Self-Adapting Cyclic Delay Diversity System

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***Abstract*—Cyclic Delay Diversity (CDD) is a simple and efficient space-time diversity technique. It can be used in OFDM and DFT-Spread-OFDM. The traditional CDD has low complexity and system overhead, however, also has some limitations on performance and is sensitive to propagation environment. In this paper, two improved CDD scheme including open-loop and close-loop strategies for uplink and downlink of EUTRA LTE are introduced. Compared with the conventional method, the new schemes can obtain higher performance and less sensitivity to environment.**

Keywords- Cyclic Delay Diversity (CDD), orthogonal frequency-division multiplexing (OFDM), DFT-Spread-OFDM (DFT-S-OFDM), self-adapting, transmit diversity

I. INTRODUCTION

As the requests of new generation mobile communication, the 3rd Generation Partnership Project (3GPP) finally adopted OFDM and DFT-Spread-OFDM (DFT-S-OFDM) as the baseline of downlink and uplink transmission scheme respectively, and details of the basic transmission scheme, such as sub-frame format, downlink and uplink numerology, etc., are included in [1].

In Long Term Evolution (LTE) project, MIMO was considered as a promising technique to meet needs of average user throughput and frequency efficiency. The regular antenna configuration is 2x2.

Space-Time coding was proposed in [2] and [3] to achieve high performance, hence is close to the outage capacity of MIMO. To improve the frequency efficiency and transmission rate, Space-Time coding combined with OFDM was introduced in [4].

To simply obtain diversity in MIMO-OFDM, as a low-overhead method, CDD was proposed in [5], where the information is propagated from the first antenna, and then the fixed length of cyclic shift of the original signal is transmitted from the second antenna, the same treatment till the last one. This technique can increase frequency diversity and bring no additional complexity in the receiver. However, CDD can only receive frequency diversity, besides, for reason of different wireless environments, it is difficult to receive full frequency diversity for every user. Therefore, we introduce two improved techniques based on CDD, called Self-Adapting CDD with hopping-delay and tracking-delay.

The structure of this paper is as follows: In Section II, the principle of CDD is explained and limitation is analyzed. Self-Adapting CDD, the new techniques, are derived in Section III. The improvement of performance by using new method is shown in Section IV, which leads to the conclusions in Section V.

II. CYCLIC DELAY DIVERSITY

The traditional CDD has the approaches in general as follows: after coding, modulation*, FFT*, sub-carrier mapping*, IFFT and etc., the signal is split into N_t antenna branches. The cyclic delay of antenna 0, the first antenna, is set to zero, while for antenna , the signal is cyclically shifted by a specific delay denoted as D_n, $n = 1, \ldots, N_t - 1$.

Generally, it is assumed that the MIMO antenna configuration in LTE is 2x2. Thus, when FFT length is N and cyclic shift length of the second branch is D, the equivalent representation in the frequency domain, called Phase Diversity (PD), can directly be expanded from IFFT with length N and corresponds to:

$$s(l) = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} S(k) \cdot e^{j\frac{2\pi}{N}kl} \tag{1}$$

$$\underbrace{s(l-D)}_{CDD\ \ signal} = \frac{1}{\sqrt{N}} \sum_{k=0}^{N-1} \underbrace{e^{-j\frac{2\pi}{N}kD} \cdot S(k)}_{PD\ \ signal} \cdot e^{j\frac{2\pi}{N}kl} \tag{2}$$

where l, k, $s(l)$, $S(k)$ denote the discrete time, discrete frequency, and the complex values in time domain and frequency domain, respectively, hence the transmitting signal is

$$\begin{bmatrix} S(k) \\ e^{-j\phi(k)} S(k) \end{bmatrix} \tag{3}$$

where $\phi(k)$ is change of phase, derived as follows

$$\phi(k)=\frac{2\pi kD}{N} \tag{4}$$

Therefore, the receiving signal can be expressed as

$$Y(k)=\begin{bmatrix} y_1(k) \\ y_2(k) \end{bmatrix}=\begin{bmatrix} H_{11}(k)+H_{12}(k)e^{-j\phi(k)} \\ H_{21}(k)+H_{22}(k)e^{-j\phi(k)} \end{bmatrix}\left[S(k)\right] \tag{5}$$

The CDD scheme leads in controllable frequency selectivity through cyclic shift in time domain, so it must be in correlation of inherent frequency selectivity of channel model. How to choose the length of cyclic delay is one of the main points of increasing performance of CDD-based system. The delay length D is settled at the initialization of CDD-based system and cannot be modified. This reason will cause low adaptability in different propagation environment, and limitation on performance.

