Cdma2000 for Spatial Modulated Full Duplex Systems

By Peizhong Ju and Xiang Cheng
School of Electronics Engineering and Computer Science, Peking University, Beijing, P. R. China.

Abstract—Cdma2000 is an international standard of the third generation wireless communication system, which is still widely used today. In our project, we attempt to apply this standard in spatial modulated full duplex (SMFD) system, which aims to test a novel self-interference (SI) cancellation method in digital domain. The SMFD system and the proposed SI cancellation scheme are both introduced in great detail and the simulations in physical layer which follow the standard of cdma2000 reveals the advantages.

Index Terms—Cdma2000, full duplex, spatial modulation (SM), self-interference (SI) cancellation.

I. INTRODUCTION

In wireless communication systems, full duplex can enable a communication node to transmit and receive at the same time and same frequency band, achieving higher bandwidth efficiency than conventional half duplex. The main problem of any full duplex system is the strong self-interference (SI). As wireless signals are attenuated quickly over distance, the power of the received signal from the local transmit antenna is much stronger than that from the communication node, which makes the desire signal undistinguishable without efficient SI cancellation method.

Conventional full-duplex systems dividing all available antennas into two parts, which are endued with different fixed functions, i.e., for transmission or reception. The newly-emerging spatial modulated full duplex (SMFD) system can develop the spatial potential, whose idea is by randomly selecting the transmit/receive antenna(s) according to spatial modulation [2]. Theoretical analysis and simulations verify that SMFD significantly outperforms conventional full duplex in terms of system capacity. However, its performance highly depends on the level of residual SI, which challenges the design of an effective SI cancellation scheme.

In this project, we propose a novel SI cancellation scheme in digital domain, which exactly suits SMFD systems. The proposed scheme is very easy to operate as there is no need to directly detect or estimate the SI channel and no additional hardware is imposed. Simulation results in physical layer which follow cdma2000 reveal its advantages.

Ⅱ. SYSTEM MODEL

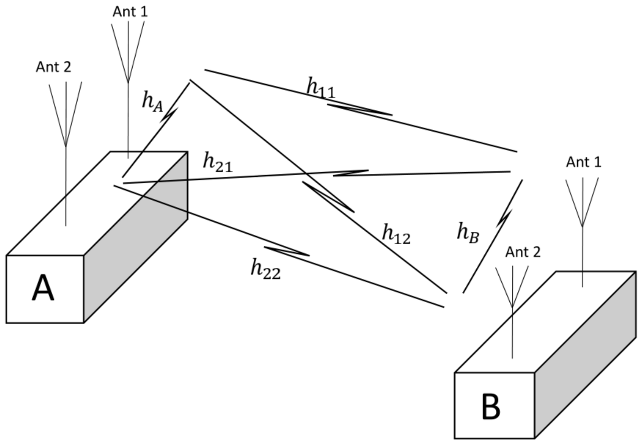

Figure 1. Bidirectional communication scenario.

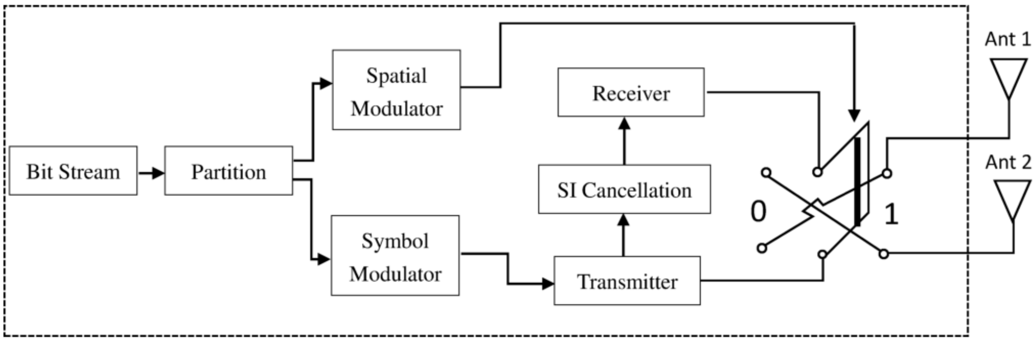

Figure 2. The block diagram of node A

Consider a point-to-point bidirectional communication scenario, in which both communication nodes, A and B, have two antennas, as shown in Fig. 1. The channel between the i^{th} antenna of node A and the j^{th} antenna of node B is represented by $h_{i,j}$, which is assumed to follow complex

