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Design and Evaluation of Resource Allocation Scheme for Downlink MIMO-OFDMA-CDM Systems

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Abstract: **In this work, we propose a new resource allocation scheme that increases the effect of diversity by considering the proportional fairness(PF) even after increasing the number of users in downlink MIMO-OFDMA-CDM (multiple input multiple output-orthogonal Frequency division multiple access-code division multiplexing)systems.In the proposed scheme resources are allocated for one subcarrier group and full code-spreading is done for each user using all sources allocated subcarriers.This increases the frequency diversity effect and also increases the multi-user diversity effect. Also the subcarrier allocation is based on the scheme which is not consider in based on the scheme which is not considered in the conventional OFDMA-CDM schemes. The proposed scheme is tested for 16 users. The improvement performances of BER and capacity are shown through MATLAB simulations.**

Keywords: **COFDM, frequency diversity, interference cancellation, SISO, spectral efficiency.**

I. INTRODUCTION

Orthogonal frequency division multiplexing (OFDM). [1]- [3] is a technology implemented in high speed and high data rate communications such as WLAN,DAB Digital audio broadcasting,DVB-T Digital video Broadcasting. In OFDM,the information symbols are transmitted over a parallel sub-channels set. By using this sub channel set only a fraction of Bandwidth could be occupied and due to this limited bandwidth the fading becomes flat fading in each sub channel.By using IFFT/FFT and including cyclic prefix(CP) and overlapping adjacent sub channels, the OFDM system can achieve high performance wideband and high spectral efficiency with less design complexity.Even though the fading is flat fading in each sub channel, the fading is frequency selective fading among each sub channel set. Because of this there exists some deep fading among few sub channels which will leads to system degradation in performance.

To minimize the degradation, it was proposed the CODED OFDM in short form it can be denoted as COFDM.[4]-[6].Another technology in diversity is used in OFDM systems. Commonly, there are four kinds of diversity techniques they are, Spatialdiversity, time diversity schemes, and polarization diversities. The spatial diversity [7],[9] provides diversity gain without avoiding the spectral characteristics. But the problem is space occupied in hardware part is much. Since it needs much space it can’t be used in mobile phone, and other handheld devices. The frequency diversity and the time diversity the complications are more.[10][12]and spectral efficiency is also less. Considering all these reasons adaptive method of diversity was proposed in [16]The method is named as AFD-OFDM in which the complete bandwidth is splitted into smaller sub-bands and the modulation scheme for each sub-band can be changed adoptively according to the channel state information. Depending on the channel state information only the spectral efficiency also could be decided. In the poor channel conditions to maintain the system performance it is necessary to reduce the spectral efficiency. In this work we have proposed a scheme of full frequency diversity in which the spectral efficiency is not at all reduced. The scheme is In this letter, a full frequency diversity COFDM (FDCOFDM) scheme without sacrificing spectral efficiency is proposed. At the transmitter, in order to improve the low spectral efficiency of frequency diversity, the sub-channel multiplexing and the frequency diversity are jointly employed. The information symbols expanded by the binary Walsh-Hadamard (WH) orthogonal code, the same as in IS-OFDM [16][29], are simultaneously transmitted on all subcarriers. Hence the signal transmitted on each subcarrier is a compound signal, and the information symbols are distinguished with each other by the WH code. As the compound signal passes through the channel, the orthogonally of the WH code is destroyed by different fading of subcarriers, resulting in inter symbol interference (ISI). The ISI energy increases with the number of symbols being multiplexed. Thus, the FD-COFDM is a self-interference system. At the receiver, an iterative receiving algorithm is adopted to obtain the diversity gain and code gain provided by the transmitter, and decodes the information bits properly in the strong ISI environment. The iterative method has been widely used in the turbo-code decoding [18] and low-density parity check (LDPC) code decoding [19] to achieve Shannon's channel capacity. It can also be extended to some other areas, such as turbo equalization [20][21][25] and interference cancelation [22][23].

Therefore, we propose a new code spreading scheme to enhance both the frequency diversity and the multi-user diversity with considering the PF for downlink MIMOOFDMA- CDM systems. In the proposed scheme, spectral resources are allocated per subcarrier unit and full code spreading is done for each user using all allocated subcarriers. Since the spreading code in this paper is Walsh code, an equivalent number of subcarriers should be allocated for all users. Therefore, we propose a new allocation algorithm considering PF based on [10] for MIMO-OFDMA-CDM. As a result, more multi-user diversity of OFDMA and frequency diversity of CDM are obtained than conventional schemes.

