l x(k-l)+z(k) \quad 0 \le k \le N-1$$

where, *hl's* (0 *l* *L* 1) are Independent complex-valued Rayleigh fading random variables and zk's ($0 \le k \le N-1$) are independent complex-valued Gaussian random variables with zero mean and variance $\sigma^2 z$ for both real and imaginary components. L is the length of the CIR. In the presence of channel frequency offset, the above equation becomes (Ma *et al*., 2001):

III. PREAMBLE STRUCTURE AND CFO COMPENSATION

The current trend of CFO compensation uses the digital compensation approach (i.e., multiplying the baseband received samples with CFO-compensating phasors) to remove the frequency offset of the received signal. The frame structure used in the existing approach consists of, preambles for synchronization (PS), preambles for channel estimation (PC), and data. Nevertheless, the phase counter-rotation cannot help recover the lost signal energy since the energy loss has already occurred after the signal passes through the misaligned Rx filter. To overcome the above issue, we propose a new approach which adopts a new frame structure and introduce an analog CFO compensation, which refers to some procedure performed before the signal is converted to digital domain (i.e., adjusting oscillator frequency which is used to mix with the received radio frequency analog signal). Specifically, in our proposed approach, according to CFO estimation based on the PS of current frame, an adjustment of the local oscillator frequency is performed. Practically, once the PS reaches at the Rx, the CFO can be estimated2 while subsequent transmitted signals keep arriving. The null duration buys the Rx the time for CFO estimation and oscillator frequency adjustment. Consequently, the ensuing Rx output signal incurs a CFO as small as the estimation error, resulting in only negligible energy loss.

A case in point is as follows. Consider the PS and PC is of the same length, which is evenly divided into 10 blocks respectively. All blocks share the same signal energy. Periodic training sequence is used for both CFO and channel estimations. Since the training sequences are periodic and known at the Rx, only one block is used as CP in the existing approach. Note that with a proper sequence design; the CFO estimation performance mainly depends on the preamble length and energy [8] while the channel estimation mainly depends on the preamble energy [9], [7] but not on the preamble length provided that the length is longer than or equal to the equivalent channel length. Hence, it is recommended that the null portion be created mostly from the PC while almost allocating the same amount of energy for channel estimation. In the proposed approach, assuming that the CFO estimation and oscillator adjustment can be done in one block duration, we keep PS the same, reducing one block from the existing PC, namely, 9 blocks for the new PC. After CP removal, there are both 9 blocks for CFO estimation and channel estimation in the existing approach, compared to 9 blocks for CFO estimation and 8 blocks for channel estimation in the proposed approach, respectively. As a result, the preamble length and energy of the proposed approach stay the same as the existing approach for CFO estimation, whereas its useful channel estimation preamble energy is 80/81 of that of the existing approach. The performances of the proposed compensation scheme compared to the existing one will be evaluated by simulation in next section.[15]

IV. VIRTUAL CARRIER BASED CFO ESTIMATION ALGORITHM IN THE PRESENCE OF I/Q IMBALANCE

In OFDM systems, virtual carriers mean the un-modulated (Or zero modulated) subcarriers in the guard band. In [10] a virtual carrier based CFO estimation algorithm is proposed without considering the I/Q imbalance effect. In the following of the section, we will examine whether it is feasible to extend this CFO estimation algorithm to the situation with I/Q imbalance in OFDM receivers. The basic idea of the virtual carrier based CFO estimation algorithm is that the total energy in the virtual carrier space should be zero, ignoring the noise component for the moment, if no CFO presents. If there is CFO in the receiver, the total energy in the virtual carrier space will be non-zero due to the ICI introduced by CFO to the virtual carrier space. In the proposed CFO estimation algorithm, to estimate the CFO the received signal should be corrected by an estimated CFO δf first. Then the energy in the virtual carrier space is calculated. The optimal CFO estimation will be the one resulting in the minimum energy in virtual carrier space.

When there are CFO and I/Q imbalance presenting in the OFDM receiver, the CFO in the received signal described by (5) cannot be completely corrected simply by complex multiplication.