Gaussian distribution of unit variance. For the conventional full-duplex system, each antenna of one node will play a redefined role, i.e., either to transmit or to receive, during the entire communication period. However, this results in a reduction of the available data throughput as the spatial resource of the 2×2 MIMO structure is not fully exploited. Contrarily, the SMFD system allows for a random antenna selection at a communication node, i.e., each antenna will be used for transmission or for reception with equal probability, so that one more bit can be modulated in the spatial domain.

Due to the symmetry, without loss of generality, we choose node A, shown in Fig. 2, for the following illustration. At node A, for transmission of signals, the incoming bits are split into two parts: one goes through the spatial modulator and controls the synchronization switches while the other is fed into the symbol modulator and generates the transmitted modulated symbol. As node A is configured with two antennas, at each time slot, the part at the input of the spatial modulator is one bit, whose value decides on which antenna for transmission and correspondingly the other antenna for reception. On the other hand, the part at the input of the symbol modulator can be any bits, whose number depends on the modulation type. For reception of signals, the strong SI from the transmitter to the receiver is cancelled and the receiver demodulates the modulated symbol as well as the spatial bit from the clean received signal.

Ⅲ. PROPOSED SCHEME

Assume that in the i^{th} time slot, node A chooses antenna a_i to transmit and node B chooses antenna b_i to transmit. Correspondingly, the receive antennas of node A and B are $\bar{a}_i$ and $\bar{b}_i$, respectively. Denote the transmitted signal of node A in the i^{th} time slot as x_A^i and that of node B as x_B^i, respectively. The SI channel coefficient at node A is h_A. The channel between the i^{th} antenna of node A to the j^{th} antenna of node B is $h_{i,j}$. The received signal in the i^{th} time slot of antenna $\bar{a}_i$ at node A is $y_{\bar{a}_i}$, the noise is $n_{\bar{a}_i}$.

The received signal at node A can be expressed as

$$\begin{bmatrix} y_{\bar{a}_1} \\ y_{\bar{a}_2} \\ y_{\bar{a}_3} \\ \vdots \end{bmatrix} = \begin{bmatrix} h_{\bar{a}_1,b_1} & 0 & 0 & \cdots \\ 0 & h_{\bar{a}_2,b_2} & 0 & \cdots \\ 0 & 0 & h_{\bar{a}_3,b_3} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix} \begin{bmatrix} x_B^1 \\ x_B^2 \\ x_B^3 \\ \vdots \end{bmatrix} + h_A \begin{bmatrix} x_A^1 \\ x_A^2 \\ x_A^3 \\ \vdots \end{bmatrix} + \begin{bmatrix} n_{\bar{a}_1} \\ n_{\bar{a}_2} \\ n_{\bar{a}_3} \\ \vdots \end{bmatrix}.$$

Then multiplying the following matrix on both sides of the equation:

$$\begin{bmatrix} x_A^2 & -x_A^1 & 0 & 0 & \cdots \\ 0 & x_A^3 & -x_A^2 & 0 & \cdots \\ 0 & 0 & x_A^4 & -x_A^3 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix}.$$

we get:

$$\begin{bmatrix} \hat{y}_1 \\ \hat{y}_2 \\ \hat{y}_3 \\ \vdots \end{bmatrix} = \mathbf{H} \begin{bmatrix} x_B^1 \\ x_B^2 \\ x_B^3 \\ \vdots \end{bmatrix} + \boldsymbol{N}.$$

where

$$\begin{bmatrix} \hat{y}_1 \\ \hat{y}_2 \\ \hat{y}_3 \\ \vdots \end{bmatrix} = \begin{bmatrix} x_A^2 & -x_A^1 & 0 & 0 & \cdots \\ 0 & x_A^3 & -x_A^2 & 0 & \cdots \\ 0 & 0 & x_A^4 & -x_A^3 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix} \begin{bmatrix} y_{\bar{a}_1} \\ y_{\bar{a}_2} \\ y_{\bar{a}_3} \\ \vdots \end{bmatrix},$$

