Multi-cell Joint Detection and Macrodiversity for TD-SCDMA Trunking System*

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Abstract. Broadcast transmission is used in the downlink for TD-SCDMA trunking systems in the same frequency and same time slot, so the MAI of multi-cell is very serious. In this paper, we discuss the classical joint detection algorithms used for interference suppression. Considering the characteristics of trunking system, we can consider multi-cell model as macro-diversity model, when users of target group are distributed in different cells. We simulate under three different channel models (described in section 2), and it is shown that joint detection and macro-diversity can significantly improve system performance. The impairing effect of error propagation on macro-diversity depends on the distribution of the target group.

Keywords: TD-SCDMA trunking system, multi-cell channel estimation, multi-cell joint detection, macro-diversity.

1 Introduction

Time Division-Synchronous Code Division Multiple Access (TD-SCDMA), which is an innovative mobile radio standard for the physical layer of a 3G air interface [1], is widely recognized in public communications because of its advanced technology and reasonable cost. Based on this, the digital trunking system with independent intellectual property rights is developed; it will help to expand the space of technology and industrial competitiveness for TD-SCDMA. In TD-SCDMA trunking system, since power control and downlink beamforming smart antenna technology can not be used and the scrambling of TD-SCDMA trunking system cell is short, the

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multiple access interference is very serious. So how to suppress MAI occupies a very important position in TD-SCDMA [2].

All along, the joint detection techniques are considered to be effective method for suppressing multiple access interference (MAI), and [3] showed that the Minimum Mean-Square-Error Block Linear Equalizer MMSE-BLE algorithm can effectively suppress MAI for CDMA system in the uplink. Considering the characteristics of trunking system, when there are users of target group in interference cells, signal of adjacent cells contains information of target groups, and so macrodiversity can improve the performance of system. This paper we propose a downlink multi-cell joint channel estimation method, two joint detection algorithms containing zero forcing block linear equalizer (ZF-BLE) and minimum mean square error block linear equalizer (MMSE-BLE), and maximum ratio combining for TD-SCDMA trunking system[4].

The rest of this paper is organized as follows. Section 2 introduces the system model as well as the channel estimation for TD-SCDMA trunking system multi-cell downlink. In section 3 the problem of classic joint detection algorithms in this system is analyzed. Section 4 described the performance of maximum ratio combining for this system. Simulations are carried out to evaluate the performance of the proposed scheme in section 5. In section 6 we analysis the results and describe the conclusions.

In the paper, vectors and matrices are in boldface. The symbols $(\bullet)^T, (\bullet)^H$ and $\|\bullet\|$ designate transposition, conjugate transposition, and the vector norm, respectively

2 System Model and Channel Estimation

In this section, the multi-cell models of TD-SCDMA trunking system downlink and channel estimation are introduced.

2.1 System Model

A block transmission TD-SCDMA system is considered in which k groups access the same channel at the same time and in the same frequency band. Each time slot consists of two data blocks, a midamble embedded between two data blocks for channel estimation, and a guard period, as shown in fig. 1.

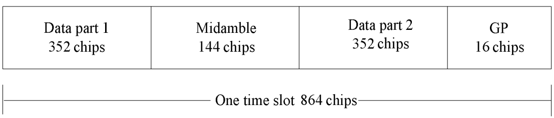

Fig. 1. Time slot structure in the TD-SCDMA system

In the following, only the first data part of each time slot is considered for simplicity. For the kth group, the transmitted data symbol can be represented as:

$$\mathbf{d}^{(k)} = \left(d_1^{(k)}, d_2^{(k)} \cdots d_N^{(k)}\right)^T \quad k = 1 \cdots K \tag{1}$$

Where, N is the number of data symbols in one data block. Each data symbol $d_n^{(k)}$ ($n = 1 \cdots N$), of group k is repeated 16 times and resulting 16-dimensional vector (OVSF) is multiplied element by the elements of the group-specific signature sequence:

$$\mathbf{c}^{(k)} = \left(c_1^{(k)}, c_2^{(k)}, \cdots c_{16}^{(k)}\right)^T \quad k = 1 \cdots K \tag{2}$$

In the downlink of single cell, a common midamble (eq.4) which is derived from a basic cell-specific midamble code (eq.3) is transmitted for all groups.

$$\mathbf{m}_{basic} = \left(m_1, m_2 \cdots m_P\right)^T \tag{3}$$

$$\mathbf{m} = \left(m_1, m_2 \cdots m_P, m_1 \cdots m_W\right)^T \tag{4}$$

Where, L is the number of path, which can be searched by terminal as strong-path. W =16 is the maximum length of channel impulse responses and $P = L \times W$. Each of the L path channels is characterized by its impulse response

$$\mathbf{h}^{(l)} = \left(h_1^{(l)}, h_2^{(l)} \cdots h_W^{(l)}\right)^T \quad l = 1 \cdots L \tag{5}$$

In this paper, two interfering cells and one target cell are discussed, and assume that the transmit power of each base station is the equal.

