A TRANSMISSION METHOD TO COMBAT MULTIPLE CARRIER FREQUENCY OFFSETS (MCFOS) IN COORDINATED MULTIPLE POINT (COMP) SCHEMES

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ABSTRACT

In CoMP, two or multiple transmitters are coordinated to establish links with users. For example, a pair of coordinated base stations can transmit Alamouti-coded data, which has two streams, with one base station being responsible for one stream. When multiple carrier frequency offsets exist, the performance of Alamouti-type schemes in CoMP degrades seriously. MCFOS can exist when transmitters are not synchronized on the level of carrier generation, or can exist when the data streams face different Doppler situations caused by the movement of the users. Many works have been devoted to solving MCFOS for Alamouti-type signaling or space multiplexing. These techniques focus on the receiver algorithms, yet they work with limited success and usually are costly in implementation. We propose a transmission method which can facilitate a simple receiver to combat MCFOS. The receiver mainly uses a parallel ICI canceller to mitigate the effect of ICI. Simulation results of a system consisting of two cooperative transmitters with LDPC as the outer code are provided to illustrate our arguments.

Index Terms— CoMP, multiple carrier frequency offset, Inter-carrier interference, Alamouti coding

1. INTRODUCTION

Distributed multiple antenna technique has drawn much attention in recent years. One advantage is that multiple transceivers can create a virtual multiple-antenna configuration. LTE-A standards lay out the use of Coordinated MultiPoint transmission (CoMP) and create a lot of interests in this type of technologies. Usually, well-known multiple-input multiple-output (MIMO) techniques, such as Alamouti-like space-frequency block coding (SFBC), can be generalized for the distributed environment. Examples are provided in [1][2].

However, unlike in conventional MIMO systems, the cooperating transmitters may be located at different spots, clocked by different oscillators, and experience different Doppler spreads such that multiple symbol timing offsets (MSTOs) and multiple carrier frequency offsets (MCFOS) may occur. It is rather impossible for the destination node to compensate MSTOs and MCFOSs perfectly. And the inter-symbol and inter-carrier interference caused by synchronization errors can greatly degrade systems’ performance. One major advantage of the Alamouti-like codes for (distributed) MIMO systems is the possibility of using very simple receiving methods, e.g., linear combiners, to harvest the performance gain that is usually associated with much more complicated algorithms such as ML. With MCFOSs, however, the performance degradation of simple receiving algorithms is so severe that no advantages can be claimed for MMIO coding [3]. In this paper, the attention is focused on developing new transmission schemes for CoMP-type scenarios such that the performance degradation due to ICI caused by MCFOSs can be effectively mitigated when relatively simple receiving algorithms are used at the receiver end.

Many methods have been proposed to mitigate the MCFOSs problem. For instance, equalization schemes to mitigate inter-carrier interference (ICI) are proposed in [4] and [5]. In [6], several data detection and complexity-reducing methods are compared. In [7], an ICI-self cancellation scheme is proposed with a price of lower data rate. In [8], a two-branch receiver structure is proposed. A two-step cancellation procedure with ICI cancellation is proposed in [9]. A receiver scheme which combines techniques in [8] and [9] is proposed in [10], and a better performance is achieved. A novel residual-ICI whitening technique is applied to cooperative OFDM signal detection with good performance; in theory it should also be suitable for scenarios with MCFOSs at the price of high complexity at the receiver side [11]. These techniques, however, are often effective in a quite limited range of MCFOSs and usually are costly in implementation. In this paper, a novel transmitter-side technique is proposed to combat ICI caused by MCFOSs. The main advantage is to enable the receiver to exploit the transmission signal features such that a simple receiver implementation is possible and the performance degradation due to ICI is manageable.

The rest of this paper is organized as follows. Section 2 describes the system model. In Section 3, the novel transmission scheme is described. In Section 4, the receiver algorithm is described. In Section 5, simulation results are shown and analyzed. Finally, Section 6 concludes the paper.

