Performance of Smart Antenna in TD-SCDMA System

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Abstract — Smart antenna technology is one of key technologies used in TD-SCDMA system. By using DSP algorithms and dynamically generating the beam patterns, smart antenna can greatly reduce the interference and increase the system capacity. In this paper, the concept of smart antenna is presented and a novel detection technique called joint space-time processing based on smart antenna is described. Simulation results on the uplink performance of TD-SCDMA in macrocell environment are also included in the paper. It can be seen that smart antenna system has much better performance than without smart antenna system and can meet the requirements of the 3rd generation system.

Key Words — TD-SCDMA, smart antenna, joint detection, joint space-time processing

I. INTRODUCTION

In recent years, the cellular communications systems have grown very rapidly. At present, the 2nd generation cellular systems, such as GSM and IS-95 CDMA, are the dominant mobile communications systems used all over the world. However, the narrowband 2nd generation systems can not fully satisfy the growing requirements of customers. The incoming demands for multimedia and high rate data services require more bandwidth and network capacity. That lead to widely research and discussion on the so-called 3rd generation mobile communications.

TD-SCDMA, proposed by CATT (China Academic of Telecommunication Technology), was accepted by the ITU in Nov. 1999 as one of the 3rd generation standards. It includes some key technologies to increase system capacity and meet the requirements of different kinds of services. Smart antenna is one of these key technologies used in TD-SCDMA.

The wireless channel is more complex than wireline channel due to the phenomena such as slow fading, fast fading and Doppler shift. Spatial diversity has been widely used in wireless communications systems to increase the radio link quality and improve the system performance. In recent years, the concept of spatial diversity has been expanded to use some digital signal processing (DSP) algorithms and dynamically generate the beam patterns according to the positions of transmitters/receivers. That technology is known as smart (adaptive) antenna. Smart antenna can greatly reduce the interference and increase the system capacity.

This paper concentrates on the uplink performance of TD-SCDMA with smart antenna at base station. It has been organized as follows: section II introduces the physical layer structure of TD-SCDMA. Section III describes the concept of smart antenna and the theory of joint space-time processing. The system model for TD-SCDMA with joint space-time processing is presented in section IV. The simulation results in macrocell are given in section V. Finally, the conclusion will be summarized in section VI.

II. PHYSICAL LAYER STRUCTURE OF TD-SCDMA

The physical channel structure of TD-SCDMA is described in [1]. As shown in Figure 1, all physical channels take four-layer structure: superframe, radio frame, subframe and time slot*.

The superframe has the duration of 720ms. It can be divided into 72 radio frames. The radio frame is subdivided into 2 subframes of 5 ms each and each subframe is then subdivided into 7 main time slots (TS) of 675 μs duration each and 3 special time slots: DwPTS (downlink pilot), GP (guard period) and UpPTS (uplink pilot).

The burst structure of the main time slots consists of two data symbol fields, a midamble of 144 chips and a guard period of 16 chips. In the code domain, each time slot can use up to 16 spreading codes. One RU

* The values presented on this paper for the different parameters reflect the status at the time of writing.

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(resource unit) is defined as one spreading code in one main time slot.

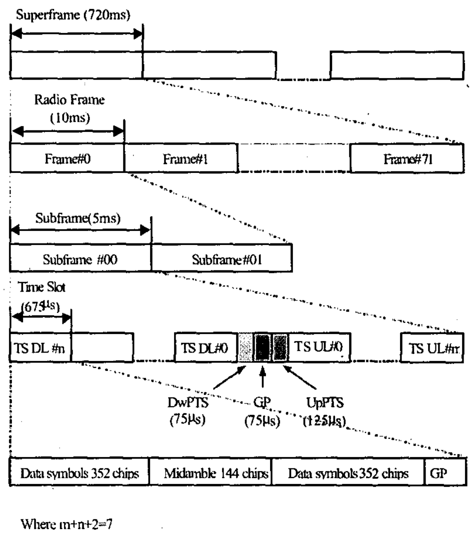


Figure 1. TD-SCDMA physical channel format

III. SMART ANTENNA AND JOINT SPACE-TIME PROCESSING

In these section, the concept of smart antenna and the theory of joint space-time processing algorithm will be presented.

