Research on the Joint Detection of TD-SCDMA

Haiyang Fu

College of Telecommunication and Information
Engineering, Nanjing University of Posts and
Telecommunications
Nanjing, P. R. China
e-mail: fuhy@njupt.edu.cn

Qun Wang, Xiangdong Jia, Kai Liu

College of Telecommunication and Information
Engineering, Nanjing University of Posts and
Telecommunications
Nanjing, P. R. China
e-mail: qwang1314@gmail.com

Abstract—**Joint detection (JD) is a core technology of TD-SCDMA system. Only many mathematical models of JD have been proposed and discussed in many references, but there is no a physical model of JD for application. So the concept of JD is not clear. The concept of JD is made clearer by its principle and algorithm with physical model presented in this paper. Also a method for eliminating multi-path interference (MPI) by using mid-amble sequence and frequency spreading code (FSC) would be presented, and a JD constructed by that method would be proposed in the paper.**

Keywords; Joint Detection; TD-SCDMA; Fast Algorithm; Interference Cancellation

I. INTRODUCTION

There are many kinds of anti-interferences technology today, which are defined as multi-user access interference (MAI) and multi-path interference (MPI) in code division multi-access (CDMA) system. When detecting some path signal of one user's signal, the other path-signals of that user and the other user's signals with multi-path propagation would be considered as MPI and MAI to be ignored or eliminated. Therefore, when the number of users increased, the capacity and performance of the system would be greatly affected by those MPI and MAI.

In order to improve the performance of the system, multi-user detection (MUD) technology came into being. This paper argues that the function of MUD could be divided into several processes: Firstly, the signals imbedded in MPI and MAI should be recovered. Secondly eliminating those MPI and MAI signals from the receiving signal, then there is only the hoped path signal of that user without MPI and MAI to be saved, so that the influence of MPI and MAI could be eliminated. The next step is to demodulating that hoped signal by dispreading. By the above method, also the signals imbedded in the MPI of that user could be separated and demodulated, and all of the demodulated signals without the infection of MPI and MAI in different propagation paths of that user could be combined together by maximum ratio combining (MRC) criterion to form a RAKE receiver.

The function of Joint detection (JD) in the TD-SCDMA system [1] should be similar to that of MUD, but the processing steps of JD in [2] is depicted only by an algorithm of elimination after signal detecting. In [2], the several processing steps depicted by us clearly are depicted by some

mathematical equations without any physical method and meaning provided.

Also the research of JD should be combined with smart antenna (SA). There are detailed descriptions of principle about SA in [3]. The research on SA and JD stays in the mathematical derivation of the theory of SA and JD separately in the past. In [4], the authors generally elaborate the processing of anti-interference within and between cell ranges, but not considering how to achieve receiver and detection with higher performance specifically.

Those mathematical equations and physical method for the realization of those several processing steps of MUD or JD provided by us would be discussed detail in the paper. The concept of JD would be made clearer by its principle and algorithm with physical model presented in this paper. Also a method for eliminating MPI by using mid-amble sequence and frequency spreading code (FSC) would be presented, and a JD constructed by that method would be proposed in the paper.

II. BRIEF INTRODUCTION OF JOINT DETECTION[5]

Suppose there are two users with two propagation paths, the receiving signal is r, then

$$r = d_{11}W_{11} + d_{12}W_{12} + d_{21}W_{21} + d_{22}W_{22} \qquad (1)$$

In which d_{ij} means the j-th path data of the user1, and so as W_{ij} the j-th path spreading code of user1. Do not considering additive white Gaussian noise (AWGN) temporarily, so the above equation can be expressed in the following matrix form:

$$r = \begin{bmatrix} W_{L11}, W_{12}, W_{21}, W_{22} \end{bmatrix} \begin{bmatrix} d_{11} \\ d_{12} \\ d_{21} \\ d_{22} \end{bmatrix} \qquad (2)$$

After channel matching, $\begin{bmatrix} W_{11}^*, W_{12}^*, W_{21}^*, W_{22}^* \end{bmatrix}$ synchronizing with those path spreading codes of user1 could be produced, then, the de-spreading process could be expressed as follows,

$$y = \begin{bmatrix} W_{11}^{*T}, W_{12}^{*T}, W_{21}^{*T}, W_{22}^{*T} \end{bmatrix}^T r \qquad (3)$$

