Research and analysis of MRC and IRC algorithm based on LTE system

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Abstract: This paper mainly studies the theoretical analysis of MRC and IRC algorithm. The users at the edge of the community will suffer much more frequency interference which comes from neighborhood users, especially in the dense urban area. To improve uplink throughput, MRC adaptive algorithm and IRC adaptive algorithm can improve the performance effectively. Through the simulation results of the two algorithms, we can come to the conclusion that the IRC algorithm is better than the MRC algorithm in the case of greater interference. If the interference is larger, choose IRC, otherwise, choose MRC. The two algorithms have different performances under different jamming and different SNR.

1. Introduction

The downlink of LTE system adopts OFDMA technique and the sub-carriers of multiple users that the downlink distributes demonstrate completely perpendicular planes while its uplink employs DFT-SFDMA and synchronization technology to ensure that there exists the orthogonality in frequency resource distributed among the users. In other words, there is little interference in frequency resource of the inside neighborhood and the interference of LTE system mainly comes from the same frequency resource in the neighboring cells with the same frequency. Additionally, the same frequency interference of neighboring cells refers that the expected cells are disturbed easily by the edge user or the base station, including the interference of uplink and downlink signals (containing four types). When the expected cells and neighboring cells are in the downlink slots, there exists the interference among the base stations; when the expected cells are in the downlink slots and neighboring cells are in the uplink slots, the interference mainly comes from the crossed time slots among the users; when the expected cells are in the uplink slots and neighboring cells are in the downlink slots, the interference is caused by the base stations; when the expected cells and neighboring cells are in the uplink slots, users are easy to produce interference. Therefore, it is necessary to adopt relevant Interference Rejection Combining [1] to guarantee the performance of TD-LTE same frequency network and improve its frequency and efficiency.

2. Algorithm analysis

Employing multi-antenna configuration, the receiving end of base station provides relevant conditions to the merging for basebank via using signal. Due to the different channel fading that the signal comes to different receiving antennas, multi-receive antennas are used to render received diversity, thus increasing the strength of signals, whether it is useful signal or interference signal. Configurating
reasonable weighted coefficient for receiving antennas could enhance the ability of receiver to prevent fading and interference so that the wireless network, capacity as well as data rate could be improved. The multi-antenna configuration of receiving end could be adopted to construct received diversity or process the interference rejection [2].

Maximum Ratio Combining (MRC), the most common received diversity technology, could adequately capture the gains of each received branch, whose performance is optimal [4]. However, when there exists strong interference among users, MRC regards the interference as noise during the process of merging, which will lead to the rapid deterioration of detection performance since the interference has played a leading role in receiving signal. Therefore, it is necessary to consider restraining the interference among the users during the checking of uplink [4]. IRC algorithm could estimate and constrain the interference, thus enhancing the checking performance and improving the throughput of uplink. What Interference Rejection technology needs to consider is the time and spatial attribute of interfered signal [4]. The IRC technology determines the weighted coefficient in accordance with the channel, spatial noise as well as the covariance matrix of interference, which not only considers the power value of interference, but also takes the dependency in time and space of interference into account [4] [8]. The interference model shown in Figure 1 is determined to effectively evaluate the performances of IRC scheme in the aspect of datalink layer.

Located in the Cell 1, UE1 is the expected users while the UE2 is the interfered users located within the overlapping area between Cell 1 and Cell 2 which is synchronous with Cell 2. The same time-frequency resources of UE1 and UE2 are allocated via schedule and the dependent fading that UE1 and UE2 experience finish the overlapping in the side of base station. The number of the interfered users and power in co-channel interference are approximately simulated by adjusting SIR.

Assume that the semidiameter of cell is smaller, the signal of multi-cell UE that the base station receives is almost the same, the length of CP is much larger than the delay spread of wireless channel and the fading that each subcarrier experiences could be considered as flat fading, the equivalent mathematics model in frequency domain could be expressed as followed:

$$r = H \cdot s + H_0 \cdot s_0 + H_1 \cdot s_1 + \ldots + H_{k-1} \cdot s_{k-1} + N$$  \hspace{1cm} (1)$$

where $H$ represents the channel response from the expected received users to base station; $H_i$ represents the channel response from the interfered users $i$ of neighboring cells to base station of expected cells; $i = 0\ldots K-1$. $K$ represents the total number of users in the interfered cells (the time-frequency resources of interfered users and expected users are the same); $s$ represents sending signal of expected users; $s_i$ represents the sending signal of interfered users.

Assume $I = \sum_{i=0}^{k-1} H_i \cdot s_i$, the equation (1-1) could be expressed as follows:

$$r = H \cdot s + \sum_{i=0}^{k-1} H_i \cdot s_i + N = H \cdot s + I + N$$  \hspace{1cm} (2)$$

Fig.1 Interference model

![Interference model](image-url)
Based on the knowledge of signal processing, it is known that the smallest checking matrix in error function
\[ e^H e = (r - H \cdot s)^H (r - H \cdot s) \]
is
\[ \hat{s} = (H^H \cdot H)^{-1} H^H r \]
(it also is MRC checking matrix when error budget \( r - H \cdot s) \) of each component has the same but irrelevant variances. When there is no interference \( I \), each component has the same but irrelevant variances so that the MRC checking is optimal. However, when there exists the interference, IRC checking matrix, the new checking matrix, is constructed since the MRC checking matrix could not meet the requirements of the assumption due to the dependency of \( I + N \), especially the relatively strong dependency among each antennas because of the smaller space between the receiving antennas.