$$\mathbf{H} = \begin{bmatrix} x_A^2 & -x_A^1 & 0 & 0 & \cdots \\ 0 & x_A^3 & -x_A^2 & 0 & \cdots \\ 0 & 0 & x_A^4 & -x_A^3 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix} \begin{bmatrix} h_{\bar{a}_1,b_1} & 0 & 0 & \cdots \\ 0 & h_{\bar{a}_2,b_2} & 0 & \cdots \\ 0 & 0 & h_{\bar{a}_3,b_3} & \cdots \\ \vdots & \vdots & \vdots & \ddots \end{bmatrix}$$

$$= \begin{bmatrix} x_A^2 h_{\bar{a}_1,b_1} & -x_A^1 h_{\bar{a}_2,b_2} & 0 & 0 & \cdots \\ 0 & x_A^3 h_{\bar{a}_2,b_2} & -x_A^2 h_{\bar{a}_3,b_3} & 0 & \cdots \\ 0 & 0 & x_A^4 h_{\bar{a}_3,b_3} & -x_A^3 h_{\bar{a}_4,b_4} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix},$$

$$\boldsymbol{N}=\begin{bmatrix} x_A^2 & -x_A^1 & 0 & 0 & \cdots \\ 0 & x_A^3 & -x_A^2 & 0 & \cdots \\ 0 & 0 & x_A^4 & -x_A^3 & \cdots \\ \vdots & \vdots & \vdots & \vdots & \ddots \end{bmatrix}\begin{bmatrix} n_{\bar{a}_1} \\ n_{\bar{a}_2} \\ n_{\bar{a}_3} \\ \vdots \end{bmatrix}.$$

For example, when we use two time slots to do the SI cancellation, the equivalent received signal is:

$$\hat{y}_1 = x_A^2 y_{\bar{a}_1} - x_A^1 y_{\bar{a}_2} = x_A^2 h_{\bar{a}_1,b_1} x_B^1 - x_A^1 h_{\bar{a}_2,b_2} x_B^2 + x_A^2 n_{\bar{a}_1} - x_A^1 n_{\bar{a}_2}.$$

When we use three timeslots to do the SI cancellation, the equivalent received signal is:

$$\begin{bmatrix} \hat{y}_1 \\ \hat{y}_2 \end{bmatrix} = \begin{bmatrix} x_A^2 y_{\bar{a}_1} - x_A^1 y_{\bar{a}_2} \\ x_A^3 y_{\bar{a}_2} - x_A^2 y_{\bar{a}_3} \end{bmatrix} = \begin{bmatrix} x_A^2 h_{\bar{a}_1,b_1} & -x_A^1 h_{\bar{a}_2,b_2} & 0 \\ 0 & x_A^3 h_{\bar{a}_2,b_2} & -x_A^2 h_{\bar{a}_3,b_3} \end{bmatrix}\begin{bmatrix} x_B^1 \\ x_B^2 \\ x_B^3 \end{bmatrix} + \begin{bmatrix} x_A^2 n_{\bar{a}_1} - x_A^1 n_{\bar{a}_2} \\ x_A^3 n_{\bar{a}_2} - x_A^2 n_{\bar{a}_3} \end{bmatrix}.$$

We can find that there are no SI terms in it, which means that SI has been cancelled. However, if we use maximum-likelihood (ML) criterion to demodulate information bits from those equations, unexpected demodulation errors will arise and an error floor will occur. To fix this problem, in analogy with the method proposed in [3], we propose to rotate the constellation of the transmitted modulated symbols artificially every other time slot at only one node of the two. The specific rotation angle depends on the modulation type. Generally, if we employ M-PSK modulation, where M is the cardinality of the constellation, the angle should be π/M, since in this case the Euclidean distance between the original constellation and the rotated constellation is maximized [3]. For instance, this angle is π/2 for BPSK modulation and is π/4 for QPSK modulation. Given the above consideration, if we choose node A to make constellation rotation, the transmitted modulated symbols are of form