If those de-spreading codes produced in receiving point is satisfying the requirement, the following results could be obtained, $W_{11}^* W_{11} = 1$, $W_{12}^* W_{12} = 1$, $W_{21}^* W_{21} = 1$, $W_{22}^* W_{22} = 1$. Define the matrix $A = \begin{bmatrix} W_{11}, W_{12}, W_{21}, W_{22} \end{bmatrix}$. By the above

equations (1) and (2), the following matrix could be obtained,

$$y = \begin{bmatrix} d_{11} + W_{11}^* W_{12} d_{12} + W_{11}^* W_{21} d_{21} + W_{11}^* W_{22} d_{22} \\ d_{12} + W_{12}^* W_{11} d_{11} + W_{12}^* W_{21} d_{21} + W_{12}^* W_{22} d_{22} \\ d_{21} + W_{21}^* W_{11} d_{11} + W_{21}^* W_{12} d_{12} + W_{21}^* W_{22} d_{22} \\ d_{22} + W_{22}^* W_{11} d_{11} + W_{22}^* W_{12} d_{12} + W_{22}^* W_{21} d_{21} \end{bmatrix} \quad (4)$$

It could be seen that every signal recovered in the above matrix is imbedded in the corresponding MPI or MAI. JD is used to remove those MPIs and MAIs and to make full use of those signals imbedded in the corresponding MPIs and MAIs. Defining matrix H, it meet the requirement of the following equation,

$$Hy = [d_{11}, d_{12}, d_{21}, d_{22}]^T \quad (5)$$

After calculating, the result of $H = [A^{*T} A]^{-1}$ could be gotten. Using weighted network architecture for JD to separate the every path data of one user's multi-path signals, those data corresponding to different paths could be combined together. There are detailed descriptions about JD principle in [5] [6].

III. THE PAST RESEARCH OF JD

The received signal could be expressed as follows:

$$e = Ad + n \quad (6)$$

In which e is used to denote the received signal, d the user data, A the system matrix, and n the (AWGN).

$$e = [e^{(1)T}, e^{(2)T}, ..., e^{(M)T}]^T \quad (7)$$

$$n = [n^{(1)T}, n^{(2)T}, ..., n^{(M)T}]^T \quad (8)$$

$$A = [A^{(1)T}, A^{(2)T}, ..., A^{(M)T}]^T \quad (9)$$

$$d = [d^{(1)T}, d^{(2)T}, ..., d^{(k)T}]^T = [d_1, d_2, ..., d_{KN}]^T \quad (10)$$

Where $A^{(m)}$ denotes a system matrix, in which every element in each column represents the parameter of the corresponding antenna, constituting by the combined channel response $b^{(k,m)}$ as follows,

$$b^{(k,m)} = c^{(k)} \times h^{(k,m)} = [b_1^{(k,m)}, b_2^{(k,m)}, ..., b_{Q+L+1}^{(k,m)}]^T$$
$$k = 1,2,...K; m = 1,2,...M \quad (11)$$

Which are the combination of spreading code and wireless channel. The matrix of $A^{(m)}$ is as following,

$$A^{(m)} = A_{ij}^{(m)}, i = 1,2,...NQ + L - 1; j = 1,2,...,kN \quad (12)$$

$$A_{Q(n-1)+tn+N(k-1)}^{(m)} = \begin{cases} b_b^{(k,m)} & k = 1,2,...,K; n = 1,2,...,N; \\ & t = 1,2,...,Q+L-1; \\ 0 & others \end{cases} \quad (13)$$

In which K denotes the number of users, M the number of antenna elements, Q the frequency spreading gain, L the maximum window length of channel response, $h^{(k,m)}$ the channel response between the base station and the mobile station.

If each user's original sequence $d^{(k)}, k = 1,2,...,K$ from e containing noise is wanted which, we should use joint detection technology to estimate every path data of the user. Detecting d, A should be known By equation (5). A is constituted by the channel response and FSC, so local de-spreading code and the channel response must be generated. Local de-spreading code is available by Figure 1, and the channel response can be measured by using uplink mid-amble sequence. Those parameters, such as amplitude fading ρ, time delay t_d, phase difference θ between the neighboring paths should be estimated for channel response.