2. SYSTEM MODEL
Figure 1: Two mobile users cooperate in an uplink situation.

Figure 2: Two base stations cooperate in a downlink.

A two-transmitter-one-receiver configuration shown in Fig. 1 is considered for the reason of simplicity. It is easy to extend the following derivations to the case with more receiving antennas. The configuration can occur in scenarios such as two mobile users cooperate in uplink transmission or two base stations cooperate in downlink transmission to users at the cell edges.

We will consider OFDM-based transmitted signals. Let \( s_k^1 \) be the transmitted signal on the \( k \)-th subcarrier at the first transmitter, and \( s_k^2 \) be at the second transmitter. Let \( r_k^1 \) be the received signal on the \( k \)-th subcarrier when the receiver tunes its carrier frequency to the first transmitter’s carrier frequency, and \( r_k^2 \) be the received signal when the receiver tunes its carrier frequency to the second transmitter’s carrier frequency. Note that the tuning can be done in the signal processing unit without actually tuning the RF path;

therefore, the receiver can generate two versions of received signal with a single RF path.

Assume that the carrier frequencies on the first and second transmitter are separated by an offset \( f_{\text{offset}} = f_1 - f_2 \). The offset normalized by the subcarrier interval is \( \epsilon_f = f_{\text{offset}} / \Delta f \). Assume that the receiver perfectly knows the channel frequency responses from both transmitters; \( H_k^i \) denotes the CFR from the \( i \)-th transmitter to the receiver. Then, the first version of the received signal (i.e., the received signal when the receiver compensates the frequency offset to the first transmitter while ignore the second transmitter’s offset) on the \( k \)-th subcarrier can be written as:

\[
r_k^1 = H_k^1 s_k^1 + e^{j\pi f_{\text{offset}} N} \frac{\sin(\pi f_{\text{offset}} N)}{N \sin(\pi f_{\text{offset}} N)} H_k^2 s_k^2 + \sum_{m=0, m \neq k}^{N-1} \frac{\sin(\pi (m-k+\epsilon_f)N)}{N \sin(\pi (m-k+\epsilon_f)N)} H_k^2 e^{j\pi (m-k+\epsilon_f)N} + w_k^1
\]

where \( w_k^1 \) is the additive noise. In the expression, \( H_k^1 s_k^1 \) is the desired signal from the first transmitter without CFO, while the second term is the desired signal from the second transmitter with a CFO factor and the summed term represents the ICI coming from subcarriers other than the \( k \)-th subcarrier. The second version of the received signal with tuning to the second transmitter can be found similarly.

3. INTERLACED TRANSMISSION SCHEME

The magnitudes of ICI caused by the Doppler effect and/or synchronization errors drop quite fast as the distance of two mutually-interfering sub-carriers increases [12][13]. Therefore, it is reasonable to only consider ICI terms come from neighboring sub-carriers when developing practical ICI-mitigating techniques. In this way, the summation appeared in the ICI terms of the received signal model can be limited to few summands.

To further simplify the expression of ICI terms, one approach is to make arrangements on the transmitter side so that the receiver may exploit the signal features towards a relatively simple signal model and eventually receiving algorithms. If the signals are transmitted in an interlaced pattern on sub-carriers, the most significant ICI terms can be “estimated” via sensing its values on the immediate neighboring sub-carriers. To improve performance, an appropriate outer FEC can be added (usually this is the case in practical situations).

The QPSK symbols \( \{d_k^1\}_{k=2}^{N} \) passes through a precoder and are differentially encoded to rescue deep faded channels, and the output is given by

\[
\begin{align*}
x_k &= -1 - j \\
x_k &= d_{k-1}^1 \times x_{k-1}^2 + j d_{k-1}^2 \times x_{k-1}^3, \text{ for } k = 2, 3, ..., N
\end{align*}
\]
where \( d_k^\text{real} \) (\( x_k^\text{real} \)) and \( d_k^\text{imag} \) (\( x_k^\text{imag} \)) are the real and imaginary parts of \( d_k \) (\( x_k \)).