Making \( \sigma^2 R_e \) become the covariance matrix of \( e = I + N \) and \( R_e = PP^H \), \( e = (r - H \cdot s) \), \( \varepsilon = P^H e \), \( x = P^H r \), the equation (2-2) is expressed as follows:
\[ x = P^H r = P^H (H \cdot s + e) = (P^H \cdot H) \cdot s + \varepsilon \]  
(3)

Covariance matrix of \( \varepsilon \) variate is
\[ \text{var}(\varepsilon) = \text{var}((P^H \cdot e) \cdot (P^H \cdot e)^H) = \text{var}(P^H \cdot e \cdot e^H P) \]
\[ = P^H \cdot \text{var}(e \cdot e^H) \cdot P = \sigma^2 P^H PP^H \]
\[ = \sigma^2 I \]  
(4)

Due to the same but irrelevant variance of \( \varepsilon \) each component, the expression of \( \varepsilon \) equivalent matrix channel \( \hat{H} = P^H \cdot H \) is as follows:
\[ x = \hat{H} \cdot s + \varepsilon \]
(5)

Because of the same but irrelevant variance of \( \varepsilon \) each component, the smallest checking matrix expression of error function \( (x - \hat{H} \cdot s)^H (x - \hat{H} \cdot s) \) is expressed as follows:
\[ \hat{s} = (P^H \cdot H)^H (P^H \cdot H)^{-1} (P^H \cdot H)^H \cdot (P^H \cdot r) \]
\[ = (H^H \cdot R_e^{-1} \cdot H)^H \cdot H^H \cdot R_e^{-1} \cdot r \]  
(6)

And the IRC checking matrix \( w = (H^H \cdot R_e^{-1} \cdot H)^H \cdot H^H \cdot R_e^{-1} \) where \( R_e \) represents interference covariance matrix and/or noise covariance matrix.

From the above analysis, it is found that MRC \( w = (H^H \cdot H)^{-1} \cdot H^H \) is the best checking matrix when there is no interference. If the MRC could not meet the requirements of testing under the interference condition, IRC \( w = (H^H \cdot R_e^{-1} \cdot H)^H \cdot H^H \cdot R_e^{-1} \) is the best checking matrix. The MRC and IRC algorithm could be be compared via two rules of the algorithms.

Successive interference cancellation zero forcing (ZF) rule:
\[ \hat{s} = \text{argmin}(r - H \cdot s)^H (r - H \cdot s) = \text{argmin} \| r - H \cdot s \|^2 \]  
(7)

Minimum mean square error (MMSE) rule[2]:
\[ \hat{s} = \text{argmin} E[(s - wr)(s - wr)^H] = \arg \min \limits_w E[(s - wr)(s - wr)^H] \]  
(8)

Compared with MMSE, ZF algorithm is simpler and easier to perform but it requires relatively high SNR since the ZF, offering receipt signal the inverse to multiply channel matrix, could eliminate the interference caused by other users. Generally speaking, when the coefficient of channel matrix is smaller than 1, its inverse is greater than 1, namely, it will amplify the noise when multiplying the divisor that
is greater than 1.

3. Simulation analysis
There are two kinds of situations when interference exists: one is low SNR, and the other one is high SNR. It is researched which method is better in low SNR situation to inhibit signals from interference; which method comes out with the best interference effects, when the divergence of the receiving angle of arrival becomes greater, that is, the directions of users enlarges; IRC and MRC algorithms will be influenced if the number of users increases and the directions of interference enlarges. Those two algorithms are compared in greater interference situations.

| parameters          | values                  |
|---------------------|-------------------------|
| system bandwidth    | 20MHz                   |
| channel environment | SCME-B 5Hz              |
| antenna polarization| 4+4 dual polarization   |
| antenna separation  | 0.5λ                    |
| simulation environment | PUSCH                 |
| occupied RB         | 6                       |
| MCS MCS            | MCS5,MCS26              |
| interference        | 1.none 2. 1 interference|
| Number of RB       | 15                      |

Fig. 2 Performance of each receiving algorithm in no SNR
Fig. 3 Performance of each receiving algorithm in SIR=-6dB
Fig. 4 Performance of each receiving algorithm in SIR=-6dB ratio

From the above simulation results, it can be seen that:

If there is no interference, two rules of MRC, MMSE and ZF perform similarly, while the two of IRC deteriorate by 1.2dB, due to the impossible exact accuracy of IRC interference estimation.

If there is interference:

In the low SNR situation, the detection performance of IRC is superior to that of MRC, because MRC simply takes interference as noise, with no consideration to interference signals, while IRC can effectively inhibit interference signals, consequently improving its detection.

In the high SNR situation, the performance of MRC gradually improves, mainly because of the increasing SIR and closing to the none interference situation. IRC, for its requirement of calculating the interference covariance matrix, which goes with inaccuracy, performs worse in this situation.

4. Conclusions

Based on the above simulation and analysis, the application of IRC algorithm possesses the following four characteristics:

IRC algorithm is applied to the low SNR situation. The detection performance of IRC is far better than that of MRC in that situation, for it with inhibition signals from interference, which is not in part of MRC calculation of MRC. IRC algorithm has better effects on inhibiting interference, with increasing divergence of receiving angle of arrival, i.e. separating directions of users. Taking SCME-B channel and MCS valued 5 as examples, SIR increases by 4dB at the point of 10% BLER, when the angle between the interference and the user is 60 degree, compared to 15 degree. The directions of receiving interference will become separating, if the number of users increases. The IRC inhibition capability will inhibit the increasing number of users and boost the total power of interfering signals, consequently worsening the performance of IRC, for example, the performance difference between two interference users and one is 6-7dB.

IRC algorithm is superior to MRC in the greater interference situation. If the interference is larger, then choose IRC, otherwise, choose MRC. On the basis of the above analysis, the two algorithms function is differently according to different interference and SNR. Thus, MRC and IRC adaptive algorithms gain greater theoretically.

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