Research on Smart Antenna Technology for Terminals for the TD-SCDMA System

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ABSTRACT

This article presents a TDD link level simulation scheme, based on the TD-SCDMA wireless telecommunication system, to study the performance improvement given by a multi-antenna receiver on a mobile terminal. The feasibility of a mobile receiver equipped with multi-antenna is discussed. Three different adaptive algorithms are compared under the specifically modeled multipath fading channel. The simulation results show that a dual-antenna arrangement on a mobile terminal can achieve better performance than a conventional single antenna.

INTRODUCTION

The increasing demand for high-quality high-speed data transmission, higher spectrum efficiency, and asymmetric operation are driving forces toward the rapid development of wireless communication technologies.

Time-division symmetric code-division multiple access (TD-SCDMA) is a third-generation (3G) wireless communication standard proposed by China. It is a CDMA system that operates in time-division duplex (TDD) fashion. TDD operation has advantages in that it does not require the allocation of symmetric frequency resources and makes possible more flexible utilization of available frequencies. Compared with frequency-division duplex (FDD) mode, TDD mode is also characterized by its simpler RF equipment, lower system cost, and the ability to provide asymmetric services easily.

Smart antenna technology [1, 2], as one of the key technologies of TD-SCDMA, increases the traffic capacity of a system, enlarges the coverage range of a cell, and improves the quality of the signal. It is therefore of practical interest to research smart antenna technology applied to wireless communication. This article investigates the feasibility of smart antenna technology applied to TD-SCDMA mobile terminals. Several different typical smart antenna algorithms are simulated and compared.

The next section of this article introduces the simulation system, which is harmonized with the physical layer structure of the TD-SCDMA wireless communication system. This section also introduces the enhanced impulse response radio channel model used for the simulations as an appropriate model for the simulation of mobile terminals.

We then analyze three typical smart antenna adaptive algorithms, Normalized Least-Mean-Square (LMS), Recursive Least Squares (RLS), and Sample Matrix Inversion (SMI). The system simulation results and data analysis are presented last.

THE SYSTEM SIMULATION MODEL

THE BLOCK DIAGRAM

As shown in Fig. 1, the source signal is first spread and modulated conforming to the requirements of TD-SCDMA standardization. Then the resultant signal is passed through a wireless propagation vector channel model and is converted to vector signals corresponding to different radio paths. The vector signals are co-processed in the smart antenna processing module, then despread and demodulated in the following module.

ARCHITECTURE OF THE TD-SCDMA SYSTEM PHYSICAL LAYER [3]

The subframe architecture of the TD-SCDMA physical layer is illustrated in Fig. 2. Each subframe consists of seven traffic time slots and two synchronization time slots. Each time slot can use 16 spreading codes at most. Each traffic time slot includes two 352-chip data domains, one 144-chip midamble, and one 16-chip guard period. The structure of a typical time slot including multiple users is shown in Fig. 3.

RADIO CHANNEL MODEL

In the link level simulation, the model of the wireless propagation channel is one important factor that can affect the final results greatly. Therefore, it is necessary to build a spatial radio channel model that can reasonably characterize the effects of the wireless channel, such as time-varying multipath fading and Doppler effects, between base station and mobile terminals. The traditional additive white Gaussian noise

(AWGN) radio channel model in many well developed simulation softwares cannot meet the demands of a multi-antenna receiver system. Moreover, many space-time channel models for antenna array systems concentrate on the base station. Relatively few channel models are available for a multi-antenna system at mobile terminals. A form of vector channel model meeting the simulation requirements of multi-antenna mobile receivers is applied in this article. First, the effect of multipath is taken into overall consideration. Each multipath varies independently in direction of arrival (DOA), time of arrival (TOA), amplitude, and phase. Therefore, the impulse response radio channel model is applied to this simulation system. Taking the smart antenna array into account, the antenna array factor is then introduced into each multipath,

$$\begin{aligned} h_k(t) &= \sum_{l=0}^{L-1} a_k(\phi_l)\rho_l(t)\delta(t-\tau_l) \\ &= \sum_{l=0}^{L-1} a_k(\phi_l)\beta_l(t)\cdot e^{j\Psi_l}\delta(t-\tau_l), \end{aligned} \quad (1)$$

where L is the number of multipaths; $\beta_l - \Psi_l$ and τ_l are the amplitude, phase, and time delay of the lth multipath, k represents the index of antenna element, and ϕ_l is the arrival angle of each multipath. The effect of the receiving antenna element on each multipath signal can be modeled as antenna array factor $a_k(\phi_l)$.