V. FREQUENCY AND TIMING SYNCHRONIZATION

Accurate frequency and time synchronization of orthogonal frequency division multiplexing (OFDM) systems is required in order to achieve good performance. The very property that these systems rely on – orthogonality of the subcarriers – will be lost if synchronization is inaccurate. In the uplink of multiple access systems, where several transmitting users must all synchronize to the base station, the need for efficient synchronization algorithms is especially evident. Here we focus on the *frequency* synchronization of a mobile terminal to the base station in a future OFDM system.

There are several publications on OFDM synchronization, covering many different scenarios. Most of them rely on the insertion of pilot symbols known to the receiver (*e.g.* [1]), while some are based only on the redundancy present in the cyclic prefix of each symbol (e.g. [2]), and a few are so-called fully blind and rely solely on the OFDM symbol structure (e.g. [3]). It can be seen, and other, examples that the attainable performance is crucially dependent on efficient use of the available information.

In this paper we present a Bayesian analysis of the frequency synchronization problem based on a model introduced in section II (this model and the analysis relies heavily on the work by Bretthorst [4]). The Bayesian approach is adopted because it focuses on efficient information processing and provides tools for inclusion of cogent prior information, consistent processing of new data, and reliability measures for estimates obtained with the actual data set. Thereafter, a general analysis is carried out in section III, which is followed by a study of two special cases in section IV, simulation studies of these cases in section V, and finally conclusions in section VI.

VI. RECEIVED SIGNAL MODEL

Consider a mobile OFDM terminal whose local oscillator is to be matched to the oscillator in the base station in order to ensure functionality. The adjustment of the oscillator will be based on an estimate of its frequency offset $\Delta\omega$ relative to the base station. This offset is the parameter of interest in this paper. In our model, the mobile is receiving an OFDM symbol consisting of quadrature amplitude modulated (QAM) sinusoids.

These complex-valued sinusoids are attenuated and phase-shifted by a dispersive channel, and when received they are also shifted in frequency by the mismatched receiver oscillator. It is assumed that symbol time synchronisation is sufficiently accurate to avoid inter-symbol interference and that the cyclic prefix is properly removed. The channel is modeled as frequency selective but constant over one symbol period (i.e. as slowly fading). Mathematically, the model of the received data d is

$$d = WB + e \qquad (1)$$

Here, W are the m frequency-shifted sinusoids,

$$W_{ik} = \exp(j[\omega_k + \Delta\omega]t_i) \quad \begin{cases} k = 1,2,......., m \\ i = 1,2,........., M \end{cases} \qquad (2)$$

corresponding to subcarriers ω_k sampled uniformly at times t_i .The sinusoids have complex-valued amplitudes B_k , and $B \equiv [B_1......B_m]^T$ therefore models the transmitted QAM symbols, their transmit energy and the channel jointly. The additive thermal measurement noise is represented by e .

VII. SIMULATION RESULTS

We tested the synchronizers by simulation of a system centered at 5 GHz, using 512 subcarriers of 50 kHz width. The guard bands are 16 subcarriers at each end. Fading frequency selective channel characteristics are from the Case II Vehicular A model of [9], at a mobile speed of 25 m/s. The channel was in the simulations constant during each symbol interval. The ignorant receiver was simulated when receiving unknown 4QAM symbols on all subcarriers (excluding guard bands and the central carrier), using both symbol rate sampling and oversampling by a factor of two. It was also simulated when receiving OFDM pilots in which only every eighth subcarrier was used and the rest were nulled. The purpose of these test cases was mainly to study the frequency acquisition performance for an ignorant mobile just switched on.

The well-informed receiver was tried on fully loaded OFDM pilot symbols in which all subcarriers carried known 4QAM symbols, as well as for the previously mentioned sparsely loaded OFDM pilots in which only every eighth subcarrier was used. Its performance for different channel prediction accuracy was assessed by studying the normalized mean squared estimation error.