In the downlink, each base station to the mobile terminal there is only one channel between a base station and the mobile terminal, so in our system model we just need estimate three channel paths, so $L = 3$.

2.2 Channel Estimation

The performance is very bad if Steiner algorithm employ in TD-SCDMA trunking system multi-cell, because signal for channel estimation of adjacent cells is processed as a white noise. In this paper, multi-cell joint channel estimation algorithm is discussed, which means that the transmission characteristics of strong-interference- cell (SIC) and target cell are estimated, and this can be divided into the following three steps:

2.2.1 Choose Strong-Interference-Cell (SIC)

As the mobile terminal is in constant, the SIC may change with time. We can select SIC by setting threshold: for example, assume the value which is 5 time of noise power is threshold. Whose power is greater than this value are considered as SIC. According to TD-SCDMA system, even if the mobile terminal moves in the speed of 120km/h, it can only move 1.6m in the time of one frame. Therefore we can confirm SIC once every many frames, in order to reduce computation. In this paper, assume that the number of SIC is fixed at two.

2.2.2 Multi-cell Joint Channel Estimation

When the channel impulse response is assumed to span with a maximum delay of W, the first $(W-1)$ chips of received midambles are contaminated by the data part preceding the midambles. Hence, the later P chips are selected for channel estimation, since they are completely determined by the midambles. The corresponding received part is expressed as:

$$\mathbf{e}_{mid} = \sum_{i=1}^{K_1} \mathbf{M}_1^{(i)} \mathbf{h}_1^{(i)} + \sum_{j=1}^{2} \sum_{i=1}^{K_2} \mathbf{M}_{j+1}^{(i)} \mathbf{h}'^{i}_{j+1} + \mathbf{n}_{mid} \tag{6}$$

Where:

$$\mathbf{e}_{mid} = \left(\mathbf{e}_{W+1}, \mathbf{e}_{W+2} \cdots \mathbf{e}_{W+P}\right)^T \tag{7}$$

$$\mathbf{M}_i = \begin{Bmatrix} m_{W+1}^i & m_W^i & \cdots & m_2^i \\ m_{W+2}^i & m_{W+1}^i & \cdots & m_3^i \\ \vdots & \vdots & \ddots & \vdots \\ m_{W+P}^i & m_{W+P-1}^i & \cdots & m_{P+1}^i \end{Bmatrix} \tag{8}$$

$K_1 = 4$ is the number of active groups in target cell, and the number of SIC is $K_2 = 2$. The midambles and channel impulse response of all groups in a cell are the same.

Now, we define $\mathbf{G}$, which is made up of $\mathbf{M}$ of target cell and $\mathbf{M}$ of SIC:

$$\mathbf{G} = \left(\mathbf{M}_1, \mathbf{M}_2, \mathbf{M}_3\right) \tag{9}$$

Eq.6 can be rewritten as:

$$\mathbf{e}_{mid} = \mathbf{G}\mathbf{h} + \mathbf{n}_{mid} \tag{10}$$

In the expression:

$$\mathbf{h} = \left[\left(\mathbf{h}^1\right)^T, \left(\mathbf{h}^2\right)^T, \left(\mathbf{h}^3\right)^T \right] \tag{11}$$

Suppose the variance of noise n_{mid} is σ^2. By applying MMSE [5] criterion in the channel estimation, the channel impulse responses are estimated as eq. 12:

$$\hat{\mathbf{h}} = \left(\mathbf{G}^H\mathbf{G} + \sigma^2\mathbf{I}\right)^{-1}\mathbf{G}^H\mathbf{e}_{mid} \tag{12}$$

2.3 Noise Reduction Processing

Noise reduction is introduced to remove unexpected noise taps. All the taps below the noise threshold are set to zero [6]. Here, assume that the threshold (χ) is changed with the channel transmission Characteristics. Three different channels are discussed in this paper, which are given Table 1 [7].