On how to obtain local de-spreading code W_{L11}, many literature authors such as [7]-[9], use some mathematical equations to deduce it. How to get a physical implementation by these equations remains to be studied. A physical implementation of producing W_{L11} is given in Figure 1, making the generated local de-spreading code being delayed continuously, when the W_{L11} in Figure 1 is synchronized with W_{11} in u_{11}, and multiplied with u_{11}, filtering by a low pass filter (LPF). Then the maximum value could be obtained, which could be used as a signal to stop the delay function for the generated local de-spreading code.
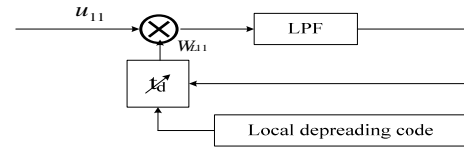

Figure 1. The generating of W_{L11}

In TD-SCDMA system, under the premise of knowing the channel response and using the forced zero block linear equalization algorithm (ZF - BLE), an appropriate weighting coefficient is chosen to make interference being reduced to 0. ISI and MAI can be eliminated in theory[5]. Under the criterion $\left\| \vec{e} - A_L \vec{d}_{ZF} \right\|^2 \to 0$, user data estimate is given by the following equation,

$$\vec{d}_{ZF} = (A^H R_n^{-1} A)^{-1} A^H R_n^{-1} e = \vec{d} + (A^H R_n^{-1} A)^{-1} A^H R_n^{-1} \vec{n} \quad (14)$$

Where $(A^H R_n^{-1} A)^{-1} A^H R_n^{-1} \vec{n}$ is an additive noise, and $A^H = A^{*T}$."*"denotes conjugate operation, R_n denotes Noise covariance matrix. A_L can be got from A by using mid-amble sequence. From the equation (14), this value makes $(\vec{e} - A\vec{d}_{ZF})^H R_n^{-1} (\vec{e} - A\vec{d}_{ZF})$ to be minimum, it is an unbiased estimation and only contain noise interference, and $A^H R_n^{-1} A$ must be reversible. As a result, additive noise increases[5]. $\vec{d}$ is the signal of multi-user, it is not contain multi-path signal, the best results is $\vec{d}_{ZF} = \vec{d}$. From this we know that $\vec{d}_{ZF}$ has not the function of RAKE receiver.

IV. CONSTITUTING JD BY THE USE OF MID-AMBLE SEQUENCE AND FSC

Below The concept of JD would be made clearer by its principle and algorithm with physical model presented in this paper.

The received signal S in a physical channel such as an carrier of a CDMA system contains signals of multi-user with multi-path. For example, assuming there are two users with two propagation paths, the received signal S in baseband could be given as follows,

$$S = d_{11}W_{11} + d_{12}W_{12} + d_{21}W_{21} + d_{22}W_{22} \quad (15)$$

Those signals involved in S should be considered with in virtual independent fading channel (VIFC) since there are mutual interferences, which were named as self-interference in CDMA system.

Before the first path signal of user2 being de-spread, those self-interference should be eliminated, so the effecting of self-interference could be eliminated. The process could be expressed as follows,

$$d_{21}W_{21} = S - \hat{d}_{11}\hat{W}_{11} - \hat{d}_{12}\hat{W}_{12} - d_{22}W_{22} \quad (16)$$

Then the first path signal of user2 could be de-spread as follows,

$$d_{21}W_{21}\hat{W}_{21} = d_{21}, d_2 = d_{21} + d_{22} \quad (17)$$

Also the second path signal of user2 could be processed by similar processes, d_{21} could be obtained. Then, doing as a RAKE receiver, we can get

$$d_2 = d_{21} + d_{22} \quad (18)$$

These above processing processes have been expressed clearly in Figure 2.

