An Improved Signal Detection Algorithm of LTE System in Interference Environment

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Abstract—In LTE system, due to resource scheduling on the same frequency, the target cell and neighboring cells must take measures to suppress the co-channel interference to improve the system performance. The time delay spread and correlation bandwidth are treated as fixed value when the correlation matrix is calculated in the interference rejection combining algorithm, which degrades the performance of IRC algorithm. So this paper proposes an adaptive interference rejection combining algorithm, which calculates the correlation matrix with different parameters depending on the channel type. At last simulation is done to test performance of adaptive interference rejection combining and other signal detection algorithm. It can be seen that this algorithm achieves at most 1dB performance gain.

Index Terms—Co-Channel Interference; Interference Rejection Combining; Maximum Likelihood; LTE System

I. INTRODUCTION

The investigation of co-channel interference mitigation techniques which includes interference cancellation through receiver processing, interference randomization by frequency hopping [1, 2], and interference avoidance through resource usage restrictions imposed by frequency and power planning, has become a key focus area in achieving dense spectrum reuse in the next generation cellular systems such as 3GPP LTE, LTE-advanced, and WiMAX [3-5].

Interference mitigation is one of the key issues currently under investigation in different standardization bodies and forums. Based on used methods, mitigation technique is generally categorized into three major classes [6, 7]. One is interference cancellation. Another is interference averaging and the third is interference avoidance technique. The basic principle of interference cancellation technique is the receiver signal processing to estimate interference and subtract it from the desired signal component. Interference averaging technique such as frequency hopping ensures user equipments to access a range of channels rather than a narrow set in a specific pattern so that interference effect is averaged out for all [8-11]. At last, the interference avoidance technique lays emphasis on finding an optimal effective reuse factor often achieved through restrictions on frequency and power allocations to achieve network performance goals. The benefits of each of these schemes are mutually exclusive, therefore a combination of the above strategies is expected in future systems [12, 13].

In the LTE system, deploying the network with the same frequency have the following superiorities, such as high frequency efficiency, deployment flexibility, low requirement of supporting frequency range for the UE, low complexity of the RF terminal and low terminal price. So it has been extensive used in outdoor network deployment [14]. Due to resource scheduling on the same frequency, the target cell and neighboring cells must take measures to suppress the co-channel interference to improve the system performance. The research on co-channel interference cancellation technologies in LTE downlink has important practical significance.

When co-channel interference exists in the channel environment, the statistical properties of interference will change. Effect of interference on transmitting signal will increase, which will make performance of traditional detection algorithm decrease. Facing co-channel interference environment that there must exist in the LTE communication system, in order to achieve downlink maximum data transmitting rate in the LTE standard, receiver detector must use detection algorithm with interference mitigation ability. For interference elimination algorithm in MIMO-OFDM systems, the research is mainly manifested on the two algorithms which are maximum ratio combining algorithm and interference suppression algorithm. Link model in interference environment is shown in Fig. 1.

There are $N_t$ independent co-channel interference signal in the channel environment. The number of transmitting antenna is $M$ and the number of receiving antenna is $N$. The receiving signal vector can be expressed as

$$
y = \sqrt{P_d} \mathbf{H}_j \mathbf{o}_d s_d + \mathbf{H}_j \mathbf{P}_j^{1/2} \mathbf{s}_j + \mathbf{n}.
$$

(1)

$s_j = (s_{j1}, s_{j2}, \cdots, s_{jN})^T$ is co-channel interference signal vector, $s_j$ is transmitted objective signal. $\mathbf{n}$ is additive Gaussian white noise of $N \times 1$ dimension. $\mathbf{H}_j$ is matrix...
of \(N \times N\) dimension. \(H_j(i,j)\) is channel frequency domain feature value corresponding to the j-th co-channel interference signal of the i-th antenna. \(H_j\) is channel frequency domain matrix of \(N \times M\) dimension from transmitter to receiver. \(P_i\) is average receiving power of objective signal. \(P_i = \text{diag}\{P_1, P_2, \cdots, P_N\}\) is average receiving power of co-channel interference signal. vector of transmitter is \(\mathbf{o}_t = \mathbf{u}_{\max} \cdot \mathbf{u}_{\max}\) is eigenvector corresponding to the maximum eigenvalue \(\lambda_{\max}\) of matrix \(H_{jj}^H H_j\). The maximum ratio combining of output signal of receiver is

\[
x_{\text{MRC}} = \mathbf{o}_t^H \mathbf{y} = \sqrt{P_i} \mathbf{u}_{\max}^H H_j H_j^H \mathbf{u}_{\max} s_d + \mathbf{u}_{\max}^H H_j^H \mathbf{P}_{\max}^{1/2} s_j + \mathbf{u}_{\max}^H \mathbf{H}_j^H \mathbf{n}
\]