According to Clark's research [4], the Doppler effect experienced by mobile terminals makes the envelope of received signals conform to a Rayleigh probability density function (PDF). The variation of amplitude and phase for receiving signals can be determined by a classical Jake model. An enhanced Jake model [5, 6] is adopted here in order to reduce computation.

Taking the characteristics of the mobile terminal in the downlink radio channel into account, the appropriate radio channel model is geometrically based single bounce (GBSB), which is mainly used to describe the radio channel in urban environments. The model has the random arrival angle ϕ_l [7].

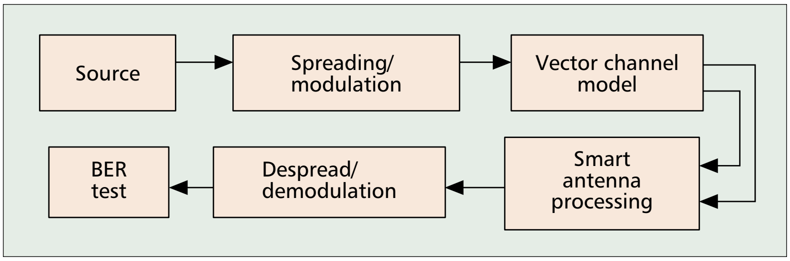

Figure 1. *The block diagram of the simulation.*

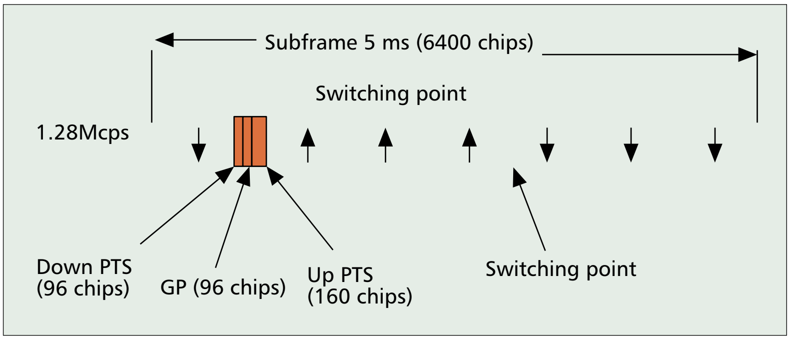

Figure 2. *A subframe of TD-SCDMA.*

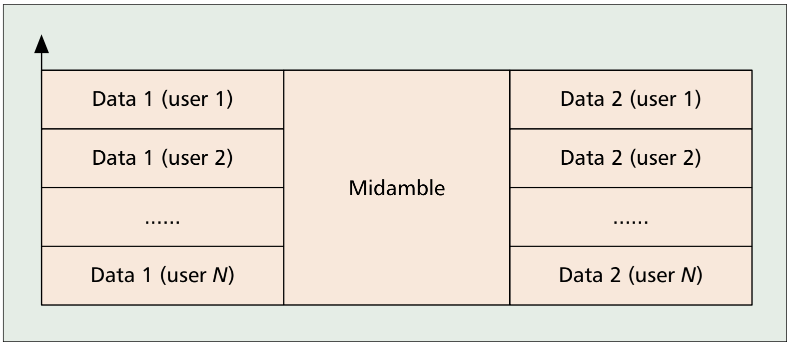

Figure 3. *Data structure of a downlink time slot in the TD-SCDMA system.*

Introduction of Smart Antenna Algorithms

The most widely used adaptive algorithms can be classified as non-blind and blind. Nonblind adaptive algorithms need a training signal, which is sent by the transmitter to the receiver during the training period. Blind algorithms do not need the training signal but use spatial and temporal characteristics to update a weighted value.

In the TD-SCDMA communication system, data is transmitted in bursts with a known 144 midamble occurring in each burst. Under this circumstance, we chose three forms of nonblind algorithms. The following is a brief introduction to these three algorithms.

Normalized LMS Algorithm [8]

The criterion of this algorithm is based on minimizing the mean squared error between the output and the reference signal. The algorithm adjusts the step size according to the input signals, so it has better performance of convergence and less signal sensitivity than the conventional LMS algorithm.

RLS Algorithm [8]

As for the RLS, the criterion for determining the weights is based on minimizing the least squared error.