In the static wireless environment, such as flat fading channel and frequency-selective fading channel with steady numerical characters, the time-varying delay will help to increase time selectivity for diversity gain. A Forward Error Correlation (FEC) code can pick up this increased diversity and thus lower Bit Error Rate (BER) and Block Error Rate (BLER).

On the other hand, for vital changing wireless environment, such as switching to high speed from low speed, and various terrains, time selectivity can reduce this kind of influences, hence improve the adaptability.

III. SELF-ADAPTING CYCLIC DELAY DIVERSITY

As mentioned at the end of section II, we introduce two kinds of new method in this section based on self-adapting cyclic delay diversity with the changeable delay $D(t)$ compared to the fixed D in old method, refers to section II.

Considering the balance of performance and overhead, we propose open-loop and close-loop schemes.

A. The open-loop self-adapting cyclic delay diversity

The main concept of the Hopping-Delay-based open-loop scheme is that the system leads into known time-selectivity via the cyclic-time-varying delay called Hopping Delay, in order to improve the stability on wireless environment.

We initial $D(t)$, the Hopping Delay, at the beginning

$D(t)\in\{1,2,\dots,N-1\}$, $D(0)=1$,

Then at $t\ (t>0)$ slot, $D(t)$ can be denoted as

$$D(t)=D(t-1)\bmod\left(N-1\right)+1 \tag{6}$$

Refers to (2) in section II, the second antenna signals are:

$$\underbrace{s(l-D(t))}_{CDD\ \ signal}=\frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}\underbrace{e^{-j\frac{2\pi}{N}kD(t)}\cdot S(k)}_{PD\ \ signal}\cdot e^{j\frac{2\pi}{N}kl} \tag{7}$$

We can choose the same length of TTI as hopping slot, and also adjust the length to meet the needs of complexity and system structure.

In this way, the delay used in different adjacent OFDM symbol is different, and the phases are time-varying values. Benefiting from combination of time-selectivity and frequency-selectivity, the errors will be dispersed and performance will be more stable despite of different channel environment or channel with dynamic numerical characters.

B. The open-loop self-adapting cyclic delay diversity

The close-loop scheme is based on Tracking Delay, the principle of which is to track and choose the better cyclic delay by calculating and comparing the received SNR relating to the delay $D(t)$ in purpose of increasing the SNR, hence boost the performance with low computation and feedback overhead.

According to the general MIMO configuration of LTE, in this section we use 2x1 antenna configuration. Then the equivalent channel responses at receiving end is expressed as

$$\begin{aligned} H &= H_0+H_1e^{-j\phi} \\ &=\alpha_0e^{j\theta_0}+\alpha_1e^{j(\theta_1-\phi)} \end{aligned} \tag{8}$$

where $\alpha_0=\left|H_0\right|$, $\alpha_1=\left|H_1\right|$

Hence SNR on each sub-carrier is

$$\begin{aligned} SNR &=\frac{\left|H\right|^2}{\sigma^2} \\ &=\frac{\alpha_0^2+\alpha_1^2+2\alpha_0\alpha_1\cos(\theta_0-\theta_1+\phi)}{\sigma^2} \end{aligned} \tag{9}$$

We can see that the coefficient ϕ makes some impact on the SNR. So as to obtain higher SNR, we need to heighten the factor $\cos(\theta_0-\theta_1+\phi)$ as much as possible. It is obvious that when ϕ is always inverse to the phase margin $(\theta_0-\theta_1)$, the SNR will be maximum, however, the conclusion in ideal assumption cannot be carried out in real situation due to the random phase margin. Otherwise, as a phasic character, $(\theta_0-\theta_1)$ has a period of 2π, namely, infinite number of equivalent phases. Therefore, we cannot use the means of MMSE to choose the best cyclic delay. We consider making choice dynamically through multi-step hopping process.

On the sub-carrier k,

$$\Delta\phi_D(k) = \left|\pi - \left[\theta_0(k) - \theta_1(k) + \phi_D(k)\right] \bmod 2\pi\right|^2 \quad (10)$$

means the square error of bias to zero phase. Where $\phi_D(k) = \frac{2\pi kD}{N}$, $k = 0 \ldots N-1$

We define $\Delta\phi_D$ be the phase-margin-factor, which denotes the sum of phase margin of N OFDM or DFT-S-OFDM symbols like:

$$\Delta\phi_D = \frac{1}{N}\sum_{k=0}^{N-1}\Delta\phi_D(k) \quad (11)$$

Comparing all the $\Delta\phi_D$ related to D ($D \in 1 \ldots N-1$) and selecting the minimum one can obtain best performance, yet the calculation is an unpractical behavior, for reason of the large-scale length N of transmitted symbols (In uplink of DFT-S-OFDM system, $N = 512$). Hence, we use a method called Tracking-Delay, which merely computes the values based on three adjacent delays, with approaches as follows:

a) *Step 0:* Set $D(0) = 1$.

