Resource Allocation of Adaptive Subcarrier Block with Frequency Symbol Spreading for OFDMA

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***Abstract*—In a wireless network, the signals transmitted from one sender to different users have independent channel fluctuation characteristics. The diversity that exists between users is called multiuser diversity and can be exploited by the sender to enhance the capacity of wireless network. In multiuser diversity OFDMA system, exploiting channel fluctuation diversity is in essence done by selecting the user with the strong subcarrier channels. The individual subcarrier selection for each user can achieve the best system performance but high signaling overhead and high system complexity are required. On the other hand, the adaptive subcarrier block method achieves worse BER than that of individual subcarrier selection. This is because the selected block contains the poor channel subcarriers. To overcome this problem, in this paper, we propose an adaptive subcarrier block selection with frequency symbol spreading for an OFDMA system.**

***Keywords*-OFDMA; Frequency Symbol Spreading; Minimum Mean Square Error Combining (MMSEC)**

I. Introduction

Orthogonal frequency division multiplexing (OFDM) is one of the most promising physical layer technologies for high data rate wireless communications due to its robustness to frequency selective fading, high spectral efficiency, and low computational complexity [1]. Moreover, OFDM has been chosen for several broadband WLAN and broadcasting standards like IEEE802.11a, IEEE802.11g, European HIPERLAN/2, terrestrial digital audio broadcasting (DAB) and digital video broadcasting (DVB) [2]-[4].

OFDM allows only one user on the channel at any given time. To accommodate multiple users, a strictly OFDM system must employ time division multiple access (TDMA) or frequency division multiple access (FDMA). Neither of these techniques is time or frequency efficient. Orthogonal frequency division multiplexing access (OFDMA) is a multi-user OFDM that allows multiple access on the same channel. It has been adopted for both uplink and downlink air interfaces of WiMAX fixed and mobile standards, i.e IEEE802.16d and IEEE802.16e respectively [5]-[8]. It has also been adopted by third generation partnership project (3GPP) long-term evolution (LTE) downlink air interface [9].

In a wireless network, the signals transmitted from one sender to different users have independent channel fluctuation characteristics. The diversity that exists between users is called multiuser diversity and can be exploited by the sender to enhance the capacity of wireless network [10]. In multiuser diversity OFDMA systems, exploiting channel fluctuation diversity is in essence done by selecting the user with the strong subcarrier channels [11]. In this case, one subcarrier is selected at once, users do not share the same subcarriers. Therefore, multiuser diversity techniques promise dramatically increased system throughput and spectral efficiency. However, high signalling overhead and high system complexity are required to select the strong subcarrier for each user.

To reduce high signalling overhead and high system complexity, the adaptive subcarrier block (ASB) method has been proposed. Low signalling overhead and low system complexity are merits of an ASB method. It means that an amount of feedback information (FBI) can be reduced. However, an ASB method contains the deep faded subcarriers. Therefore, many errors occur in the deep faded subcarrier. If we can improve the system performance of an ASB method with reduced FBI, the resource allocation is a promising method. In this paper, we propose the resource allocation of an ASB method with frequency symbol spreading for multiuser diversity OFDMA for enhancement of the BER performance. This paper is organized as follows. The system model is described in Section II. In Section III, we describe the proposed multiuser diversity for OFDMA with frequency symbol spreading. In Section IV, we show the simulation results. Finally, the conclusion is given in Section V.

II. System Model

A. Channel Model

We assume that a propagation channel consists of L discrete paths with different time delays. The impulse response $\hbar_k(\tau, t)$ for user k is represented as [12]

$$\hbar_k(\tau, t) = \sum_{l=0}^{L-1} \hbar_{k,l}(t)\delta(\tau - \tau_{k,l}), \tag{1}$$

where $\hbar_{k,l}$ and $\tau_{k,l}$ are the complex channel gain and time delay of the lth propagation path for user k, and $\sum_{l=0}^{L-1} E|\hbar_{k,l}^2| = 1$, where $E|\cdot|$ denotes the ensemble average operation, respectively. The channel transfer function

 ISBN: 978-1-61208-100-7

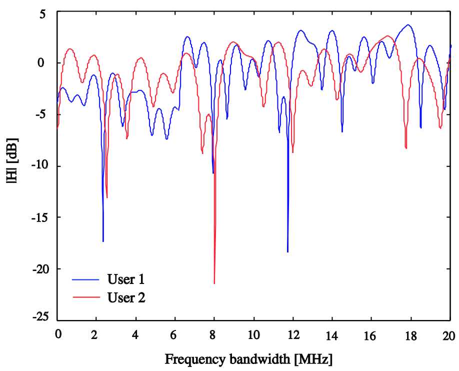

Figure 1. Magnitude of channel transfer function for a radio channel with multiptath.