II. FD-COFDM SYSTEM MODEL

A. The OFDM System and Channel Model

In the OFDM system, the transmitted OFDM signal can be expressed as,

$$s(t_X,t)=\frac{1}{\sqrt{N_c}}\sum_{n=0}^{N_c-1}\left(\sum_{k=1}^{K}d_W(k,n)\right)\exp(j2\pi(n/T)t) \qquad (1)$$

$$t_X=1\sim T_X,\ \ 0<t<T$$

where*dW*(*k*,*n*) is the data symbol for user *k* and subcarrier *n* after code multiplexing, *tX*is the *tX*–th element of transmit antennas, *T* is the OFDM symbol period and also 1/*T* is the subcarrier interval time period. The subcarrier interval is set to 1/*T*=15kHzin this paper. *dW*(*k*,*n*) is explained later. When *Tx* and *Rx* are the number of transmit and receive antennas, respectively, the number of users is *K*, and the number of subcarrier is *Nc*, the channel matrix of user *k* at the subcarrier *n* becomes *Rx* rows and *Tx*columns which is given by

$$\mathbf{H}_{k,n}=\begin{bmatrix} h_{1,1}^{\ k,n} & h_{1,2}^{\ k,n} & \cdots & h_{1,Tx}^{\ k,n} \\ h_{2,1}^{\ k,n} & h_{2,2}^{\ k,n} & \cdots & h_{2,Tx}^{\ k,n} \\ \vdots & \vdots & \ddots & \vdots \\ h_{Rx,1}^{\ k,n} & h_{Rx,2}^{\ k,n} & \cdots & h_{Rx,Tx}^{\ k,n} \end{bmatrix} \qquad (2)$$

where*k nrxtxh* ,, is the channel gain between transmit antenna *tX*and receive antenna *rX*of user *k* at the subcarrier *n*.

To simplify the analysis, we suppose that the delay of each path (τi) is an integer multiple of the sampling interval ($\tau i= li$T0). Using the tapped-delay line model, the channel impulse response can be written as,

$$h\ (n)=\sum_i h_i\delta\ (n-l_i)$$

Where $hi$is the fading factor of the ith path, and is a complex Gaussian random variable with mean 0 and variance σi^2. Let the variances satisfy $\Sigma i\sigma^2\ i= 1$, if $i= j$, $\sigma i= \sigma j$. Then the channel frequency response is,

$$H(k)=\frac{1}{\sqrt{N}}\sum_{i=0}^{L-1}h_i\cdot\exp\left(-j\left(2\pi kl_i\right)/N\right),0\leq k<N \qquad (3)$$

Where L is the number of the paths of the channel. Since $H(k)$ is the linear combination of L independent complex Gaussian random variables, it must be a complex Gaussian random variable with mean 0 and variance 1/2. Hence, $|H(k)|^2$ satisfies the chi-square distribution with 2 degrees of freedom and $|H(k)|$ has a Raleigh distribution. The correlation matrix of the channel frequency response vector $\mathbf{H} = [H(0), (1), \cdots, H(N-1)]$ is,

$\mathbf{R}_H = E[\mathbf{H}^H\mathbf{H}]$

$$= \begin{pmatrix} G_h(0) & G_h^*(1) & \cdots & G_h^*(N-1) \\ G_h(1) & G_h(0) & \cdots & G_h^*(N-2) \\ \vdots & \vdots & \vdots & \vdots \\ G_h(N-1) & G_h(N-2) & \cdots & G_h(0) \end{pmatrix} \quad 4)$$

Where $E[\cdot]$ denotes the expectation. $G_h(k)$ is the delay power spectrum which is the Discrete Fourier transform of the power delay profile. The channel correlation bandwidth approximately equals to $1/\tau_{max}$. It means that the fading of L neighboring subcarriers are correlated and the rank of matrix $\mathbf{R}_H$ is L. The channel can be described by L independent random variables. It also means that there are at most L diversity paths in the channel.