$$\begin{bmatrix} x_A^1 \\ x_A^2 \\ x_A^3 \\ x_A^4 \\ \vdots \end{bmatrix} = \begin{bmatrix} (x_A^1)_{origin} \\ e^{\frac{i\pi}{M}}(x_A^2)_{origin} \\ (x_A^3)_{origin} \\ e^{\frac{i\pi}{M}}(x_A^4)_{origin} \\ \vdots \end{bmatrix} \text{ and } \begin{bmatrix} x_B^1 \\ x_B^2 \\ x_B^3 \\ x_B^4 \\ \vdots \end{bmatrix} = \begin{bmatrix} (x_B^1)_{origin} \\ e^{\frac{i\pi}{M}}(x_B^2)_{origin} \\ (x_B^3)_{origin} \\ e^{\frac{i\pi}{M}}(x_A^4)_{origin} \\ \vdots \end{bmatrix},$$

where $(\cdot)_{origin}$ indicates an un-rotated constellation.

Ⅳ. SIMULATIONS

In order to reveal the advantages, we do simulations of bit error rate (BER) in physical layer to show the performance of the proposed scheme.

1. Parameters

As we choose cdma2000 to check the performance of the proposed scheme, most parameters in simulations follow the standard. We use convolutional codes to do forward error correction (FEC). In cdma2000, all convolutional codes have a constraint length of 9. Convolutional encoding involves the modulo-2 addition of selected taps of a serially time-delayed data sequence. The length of the data sequence delay is equal to K-1, where K is the constraint length of the code. For our simulations, we use rate 1/4 and rate 1/3 convolutional code. The Fig. 3, i.e., the figure 2.1.3.1.5.1.1-1 in [1], illustrates the detail of rate 1/4 convolutional encoder. The Fig. 4, i.e., the figure 2.1.3.1.5.1.2-1 in [1], illustrates the detail of rate 1/3 convolutional encoder.

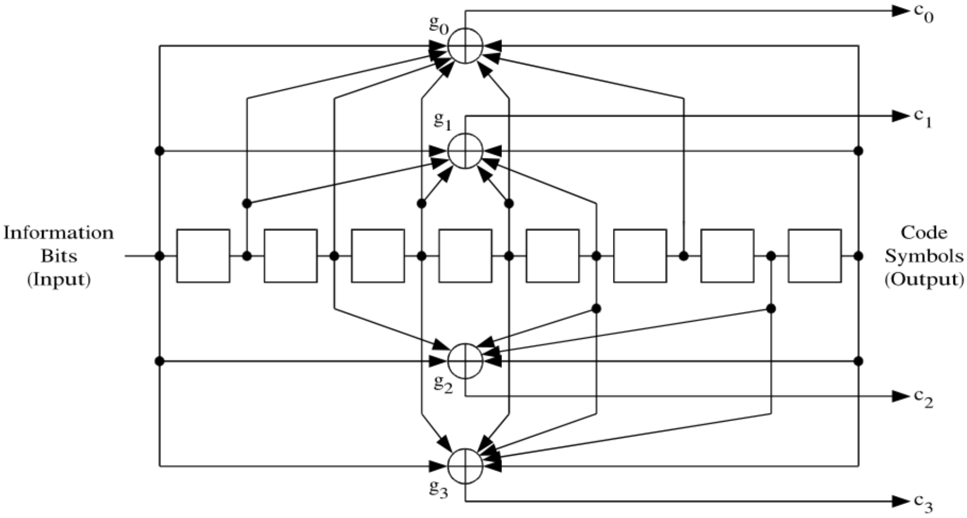

Figure 3. K=9, Rate 1/4 Convolutional Encoder. (i.e., Figure 2.1.3.1.5.1.1-1 in [1])

