Carrier Interference Compensation using PSO algorithm.

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Abstract

The Single Carrier Frequency Division Multiple Access (SC-FDMA) faces a major drawback of Inter Carrier interference (ICI) due to frequency offset mismatch between the transmitter and the receiver. This results in the disruption of the orthogonality in the system. In this paper, an uplink MIMO SC-FDMA is designed with the perfect knowledge of the Cyclic Frequency Offsets (CFO). Particle Swarm Optimization (PSO) algorithm which is a population-based meta heuristic algorithm is used to mitigate the effect of ICI without the assumption of CFO. The system provides better performance when compared to the other existing systems from the results obtained through simulation.

Index Terms— MIMO SC-FDMA, CFO, ICI, PSO algorithm.

1.INTRODUCTION

The long term evolution (LTE) is a key agent that drives a significant portion of growth for the mobile communications. An alternate wireless standard to orthogonal frequency division multiplexing is Single Carrier FDMA. This standard is incorporated due to its low peak to average power ratio (PAPR) and has also received tremendous attention for inter carrier interference (ICI) compensation. ICI reduction schemes based on estimation are given in [2-4] where CFOs are determined using pilot signals. In [2], the authors have proposed a zero Forcing (ZF) technique for the reconstruction of the spectrum of the transmitted signal in the linear filters and this scheme is referred as CTYH scheme. In spite of showing better performance, the practical implementation of the scheme is tedious due to its complex matrix calculation and it also further increases in the case of MIMO. At the receiver side, a raised cosine window was recommended by the author in [3], to reduce the banded approximation error. A joint equalization and CFO compensation scheme known as (JMMSE) is done after de-mapping of subcarrier at the receiver in SC-FDMA. A more regularized compensation using JMMSE is performed in [5]. In [6], [7] the authors have extended the ICI compensation analysis to MIMO SC-FDMA and also a low complex ICI cancelation scheme(JLRZF) for 2x2 MIMO systems.

All the above mentioned methods are executed by the perfect knowledge of the CFOs. Blind CFO estimation and ICI compensation are performed in [8-10]. In [1] the author has proposed a blind ICI compensation technique using firefly algorithm. Other population based meta-heuristic algorithms exist which is useful in ICI compensation and one such power algorithm is particle swarm optimization (PSO) algorithm. Many schemes have been proposed by the authors for the mitigation of ICI in MIMO SC-FDMA. All these schemes are extensions of the concepts proposed for OFDMA where trade-off exists.

In this paper a model for MIMO SC-FDMA for the uplink in constructed using the presence of CFO. A PSO based blind ICI cancelation scheme is proposed using linear filtering approach. The rest in this paper explains the system model of MIMO SC-FDMA in section II. Section III explains the PSO algorithm followed by simulation results and conclusion in section IV and V. While designing the
system model all the expression in bold face represents the equations in MIMO and the regular equations represent the SISO case.

2. SYSTEM MODEL

An uplink MIMO SC-FDMA system [7] with receiver antennas and transmitted antennas are considered. Block of symbols transmitted by each user through an antenna is given as $M = \frac{N}{Q}$, where $N$ are the subcarriers and $Q$ is the number of users in the system. The transmitted signal by the $n$th user is given by

$$y_n^a = P_H R_n^a E_r^a x_n^a$$  \hspace{1cm} (1)

where $y_n^a = [y_1^a, y_2^a, \ldots, y_{N_r}^a]^T$.

$P_H = I_{N_r} \otimes F_H^H$ Denotes IFFT

$F_H^H = I_{N_r} \otimes F_M^H$ FFT describes block FFT spreading

$E_r^a = I_{N_r} \otimes E^a$ Subcarrier mapping matrix

$x_n^a = [x_1^a, x_2^a, \ldots, x_{N_r}^a]^T$ data symbols

At the base station the received signal is given by

$$R = \sum_{a=1}^{Q} S^a \Lambda^a \tilde{X}^a + W$$  \hspace{1cm} (2)

where $S^a$ is the block matrix [1] where each block represents frequency domain channel between the transmitter and the receiver. The diagonal interference matrix is expressed as

$$S^a = T_N \Psi^a T_N^H$$  \hspace{1cm} (3)

Here, $\Psi^a$ is the frequency offset matrix in time domain and expressed as $\text{diag}(\frac{j2\pi Qk}{N})$ for $k=0,1,2,\ldots,N-1$.