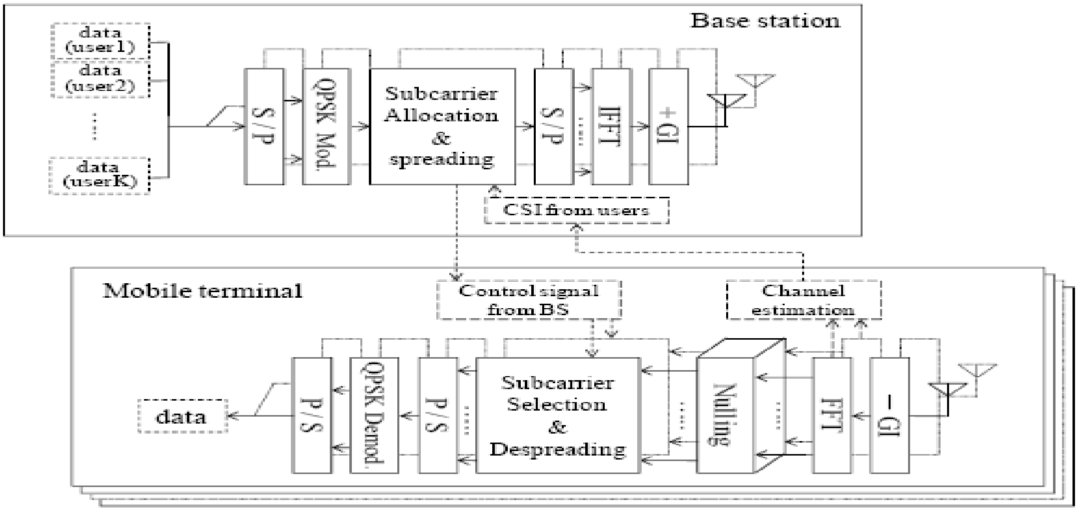


Fig. 1. Block diagram of MIMO-OFDMA-CDM system.

B. FD-COFDM Transmitter

The diversity methods are the effective ways to overcome the fading. The channel coding is usually used in communication systems to protect the information bits from noise and interference. Combining these two methods in OFDM, the system can yield better performance and become more robust to interference and noise. However, the cost is the severe reduction of data rate. To overcome this demerit, the subcarrier multiplexing is employed in FD-COFDM systems. The block diagram of the spectral efficient FD-COFDM transmitter is shown in Fig. 1. The information blocks $\mathbf{X} = [x_1, x_2, \cdots, x_N]$ are sent to the channel coder that outputs coding blocks $\mathbf{C} = [c_1, c_2, \cdots, c_{2M}]$. Processed by the serial-to-parallel converter and the modulator in which each subcarrier is QPSK modulated, the coding block $\mathbf{C}$ is changed to a modulated symbol block and can be expressed as $\mathbf{S} = [s_1, s_2, \cdots, s_M]$. The component s_m in $\mathbf{S}$ is the modulated symbol of the mth subcarrier. After subcarrier multiplexing, the output signal vector $\mathbf{Y} = [y_1, y_2, \cdots, y_M]$ is,

$$\mathbf{Y} = \frac{1}{\sqrt{N}}\mathbf{S}\mathbf{F}_{FDM} \quad (5)$$

Where $1/\sqrt{N}$ is a normalization factor, $\mathbf{F}_{FDM}$ is the N order WH orthogonal matrix. (5) is also called Hadamard Transformation and can simultaneously achieve the frequency diversity and subcarrier multiplexing. Finally, the signal $\mathbf{Y}$ is processed by IFFT and added by a CP. The time domain FD-COFDM baseband signal y is thus produced.

III. PERFORMANCE OF FD-COFDM

After the FD-COFDM signal passes through the frequency selective fading channel, the receiver discards CP and performs FFT on the last Nsamples of each OFDM symbol. Then the received signal is,

$$\mathbf{R} = \frac{1}{\sqrt{N}}\mathbf{S}\mathbf{F}_{FDM}\mathbf{H} + \mathbf{N} \qquad (6)$$

Where **H** = $diag(H1,2, \cdots,HN)$ is the channel transfer matrix, $Hi$is the fading factor of the ith sub-channel. **N** is the noise vector. Each component of the noise vector is independent complex Additive White Gaussian Noise (AWGN) with mean 0 and variance $\sigma 2/2$.

The symbol error probability (SEP) is commonly used to measure the performance of a system with diversity and coding. Usually, it is difficult to obtain the closed form expression of SEP. However, the asymptotic behavior of SEP is governed by the pairwise error probability (PEP).

