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Performance Analysis of CDMA-OFDM System via Cooperative Communication in Wireless Fading Environment

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Abstract

Signal distortion due to the path loss, shadow, and multi-path fading is very serious in radio channel. In this paper, we propose CDMA-OFDM cooperative communication system based on DFP(Decode and Forward Protocol) to overcome these phenomena using spread spectrum technique, orthogonal sub-carrier, and the space diversity. We simulated proposed system under Rayleigh flat fading channel environment. A variety of simulation results reveal the cooperation can provide performance gain of up to 12 dB over direct communications in ideal inter-user case at BER of 10^{-3}. And we can also confirm variation of diversity effect as channel environment changes.

Key words : CDMA-OFDM, Cooperative Communication, Diversity Decode and Forward, MRC, ML Detect.

Ⅰ. Introduction

It is known that signal fading from multi-path propagation is very serious problem in wireless environment. So far, many efficient technologies that can overcome such serious effects have been studied actively[1]. OFDM(Orthogonal Frequency Division Multiplex) system that uses orthogonal sub-carriers and CDMA (Code Division Multiple Access) based on spread spectrum that uses wide frequency band can provide high communication capacity as well as overcoming signal distortion. Moreover, spatial diversity that can be made from antenna array at transmitter and receiver can overcome efficiently against adverse effects due to multi-path[4]. However, due to limitations of size, complexity or transmission power, we can't get diversity. To overcome these limitations, cooperative communication is proposed[4]. In multi-user environment, two of more users can share their data, and transmit data through virtual multiple antenna array which is same as MIMO system[5],[6]. In this paper, we propose CDMA-OFDM cooperative communication system that can overcome efficiently against the effect of various fading effect. The performance can be improved by spread spectrum in CDMA and orthogonal sub-carriers in OFDM. And various adverse effects made from multi-path fading can be overcome efficiently by the diversity effect through the cooperative communication[4]. For the signaling method of cooperation between users, we employ DFP (Decode and Forward Protocol), which each user decode received data from its partner and transmits with its own data together toward BS(Base Station). At BS, maximum diversity effect can be gotten through MRC (Maximum Ratio Combiner), and information can be detected correctly by using simple calculation. We compare and analyze proposed CDMA-OFDM cooperative communication system over Rayleigh fading environment.

The rest of the paper is organized as follows. The CDMA-OFDM schemes are presented in section 2. Then, the proposed cooperative communication system and simulation results are described and analyzed in section 3 and 4, respectively. Finally, the paper is closed in section 5 with some comments.

Ⅱ. CDMA-OFDM System

The block diagram of proposed system is described in Fig. 1.

This proposed system enables to improve the bandwidth efficiency due to sub-carriers of OFDM and system performance caused by orthogonality via spread spectrum in CDMA and orthogonal sub-carriers in OFDM. Spread spectrum has a characteristic which is powerful phenomenon of fading by multi-path due to transmitting signals that spreads wide band. Moreover, OFDM[2] that divides usable frequency band into several sub-channels makes narrow band of all sub-channels. So each sub-channel makes change frequency selective fading into flat fading. So it is easy to make channel equalization. Transmitting signal $s(t)$ of a user in Fig. 1 (a) is as follows.

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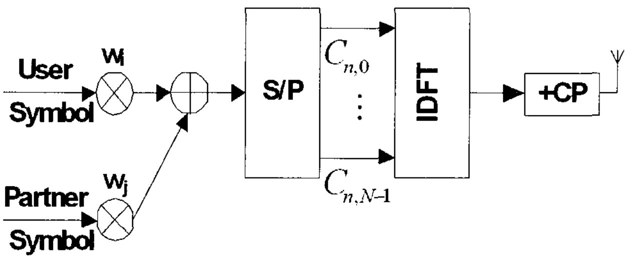
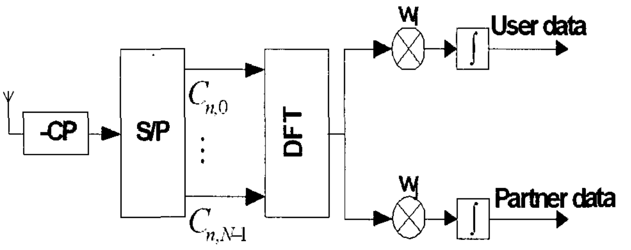


(a) Transmitter



(b) Receiver

Fig. 1. The block diagram of the proposed CDMA-OFDM cooperative communication system.