Table 1. Propagation Conditions for Multi-path Fading Environments

Case 1 speed 3km/h		**Case 2 speed 3km/h**		**Case 3 speed 120km/h**	
Relative Delay [ns]	***Average power [db]***	***Relative Delay [ns]***	***Average power [db]***	***Relative Delay [ns]***	***Average power [db]***
0	0	0	0	0	0
2928	-10	2928	0	781	-3
		12000	0	1563	-6
				2344	-9

In case 1, χ is the second biggest of the $\hat{\mathbf{h}}$, in case 2 is third and in case 3 is fourth. $\hat{\mathbf{h}}$ after noise reduction are denoted as $\hat{\mathbf{h}}_i$.

3 Data Estimation Techniques

As we can know from eq. 2 and eq. 12, MAI arises due to impaired orthogonality between OVSF codes under channel distortion. The combined channel impulse response with code spreading is defined by convolution:

$$\mathbf{b}_i^{(k)} = \mathbf{c}^{(k)} * \hat{\mathbf{h}}_i = \left(b_{1,i}^{(k)}, b_{2,i}^{(k)} \cdots b_{16+W-1,i}^{(k)}\right)^T \begin{cases} i = 1,2,3 \\ k = 1 \cdots K_i \end{cases}. \tag{13}$$

The received data signal e of mobile terminal can be written as:

$$\begin{aligned} \mathbf{e} &= \mathbf{A}\mathbf{d} + \mathbf{n} \\ &= \left(\mathbf{A}^1, \mathbf{A}^2, \mathbf{A}^3\right) \begin{pmatrix} \mathbf{d}_1 \\ \mathbf{d}_2 \\ \mathbf{d}_3 \end{pmatrix} + \mathbf{n} \end{aligned} \tag{14}$$

Where, system matrix $\mathbf{A}^i$ of i-th cell is defined in eq. 15, $\mathbf{d}_i$ is the summed data for all groups of i-cell , and $\mathbf{n}$ is the additive white Gaussian noise (AWGN) vector.

$$\mathbf{A}^i_{16(n-1)+t;n+16(k-1)} = \begin{cases} b_t^k & k=1\cdots K_{\mathrm{i}}; n = 1\cdots N; \\ & t = 1\cdots(16+W-1) \\ 0 & \text{others} \end{cases} \tag{15}$$

3.1 Whitening Matched Filter

Although the MF treats ISI and MAI as noise, it is introduced here, because all data estimation techniques presented in the following, which take into account both ISIand MAI can be interpreted as an extension of the MF. The continuous valued estimate of d_{MF} is given by:

$$\mathbf{d}_{MF} = \mathbf{A}^H \mathbf{e} \tag{16}$$

3.2 Zero-Forcing Block Linear Equalizer

Joint Detection is implemented in TD-SDMA as a key technique. The system model can be written as eq. 15, where matrix A consists of spreading codes, scrambling code and channel impulse responses obtained by channel estimator described in section 2. ZF-BLE algorithm presented in [3] lead can be expressed as:

$$\mathbf{d}_{ZF-BLE} = \left(\mathbf{A}^H \mathbf{A}\right)^{-1} \mathbf{A}^H \mathbf{e} \tag{17}$$

3.3 Minimum Mean-Square-Error Blocvk Linear Equalizer

Minimum mean square error criterion is to make $\mathbf{E}(|\mathbf{d}_{MMSE-BLE} - \mathbf{d}|^2)$ tending to zero as much as possible, so $\mathbf{d}_{c,MMSE-BLE}$ can be re-described as:

$$\mathbf{d}_{c,MMSE-BLE} = (\mathbf{A}^H \mathbf{A} + \sigma^2 \mathbf{I})^{-1} \mathbf{A}^H \mathbf{y} \tag{18}$$

4 Macrodiversity

In this method, we assume users of target group distributed in different cell, so base stations transmit the signal of target group simultaneously. Based on this, we can kwon signal that users of target group receive from neighbor cell is useful instead of interference, which can strengthen the useful signal and lower the interference.

We assume that receiver of target group can keep signals synchronization, so we can think maximum ratio combination can improve the performance of the system

$$\mathbf{d}_{out} = \sum_{i=1}^{a} \lambda_i \mathbf{d}_i \quad . \tag{19}$$

Where, a is the number of SIC which contains the users of target group, and λ_i is weighting coefficient of i-cell, and $\mathbf{d}_i$ is output of i-cell using an algorithm above-mentioned.