IV. RECEIVING ALGORITHM

The FD-COFDM system can provide both frequency diversity and coding gains. To explore the property, the maximum likelihood estimation algorithm needs to be used at the receiver. That is, the receiver has to search the whole codebook to find the code word that has the nearest Euclidean distance to the received signal vector. The computational complexity of the searching algorithm is exponentially increasing with the length of the codeword. Finding a receiving algorithm with low complexity and reasonable performance is the main challenge in the FD-COFDM receiver design.

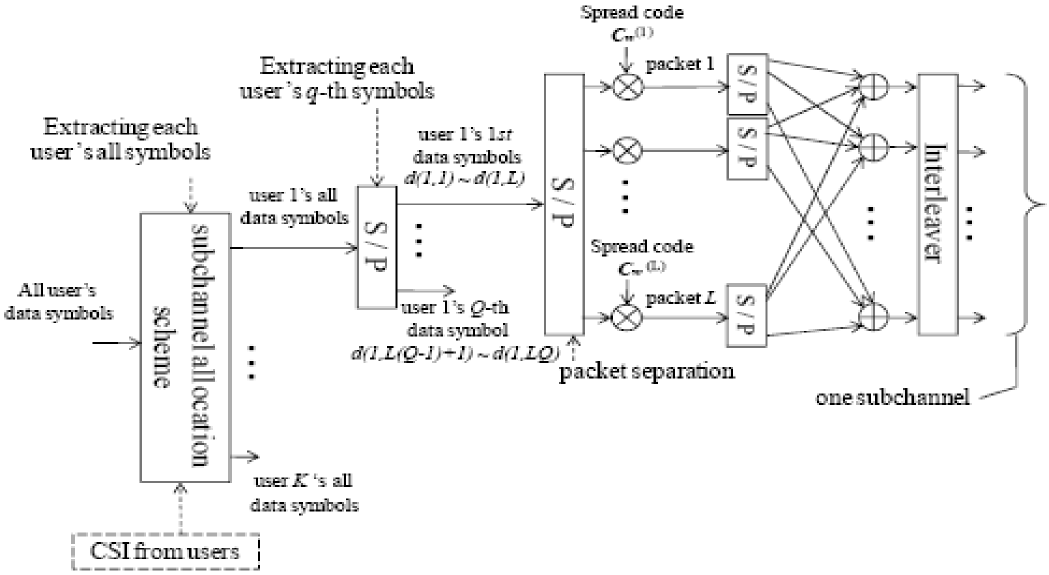


Fig. 2: Block diagram of the conventional spreading algorithm.

A. FD-COFDM Receiving Algorithm

Fig. 2 shows the conventional code-spreading scheme in OFDMA-CDM where L is the number of multiplexed packets for single user, equal to the spreading code length, and Q is the count of symbols in one packet. As shown in Fig. 2, on one user, q-th codes of number of L packets are spread by L length code, combined, and placed at from {L(q-1)+1}-th to Lq- subcarriers. Thus, one user uses LQ subcarriers and if the number of active user is K, the total number of subcarriers becomes Nc=KLQ. Fig. 3 shows the block diagram of this process. One user's data to be transmitted are once serial-to-Q-parallel transformed, again serial-to-L-parallel transformed, code - spread with interleaving, and placed at subcarriers. The data symbol for user k and subcarrier n after code multiplexing of conventional scheme *dW_conv(k,n)* can be described using *CwL*(*l*) , *l*-th chip of code with code length *L* as As the iteration goes on, ISI will be gradually reduced and the system performance improved.