Modifying the system to a single user system the net ICI matrix is given by

$$S_{\text{eff}} = \sum_{a=1}^{Q} S^a E_r^a (E_r^a)^H$$  \hspace{1cm} (4)

$S_{\text{eff}}$ can be modeled as a ICI circulant matrix in the case of SC-FDMA with order of blocks $Q$ [10]. Similarly the net channel matrix is in the form

$$\Lambda_{\text{eff}} = \sum_{a=1}^{Q} \Lambda^a E_r^a (E_r^a)^H$$  \hspace{1cm} (5)

The transmitted symbols are estimated when the receiver undergoes IFFT operation on $R$ and is given by

$$\hat{X}_{\text{eff}} = \Lambda_{\text{eff}} H_{\text{eff}} X_{\text{eff}} + \hat{W}$$  \hspace{1cm} (6)

where $X_{\text{eff}}$ consists of time domain data symbols. $A_{\text{eff}}$ gives the ICI channel matrix and is given by

$$A_{\text{eff}} = I_{N_r} \otimes A_{\text{eff}}$$  \hspace{1cm} (7)
Further simplifying the effective channel matrix and using inverse block diagonal principle the channel matrix is given by

\[ H_{\text{eff}} = (T^H_{\text{me}})^H \Lambda_{\text{eff}} F^H_N \]  

(8)

The base station needs to compensate the effective ICI matrix and the channel matrix for a better result. Hence a liner filtering technique is adopted in order to reduce the effects of ICI which is the primary objective of the paper. This can be achieved by having a complete knowledge of the CFO which makes it easier for the construction of the linear filter.

Let \( G_{\text{prop}} \) and \( G_{\text{eq}} \) be denoted as the ICI compensation and channel compensation matrix. The solution to the ICI compensation and channel compensation matrix is given by

\[ G_{\text{prop}} = [A^H_{\text{eff}}A_{\text{eff}} + \alpha I_NR_r]^{-1}A^H_{\text{eff}} \]  

(9)

\[ G_{\text{eq}} = [H^H_{\text{eff}}H_{\text{eff}} + \alpha I_NR_r]^{-1}H^H_{\text{eff}} \]  

(10)

3. PSO ALGORITHM

PSO is a nature inspired meta-heuristic technique developed by Eberhart and kennedy which is influenced by the social behavior of bird flocking and fish schooling. A population of random solutions is initialized in the PSO and the optima are attained when the initial population evolves over generations. Each particle in the population contains velocity which facilitates it to fly through the decision space. Each particle is therefore represented by a velocity vector and a position. The dimensions of the position and the velocity vectors are described based on the number of decision variables in the optimization problem. The change in the particle is executed based on the information obtained from the previous position of the particle and its current velocity.

Let \( \vec{x}(t) \) be denoted as the particle position \( p_k \) at time step \( t \), the \( p_k \) position is changed by adding velocity to the current position i.e.

\[ \vec{x}(t) = \vec{x}(t - 1) + \vec{v}(t) \]  

(11)

The value of objective function helps in determining the best position (personal best- \( p_{\text{best}} \)) and (global best – \( g_{\text{best}} \)) of a particle. The \( g_{\text{best}} \) expression gives the solution for the optimization problem after a number of iterations. These principles can be formulated as

\[ \vec{v}(t) = \vec{v}(t - 1) + C_1 r_1 \left( \vec{x}_{\text{pbest}} - \vec{x}(t) \right) + C_2 r_2 \left( \vec{x}_{\text{gbest}} - \vec{x}(t) \right) \]  

(12)

where \( C_1, C_2 \) are constants and \( r_1, r_2 \) are random variables.