A. The Concept of Smart Antenna

Figure 2 shows a typical structure of smart antenna. The smart antenna system is composed of an antenna array with M antenna elements and M coherent transceivers in RF parts. Following the RF part, the digital signal processing module in baseband capitalizes on the spatial dimension by adaptively suppressing the interference and optimally combining signals from the desired users. Enhancing therefore the performance and capacity of system.

Smart antenna systems usually use circular antenna arrays or linear antenna arrays. In this paper, circular arrays with 8 elements are used (As shown in Figure 3). It is proved to be particularly effective for interference cancellation [2].

Because the location of the smart antenna elements is different, the phases of the received signals are different. Let the first reference element A_1 located at the position of $(R, 0)$, where R is the radius of the circular arrays. The m-th element has the position of $(R\cos[2\pi(m\text{-}1)/M], R\sin[2\pi(m\text{-}1)/M])$, where M is the total number of antenna elements. If a plane wave arrives at the circular array with an angle θ_i, the differential optical of distance between the first reference element and m-th antenna element will be:

$$D_{im} = R[2(1-\cos(2\pi(m-1)/M))]^{\frac{1}{2}}\cos\delta_{im}, \quad (1)$$

where

$$\delta_{im} = \theta_i + \pi[1/2-(m-1)/M], \quad m = 2\cdots M \quad (2)$$

So the phase difference between the first reference element and m-th element φ_{im} is:

$$\varphi_{im} = 2\pi D_{im}/\lambda \quad (3)$$

λ is the wavelength.

The amplitude and phase of each antenna element are different. All these information will be sent to the DSP in baseband and combined by the beamforming algorithm. It is the so-called uplink beamforming. The downlink beamforming [3][4] is not discussed in this paper.

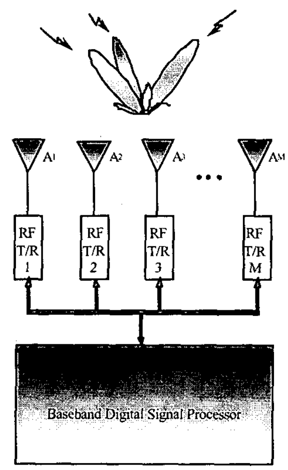


Figure 2. A typical smart antenna architecture

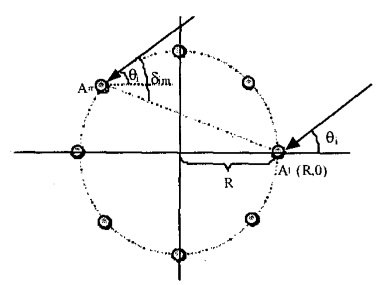


Figure 3. The geometric illustration of circular array

B. Joint Space-time Processing Algorithm

Joint space-time processing incorporates the spatial covariance matrix of the interference from neighboring cells with the joint space-time algorithm [4]. That greatly reduces intercell and intracell interference.

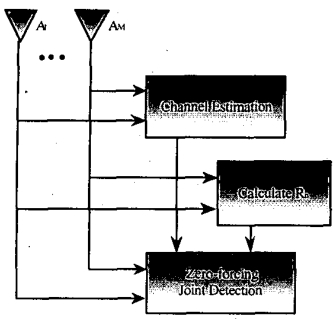


Figure 4. Basic principle of the joint space-time processor

Intracell interference is eliminated by Joint Detection anyway, already without smart antennas. In addition, smart antenna reduces the impact of intercell interference.

Figure 4 shows the basic principle of the joint space-time processing receiver.

The covariance matrix R_N is estimated while receiving the uplink data. This combined space-time covariance matrix is used in the commonly known zero forcing algorithm [6][7].

IV. SYSTEM MODEL

In this section, the uplink model of TD-SCDMA with smart antenna is described. It is assumed that smart antenna arrays are only used in the base station side. Antenna arrays have not been suggested in mobiles due to the size limitation of actual mobile.