The process of eliminating an MPI of a single user with two-path is depicted in Figure 3, the first line is the transmitted symbol spread by W_{11}, the second line is the received signal S_R with two paths denoted by u_{11} and u_{12} respectively. The lowest line denotes the recovered W_{L11} by Figure 1.
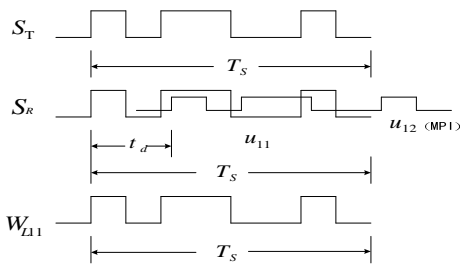

Figure 3. Transmitting and receiving signals with two-path for a user

From Figure 3, the method for eliminating MPI by using mid-amble sequence and FSC, e.g. W_{L11} would be deduced in Figure 4.

In Figure 4, S_{rd} denotes the signal output from the coherent demodulator, T_s denotes the symbol duration, t_d the MPI delay, $P_{u11}(0,t_d)P_\theta$ and $P_{u11}(t_d,T_S)P_\theta$ denote the polarity of MPI respectively since the polarity of the interference symbol is decided by those polarities of two symbols of the data stream in the first path for delay, where $P_{u11}(0,t_d)$ and $P_{u11}(t_d,T_S)$ denote the polarity of those two symbols respectively. That P_{u11} could be get from the de-spread signal of u_{11}. That P_θ is used to denote the polarity change caused by the phase difference θ between the carrier of u_{11} and that of u_{12}. Here ρ denotes the amplitude of MPI, it is up to $\cos\theta$ and propagation fading, which can be measured by the mid-amble sequence. Also, P_θ and t_d can be measured by the mid-amble sequence, too. So the processing process for the second path of the first user needed in Figure 2 is not needed in Figure 4, and a new method of eliminating MPI by using mid-amble sequence and FSC has been deduced in this paper.

Of cause, the above method could be used for JD. Here only three paths of radio propagation are assumed. In Figure 4, that I_{12} is used to denote the MPI of the second path signal of the first user, so as that I_{12} for the MPI of the second path signal of the first user, and that I_{K3} for the MPI of the third path signal of the K- user. So that the output of M_1 is the signal of the first path of user1 without MPI and MAI, and the output u_{11} of M_2 is the de-spreading signal of the first path of user1 without the effect of MPIs and MAIs. By the similar method, u_{12} and u_{13} without the effect of MPIs and MAIs could be get. So the signals for three paths of user1 could be added together as shown in Figure 4, as that being done in RAKE receiver. It is obvious that there is no problem for the presented scheme to be used for the multi-user JD.

The corresponding mathematical equations for Figure 4 could be deduced, and be given as follows,

$$S_{r1} = u_{11}W_{11} + u_{12}W_{12} = S_{r11} + S_{r12} \quad (19)$$

$$I_{12} = S_{r12} = u_{12}W_{L11} \quad (20)$$

$$u_{12} = \rho \cdot u_{12}(t-t_d)P_\theta \quad (21)$$

$$S_{r12} = \rho \cdot u_{11}(t-t_d)W_{L11}P_\theta$$
$$= \rho \cdot P_{u11}(0,t_d)W_{L11}(t-t_d)W_{L11}P_\theta$$
$$+ \rho \cdot P_{u11}(t_d,T_s)W_{L11}(t-t_d)W_{L11}P_\theta$$
$$= S_{r121} + S_{r122} \quad (22)$$

$$I_{12} = S_{r12} = \rho \cdot P_{u11}W_{L11}(t-t_d)W_{L11}P_\theta \quad (23)$$

Where

$$P_{u11}W_{L11}(t-t_d) = u_{11}(t-t_d) \quad (24)$$

V. SUMMARY

The principle and model of eliminating MPI and MAI in the TD-SCDMA system are proposed in this paper. At the same time, a multi-user joint receiver (JD) based on the above model has been given in this paper. Those previous researches have stayed on the level of mathematical derivation, but the physical model matching to those mathematical models, e.g. the block diagrams used for the realization are still needed to be studied further. A realizable physical model based on adequately studying the principle of joint detection in TD has been given in this paper, and the patents for the JD presented in this paper have been issued in [10].

REFERENCES

[1] Haiyang Fu, and Zaide Deng, 3G Technology TD-SCDMA and Its Progress, Telecom Engineering Techniques and Standardization, Beijing, 2005, pp.39-42.