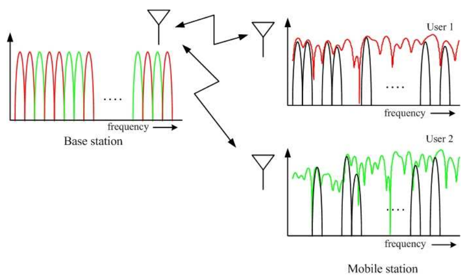

Figure 2. Resource allocation method of maximal sum capacity method for each user.

$h_k(f,t)$ is the Fourier transform of $\hbar_k(\tau,t)$ and is given by

$$\begin{aligned} h_k(f,t) &= \int_0^\infty \hbar_k(\tau,t)\exp(-j2\pi f\tau)d\tau \\ &= \sum_{l=0}^{L-1} \hbar_{k,l}(t)\exp(-j2\pi f\tau_{k,l}). \end{aligned} \quad (2)$$

B. Resource Allocation for Multiuser Diversity OFDMA

Figure 1 shows the magnitude of channel transfer function for different users in a single cell. From Figure 1, each subcarrier fades differently from user to user. Therefore, exploiting channel fluctuation diversity is in essence done by selecting the user with the strong subcarrier. The diversity that exists between users is called multiuser diversity and can be exploited by the transmitter to enhance the capacity of wireless network. Moreover, the combination of multiuser diversity and resource allocation makes great synergy to increase the capacity of wireless network. In multiuser diversity OFDMA systems, the resource allocation criteria for each user is given by

$$Z_{msc}=\sum_{k=0}^{K-1}\sum_{n=0}^{N_c-1}|h_k(n)|^2\alpha_{k,n},\ \alpha_{k,n}=\begin{cases} 1 & \text{allocation} \\ 0 & \text{no allocation} \end{cases} \quad (3)$$

where $h_k(n)$ is the channel impulse response for k user and n subcarrier, $\alpha_{k,n}$ is the selection parameter, N_c is the number of subcarriers, and K is the number of users, respectively. This resource allocation method is called the maximal sum capacity (MSC) as shown in Figure 2 [12]. From Eq. (3), the subcarrier is selected for maximization of Z. In this case, one subcarrier is selected at once, users do not share the same subcarriers. Therefore, multiuser diversity techniques promise dramatically increased throughput and spectral efficiency. However, no data rate proportionality among users and high signalling overhead are serious matters [12]. To improve the data rate fairness, the maximal weighted sum capacity (MWSC) method has been proposed. The resource allocation criteria of the MWSC method is given by

$$Z_{mwsc}=\sum_{k=0}^{K-1}\sum_{n=0}^{N_c-1}\omega_{k,n}|h_k(n)|^2\alpha_{k,n}, \quad (4)$$

where $\omega_{k,n}$ is the weight. However, the MWSC method has no guarantee for meeting proportional user data rates, high signalling overhead and high system complexity are still remained [13]. In an OFDM, the channel response at a particular subcarrier frequency is not supposed to be totally different from its neighboring frequencies, and hence, they must have correlation which depends on the coherence bandwidth of the channel B_c. By using the concept of coherence bandwidth, resource allocation method with the adaptive subcarrier block (ASB) has been proposed for user data rate fairness with reduced complexity as shown in Figure 3 [14]. The resource allocation criteria of an ASB method is given by

$$Z_{asb}=\sum_{k=0}^{K-1}\sum_{\varsigma=0}^{N_c/N_{SF}-1}\{\sum_{q=0}^{N_{SF}-1}|h_k(\varsigma\cdot N_{SF}+q)|^2\}\cdot\alpha_{k,\varsigma}. \quad (5)$$

An ASB method achieves worse BER than that of a MWSC method. This is because an ASB method contains the deep faded subcarriers. Therefore, many errors occur in the deep faded subcarrier. However, low signalling overhead and low system complexity are merits of an ASB method. It means that an amount of FBI can be reduced. Although, the performance degradation of an ASB method is still considerable problem. If we can improve the system performance of an

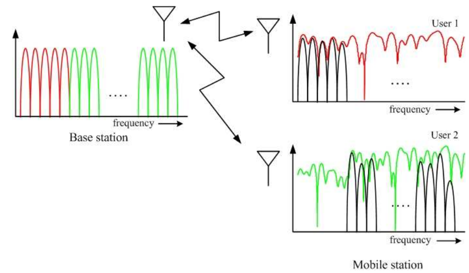

Figure 3. Resource allocation method with adaptive subcarrier block for each user.