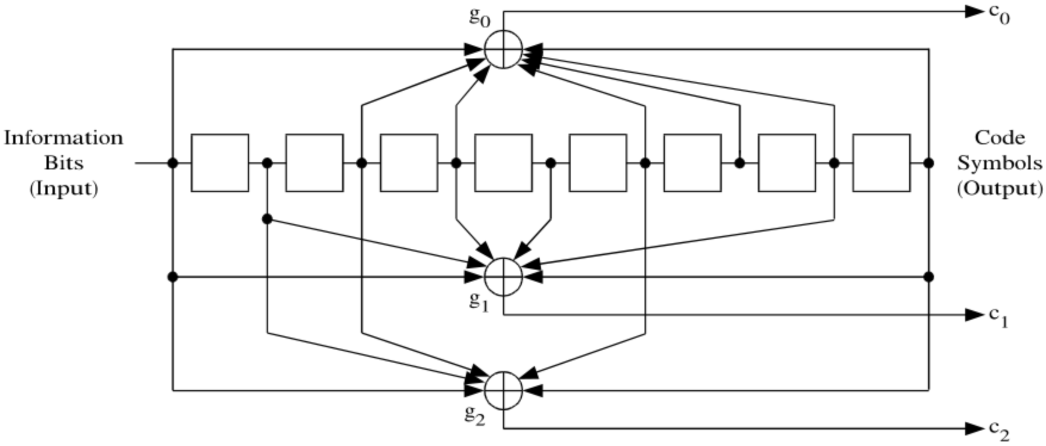

Figure 4. K=9, Rate 1/3 Convolutional Encoder. (i.e., Figure 2.1.3.1.5.1.2-1 in [1])

We use BPSK modulation, which is also used in cdma2000, to map the coded bits to the constellation points. Considering the contribution of spatial modulation and full duplex, we use 16-PSK modulation in conventional half duplex to make a fair comparison under the same bit rate in BERs.

About the channel, we assume each channel between two antennas is independent Rayleigh fading channel with additive white Gaussian noise (AWGN).

2. Results

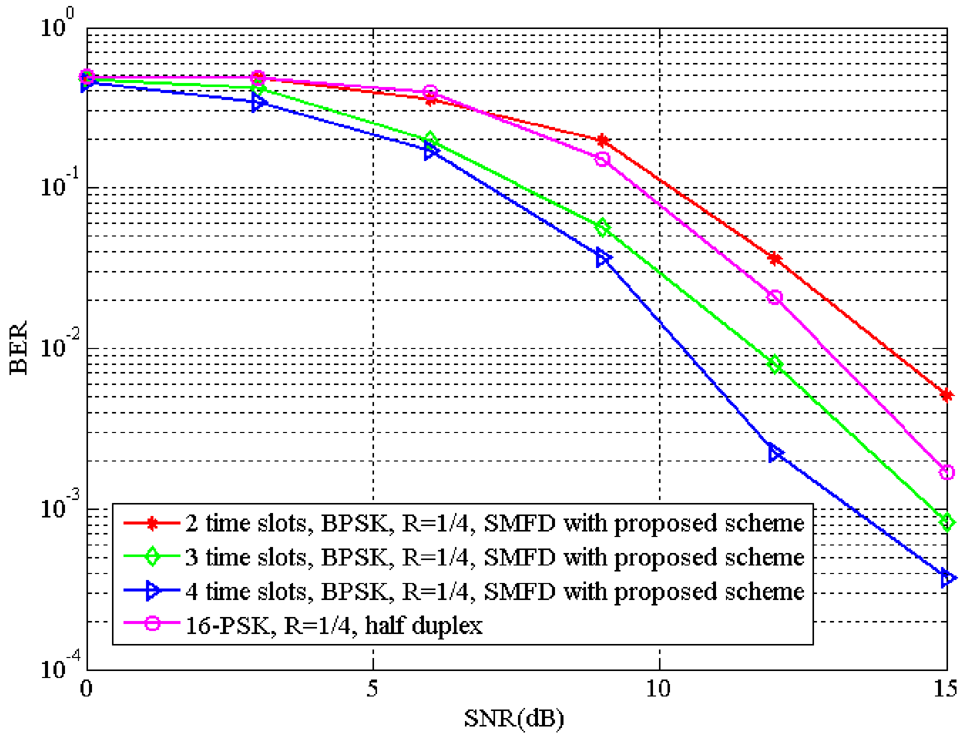

Figure 5. Comparison of the BER with rate 1/4 convolutional encoder achieved by the SMFD system adopting the proposed scheme with 2, 3, 4 time slots involved and that achieved by the conventional half duplex.