$$s(t)=w_i\sum_{n=-\infty}^{\infty}\left[\sum_{k=0}^{N-1}C_{n,k}g_k(t-nT_s)\right]$$

$$g_k(t)=\begin{cases}e^{j2\pi f_k t}, & t\in(0,\ T_s)\\ 0 & ,\ otherwise\end{cases}$$

$$f_k=f_0+k/\ T_s \tag{1}$$

Where w_i is spreading code assigned user i, $C_{n,k}$ is symbol transmitted at k times sub-carrier in n^{th} time slot, T_s is symbol duration, N is the number of sub-carriers of OFDM system, and f_k means frequency of k^{th} sub-carrier, respectively. After converting serial data to parallel data, the information $C_{n,k}$ is spread by spreading code w_i that is assigned to each user. Then each spread data multiplies by each sub-carrier $g_k(t)$. Finally transmitting signal $s(t)$ is made. In order to reduce the effect of ISI of transmitting signal, it adds CP after IDFT (Inverse Discrete Fourier Transform). If whole duration of one OFDM symbol is given as T_s and protecting section is $T_{op'}$, we denote available symbol length as follows.

$$T_{available}=T_s-T_{cp} \tag{2}$$

At the receiver, we get equation (3) by dispreading after removing CP, passing DFT.

$$C^*_{n,k}=\frac{1}{T_w}\int_0^{T_w}r(t)w_i(t)dt \tag{3}$$

$$C^*_{n,k}=s(t)g^*_k(t) \tag{4}$$

Here T_w is length of spreading code, $C^*_{n,k}$ is dispreading signal, respectively. Finally we decode original data passing through equalizer. Decoded information data $\overline{C}_{n,k}$ describes as follows.

$$\overline{C}_{n,k}=\frac{1}{T_s}\int_{nT_s}^{(n+1)T_s}s(t)g^*_k(t)dt \tag{5}$$

As we see equation (1) and (5), OFDM system can compensate signal distortion due to fading simply using single tab equalizer at the receiver[2],[3]. With the proposed system of Fig. 1, we only add spreading and dispreading process to OFDM, there is advantage that doesn't increase complexity of system. And it can improve performance of system against multi-path fading through advantages of spread, CP, sub-carrier and effect of diversity[3].

Ⅲ. The Proposed Cooperative Communication System

The proposed cooperative communication system is consisted of the one destination that receives data and two users which are defined by *MS1*, *MS2*. Fig. 2 shows cooperative process between two users, and BS[4],[5].

DFP, which is one of three signaling methods (amplify and forward, decode and forward, coded coopeartion) for cooperative communication, is that each user decodes signals transmitted from partner, then transmit to BS including user's own data. Then BS detects data comparing signals transmitted from two users. And in DFP algorithm we don't need to consider amplification factor about transmitting signal. So the proposed system can be designed simply to compare with other signaling methods.

The proposed CDMA-OFDM cooperative communication system operates as Fig. 2, and performance improves by maximum diversity effect via using MRC (Maximal Ratio Combiner), and ML(Maximum Likelihood) detection at BS. We assume as follows: A) Maximum delay spreading between transmitter and receiver exists within length of cyclic prefix. By this assumption

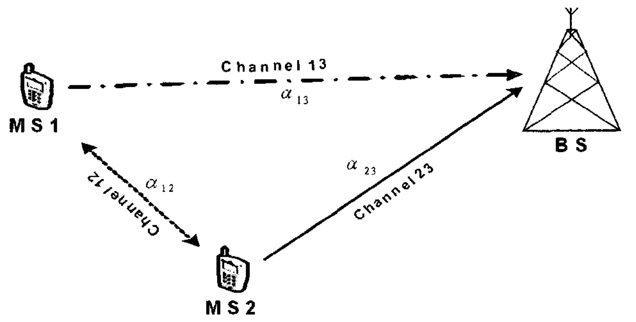


Fig. 2. Relation of relay at each user in the cooperative communication scheme.

ISI doesn't occur. B) Perfect channel state information is available at all receivers. Because perfect channel estimation is available at the receiver over slow fading. C) User and partner know user own and partner's orthogonal spreading code for data sharing. User and partner are essential to share their spreading code for purpose of cooperative communication. D) All amplification factors have value of beta at cooperative communication process. In DFP, they always transmit signals amplified by the same level.

The cooperative communication process of the proposed CDMA-OFDM system is described in Table 1, and act with cycle of three time slots[4]. Various modulation techniques can be applied, but we analyses using BPSK modulation in this paper for simple understanding.