Next, the DeMUX generates a simple even-odd interlaced pattern. Let \( x_k \) represent the symbol output from a precoder to be transmitted on the \( k \)-th subcarrier. Then the odd-indexed symbols will be transmitted on the first transmitter while even-indexed symbols will be transmitted on the second transmitter. The subcarriers not chosen by the above arrangement will simply transmit null symbols (i.e., \( s_{\text{odd}}^1 = x_{\text{odd}} \) and \( s_{\text{even}}^1 = 0 \), while \( s_{\text{even}}^2 = x_{\text{even}} \) and \( s_{\text{odd}}^2 = 0 \)).

The second transmitter does not transmit data symbols on subcarrier 1 and 3, it is relatively easy for the receiver to estimate these two prominent ICI terms by sensing the signals \( r_2^1 \) and \( r_2^2 \). Define

\[
I(c,e_j) = e^{j\pi(c(N-1)/N)} \frac{\sin(\pi(e_j + c))}{N \sin(\pi(e_j + c)/N)}
\]

where \( c \) is the index distance between the subcarriers. Then, for the 2nd subcarrier, the most prominent ICI terms (coming from the 1st and 3rd subcarrier) are:

\[
H_1^2 I(-1,-e_j)x_1 + H_2^2 I(1,-e_j)x_3
\]

To cancel the ICI at the 2nd subcarrier, the transmitted symbols on the 1st and 3rd subcarrier need to be estimated, and this in turn can be accomplished by sensing the signals \( r_2^1 \) and \( r_2^2 \) and finding the zero-forcing solution in first iteration for \( x_1 \) and \( x_3 \) via

\[
\hat{x}_1(0) = \frac{r_2^1}{H_1^2 I(0,-e_j)} \quad \text{and} \quad \hat{x}_3(0) = \frac{r_2^2}{H_2^2 I(0,-e_j)}
\]

The similar steps are applied to \( x_2 \) and \( x_4 \) respectively by

\[
\hat{x}_2(0) = \frac{r_2^1}{H_1^2 I(0,e_j)} \quad \text{and} \quad \hat{x}_4(0) = \frac{r_2^2}{H_2^2 I(0,e_j)}
\]

where \( \hat{x}_i(0) \) is \( x_i \) symbol estimations of initialization. After subtracting the ICI term, a more accurate estimation for \( x_2 \), \( x_3 \) can be obtained roughly; namely,

\[
\bar{x}_2 = \frac{r_2^2 - \hat{x}_1(n-1)H_1^2 I(-1,-e_j) - \hat{x}_3(n-1)H_2^2 I(1,-e_j)}{H_1^2}
\]

and

\[
\bar{x}_3 = \frac{r_2^1 - \hat{x}_1(n-1)H_1^2 I(-1,e_j) - \hat{x}_3(n-1)H_2^2 I(1,e_j)}{H_2^2}
\]

where \( \hat{x}_i(n-1) \) is \( x_i \) estimations of \( n-1^{th} \) iteration. The similar steps are applied to all even and odd subcarriers by equation (7), (8) respectively. Here the case of subcarrier 2 and 3 are used as an example for easy explanations.