5 Simulation Results

In this section, the performance of three data estimation techniques introduced in section 3 and macro-diversity introduce in section 4 is analyzed by simulations for transmission over mobile radio channel mentioned in Table 1. We assume base stations transmit data to K_i active groups (K_i of target cell is 4, and SIC is 2), at the same time and QPSK modulation is used at transmitters.

As depicted in Fig. 2, since we assume that path loss of each base station to the terminal is equal, inter-cell MAI is very serious. We can see that joint detection (MMSE-BLE and ZF-BLE) can significantly improve system performance, and the performance of MMSE-BLE is slightly better than ZF-BLE in all three cases.

As we can see form Fig2-4, when macro-diversity exist, target groups is distributed more cells, the performance of system is better, and performance of MMSE-BLE is higher than ZF-BLE by about 0.5-1db.

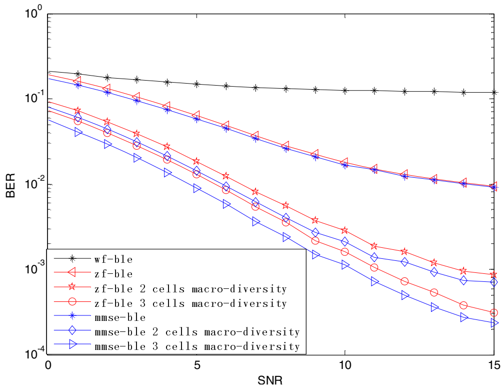

Fig. 2. The performance curves of system in case 1

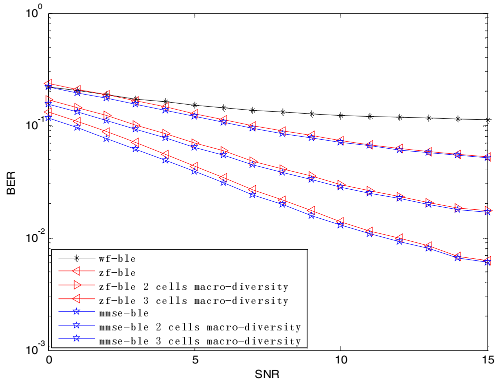

Fig. 3. The performance curves of system in case 2

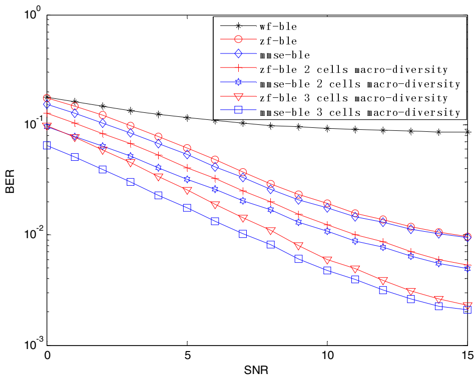

Fig. 4. The performance curves of system in case 3

6 Conclusion

In this paper, we first introduce a channel estimation method which is for downlink multi-cell model, and then two detection techniques have been presented performing channel equalization in TD-SCDMA trunking system, at last according to the characteristics of trunking system, we proposed that diversity combining technique is used for trunking system. Simulation results show that the macro-diversity further improves the system on the basis of joint detection.

References

1. Li, B., Xie, D., Chen, S., Zhang, P., Zhu, W., Li, B.: Recent Advances on TD-SCDMA in China. IEEE Communications Magazine 43(1), 30–37 (2005)
2. 3GPP TR 25.928 V4.0.1: 1.28 Mcps Functionality for UTRA TDD Physical Layer (March 2001)
3. Klein, A., Kaleh, G.K., Baier, P.W.: Zero Forcing and Minimum-Mean-Square Error Equalization for Multiuser Detection in Code-Division Multiple-Access Channels. IEEE Transactions on Vehicular Technology 45(5), 276–287 (1996)
4. Yue, L., Johnson, D.H.: Type-based detection in macro-diversity reception for mobile radio signals. In: IEEE International Conference on Acoustics, Speech, and Signal Processing (ICASSP 1997), vol. 5, pp. 4013–4016 (1997)
5. Dietrich, F.A., Utschick, W.: Pilot-assisted channel estimation based on second-order statistics. IEEE Trans. Signal Process. 53(3), 1178–1193 (2005)
6. Weber, T., Meurer, M.: Iterative multiuser detection for TD-SCDMA exploiting data estinate refinement techniques. In: Proc. IEEE 56th Vehicular Technology Conference (VTC 2002), Vancouver, vol. 3, pp. 1642–1646 (2002)
7. 3GPP TS 25.221 V.7.3.0-2007: Physical channels and mapping of transport channels onto physical channels (TDD)