In first time slot of Table 1, user transmits its own data to the partner, and receive signal as follows.

$$r_{11} = \alpha_{12}\beta d_{21} C_2 + n_{21} \qquad (6)$$

$$r_{21} = \alpha_{12}\beta d_{11} C_1 + n_{11} \qquad (7)$$

Where r_{ij} is signal that user i received at time j, α_{ij} is fading coefficient of inter user channel, and n_{ij} denotes AWGN with mean '0', variance '1', respectively. And d_{ij} is user i^{th} modulated symbol at j^{th} time slot, β is amplification factor of users, and C_i is spreading code of user i, which uses Walsh code made by 64×64 Hadamard matrix. And i=1 denotes user 1, and i=2 is user 2.

As following DFP, each user decodes data that receive from partner[4]. Partner's signal pass through DFT and dispreading process is

$$\overline{r}_{11} = \frac{r_{11} C_2}{64} = \alpha_{12}\beta d_{21} + \overline{n}_{21} \qquad (8)$$

$$\overline{r}_{21} = \frac{r_{21} C_1}{64} = \alpha_{12}\beta d_{11} + \overline{n}_{11} \qquad (9)$$

Users transmit their own data and decoded partner's data together to the BS. Data transmitted to their partners are

$$r_{12} = \alpha_{12}\beta(- d_{22} C_2 + \overline{r}^*_{21} C_1) + n_{12} \qquad (10)$$

$$r_{22} = \alpha_{12}\beta(- d_{12} C_1 + \overline{r}^*_{11} C_2) + n_{22} \qquad (11)$$

Table 1. Data transmit pattern of cooperative communication.

	MS1(User 1)		MS2(User 2)		BS
	Tx	Rx	Tx	Rx	Rx
1	$\beta d_{11} C_1$	r_{11}	$\beta d_{21} c_2$	r_{21}	
2	$-\beta d^*_{12} C_1 + \beta r^*_{11} C_2$	r_{12}	$-\beta d^*_{22} C_2 + \beta r^*_{21} C_1$	r_{22}	r_{d_2}
3	$\beta d_{11} C_1 - \beta r^*_{12} C_2$		$\beta d_{21} C_2 - \beta r^*_{22} C_1$		r_{d_3}

In the equations (10) and (11), r_{i2} is received signal of user i in second time slot, and $\overline{r}^*_{i1}$ is decoded data that each user received from partners. At the same time, the received signal at BS can express combined signal that two users transmitted together.

$$r_{d2} = \alpha_{13}\beta(- d_{12} C_1 + \overline{r}^*_{11} C_2) + \alpha_{23}\beta(- d_{22} C_2 + \overline{r}^*_{21} C_1) + n_{02} \qquad (12)$$

The received signals from each user in the equations (10) and (11) are decoded as follows.

$$\overline{r}_{12} = \frac{r_{12} C_2}{64} = \alpha_{12}\beta d_{22} + \overline{n}_{22} \qquad (13)$$

$$\overline{r}_{22} = \frac{r_{22} C_1}{64} = \alpha_{12}\beta d_{12} + \overline{n}_{12} \qquad (14)$$

Each user transmits their own first data and received data in second time slot together toward BS. We show this data format on equation (15).

$$r_{d3} = \alpha_{13}\beta(d_{11} C_1 - \overline{r}^*_{12} C_2) + \alpha_{23}\beta(d_{21} C_2 - \overline{r}^*_{22} C_1) + n_{03} \qquad (15)$$

Received signals from second and third time slot at the BS can be divided by orthogonal spreading code perfectly, and detected.

The Case of User 1

At BS, it can be divided received signal for two time slot by orthogonal code C_1 of user i.

$$r_{d11} = \frac{r_{d3} C_1}{64} = \alpha_{13}\beta d_{11} - \alpha_{23}\beta \overline{r}^*_{22} + \overline{n}_{03} \qquad (16)$$

$$r_{d12} = \frac{r_{d2} C_1}{64} = - \alpha_{13}\beta d_{12} + \alpha_{23}\beta \overline{r}^*_{21} + \overline{n}_{02} \qquad (17)$$

As we assume as follows at equations (16) and (17), and adjust, we can get equations (18) and (19)[4],[5].

$$\mu_{11} = \alpha_{13}\beta, \qquad \mu_{12} = \alpha_{23}\beta$$

$$y_{d11} = \mu_{11} d_{11} + \mu_{12} d_{12} + \overline{n}_{03} \qquad (18)$$

$$y_{d12} = - \mu_{11} d^*_{12} + \mu_{12} d^*_{11} + \overline{n}_{02} \qquad (19)$$