b) *Step 1:*Calculate the adjoining value D of the current cyclic delay $D(t)$: $D^+(t) = \left[D(t) \bmod (N-1)\right] + 1$, $D^-(t) = N - 1 - \left[(N - D(t)) \bmod (N-1)\right]$.

c) *Step 2:* Calculate the phase-margin-factor $\Delta\phi_D$, $\Delta\phi_{D^+}$, $\Delta\phi_{D^-}$ corresponding to $D(t)$, $D^+(t)$, $D^-(t)$.

d) *Step 3:* $D_{new} = \arg\min_D \left\{\Delta\phi_D, \Delta\phi_{D^+}, \Delta\phi_{D^-}\right\}$.

e) *Step 4:* According to the feedback information D^-, D^+, D, UE change the value of D by forward, backward, and fix. And UE will adopt the new value of D for cyclic delay diversity transmitting in next hopping period.

f) *Step 5:* $D(t+1) = D_{new}$, go to *Step 1*.

The same as (7) in section 3.1, after getting the $D(t)$ of slot, the transmitting signals on the second antenna can be denoted as:

$$\underbrace{s(l - D(t))}_{CDD\ signal} = \frac{1}{\sqrt{N}}\sum_{k=0}^{N-1}\underbrace{e^{-j\frac{2\pi}{N}kD(t)} \cdot S(k)}_{PD\ signal} \cdot e^{j\frac{2\pi}{N}kl} \quad (6)$$

During the procedure of Tracking-Delay, the period of hopping and feed-back is the length of TTI, and also can be adjusted to meet the demands of complexity and accuracy. Moreover, the feedback information merely cost 1-2 bits to denote D^-, D^+, D, indicating forward, backward, and fix behavior respectively.

Through the close-loop controlling, the system modulates value of D step by step in conformity to channel changes. Tracking better delay in uplink or downlink will increase the SNR and reduce error. However, it has low complexity and feedback overhead.

A simplified algorithm based on (12) is as follow, compared with (10) above. We use arithmetical-mean-error instead of mean-square-error.

$$\Delta\phi_D(k) = \left|\pi - \left[\theta_0(k) - \theta_1(k) + \phi_D(k)\right] \bmod 2\pi\right| \quad (12)$$

where $\phi_D(k) = \frac{2\pi kD}{N}$, $k = 0 \ldots N-1$. $\Delta\phi_D(k)$ denotes the bias to zero phase on sub-carrier k.

This simplified algorithm, which is used in following simulations (section IV), reduces the complexity further with avoidance of multiplication and division, and yet has similar performance with un-simplified method.

IV. SIMULATION

In this section, we show simulation results for a DFT-S-OFDM transmission system with CDD, Hopping-Delay-CDD, and Tracking-Delay-CDD. The length of hopping slot is 1 TTI. We used SCME as channel model described in WINNER project, detailed in [13] and [14]. The parameters are listed in Table 1.

TABLE I. SIMULATION PARAMETERS

Items	**Parameters**
Bandwidth	5 MHz
FFT size	512
CP size	31
Modulation	QPSK
Coding	Turbo (1/2)
Channel Model	SCME (Urban Macro)

In DFT-S-OFDM and OFDM system, the sub-carriers, which are allocated to a user, are either a set of neighboring ones, called localized allocation, or several not adjacent ones dispersed uniformly to whole band, called distributed allocation, shown in Fig.1 (a) and (b) respectively.

Figure 1. (a) Distributed allocation structure

Figure 1. (b) Localized allocation structure

Fig. 2 shows the BLER of integrated DFT-S-OFDM system with CDD, Hopping-Delay-CDD, and Tracking-Delay-CDD. The case of localized allocation is shown in (a), and that of distributed allocation is corresponding to (b). From the structure shown in Fig. 1, we can notice that the distributed case can obtain frequency diversity gain, thus with which, outperforms localized case. Therefore, the BLER in Fig.2 (b) are lower compared with the BLER for localized case in Fig.2 (a).

In Fig.2, it is easy to see that the Self-Adapting CDD outperforms usual CDD in any case. Tracking-Delay-CDD has best performance with 1-bit feedback, besides, Hopping-Delay-CDD is better than the usual scheme using constant delay. The advantage improves by increasing Eb/N0, however, difference is lower in Fig. 2, due to the higher diversity gain, which means the same kind of benefit from varying delay is limited.