The block structure of transmitter in mobile is shown in Figure 5. A bit stream representing voice or data is encoded by convolutional encoder and then interleaved by interleaver. It is then modulated. After spreading by a user-specific sequence and D/A conversion, the signal is passed through filter and amplifier and then transmitted.

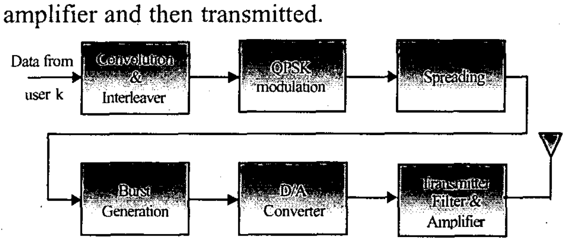


Figure 5. Block structure of transmitter

For a smart antenna simulation, a channel model with spatial information is required. In [8], a number of spatial channel models are introduced. In the paper a so-called ray tracing[8][9] model is assumed. This channel model is based on the geometric theory by using some specific information such as scatter locations, antenna coordinates, mobile speeds and moving path.

In the receiver, a joint-space-time algorithm is used. Figure 6 shows the structure of the receiver with smart antennas. The signals from different antennas are amplified and filtered and then sent to A/D converter. The channel estimation is done by the midamble. This information is sent to the joint space-time processor together with other data symbols. After that, the data streams are separated into K users, deinterleaved and convolutional decoded.

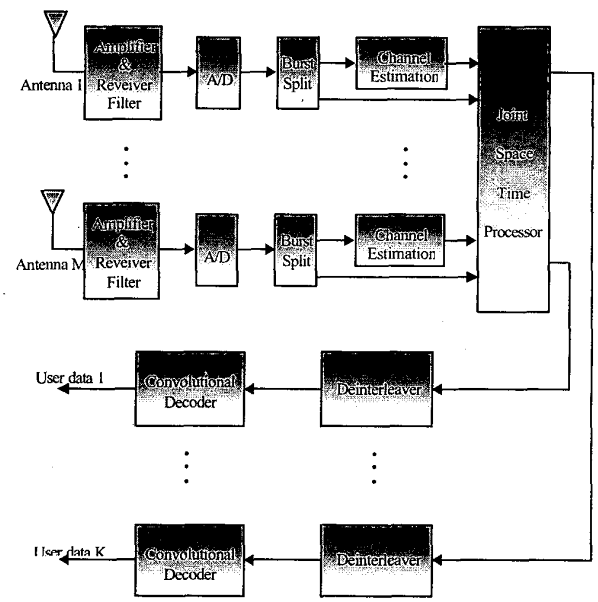


Figure 6. Block structure of uplink receiver with Smart antennas

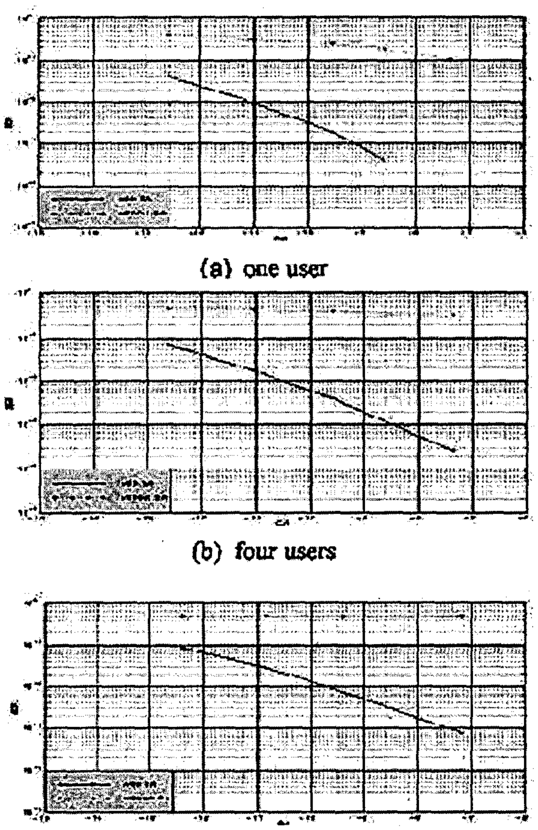
V. SIMULATION RESULTS

In this section, the uplink performance of a generic voice service has been simulated. 1, 4 and 8 users with or without smart antennas are selected in this paper. The users are assumed to uniform distribution in the cell. All the simulations are based on the macrocell channel. The following assumptions are made for the simulations:

- Smart antenna: circular array with 8 elements at base station (as described in section III);
- Channel model: ray tracing model for macrocell. The angular spreading is 7 degrees. The mobiles are assumed to move in a small circle far away from the base station and the mobile speed is 120km/h;

- Channel coding: convolutional coding as used in 3GPP;
- Frame structure: 5ms length (as described in section II);
- Modulation/Demodulation: QPSK;
- Each user uses 2 resource units;
- Carrier Frequency: 2GHz;
- Interleaving Depth: 20ms;

In figure 7, the results of userBER vs C/I for different users are given. UserBER compares the bitstreams at the beginning and the end of the simulation chain. It can be obviously seen that smart antenna system has much better performance than system without smart antenna. The required C/I at 0.1% BER of smart antenna system for one, four and eight users are –9.8dB, –8.5dB and –7.4dB respectively. The smart antenna system can use up to 16 codes in one time slot with relative low C/I (about –7.4dB).



(a) one user

(b) four users

(c) eight users

Figure 7. Simulation Results of voice service for different numbers of active users

VI. CONCLUSION

In the present paper, the uplink of TD-SCDMA system applying smart antenna and joint space-time processing has been presented. Its performance with different active users has been investigated in macrocell channel. The performance improvement can been seen by comparing with or without smart antenna results. The smart antenna system can support much more users than without smart antenna system. Smart antennas are used at base station, leading to both diversity gain and intercell interference cancellation. With the increasing number of active users, the *C/I* performance of system gradually degrades. Other enviroments such as microcellular or picrocellular models need further investigation not including in this paper.

References

[1] CWTS, "Physical channels and mapping of transport channels onto physical channels", TS C102 V3.0.0, October 1999.

[2] Weichen Ye, Bar-Ness, Alexander M.Haimovich, "Usage of Smart Antenna for Cancelling Neighboring Base-Station Interferences in Wireless CDMA Communications", IEEE Signals, Systems & Computers, 1997 Conference Record of the Thirty-first Asilomar Conference on Vol 1. 1998.

[3] Tiirola ESA, "Adaptive Antennas in Wideband CDMA", University of Oulu, Department of Electrical Engineering. Diploma Thesis, 1998.

[4] CWTS WG1, "Smart Antennas Technology", TSG RAN WG1 meeting #5, June 1999.

[5] Arogyaswami J. Paulraj and B. papadias, "Space-Time Processing for Wireless Communications ", IEEE Signal Processing Magazine, November 1997.

[6] Anja Klein, Ghassan Kawas Kaleh and Paul Walter Baier, "Zero Forcing and Minimum Mean-Square-Error Equalization for Multiuser Detection in Code-Division Multiple-Access Channels ", IEEE Transactions on Vehicular Technology, Vol 45, No. 2, May 1996.

[7] Josef Blanz, Anja Klein, Markus Naβhan and Andreas Steil, "Performance of a Cellular Hybrid C/TDMA Mobile Radio System Applying Joint Detection and Coherent Receiver Antenna Diversity", IEEE Journal on Selected Areas in communications, Vol. 12. No.4, May 1994.

[8] R.B.Ertel, P. Cardieri, K.W.Sowerby, T.S. Rappaport and J.H.Reed, "Overview of Spatial Channel Models for Antenna Array Communication System", IEEE Personal Communications, Feb. 1998.

[9] Shihe Li, "Key Technologies in SCDMA wireless Access", Asia Pacific Conference, 1997.

[10] Kurt R. Schaubach, Nathaniel J. Davis IV. and Theodore S. Rappaport, "A Ray Tracing Method for Predicting Path Loss and Delay Spread in Microcellular Environments", IEEE vehicular technology conference, 1992.

[11] Ryuji Kohno, "Space and Temporal Communication Theory Using Adaptive Antenna Array", IEEE Personal Communications, Feb. 1998.