The soft output of the preceding decoder represents the log likelihood ratio (LLR) of the probabilities of a bit. A simple way to do ICI cancellation is to feedback the estimated ICI to an ICI equalizer. There are two steps in each iteration of the preceding decoder: SISO decoding and soft decision-feedback. In order to implement the decoder we need to obtain posteriori distribution

\[
p(x_1,x_3|x_2^1,x_2^2,\hat{x}(n-1))
\]

where \( \hat{x}(n-1) \) is all symbol estimations of \( n-1 \)th iteration. In the first step we rewrite the equation (1)
The similar steps are applied to all symbols by this procedure. The soft decision-feedback procedure will first “pseudo-encode” \( \hat{d}_k \) into symbols, then the encoded output \( \hat{x}_k(n) \) will be fed into the ICI equalizer. The encoding is carried out according to equation (2). The absolute value of \( \hat{d}_k^{\text{real}} \) and \( \hat{d}_k^{\text{imag}} \) represents the reliability of bits. A “soft” encoded output \( \tilde{x}_k(n) \) can be constructed via the following equation:

\[
\tilde{x}_k(n) = \text{sgn}(x_{k-1} \times \hat{d}_k^{\text{real}}) \times \left( \frac{\hat{d}_k^{\text{real}} + \hat{d}_k^{\text{imag}}}{2Q} \right), \quad \text{for } k = 2, 3, \ldots
\]

where \( \hat{d}_k^{\text{real}} \) is a limited version of \( \hat{d}_k^{\text{real}} \) and the limiting range is set by \( Q \). The value of \( \hat{d}_k^{\text{imag}} \) is obtained in similar fashion. However the encoded output may still cause error propagation. To solve this problem, the encoded output will be compared to that of (7) or (8). If the values of \( \tilde{x}_k \) and \( \tilde{x}_k \) differ over a pre-set threshold, then use \( \tilde{x}_k \) instead of \( \tilde{x}_k \) for the following process. The above procedure is also used to process the LDPC decoder output to form the soft decision feedback.

Finally, in the preceding decoder an initial term is weighted-sum with \( \tilde{x}_k \) to form the final soft decision feedback in (19) to enhance numerical stability. Once the symbol estimations are obtained after subtracting the \( n \)-th estimations of the ICI, the procedure can be reiterated, this time with an improved estimations of \( \hat{x}_k(n) \).

\[
\hat{x}_k(n) = w(n)\tilde{x}_k + (1 - w(n))\tilde{x}_k(0), \quad \text{for } n = 2, 3, \ldots
\]

To verify that this simple receiver aided by the interlaced transmission scheme can be effective at combating MCFOs, MATLAB simulations are conducted. The system consists of 2×1 CoMP configuration with 512-point OFDM signaling, QPSK modulation. The Rayleigh block-fading channel obeyes the power profile listed in the table below. Figure 6 shows the diagram of the simulation set-up. The performance of an Alamouti-type system with linear receiver is compared to that of a system with a parallel ICI

<table>
<thead>
<tr>
<th>Channel delay ‘sample’</th>
<th>Channel tap power profile ‘dB’</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>-8</td>
</tr>
<tr>
<td>5</td>
<td>-17</td>
</tr>
<tr>
<td>6</td>
<td>-21</td>
</tr>
<tr>
<td>8</td>
<td>-25</td>
</tr>
</tbody>
</table>
canceller. The value of \( \varepsilon_f \) and \( Q \) are 0.20, 2 respectively. The length of LDPC is 64800 with a code rate of 0.4.

Figure 7 shows the BER results of four conditions. The solid red curve represents a linear receiver working in an Alamouti-type SFBC system with LDPC code. The solid blue curve represents our transmission scheme with a decision-feedback ICI equalizer and the LDPC is directly decoded without doing further turbo process. The dashed lines shows the performance with two turbo iterations. As can be seen, this simple receiver working with the interlaced transmission scheme can improve the coded performance by almost two orders at SNR=3dB.

![Figure 7: BER performance with \( \varepsilon_f = 0.20 \).](image)

6. CONCLUSIONS

In this paper, a simple transmission scheme is developed to combat ICI caused by MCFOs. The coordinated transmitters transmit a copy of coded data on subcarriers in a completely or partially interlaced manner. The receiver can take advantage of the interlaced transmission pattern and use a simple parallel ICI canceller to mitigate the effects of ICI. It can achieve reasonable performance with relatively low computational cost.

7. REFERENCES