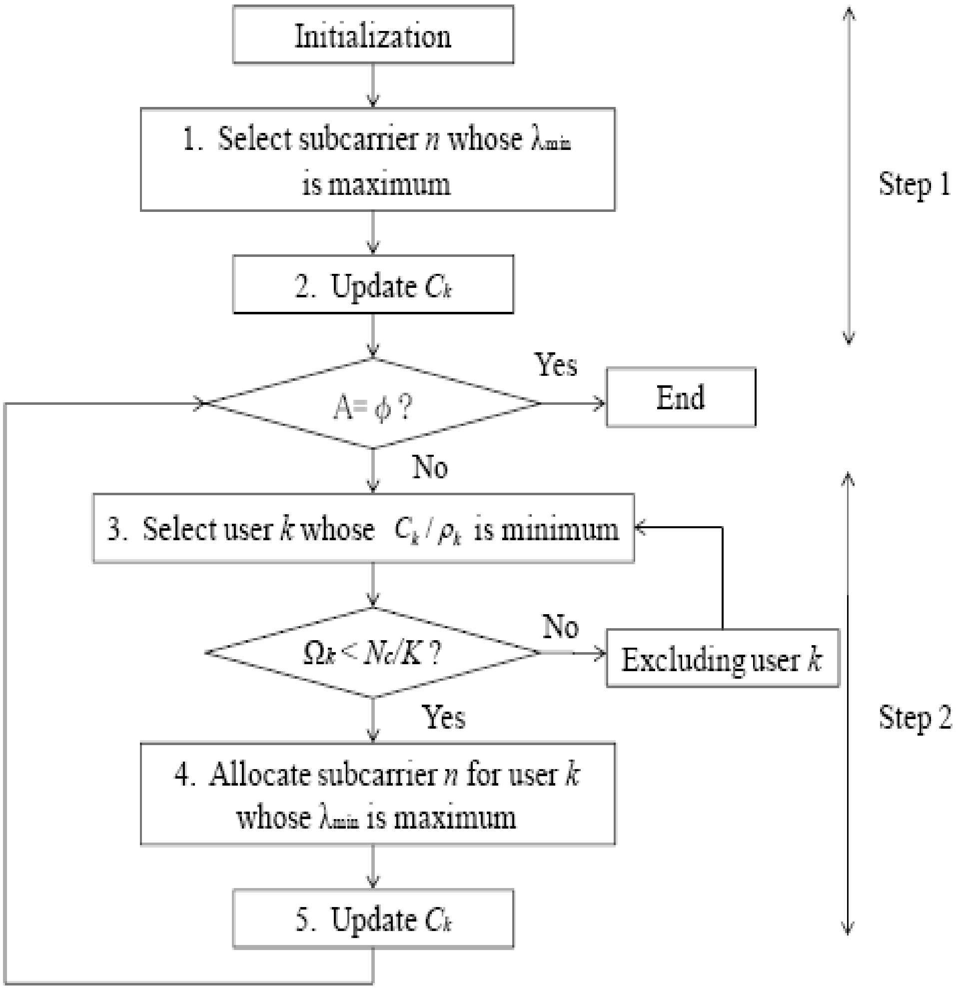
$$d_{W\_conv}(k,n)=\sum_{q=0}^{Q-1}\left(\frac{1}{\sqrt{L}}\sum_{p=0}^{L-1}Cw_L^{(p+1)}d(k,Lq+p)\right)\exp(j2\pi f_{k,n}t)$$

$$k=1\sim K,\quad L=N_c/KQ$$

where*d*(*k*,*Lq*+*p*) is the {*Lq*+*p*}-th data symbol for user *k* and *fk*,*n*is the subcarrier according to the resource allocation scheme. The successive *L*-subcarriers are treated as one sub channel and the frequency allocation is conducted per sub channel-unit.

PROPOSED SCHEME

In the conventional scheme, sometimes the frequency or multi-user diversity gain is not fully obtained because the spreading is done within one sub channel and the user allocation is also done on sub channel unit. Thus, we propose a spreading with subcarrier extraction. The frequency allocation is conducted on subcarrier unit, not on sub channel unit. Fig. 4 shows the spreading process in the proposed scheme. One user’s *L* subcarriers are selected from all subcarriers by allocation algorithm. *L* symbols are allocated after *L*-spreading and multiplexing.



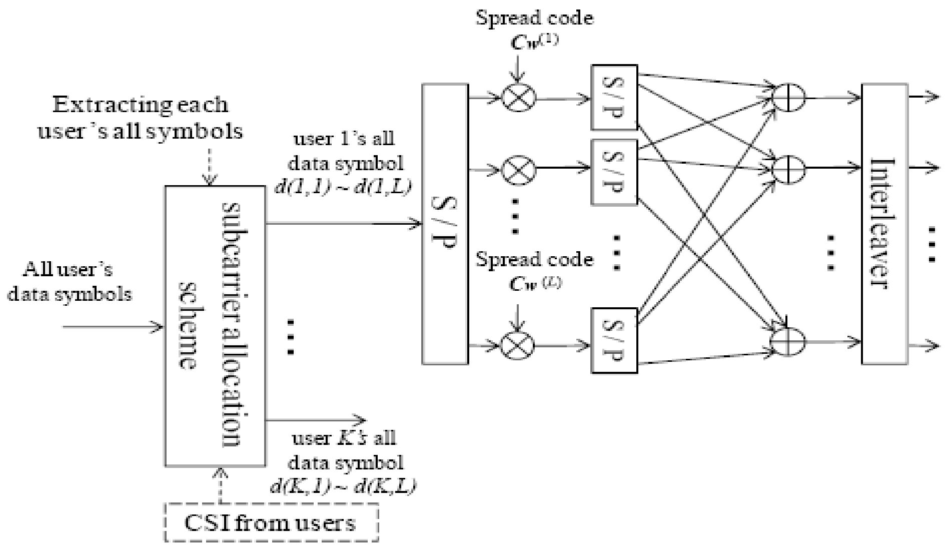
The calculated *L* signals are reallocated to each subcarrier after interleaving. The conventional scheme uses the intermediate packets and spread them, while the proposed scheme spreads directly to the allocated subcarriers. Hence, the proposed scheme can increase the frequency diversity effect. If the active *K* usersexist, the total subcarrier becomes