V. CONCLUSIONS

In this paper, we introduce two new improved cyclic delay diversity techniques based on self-adapting delay. For DFT-S-OFDM and OFDM system with a lot of users in different channel environment, CDD can not provide good diversity to every user. Hence, Hopping-Delay-CDD increases the time selectivity, not only for diversity gain when user is in static channel environment, but also giving adaptability when user is in vital changing channel condition. Furthermore, Tracking-Delay-CDD enhance the performance with a little bit of feedback, by tracking better delay quickly according to user's channel statistics during transmission. Both techniques lead to lower block error rates.

REFERENCES

[1] 3GPP TR 25.814 v7.1.0, "Physical Layer Aspects for Evolved UTRA", Oct. 2006.

[2] S. M. Alamouti, "A simple transmitter diversity scheme for wireless communications," IEEE J., Commun., vol. 16, no. 8, 1998, pp. 1451-1458.

[3] V. Tarokh, H. Jafarkhani, A. R. Calderbank, "Space-time block coding for wireless communications: performance results," IEEE J., Commun., vol. 17, no. 3, Mar. 1999, pp. 451-460.

[4] D. Agrawal, V. Tarokh, A. N. aguib, "Space-time coded OFDM for high datarate wireless communication over wideband channels," in Proc. IEEE Veh. Technol. Conf., 1998, pp. 2232-2236.

[5] K. Witrisal, Y. H. Kim, R. Prasad, "Antenna diversity for OFDM using cyclic delays," Proc. IEEE SCVT, 2001, pp. 13-17

[6] A. Huebner, F. Schuehlein, M. A. Bossert, "Simple space-frequency coding scheme with cyclic delay diversity for OFDM," Glasgow U K, 2003.

[7] D. Gore, S. Sandhu, and A. Paulraj, "Delay diversity codes for frequency selective channels," in Proc. Int. Conf. Commun., Apr. 2002, pp. 1949-1953.

[8] G. Bauch, "Capacity optimization of cyclic delay diversity," in Proc. OFDM Workshop, 2002.

[9] A. Dammann, R. Raulefs, G. Auer, and G. Bauch, "Comparison of space-time block coding and cyclic delay diversity for a broadband mobile radio air interface," in Proc. Int. Symp. Wireless Pers. Multimedia Commun., Oct. 2003.

[10] G. Auer, "Channel estimation for OFDM with cyclic delay diversity," in Proc. IEEE Int. Symp. Pers., Indoor, Mobile Radio Commun., pp. 1792-1796, Sep. 2004.

[11] B. L. Hughes, "Differential space-time modulation," IEEE Trans. Inf. Theory,. vol. 46, no. 11, pp. 2567-2578, Nov. 2000.

[12] G. Bauch, "Multi-stream differential modulation for cyclic delay diversity in OFDM," in Proc. IEEE Int. Conf. Commun., pp. 3207-3211, Jun. 2004.

[13] 3GPP TR 25.996 V6.1.0, "Spatial channel model for Multiple Input Multiple Output (MIMO) simulations", Sep. 2003

[14] WINNER of the European Union's Framework Program 6, WP5, D5-4: "Final report on link level and system level channel models", Oct. 2005

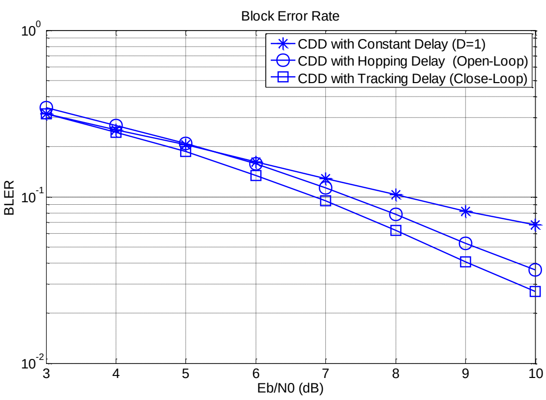

Figure 2. (a) BLER vs. Eb/N0 (dB) with localized allocation for sub-carrier mapping

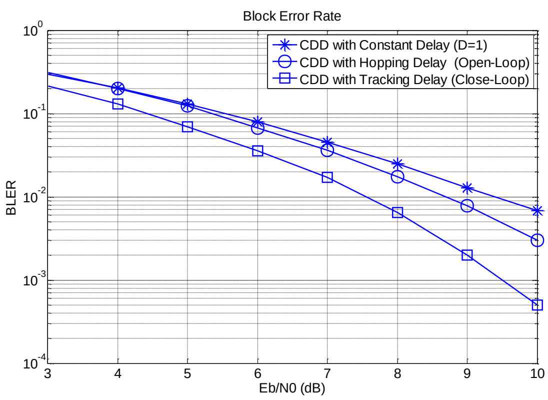

Figure 2. (b) BLER vs. Eb/N0 (dB) with localized allocation for sub-carrier mapping