Estimating the CFO in the communication scenario is a multidimensional problem where all the CFO coefficients for each active user have to be determined. The estimated transmitted data can be obtained by the expression given below

\[ x_{\text{eff}}(\vec{e}) = \text{dec}(G_{\text{eq}}G_{\text{prop}}(\vec{e})\hat{x}_{\text{eff}}) \]  

(13)
where $\xi$ the running trivial value and $\text{dec}(x)$ denote the decision about the observation in the search space. The optimum solution for the ICI compensation that is to be used in the algorithm is given by

$$f(\xi) = \|A_{\text{eff}}(\xi)H_{\text{eff}}x_{\text{eff}}(\xi) - \tilde{x}_{\text{eff}}\|^2 \quad (14)$$

Here according to our system each particle is considered as a CFO. The CFO value changes based on the current velocity and the information provided from the previous position. The value that produces the best objective function for each generation is termed as personal best and the optimum value is considered as the global best. The $\tilde{x}$ that provides the minimum objective function is the final estimate of the CFO and the respective $x_{\text{eff}}(\xi)$ is the demodulated data.

### 4. SIMULATION RESULTS

An uplink MIMO SC-FDMA model is executed in MATLAB using the parameters listed in table 1. The model is designed with perfect knowledge of the CFO and is removed later for the cancelation of ICI using PSO algorithm.

<table>
<thead>
<tr>
<th>TABLE 1</th>
<th>SIMULATION PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARAMETERS</td>
<td>VALUES</td>
</tr>
<tr>
<td>Number of Subcarrier ($N$)</td>
<td>256</td>
</tr>
<tr>
<td>Number of users ($Q$)</td>
<td>4</td>
</tr>
<tr>
<td>Transmitting antenna ($N_t$)</td>
<td>2</td>
</tr>
<tr>
<td>Receiving antenna ($N_r$)</td>
<td>4</td>
</tr>
<tr>
<td>Modulation Scheme</td>
<td>QPSK</td>
</tr>
<tr>
<td>Channel model</td>
<td>Vehicular A outdoor</td>
</tr>
<tr>
<td>Cyclic prefix length</td>
<td>20</td>
</tr>
<tr>
<td>Range of CFO</td>
<td>uni(-0.3,0.3)</td>
</tr>
<tr>
<td>Number of channel taps</td>
<td>6</td>
</tr>
</tbody>
</table>

The effect of the ICI compensation using the PSO algorithm can be viewed from the BER performance. The figure 1 shows the BER performance with the CFO compensation. It is evident the PSO shows better performance compared to other techniques. A BER of 0.009 was obtained at an SNR of 6dB.

![Figure 1 BER Vs SNR using PSO algorithm](image-url)
The CTYH scheme is inferior to other schemes because of its two step processing technique and also due to banded approximation. From figure 1 it is also clear that there is tremendous difference in the BER values before and after the use of the PSO algorithm. The PSO algorithm has greater advantage when compared to other schemes because the time required in determining the optimum solution is less as the speed for searching the optimum solution is done in a faster rate.

![BER performance with PSO based ICI compensation](image)

The BER performance of PSO based ICI compensation is shown in figure 2. There is better performance found in the ICI compensation with PSO compared to the system that does not compensate CFO. Therefore the PSO is best suited for ICI cancelation for multi user SC-FDMA system.

5. CONCLUSION

In this paper an uplink MIMO SC-FDMA system model is designed and the detrimental effects of the CFO is analyzed. In the system, a linear filter is modelled using the perfect knowledge of the CFO. Later the assumption of the CFO is removed ICI cancelation problem is solved using PSO algorithm. The results obtained from the simulation clearly states that the system using the PSO optimization algorithm provides better performance as it provides less SNR when compared to other schemes. The ICI compensation is comparatively more without the assumption of CFO rather than the ICI compensation with using CFO. The analysis can be further extended to other optimization algorithms.

REFERENCES