Nc=*KL*, and under the equivalent *Nc*condition, the proposed scheme obtains *Q*-times larger frequency-diversity effect. In addition, since the allocation unit is a subcarrier, the multi-user diversity effect is also developed. As a result, BER performance enhancement is obtained in trade-off with the calculation increase by subcarrier-unit allocation. The data symbol for user *k* and subcarrier *n* after code multiplexing of proposed scheme *d*W*_prop*(*k*,*n*) can be described as

$$d_{W\_prop}(k,n)=\left(\frac{1}{\sqrt{N_k}}\sum_{p=0}^{N_k-1}Cw_L^{(p+1)}d(k,p)\right)\exp(j2\pi f_{k,n}t)$$

$$k=1\sim K,\quad N_k=L=N_c/K$$

The proposed is scheme is shown the block diagram as follows



SUBCARRIER ALLOCATION SCHEME

In this subsection, resource allocation schemes of downlink MIMO-OFDMA-CDM are described.

A. Conventional Scheme

Fig. 5 and 6 show the conventional allocation algorithm in [12] and [13]. First, the base station calculates the all subcarrier capacities based on the feedback CSI (channel state information) from users, which is given by

$$C_k=\sum_{n\in\Omega_k}\sum_{r=1}^{RANK(\mathbf{H}_{k,n})}\log_2(1+SNR\lambda_{k,n,r})$$

where *k* Ω is the allocated subcarrier set for user *k*, SNR is signal to noise ratio, *k* ,*n*,*r*λ is the *r*-th eigenvalue of **H***k*,*n*, and RANK(**H***k*,*n*) is the rank of **H***k*,*n*at user *k*. When *L* is the number of subcarriers per subchannel which is equivalent to the spreading code length, the *i*-thsubchannel and *l*-th subcarrier corresponds to {(*i*-1)*L*+*l*}-th subcarrier. Each user calculates the following feedback parameter *F(k,i)* as

$$F(k,i)=\min_{l} I(k,i,l)$$

where*k* is the user number and *I(k,i,l)* is the subcarrier channel capacity. Using (8), each user calculates the minimum subchannel capacity and sends back it to the base station. The base station receives the feedback CSI and allocates the subchannel*i* to user *kallocate*(*i*) which is given by

$$k_{allocate}(i)=\arg\max_{k} F(k,i)$$

which means the base station allocates the subchannel$i$ to the user having maximum $F(k,i)$. This algorithm improves the multiuser diversity effect. However, compared with subcarrier-unit allocation, that effect is reduced because of the larger subchannel-unit. Moreover, this algorithm cannot keep the proportional fairness and the subchannel tends to be allocated to the users nearer to the base station.

The proposed scheme exploits the subcarrier allocation with considering PF based on [10], in which the user having the lower transmission rate is selected and the subcarrier is allocated by priority to the user with taking the user's desiring rate into account. Fig. 7 shows the algorithm. For allocating subcarriers, $\lambda\min(\mathbf{H}k,n)$ which is the minimum eigenvalue obtained by singular value decomposition of channel matrix $\mathbf{H}k,n$for all k is utilized. Since $\lambda\min(\mathbf{H}k,n)$ is proportional to the average channel gain, the channel condition of all users can be obtained by comparing the component of $\lambda\min(\mathbf{H}k,n)$. In [10], the subcarrier n having the largest gain is chosen for each user by using $\lambda\min(\mathbf{H}k,n)$. First, the users temporarily select the best subcarrier n based on $\lambda\min(\mathbf{H}k,n)$., the rates of k kC /ρ are calculated, the one user k having the smallest k kC / ρ is selected, and the subcarrier n is allocated to that user k. The k-th user's channel capacity is given by (7). According to Fig. 7, the allocation process is described as follows.