ASB method with reduced FBI, the resource allocation is a promising method. In this paper, we propose the resource allocation of an ASB method with frequency symbol spreading for multiuser diversity OFDMA for enhancement of the BER performance.

III. Proposed System

A. Transmitter Structure

The transmitter block diagram of OFDMA with an ASM method using frequency symbol spreading is shown in Figure 4(a). The binary data sequence for user k is modulated, and N_p pilot symbols are appended at the beginning of the sequence. The symbol sequences consist of serial to parallel (S/P) converted to N_{SF} parallel sequences. The N_{SF} parallel sequences are assigned on the adequate frequency symbol spreading block by using Eq.(5), as illustrated in Figures 4(a) and 5(a), where N_{SF} is the spreading code length. Each parallel sequence(subcarrier bock) feds into the frequency symbol spreading block is copied by the same length of spreading code N_{SF}, as shown in Figure 5(a). These copied parallel sequences are spread by the spreading code with N_{SF} and combined. The transmitting signal waveform is obtained by applying an inverse Fourier transform (IFFT). The proposed transmitting signal for user k can be expressed in its equivalent baseband representation as [12]

$$s_k(t) = \sum_{i=0}^{N_p+N_d-1} g(t-iT)\cdot\Big\{\sqrt{\frac{2S}{N_c}}\sum_{n=0}^{N_c-1} u_k(n,i) \cdot \exp\left[j2\pi(t-iT)n/T_s\right]\Big\}, \quad (6)$$

where N_d, N_p are the number of data and pilot symbols, T_s is the effective symbol length, S is the average transmitting power, T is the OFDM symbol length, and $u_k(n,i)$ is the nth subcarrier of the ith OFDM symbol for user k. The power spectra of the input and output signals of the frequency symbol spreading block are shown in Figure 5(b). As indicated by Figure 4, the parallel converted data $d_k(n,i)$ is fed into the ξ_kth frequency symbol spreading block. The input data $d_k(n,i)$ is copied N_{SF} times and multiplied as shown in Figure 5. In the same frequency symbol spreading block, the output spread signals are combined. Therefore, all data are superimposed over the frequency domain. As shown in Figure 5(b), the energy of each input data is divided over N_{SF} subcarriers by means of a spreading subcode, and each subcarrier conveys N_{SF} divided data. The frequency separation between adjacent orthogonal subcarriers is $1/T_s$ and can be expressed, by using the nth subcarrier of the ith modulated symbol $d_k(n,i)$ with $|d_k(n,i)|=1$, as

$$u_k(n,i) = \begin{cases} \sum_{q=0}^{N_{SF}-1} c_q(n \bmod N_{SF}) \\ \cdot d_k(\xi_k N_{SF}+q,i) & \text{for } \xi_k \le \lfloor \frac{n}{N_{SF}} \rfloor < \xi_k+1 \\ 0 & \text{otherwise} \end{cases} \quad (7)$$

where $\xi_k \in \{0,1,\cdots,N_c/N_{SF}-1\}$ is the assigned subcarrier block for user k, "mod" denotes modulus, and $\lfloor x \rfloor$ denotes the largest integer less than or equal to x. From Eq. (7), the subcarrier block is adaptively assigned for each user. The orthogonal spreading sequences $c_q(m)$ satisfy

$$\sum_{m=0}^{N_{SF}-1} c_q(m)c_w^*(m) = \begin{cases} N_{SF} & \text{for } q=w \\ 0 & \text{for } q \neq w \end{cases} \quad (8)$$

where $|c_q(m)|=1$, where $*$ denotes the complex conjugate. In Eq. (6), $g(t)$ is the transmission pulse given by

$$g(t) = \begin{cases} 1 & -T_g \le t \le T_s \\ 0 & \text{otherwise} \end{cases}. \quad (9)$$