From equations (18) and (19), they pass through MRC, making $\overline{d}_{11}$ and $\overline{d}_{12}$ for ML detection. Information signals after passing MRC denote as follows

$$\overline{d}_{11} = y_{d11}\mu^*_{11} + y^*_{d12}\mu_{12} \qquad (20)$$

$$\overline{d}_{12} = y_{d11}\mu^*_{12} + y^*_{d12}\mu_{11} \qquad (21)$$

y_{d11} and y_{d12} from equations (18) and (19) substitute into equations (20) and (21), and then adjust,

$$\bar{d}_{11} = (|\mu_{11}|^2 + |\mu_{12}|^2) d_{11} + n_{111} \tag{22}$$

$$\bar{d}_{12} = (|\mu_{11}|^2 + |\mu_{12}|^2) d_{12} + n_{112} \tag{23}$$

is gotten. Here,

$$n_{111} = \bar{n}_{03}\mu_{11}^* + \bar{n}_{02}^*\mu_{12} \tag{24}$$

$$n_{112} = -\bar{n}_{02}\mu_{11} + \bar{n}_{03}\mu_{12}^* \tag{25}$$

The proposed cooperative communication system via equations (20) and (21) can express the performance of MRC of two levels. Information that passed through MRC can be detected using ML detection.

The Case of User 2

User 2 can also detect the same process as the case of user 1. Using orthogonal code, C_2, they can divide data for user 2 from second and third time slot perfectly, and detect via next process.

$$r_{d21} = \frac{r_{d3}C_2}{64} = \alpha_{23}\beta d_{21} - \alpha_{13}\beta \bar{r}_{12}^* + \bar{n}_{03} \tag{26}$$

$$r_{d22} = \frac{r_{d2}C_2}{64} = -\alpha_{23}\beta d_{22} + \alpha_{13}\beta \bar{r}_{11}^* + \bar{n}_{02} \tag{27}$$

We adjust equations with assumption as follows.

$$\mu_{21} = \alpha_{13}\beta, \qquad \mu_{22} = \alpha_{23}\beta$$

$$y_{d21} = \mu_{21}d_{21} + \mu_{22}d_{22} + \bar{n}_{03} \tag{28}$$

$$y_{d22} = -\mu_{21}d_{22}^* + \mu_{22}d_{21}^* + \bar{n}_{02} \tag{29}$$

Information for ML detection of user 2 can be denoted as follows.

$$\bar{d}_{21} = (|\mu_{21}|^2 + |\mu_{22}|^2) d_{21} + n_{211} \tag{30}$$

$$\bar{d}_{22} = (|\mu_{21}|^2 + |\mu_{22}|^2) d_{22} + n_{212} \tag{31}$$

Here,

$$n_{211} = \bar{n}_{03}\mu_{21}^* + \bar{n}_{02}^*\mu_{22} \tag{32}$$

$$n_{112} = -\bar{n}_{02}\mu_{21} + \bar{n}_{03}\mu_{22}^* \tag{33}$$

Ⅳ. Simulation Result

We simulated to compare of performance between cooperative and non-cooperative mode. We simulated two cases, considering AWGN only and fading plus AWGN between user and partner. In Table 2, we denote some parameters to compare the performances exactly.

Table 2. Parameters for describing performance.

P BER MS1	Performance of proposed system of user 1
BER MS1n	Performance of user 1 in non-cooperative mode
P BER MS2	Performance of proposed system of user 2
BER MS2n	Performance of user 2 in non-cooperative mode

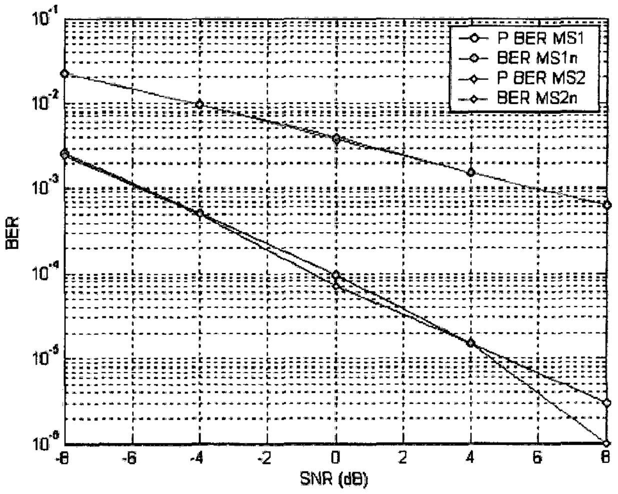


Fig. 3: The case of non-fading in inter user channel.