.B. Performance of the system

Proportional fairness among users is an important factor in OFDMA. We simulate the distribution of the channel capacity and show the effectiveness of the proposed scheme. Figs. 9 and 10 show the probability density function of the channel capacity in one OFDM symbol for each user when Tx=2, Rx=2, K=8, Nc=1024 and SNR=10 [dB]. The channel

capacity is calculated by (7). Fig. 9 indicates that the capacity is dispersed and PF is not achieved. Since the algorithm aims to maximizing the channel capacity, largely different channels are obtained for each user. Fig. 10 shows the pdf of the proposed scheme. Almost all users have a capacity between 4.25 and 4.85 [bit/s/Hz]. It means the capacities for each user are similar and the PF is preserved.

V. SIMULATION RESULTS

We evaluated the performance of the proposed scheme by computer simulations. The simulation conditions are listed in Table I. K and L are the same as in [12] and [13], which are the conventional schemes in this simulation. The delay profile in simulation is shown in Fig. 11 and the results are shown in Fig. 12. The BER performance of the proposed scheme is better than the conventional scheme. At BER of 10-5, the performance improvements are about 5 dB with 8 users and about 2 dB with 16 users. This improvement is achieved by

the enhancement of frequency diversity and multi-user diversity. In addition, the proposed scheme preserves PF as shown in Fig. 10.The parameters considered for the simulation has been given below.

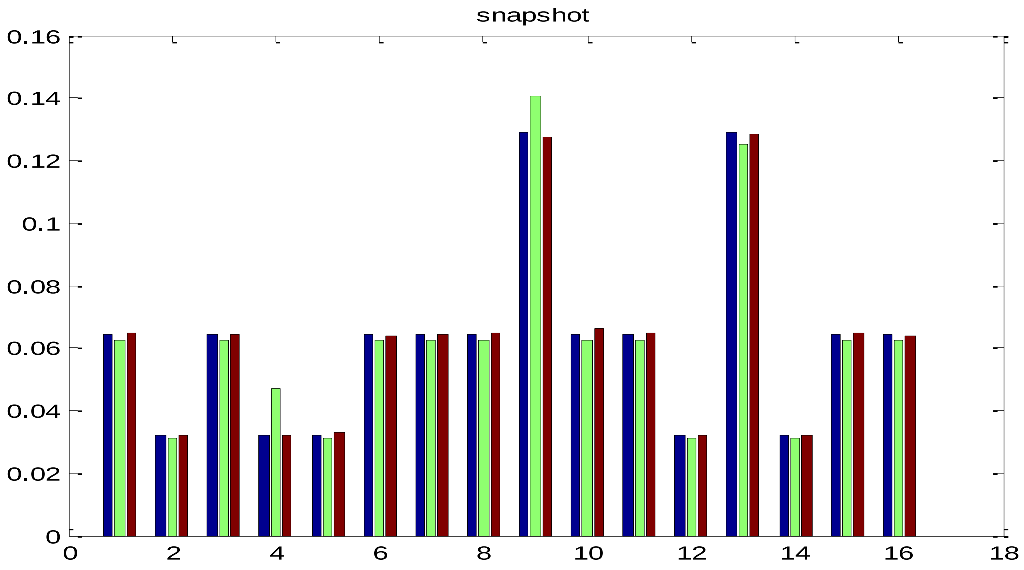


Fig. 3: Proportional fairness for 16 users

SIMULATION PARAMETERS

	conventional	proposed
Transmission scheme	MIMO-OFDMA-CDM	
Modulation	QPSK	
Number of antennas	(Tx, Rx)=(2, 2)	
Spreading code	Walsh	
Subcarrier allocation scheme	Algorithm of Fig. 5.	Algorithm of Fig. 7.
Desired rate ratio ρ_k		1 for all users
Number of subcarriers N_c	64	
Number of users K	8,16	8,16
packet L	8,4	
Packet length Q	16	
Spreading length L	8,4	128,64
Channel	16path 1dB-decayed Quasi-static Rayleigh Fading	
Channel Estimation	Perfect	
MIMO detection and Equalization	Nulling (MMSE criteria)	
1 symbol length	Ts	
1 OFDMsymbol length T	64 Ts	
Guard interval length	$16Ts$	