B. Receiver Structure

The receiver structure is illustrated in Figure 4(b). By applying the FFT operation, the received signal $r(t)$ is resolved into N_c subcarriers. First, the received signal is frequency equalized to reduce the frequency distortion due

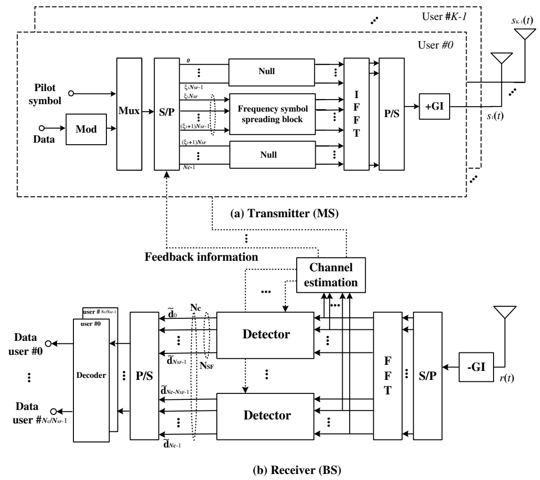

Figure 4. Proposed multiuser diversity OFDMA with frequency symbol spreading and adaptive subcarrier block selection.

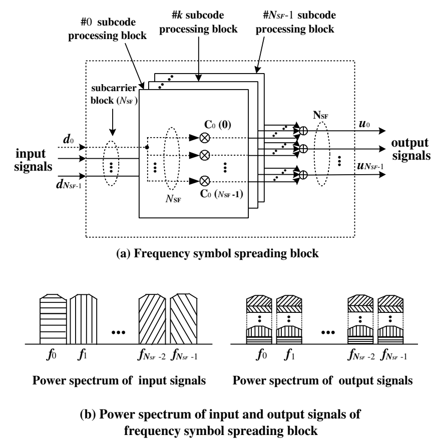

Figure 5. The structure of frequency symbol spreading block and power spectrum of input and output signals of frequency symbol spreading block.

to the frequency-selective fading. The received signal $r(t)$ in the equivalent baseband representation can be expressed as

$$r(t) = \sum_{k=0}^{K-1} \int_{-\infty}^{\infty} h(\tau, t) s_k(t-\tau) d\tau + n(t), \qquad (10)$$

where $n(t)$ is additive white Gaussian noise (AWGN) with a single sided power spectral density of N_0. The nth subcarrier of the ith received signal $\tilde{r}(n,i)$ is given by

$$\begin{aligned}\tilde{r}(n,i) &= \frac{1}{T_s}\int_{iT}^{iT+T_s} r(t)\exp\left[-j2\pi(t-iT)n/T_s\right]dt \\ &= \sqrt{\frac{2S}{N_c}}\sum_{k=0}^{K-1}\sum_{e=0}^{N_c-1} u_k(e,i)\cdot\frac{1}{T_s}\int_0^{T_s}\exp[j2\pi \\ &\quad \cdot(e-n)t/T_s]\cdot\Big\{\int_{-\infty}^{\infty} h(\tau, t+iT) g(t-\tau) \\ &\quad \cdot\exp(-2\pi e\tau/T_s)d\tau\Big\}dt + \hat{n}(n,i) \qquad (11)\end{aligned}$$

where $\hat{n}(n,i)$ is AWGN noise with zero-mean and a variance of $2N_0/T_s$. After abbreviating, Eq. (11) can be rewritten as

$$\begin{aligned}\tilde{r}(n,i) &\approx \frac{1}{T_s}\sqrt{\frac{2S}{N_c}}\sum_{k=0}^{K-1}\sum_{e=0}^{N_c-1} u_k(e,i) \\ &\quad \cdot\int_0^{T_s}\exp[j2\pi(e-n)t/T_s] + \hat{n}(n,i) \\ &= \sqrt{\frac{2S}{N_c}}\sum_{k=0}^{K-1} H(n/T_s, iT) u_k(n,i) + \hat{n}(n,i). \qquad (12)\end{aligned}$$

Observing Eq. (12), we can see that the received signals have frequency distortion arising from the frequency-selective fading. To reduce this frequency distortion, frequency equalization combining is necessary. Here, we explain a channel estimation scheme using N_p pilot symbols. The channel response of the nth subcarrier is given by

$$\tilde{H}(n/T_s) = \frac{1}{N_p\sqrt{2P/N_c}}\sum_{i=0}^{N_p-1}\tilde{r}(n,i)\cdot p^*(n,i), \qquad (13)$$

where $\{p(n,i),\ 0 \le i \le N_p-1\}$ and P are the transmitted pilot symbol and the power, respectively. In frequency-selective fading, the orthogonality among spreading codes may be destroyed. To compensate for the possible broken orthogonality among the spreading codes, frequency equalization schemes such as orthogonal restoration combining (ORC) and minimum mean square error combining (MMSEC) are used for detection.