(2)

\[
\mathbf{u}_{\max}^H H_j^H \mathbf{H}_j \mathbf{u}_{\max} = \lambda_{\max}
\]

(3)

(3) is substituted into (2) and (4) is obtained.

\[
x_{\text{MRC}} = \sqrt{P_i} \lambda_{\max} s_d + w
\]

(4)

\(w\) is sum of co-channel interference and noise of receiver.

\[
w = \mathbf{u}_{\max}^H H_j^H \mathbf{H}_j \mathbf{P}_{\max}^{1/2} s_j + \mathbf{u}_{\max}^H \mathbf{H}_j^H \mathbf{n}
\]

(5)

The output signal-to-noise ratio of MRC receiver is (6).

\[
\gamma_{\text{SNR}} = \frac{P_i \lambda_{\max}^2}{\mathbf{u}_{\max}^H (H_j^H \mathbf{H}_j + \sigma_n^2 I) H_j \mathbf{u}_{\max}}
\]

(6)

When there is not co-channel interference in the channel, (6) can be expressed as \(\gamma_{\text{SNR}} = \frac{P_i \lambda_{\max}^2}{\sigma_n^2}\).

IRC algorithm can be regarded as extension of MMSE algorithm based on minimum mean square error criterion. The difference is interference of IRC algorithm not only consider the effect of noise, but also consider the effect of co-channel interference.

In the next section, we introduce principle of interference rejection combining algorithm [15-20]. In Section 3 we propose an adaptive interference rejection combining algorithm. In Section 4, we test the performance of different signal detection algorithm. In Section 5 we conclude the paper and give some remarks.

II. INTERFERENCE REJECTION COMBINING ALGORITHM

Principle of interference rejection combining algorithm is as follows.

\[
E[\|x - Cy\|^2] = tr\{E[(x - Cy)(x - Cy)^H]\} = tr\{E[xx^H - xy^H C^H - Cyx^H + Cyy C^H]\}
\]

(7)

\[
= tr\{E(xx^H)\} - tr\{E(xy^H C^H)\} - tr\{E(Cyx^H)\} + tr\{E(Cyy C^H)\}
\]

Total transmitting power of transmitter is \(P\), autocorrelation matrix of transmitting signal can be expressed as (8).

\[
R_{xx} = E(xx^H) = \frac{P}{n_t} I
\]

(8)
\[ P = \sum_{i=1}^{n} P_i = \sum_{i=1}^{n} \left( \mu - \frac{\sigma_i^2}{\delta_i} \right) \]  

(9)

\[ P \] is accumulated value of \( n \) number of transmitting antenna power. \( \mu \) is a constant and is equal to \( 1/L \ln 2 \).

\( L \) is Lagrange multiplier. \( \delta_i \) is the i-th singular value of channel matrix \( H \). \( \sigma_i^2 \) is variance of noise. In order to facilitate analysis, assumptions on the transmitting antenna transmission power is the same, and equal to 1. (7) can be expressed as (11).

\[ E(xx^H) = 1. \]  

(10)

\[ E\left[ \|x - Cy\|^2 \right] = tr\{E(xx^H)\} - tr\{E(xy^HC^H)\} - tr\{E(Cyx^H)\} + tr\{E(Cyy^HC^H)\} \]  

(11)

\[ = tr(I_m) - tr(HH^H) \]  

\[ - tr(CH) + tr(C(HH^H + R_{ww})C^H) \]  

Do partial derivative to \( C \) on both sides of (11). The left side is set to 0 and IRC filter matrix (12) is obtained. IRC algorithm can be expressed as (14) and \( R_{yy} \) can be calculated by (15).

\[ C_{IRC} = H^H(HH^H + R_{ww})^{-1} \]  

(12)

\[ = H^H(HH^H + \sum_{i} G_i G_i^H + \sigma_i^2 I)^{-1} \]  

\[ C_{IRC} = H^H R_{yy}^{-1} \]  

(14)

\[ R_{yy} = \frac{1}{LB} \sum_{l=1}^{L} \sum_{k=1}^{B} y_{lk} y_{lk}^H \]  

(15)

III. AN IMPROVED ADAPTIVE IRC ALGORITHM

From the above analysis, we can know that the maximum ratio combining algorithm only used the frequency domain channel response value of the target signal for filtering of receiving signal, without using the space-time characteristics of interference against interference. MRC algorithm need to feedback weighted vector to the transmitter, which is used to send weighted signals by transmitter and increases a certain amount of overhead. The LTE standard did not make this kind of request to the design of a base station transmitter, so the LTE system does not use MRC algorithm. IRC algorithm is recommended to use, which is superior to maximum ratio combining algorithm.