[2] Mengke Wang and Zurong Zhou, Impact of MUD on the capacity of CDMA system, Information Technology, Beijing, 2006, pp.63-67.

[3] Shihe Li, The Principle of Smart Antenna Technology and Its Implementation, Beijing Telecom Science & Technology, Beijing, 2001.1, pp.12-19.

[4] Ping Chen, Research on WCDMA system capacity performance and radio resource management algorithm, Chengdu: Southwest Jiaotong University, 2006.

[5] Wenyun Xia, Research on multi-user detection techniques application, Nanjing: Nanjing University of Posts and Telecommunications, 2010.

[6] Pingbao Lv, and Jianying Xie, Combined Power Control and Multiuser Detection in CDMA Systems, Communications Technology, Sichuan, 2002, pp.90-93.

[7] Peter Aberl, and Lan Gatherer., "An efficient software-based implementation of a joint-detection/spatial processing receiver for TD-SCDMA," Radio and Wireless Conference, 2004 IEEE, Sept. 2004, pp. 295 - 298, doi: 10.1109/RAWCON.2004.1389134.

[8] Chunjiang Tu, Rong Lin, and Bo-an Liu, "Downlink joint detection in TD-SCDMAfor hardware implementation," ASIC, 2003. Proceedings. 5th International Conference on, Vol.2, 2003, pp. 796 – 799, doi: 10.1109/ICASIC.2003.1277330.

[9] Sukumar, C. P, Shen, C.-A., and Eltawil, A. M., "Joint Detection and Decoding for MIMO Systems Using Convolutional Codes: Algorithm and VLSI Architecture," Circuits and Systems I: Regular Papers, IEEE Transactions on, Vol.59, 2012, pp. 1919 – 1931, doi: 10.1109/TCSI.2011.2180442.

[10] Haiyang Fu, and Junfeng Fan, Multi-user joint receiving device, Utility model patents: China, ZL, 2010 2 0137086.X[P].2010-12-1.
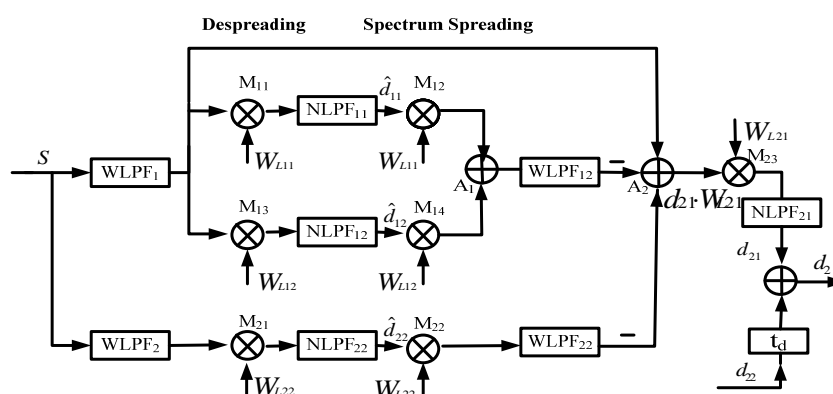
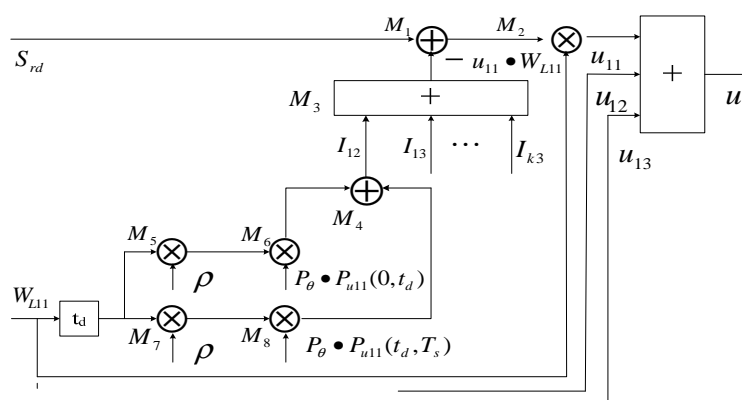

Figure 2. The working principle of JD

Figure 4. The method for eliminating MPI by using mid-amble sequence and FSC