1) ORC: ORC uses a combining weight that is inversely proportional to the channel transfer function $H(n/T_s)$, in order to perfectly restore the orthogonality. The ORC weight $\omega_{orc}(n,i)$ is given by

$$\omega_{orc}(n,i) = \frac{1}{\tilde{H}(n/T_s)} \qquad (14)$$

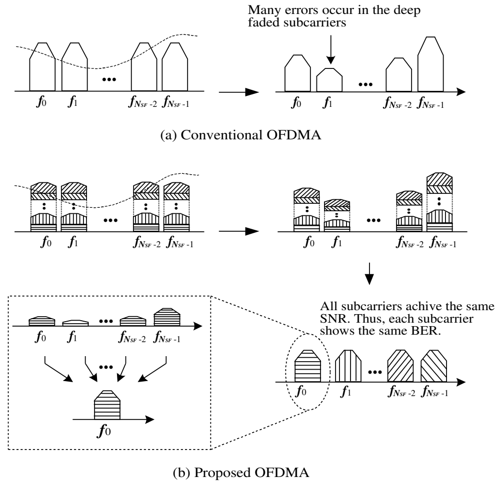

Figure 6. Power spectrum of the proposed OFDMA system.

and the weight $\{\hat{u}_k(n,i),\ n = 0, 1, \cdots, N_c-1\}$ of the nth subcarrier becomes

$$\begin{aligned}\hat{u}_{k,orc}(n,i) &= \omega_{orc}(n,i)\tilde{r}(n,i) \\ &= \sqrt{\frac{2S}{N_c}}\eta(n,i)u_k(n,i) + \frac{\hat{n}(n,i)}{\tilde{H}(n/T_s)}, \\ &\quad \text{for } \ \xi_k \le \lfloor \tfrac{n}{N_{SF}} \rfloor < \xi_k + 1 \qquad (15)\end{aligned}$$

where

$$\eta(n,i) = \frac{H(n/T_s, iT)}{\tilde{H}(n/T_s)}. \qquad (16)$$

The decision variable $\tilde{d}_{k,orc}(n,i)$ of the nth subcarrier of ith data symbol for user k as

$$\begin{aligned}\tilde{d}_{k,orc}(n,i) &= \sum_{q=0}^{N_{SF}-1}\hat{u}_{k,orc}(\xi_k N_{SF}+q, i)c^*_{n \ mod \ N_{SF}}(q) \\ &= \sum_{q=0}^{N_{SF}-1}\Big(\sqrt{\frac{2S}{N_c}}\eta(\xi_k N_{SF}+q, i) \\ &\quad \cdot u_k(\xi_k N_{SF}+q, i) + \frac{\hat{n}(\xi_k N_{SF}+q, i)}{\tilde{H}((\xi_k N_{SF}+q)/T_s)}\Big) \\ &\quad \cdot c^*_{n \ mod \ N_{SF}}(q) \\ &= \sqrt{\frac{2S}{N_c}}\sum_{q=0}^{N_{SF}-1}\eta(\xi_k N_{SF}+q, i) \\ &\quad \cdot d_k(\xi_k N_{SF}+q, i) \\ &\quad +\sqrt{\frac{2S}{N_c}}\sum_{q=0}^{N_{SF}-1}\eta(\xi_k N_{SF}+q, i) \\ &\quad \cdot d_{intr}(\xi_k N_{SF}+q, i)c_w(q)c^*_{n \ mod \ N_{SF}}(q) \\ &\quad +\sum_{q=0}^{N_{SF}-1}\frac{\hat{n}(\xi_k N_{SF}+q, i)c^*_{n \ mod \ N_{SF}}(q)}{\tilde{H}(\xi_k N_{SF}+q/T_s)} \\ &\quad \text{for } \ \xi_k \le \lfloor \tfrac{n}{N_{SF}} \rfloor < \xi_k + 1 \ , \qquad (17)\end{aligned}$$

ISBN: 978-1-61208-100-7

where d_{intr} is the interference term. From Eq. (17), we can observe that the first term is the desired signal, the second term is the interference, and the third term is a noise term. From the third term, ORC scheme can restore the orthogonality, but it enhances the noise term for a deep faded subcarrier.