The weight update equation is

$$W(k+1) = W(k) + R-1(k)X(k)e^*(k), \quad (2)$$

where $0 < \lambda < 1$ is the forgetting factor, and $R^{-1}(k)$ the inverse of correlation matrix using the previous K samples; $R^{-1}(k)$ is given by

$$R^{-1}(k) = \frac{1}{\lambda}\left[\begin{array}{l} R^{-1}(k-1) - \\ \dfrac{R^{-1}(k-1)x(k)x^H(k)R^{-1}(k-1)}{\lambda + x^H(k)R^{-1}(k-1)x(k)} \end{array}\right]. \quad (3)$$

SMI Algorithm [9]

In the SMI algorithm, the optimal weights are computed by estimating the correlation matrix $\hat{R}$ and the cross-correlation vector $\hat{r}$ using their unbiased estimation.

Case 1: 3 km/h		Case 3: 120 km/h	
Delay (ns)	**Average power (dB)**	**Delay (ns)**	**Average power (dB)**
0	0	0	0
3125	–10	781	–3
		1563	–6
		2344	–9

Table 1. *Multipath propagation in a fading environment.*

Number of antenna elements	2
Carrier frequency	2 GHz
Chip rate	1.28 Mchip/s
Bandwidth of carrier	1.6 MHz
Number of time slots per frame	7
Length of midamble	144 chips
Modulation	QPSK
Pulse-shaping filter	RRC__ = 0.22
RLS forgetting factor λ	0.90

Table 2. *Other basic simulation parameters.*

According to the Wiener-Hopf solution, the weight can be computed using

$$\hat{W}_k = \hat{R}_k^{-1}\hat{r}_k. \quad (4)$$

SIMULATION RESULTS

In the simulation, parameters of the radio channel model are obtained by the measurements in scenarios of 3 km/h and 120 km/h provided by the TD-SCDMA standard as shown in Table 1.

It is assumed here that the base station uses the omni-antenna, and all the users adopt the same midamble code. Considering the limited size of mobile terminals, the receiver is assumed to be only equipped with dual-antenna and the spacing between them is half a wavelength. Other simulation parameters are presented in Table 2.

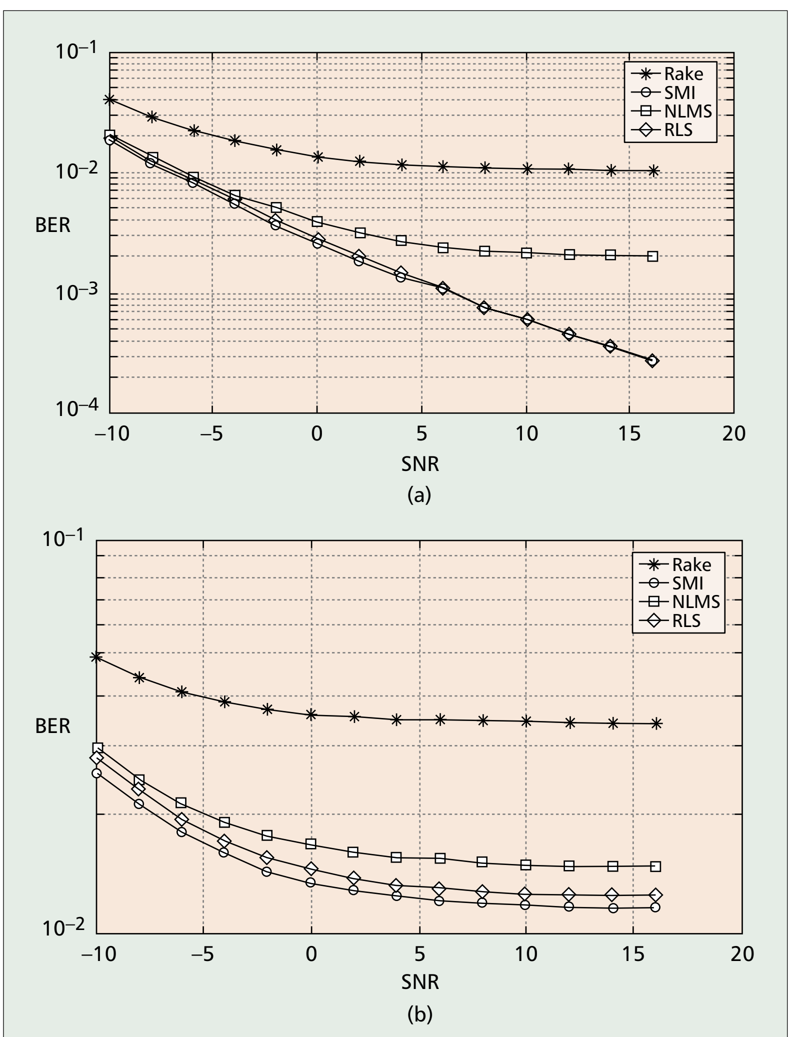

Figure 4. *BER vs. SNR: a) eight users, 3 km/h; b) eight users, 120 km/h.*

Figure 4 illustrates the performance of bit error rate (BER) vs. signal-to-noise ratio (SNR) with different smart antenna algorithms for scenarios of 120 km/h and 3 km/h.