IRC method use average of multiple samples to replace statistical average. In theory, When the statistical characteristics of random variables is not changed, the more the number of sample points, the closer it gets to the statistical average. In the LTE system, interference is considered to be colored noise and its statistical properties is changing, so we don't know its statistical characteristics. If the samples is too little, the sample average approximation to statistical average method can not reach good results. If sample number is too large, due to the mistake of adding sample points of different statistical properties to calculate, it will affect performance.

Because of signal transmitted by co-channel interference source is a symbol of some modulation mode, resource allocation in LTE system is based on physical resource block unit. Statistical characteristics of signal transmitted by co-channel interference resource is constant in a physical resource block, so channel environment of interference signal is the main factor which decides statistical properties of interference. In the study of channel environment, two terms are defined namely related time and related bandwidth. Within related time and related bandwidth, channel environment can be thought to be slowly changing. Using this feature, we can decide values of \( L \) and \( B \) according to different channel environment and our proposed algorithm is called IRC algorithm. LTE system defines three types of channel, the corresponding parameters of different types of channel are shown in TABLE I.

<table>
<thead>
<tr>
<th>Model</th>
<th>Number of tap</th>
<th>R.M.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extended Pedestrian A (EPA)</td>
<td>7</td>
<td>45 ns</td>
</tr>
<tr>
<td>Extended Vehicular A model (EVA)</td>
<td>9</td>
<td>357 ns</td>
</tr>
<tr>
<td>Extended Typical Urban model (ETU)</td>
<td>9</td>
<td>991 ns</td>
</tr>
</tbody>
</table>

A formula between relative bandwidth and delay spread is (16).

\[ R_e \approx \frac{1}{2\pi f_{\text{max}}}. \]  

(16)

Relation of related bandwidth and PRB under various channel environment is shown in TABLE II.

Related time and Doppler frequency shift is (17).

\[ T_r \approx \frac{9}{16\pi f_m}. \]  

(17)

In LTE system, different channel environment can correspond to different maximum Doppler frequency shift and these are 5Hz, 7Hz and 300Hz. Substitute them into (17), relation of related time and number of OFDM symbol is shown in TABLE III.
When number of OFDM symbol is bigger than number of OFDM in a PRB, statistical properties of interference signal may change. Number of OFDM symbol can be defined as number of OFDM symbol in a time slot. When using ordinary CP, number of OFDM symbols is equal to 7, and when using extension CP, number of OFDM symbols is equal to 6. Expression of adaptive IRC algorithm is (18).

The process of adaptive IRC algorithm is as follows.

Step1. Determine channel model of current service area and interference area. Find out number of PRB from table according to channel model. Then take the minimum value and compare it with downlink bandwidth allocated by current sub-frame.

Step2. According to CP type of current downlink sub-frame, determine the value of \( L_{\text{sym}} \).

Step3. Calculate autocorrelation function of receiving signal and use sliding window method to calculate. For the first beginning and the last ending \( B_{\text{adaptive}} / 2 \) number of sub-carriers in the downlink bandwidth, choose the first and the last \( B_{\text{adaptive}} \) number of sub-carriers data to calculate \( R_{yy} \). For sub-carriers in other places, choose sub-carrier in this place and the front \( B_{\text{adaptive}} / 2 \) number of sub-carriers and back \( B_{\text{adaptive}} / 2 - 1 \) number of sub-carriers as sample data, which is shown in Fig. 2.

Step4. Calculate IRC filter matrix of each sub-carrier.

Step5. Transmitting signal is obtained after filter matrix.

### IV. SIMULATION AND ANALYSIS

This simulation adopts long delay CDD transfer scheme, and the number of transmitting and receiving antennas is 2. Specific link parameter is shown in TABLE IV. Respective bit error rates are simulated under different SNR environment. Fig. 3 is detection algorithm simulation performance under interference environment case 1 and Fig. 4 is detection algorithm simulation performance under interference environment case 2. In Fig. 3 and Fig. 4, the dark blue line represents ZF algorithm, the green line represents MMSE algorithm, the red line represents OSIC MMSE algorithm and the light blue line represents ML algorithm. ZF is zero forcing algorithm, OSIC MMSE is ordered sequence interference cancellation algorithm under minimum mean square error criterion. MMSE is minimum mean square error algorithm. ML is maximum likelihood algorithm. For Fig. 3 and Fig. 4, modulation methods are QPSK, interference source number is 1, and the target cell ID = 0. Other configurations of interference cell link are the same with configurations of objective cell link, which ensures each sub-carrier transmitted by objective cell to be disturbed additively by interference cell and can ensure credibility of simulation results. In Fig. 3, when SIR is less than -5dB, BER(bit error rate) performance of ZF, MMSE, OSIC MMSE and ML is nearly the same. With the increasing of SIR, BER of ML algorithm decreases quickly. So ML algorithm has the best BER performance and ZF algorithm has the worst BER performance. MMSE algorithm is better than ZF algorithm. OSIC MMSE algorithm is a little worse than ML algorithm. In Fig. 4, when SIR is less than 0dB, BER performance of ZF, MMSE, OSIC MMSE and ML is nearly the same. With the increasing of SIR, BER of ML algorithm decreases quickly which is the same as Fig. 1. ML algorithm also has the best BER performance and ZF algorithm also has the worst BER performance. MMSE algorithm is also better than ZF algorithm. OSIC MMSE algorithm is also a little worse than ML algorithm.