2) MMSEC: MMSEC combining weight $\omega_{msc}(n,i)$ is given by

$$\omega_{msc}(n,i) = \frac{\sqrt{\frac{2S}{N_c}} \cdot \tilde{H}(n/T_s)}{\left|\sqrt{\frac{2S}{N_c}} \cdot \tilde{H}(n/T_s)\right|^2 + 2\tilde{\sigma}^2} \qquad (18)$$

where $\tilde{\sigma}^2$ is the estimated noise power per subcarrier, which is assumed identical for all subcarriers in this paper. The received modulated data symbol for user k can be written as

$$\tilde{d}_{k,msc}(n,i) = \begin{cases} \sum_{q=0}^{N_{SF}-1} \hat{u}_{k,msc}(\xi_k N_{SF}+q,i) & \\ \cdot c^*_{n \ mod \ N_{SF}}(q) & \text{for } \xi_k \leq \lfloor \frac{n}{N_{SF}} \rfloor < \xi_k+1 \\ 0 & \text{otherwise} \end{cases} \qquad (19)$$

where $\{\hat{u}_{k,msc}(\xi_k N_{SF}+q,i), \quad q=0,1,\cdots,N_{SF}-1\}$ is the weighted component of the user k and is given by

$$\hat{u}_{k,msc}(n,i) = \begin{cases} \sqrt{\frac{2S}{N_c}} u_k(n,i) & \\ \cdot w_{msc}(n,i) & \\ +\hat{n}(n,i) w_{msc}(n,i) & \\ & \text{for } \xi_k \leq \lfloor \frac{n}{N_{SF}} \rfloor < \xi_k+1 \\ 0 & \text{otherwise} \end{cases} \qquad (20)$$

Eq. (20) is made by Eqs. (12) and (18). In OFDMA with an ASB method using frequency symbol spreading, each S/P transformed signal is spread by an orthogonal spreading code with length N_{SF} over N_{SF} subcarriers and combined. This means that each subcarrier holds several superimposed S/P transformed signals with the same power rate. In this case, frequency-selective faded subcarriers are obtained with the same power rate for each S/P-transformed signal. Therefore, the detected signals also have the same SINR. As a result, each subcarrier shows the same BER performance under the frequency selective fading. From this reason, the proposed method can improve the system performance with maintaining low signalling overhead and low system complexity. Moreover, each operation is carried out symbol by symbol. Therefore, the latency is necessary only one symbol time. Since the current systems such as LTE and WiMAX, use the subcarrier block method for each user, it is easy to embed the proposed method on the current systems.

IV. Computer Simulated Results

Figure 4 shows a simulation model of the proposed multiuser diversity OFDMA with $N_c = 64$ subcarriers and its bandwidth 20MHz. On the transmitter side, the bits are QPSK modulated and then serial-to-parallel transformed. The OFDM time signals are generated by an IFFT and transmitted over the frequency selective and time variant radio channel after cyclic extensions have been inserted. The transmitted signals are subject to broadband channel propagation. In this model, $L = 15$ path Rayleigh fadings have exponential shapes with path separation $T_{path} = 140nsec$ and the RMS delay spread is $\tau_{rms} = 0.65\mu s$. This situation causes severe frequency selective fading. The maximum Doppler frequency is assumed to be 10Hz. The packets consist of 64 subcarriers and 22 OFDM symbols (number of pilot signals: $N_p = 2$, number of data signals: $N_d = 20$). Table 1 shows the simulation parameters.

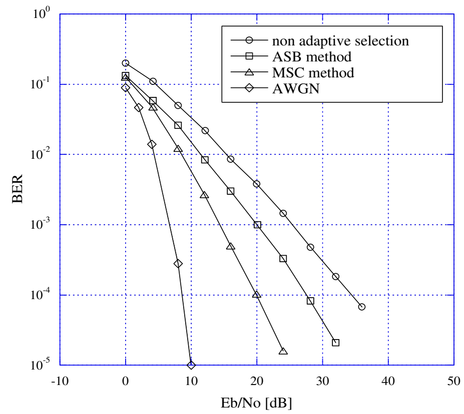

Figure 7. BER of non adaptive selection, the ASB method and the MSC method for multiuser diversity OFDMA system with 4 users and N_{SF}=16 for Doppler frequency of 10Hz.