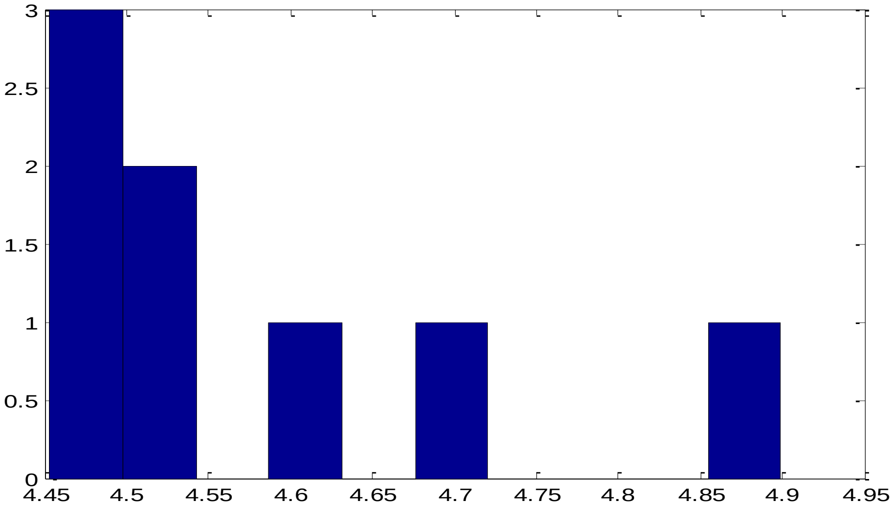


Fig. 4: Probability density function with conventional method

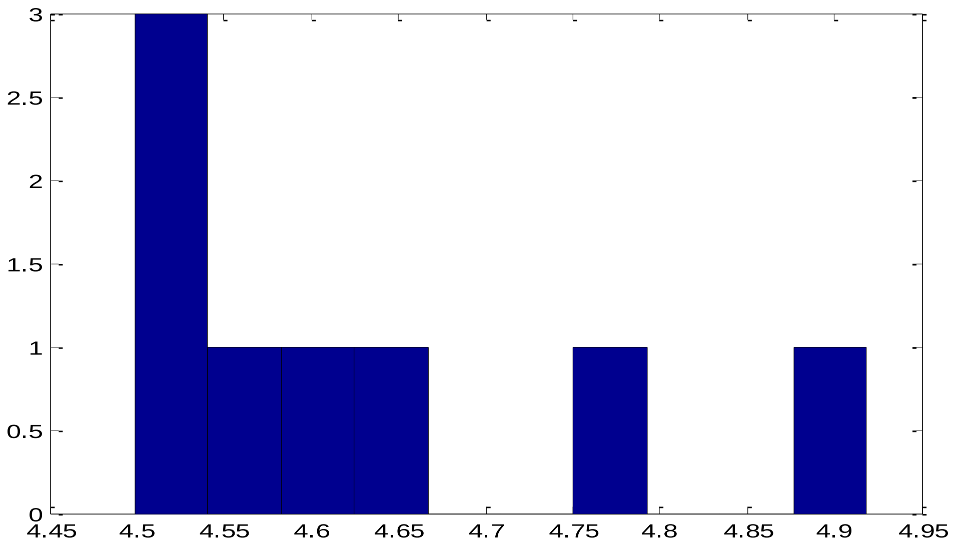


Fig.5. Probability density function with proposed method

The receiving algorithm in Fig. 2 is an iterative decoding method. The BER performance versus the iteration times is shown in Fig. 6. It can be observed that the BER performance improves as increasing iterations. After the number of iteration exceeds four, the performance becomes unchanged. Thus, the iteration can be stopped after four times of iteration.

VI. CONCLUSIONS

In this work, we proposed a resource allocation scheme for downlink MIMO-OFDMA-CDM with considering PF in which the frequency diversity and multi-user diversity effects were improved by the subcarrier-unit allocation. The proposed algorithm allocates subcarriers for each user. One user's allocated subcarriers are once extracted, code-spread and multiplexed, and then, reallocated to the original frequencies. By this process, one user can utilize all subcarriers assigned and the frequency diversity gain obtained by CDM is increased. From simulation results, the improved BER performance and the preservation of PF are obtained by the proposed scheme. The system had been implemented for 16 users and fairness had been tested. For further studies, more effective allocation algorithm, application of channel coding, and channel estimation are subjects to consider.

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