SNR represents the ratio between average signal power of the main path in the receiving antenna and the noise. The Rake receiver uses the Maximum Ratio Combining (MRC) algorithm. The investigations and related simulation results on joint detection (JD) instead of a Rake receiver can be delivered in the near future. It is obvious in Fig. 4a that when the SNR is more than 0 dB, the BER of a smart antenna is decreased by one to two orders of magnitude from the performance of a conventional mono-antenna receiver. Moreover, comparing Fig. 4a and b, we can see that with increasing velocity of the mobile, the performance is degraded. However, smart antenna technology still achieves a good performance improvement.

Through the comparisons of different smart antenna algorithms, it is noted that the performance of SMI and RLS is similar, and both are better than NLMS. The reason is that the convergence speed of NLMS depends on the divergence of eigenvalue of correlated matrix of receiving signals. When the radio propagation environment is bad, the speed of convergence is very slow. Traditional open-loop SMI needs to consider the complexity of inverse computation of correlated matrix and its stability. Adaptive RLS can balance the better convergence speed and complexity well. SMI is equivalent to RLS when the forgetting factor λ is 1. In such an extreme case, their performance is very close to each other in TDD mode.

Figure 5 presents the relationship between the BER of receiving signals and number of users within a time slot. Due to the interference of multiple users, the BER is naturally increased. Obviously, the NLMS algorithm can make traditional Rake BER decrease by an order of magnitude. However, the RLS and SMI algorithms can make the amplitude of BER decrease by more than one order of magnitude. Mobile terminals equipped with smart antenna technology can allow the base station to support more users for a given BER, thus increasing the traffic capacity of the system.

Conclusion

This article is based on the TD-SCDMA wireless communication system. The receiving characteristics of mobile terminals equipped with dual-antenna have been numerically simulated and different smart antenna algorithms compared. Although the directivity of beamforming by a dual-antenna array is by no means perfect, the addition of such a system in the front-end reduces the effects of multipath more than an equivalent Rake receiver. By comparisons of simulation results, it can be seen tjat the improvement of receiving performance in the case of lower mobility is more obvious than that of higher mobility. Mobile terminals enhanced by smart antenna technology can increase the user capacity within a cell. Therefore, it is of potential value to apply multi-antenna and smart antenna technology to TD-SCDMA receivers.

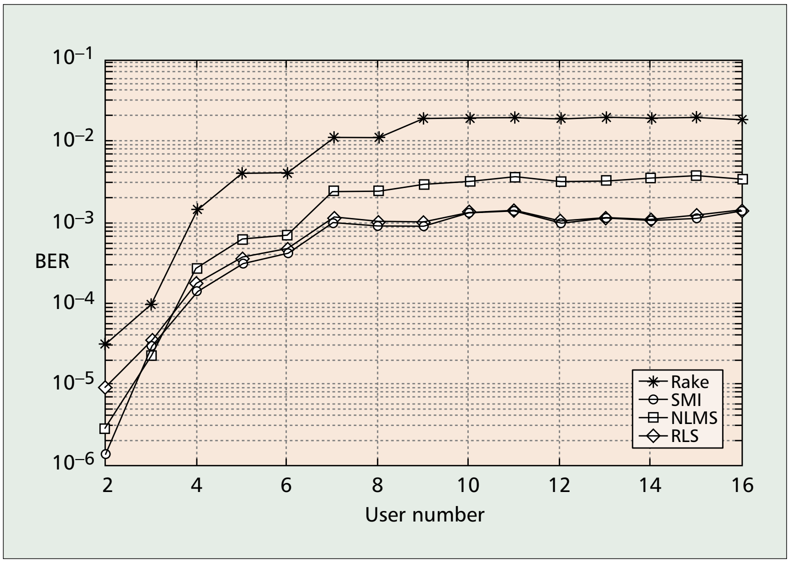

Figure 5. *BER vs. user numbers (velocity of 3 km/h, SNR 7 dB)*

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Biographies

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