Figure 7 shows the BER of non adaptive selection, the ASB method and the MSC method for multiuser diversity OFDMA system with 4 users and N_{SF}=16 for Doppler frequency of 10Hz. From the simulation results, the MSC method achieves the best BER performance compared with non adaptive selection and the ASB method. This is because the MSC method can select subcarriers with highest SNR for each user. On the other hand, the ASB method shows worse BER than that of the MSC method. This is because the selected block includes the poor subcarriers.

Figure 8 shows the BER of non adaptive selection, the

Table I
Simulation parameters.

Modulation	QPSK
Demodulation	Coherent detection
Effective data rate	20 Msymbol/s
Number of users	4
Number of carriers	$N_c = 64$
Bandwidth	20MHz
Guard interval	16 sample times
Frame size	22 symbols ($N_p = 2, N_d = 20$)
Fading	15 path Rayleigh fading
Doppler frequency	10 Hz
Subcarrier block size	$N_{SF} = 16$

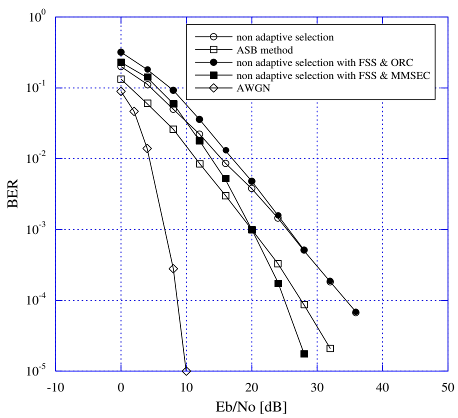

Figure 8. BER of non adaptive selection, the ASB method, non adaptive selection with frequency symbol spreading (FSS) and ORC and the ASB method with frequency symbol spreading and MMSEC with 4 users and N_{SF}=16 for Doppler frequency of 10Hz.

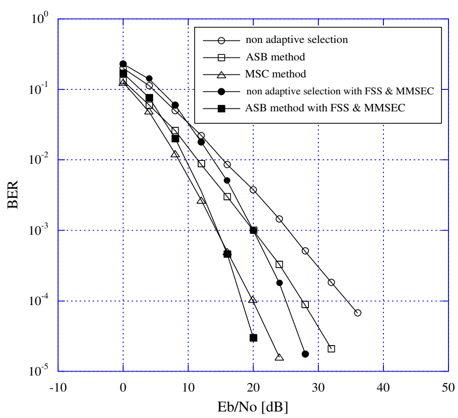

Figure 9. BER of non adaptive selection, the ASB method, the MSC method, non adaptive selection and the ASB method using frequency symbol spreading and MMSEC with 4 users and N_{SF}=16 for Doppler frequency of 10Hz.

ASB method, non adaptive selection with frequency symbol spreading and ORC and the ASB method with frequency symbol spreading and MMSEC with 4 users and N_{SF}=16 for Doppler frequency of 10Hz. Non adaptive selection with frequency symbol spreading and ORC shows worse BER than that of non adaptive selection in low E_b/N_o. This is because the ORC based non adaptive selection with frequency symbol spreading enhances the noise although no error floor is seen. The MMSEC provides the best BER performance, since the MMSEC minimize the power loss while suppressing the noise enhancement.

Figure 9 shows the BER of non adaptive selection, the ASB method, the MSC method, non adaptive selection and the ASB method using frequency symbol spreading and MMSEC with 4 users and N_{SF}=16 for Doppler frequency of 10Hz. From the simulation results, the proposed ASB method with frequency symbol spreading and MMSEC provides the best BER performance in high E_b/N_o, since the ASB method obtains the highest SNR subcarrier block and the frequency symbol spreading and MMSEC minimize the noise enhancement.

V. Conclusion

In this paper, we have proposed the ASB method with frequency symbol spreading for OFDMA system. From the simulation results, the proposed ASB method with frequency symbol spreading and MMSEC achieves 1dB gain compared with the conventional MSC method at BER of 10^{-4}. Moreover, the proposed method can reduce the quantities of FBI compared with the MSC method.

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