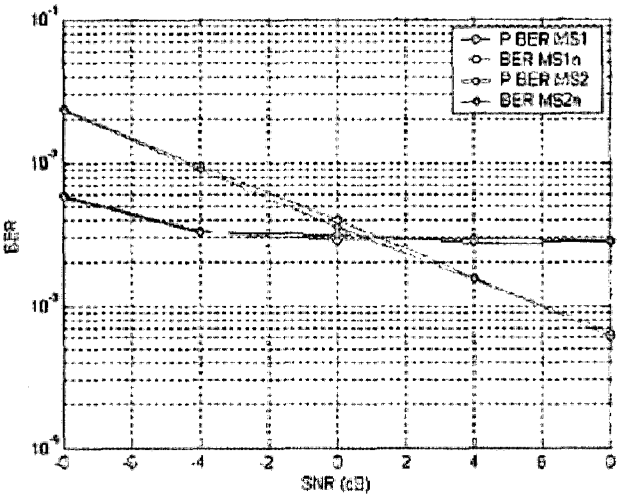


Fig. 4. The case of 0 dB in inter user channel.

In the Fig. 3, we can make sure of performance improvement of 12 dB in BER 10^{-3} by diversity effect via cooperation in the case of AWGN only between two users. However, we can confirm that BER curves of two systems are cooperative and non-cooperative system intersect according to changing of channel environment between users in Figs. 4 and 5. Because users can get diversity effect when users transmit their own and partner's data to BS in DFP, but as inter-user channel

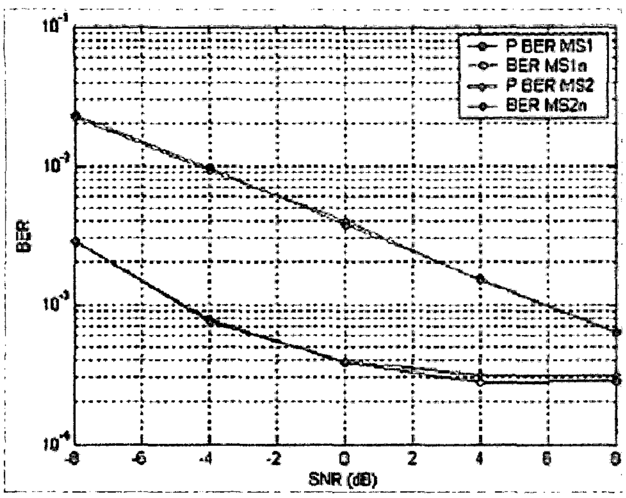


Fig. 5. The case of +10 dB in inter user channel.

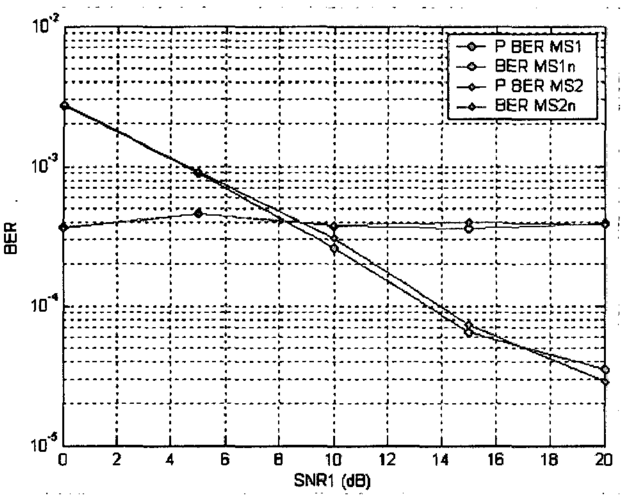


Fig. 6. Performance curve according to change of inter user channel SNR(0 dB~20 dB).

is getting worse, it can be occurred the case that users can't decode their partner's data exactly. As a result, they transmit their own data and wrongfully decoded partner's data. In Fig. 6, it appears the performance curve in the case that channel between user and BS is fixed (SNR=10 dB) and changed between users only.

As inter-user channel is changed, we can see that the performance is improved by diversity effect. As a result, when each user can detect partner's data exactly, they can know that bigger performance improvement is available through simulation.

V. Conclusion

In this paper, we propose CDMA-OFDM system through cooperation between users and analyzed performance over frequency Rayleigh non-selective fading plus AWGN. According to channel situation between user and partner, we can see the variation of diversity effect and performance. Afterwards, we'll remain how to detect partner's data more exactly as future works to do.

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