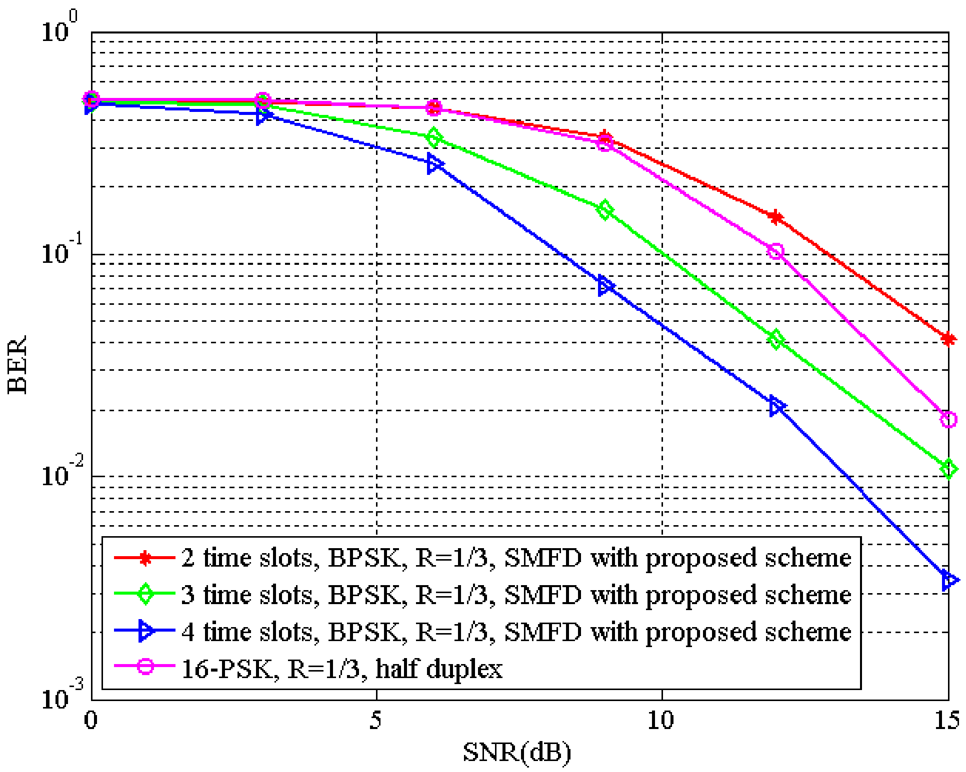

Figure 6. Comparison of the BER with rate 1/3 convolutional encoder achieved by the SMFD system adopting the proposed scheme with 2, 3, 4 time slots involved and that

achieved by the conventional half duplex.

3. Analysis

Fig. 5 and Fig. 6 show us that BERs are lower when more time slots involved in the proposed scheme. That is as expected since a loss of spatial degrees of freedom is incurred by the SI cancellation while this loss becomes smaller when more time slots are involved. Specifically, when *m* time slots are involved in the proposed scheme, the spatial degree of freedom drops from one to $(m-1)/m$. Another significant phenomenon we can observe from Fig. 5 and Fig. 6 is that under the fair comparison, performances of SMFD with proposed scheme of 3 and 4 time slots outperform the conventional half duplex. Specifically, in Fig. 5, the situation of 2 time slots involved is only 1 dB worse than the conventional half duplex while the curve of 3 time slots is 1 dB better than the conventional half duplex when BER is under 10^{-2} and the curve of 4 time slots is 2 dB better.

Ⅴ. CONCLUSTION

In this project, we presented an effective SI cancellation scheme especially for SMFD systems under the standard of cdma2000. Procedures of the proposed scheme have been displayed step by step. The parameters, results and analysis of simulations have been also discussed in detail. Besides, by means of calibrating the number of time slots, it has been found that the proposed scheme is feasible to achieve balance between receiver complexity and system performance.

Ⅵ. REFERENCE

[1] 3GPP2 C.S0002-D, “Physical layer standard for cdma2000 spread spectrum systems (revision D),” version 2.0, Sept. 2005.

[2] B. Jiao, M. Wen, M. Ma, and H. V. Poor, “Spatial modulated full duplex,” *IEEE Wirel. Commun. Lett.*, vol. 3, no. 6, pp. 641–645, Dec 2014.

[3] J. Harshan and B. S. Rajan, “On two-user Gaussian multiple access channels with finite input constellations,” *IEEE Trans. Inf. Theory*, vol. 57, no. 3, pp. 1299–1327, Mar. 2011.

Peizhong Ju is an undergraduate in the School of Electronics Engineering and Computer Science, Peking University.