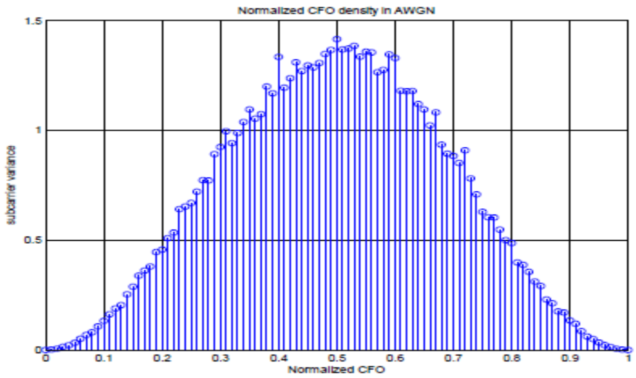

Fig.2. Normalized CFO density in AWGN

The ignorant receiver needs several symbols for acquisition From Figure 1 that the ignorant synchroniser in (10) is not very successful in estimating the frequency offset by use of only one OFDM symbol, unless the SNR is very high. This is mostly due to the multiple modes in the posterior. But we also see that updating of the posterior according to (6) results in a considerable improvement over the next few symbols (by suppressing all modes but one). Actually, the simulations were carried out using a simplified updating

$$p(\Delta\omega | d_1, d_2, \Gamma) \alpha\, p(d_2 | \Delta\omega, \Gamma) p(\Delta\omega | d_1, \Gamma)$$

where the logical dependence between $d1$ and $d2$ was ignored.

Oversampling improves the ignorant receiver*:* As noted in section IV-A, it is suggested by (10) that oversampling might improve the estimation accuracy. This is indeed shown in Figure 1 were oversampling by a factor of two reduces the error noticeably. In order to achieve estimation accuracies approaching $10-3$ at an SNR as low as 6 dB, over-sampling could be an option during acquisition.

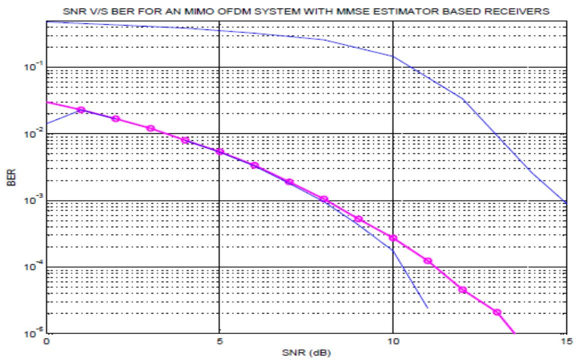

fig 3. SNR v/s BER for an MIMO-OFDM system with MMSE estimator based receivers.

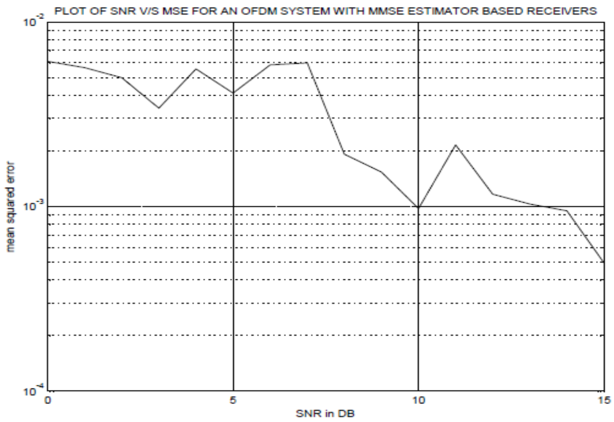

fig 4. Mean Square Error versus SNR for MMSE based receiver

VIII. CONCLUSION

Since radio resources are scarce and data rate requirements keep increasing, spectral efficiency is a stringent requirement in present and future wireless communications systems. MIMO-OFDM has become a new star in the constellation of wireless and mobile communications. In addition to increasing spectral efficiency, MIMO can also be used to reduce transmitting power while keeping coverage areas constant. The use of MIMO technique in future transmission systems for broadcasting, multicasting and unicasting represents real business logic also for broadcasting corporations because of the possible reduction in transmission stations. By using MIMO-OFDM technique BER rate will greatly reduced it is shown in the waveform which is necessary in new wireless applications.

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