It can be seen from Fig. 3 and Fig. 4, interference has a great influence on the performance of detection algorithm. When signal to noise ratio is 10dB, performance of ML algorithm decreases by 10dB compared with white noise environment. Only when signal to noise ratio increases to 20 dB, the influence of interference weak gradually, which reflect the detection performance of white noise environment.

### TABLE IV. DIFFERENT TYPES OF CHANNEL RELATED TIME

<table>
<thead>
<tr>
<th>parameter</th>
<th>configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wireless frame length</td>
<td>10ms</td>
</tr>
<tr>
<td>Sub-frame length</td>
<td>1ms</td>
</tr>
<tr>
<td>Length of time slot</td>
<td>0.5ms</td>
</tr>
<tr>
<td>Cyclic prefix type</td>
<td>Common cyclic prefix</td>
</tr>
<tr>
<td>Cyclic prefix length</td>
<td>144/160</td>
</tr>
<tr>
<td>Sub-carrier interval</td>
<td>15KHz</td>
</tr>
<tr>
<td>Time slot symbol number</td>
<td>7 OFDM symbol</td>
</tr>
<tr>
<td>FFT points</td>
<td>2048</td>
</tr>
<tr>
<td>Modulation method</td>
<td>QPSK, 16QAM</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>30.72MHz</td>
</tr>
<tr>
<td>Code word number</td>
<td>2</td>
</tr>
<tr>
<td>Transmission block size</td>
<td>3000</td>
</tr>
<tr>
<td>The resource block number</td>
<td>15PRB</td>
</tr>
<tr>
<td>channel model</td>
<td>EPA5</td>
</tr>
<tr>
<td>Turbo decoding iteration times</td>
<td>20</td>
</tr>
<tr>
<td>Loop iteration times</td>
<td>300 times per SNR</td>
</tr>
</tbody>
</table>

Fig. 5 is detection algorithm simulation performance under EPA5. Fig. 6 is detection algorithm simulation performance under EV5A and Fig. 7 is detection algorithm simulation performance under ETU70. In Fig. 5, Fig. 6 and Fig. 7, the dark blue represents ML algorithm, the green line represents IRC adaptive
algorithm and the red line represents IRC fix algorithm. ML represents maximum likelihood algorithm, IRC fix represents interference rejection combining algorithm and IRC adaptive represents our proposed adaptive interference rejection combining algorithm. It can be seen when SIR is smaller than a certain value, IRC algorithm has certain gain than maximum likelihood algorithm and the gain is slightly different under different channel environment. When SIR is 10dB, gain in environment EPA5 is higher than gain in environment EVA5 and gain in environment ETU70. In different channel environment, the proposed adaptive IRC algorithm has some gain than fixed IRC algorithm. In environment ETU70, adaptive IRC algorithm and fixed IRC algorithm nearly have the same BER performance.

With the increase of SIR, maximum likelihood algorithm and IRC algorithm will have a performance intersection point. This is because co-channel interference at this time is small enough compared to the target signal. So the advantage performance of the maximum likelihood algorithm will be reflected and the IRC algorithm is restricted to minimum mean square error criterion. As SIR continues to increase, the performance of the maximum likelihood algorithm will surpass the IRC algorithm. When using this algorithm, we suggest to set up a SIR threshold. When it is less than the threshold, IRC algorithm is used. When it is more than the threshold, maximum likelihood algorithm is used. It can be seen from the intersection point that adaptive IRC algorithm has a performance gain of 0-1dB compared with fixed IRC algorithm under different channel environment. Fig. 8 is 16QAM modulation symbol constellation of MMSE detection. Under 16QAM modulation method, the performance of several detection algorithm is approximately the same with QPSK, but bit error rate is high.

V. CONCLUSIONS

The IRC algorithm is adopted to cancel the co-channel interference in the signal detection phase in LTE system. For the reason that the time delay spread and correlation bandwidth are treated as fixed value when the correlation matrix is calculated, which degrades the performance of IRC algorithm. This paper proposes an adaptive IRC algorithm, which calculates the correlation matrix with different parameters depending on the channel type. Through simulation, it can be seen that this algorithm achieves at most 1dB performance gain.


