Adaptive Subcarrier Allocation in Synchronous Reverse Links of a Multicarrier CDMA System with Time and Frequency Spreading

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***Abstract*—Multicarrier code-division multiple access (CDMA) with time and frequency spreading has been recently considered as a candidate for fourth-generation (4G) wireless systems. This signaling scheme simultaneously utilizes code spreading in the time and frequency domains to simultaneously improve frequency diversity and minimize multiuser access interference. As a result, it is capable of outperforming multicarrier CDMA systems that employ 1-D spreading. In this paper, a novel adaptive subcarrier allocation algorithm is developed for multicarrier CDMA with time and frequency spreading to improve the overall bit error rate (BER) performance for all spreading configurations. This algorithm assigns users to subcarrier groups that provide favorable fading characteristics while simultaneously reducing the amount of interference caused to other users. The proposed algorithm is shown to provide a performance improvement, ranging from 1.5 dB with 2 × 16 (time × frequency) and spreading to 7 dB with 16 × 2 (time × frequency) spreading. The algorithm is also shown to maintain or improve the BER floor for each spreading configuration. It is concluded that at higher and lower levels of E_b/N_o, a higher frequency- and time-domain spreading should be, respectively, employed to improve BER performance. Furthermore, the E_b/N_o threshold level to switch between time and frequency spreading for the analyzed system is found to be 2.5 dB.**

***Index Terms*—Adaptive subcarrier allocation, multicarrier code-division multiple access (CDMA), synchronous reverse links, time- and frequency-domain spreading.**

I. Introduction

THE fourth generation (4G) of wireless systems is intended to support high-throughput applications such as streaming video, multimedia, and Internet access. These services generally require throughput in the megabit-per-second range. To support these high data rates, the channel bandwidth for 4G is as high as 100 MHz in the forward link and 20 MHz in the reverse link. To accommodate this large bandwidth, several 4G systems that utilize multicarrier modulation to minimize the intersymbol interference that occurs when transmitting through wideband wireless channels have been proposed.

In particular, multicarrier direct-sequence code-division multiple access (MC-DS-CDMA) has been proposed [1], where DS-CDMA waveforms are transmitted over orthogonal subcarriers. This transmission method is capable of providing multiple access with low interference by employing user-specific spreading sequences with low cross correlation. Another proposed 4G architecture is multicarrier CDMA (MC-CDMA) [2]–[4], where spreading occurs in the frequency domain. Each bit is copied to several parallel subcarriers and modulated with chips from the frequency-domain spreading sequence to provide orthogonality between users. Since each bit is transmitted over several independently faded subcarriers, performance is improved due to frequency diversity. The drawback of this approach, however, is that the frequency-selective channel destroys the orthogonality between spreading sequences, which may cause high levels of multiuser access interference (MAI).

A recently introduced variant of multicarrier CDMA simultaneously combines time- and frequency-domain spreading. This technology, called *multicarrier CDMA with time and frequency spreading* in this paper, has been shown to improve performance over MC-CDMA and MC-DS-CDMA systems [5], [6]. This system benefits from frequency diversity while minimizing the amount of MAI by employing time-domain spreading. Further improvements can also be achieved by flexibly controlling the time- and frequency-domain spreading factors based on the fading characteristics and channel load [15]–[17].

Adaptive subcarrier allocation has recently become an active research area for multicarrier systems. Several algorithms have been proposed for MC-CDMA. In [8], the subcarriers are divided into small groups and separated throughout the spectrum. This is shown to minimize MAI and maximize gains from frequency diversity. In [9], the subcarriers are adaptively assigned based on the fading process, whereas [10] examines the effect of equalizing the interference in each subcarrier group. Adaptive subcarrier allocation is also effective for MC-DS-CDMA. In particular, forward link adaptation algorithms are developed in [12] and [13], which select subcarriers based on the fading gains. In [14], a reverse link algorithm is proposed, which employs the water-filling principle to assign users to subcarriers with a favorable signal-to-interference-plus-noise ratio (SINR), while simultaneously minimizing the interference to other users.

In this paper, we develop a novel low-complexity adaptive subcarrier allocation algorithm for multicarrier CDMA systems with time and frequency spreading to improve the bit error rate (BER) performance for all spreading factors. To the best of the authors' knowledge, this is the first paper that adaptively

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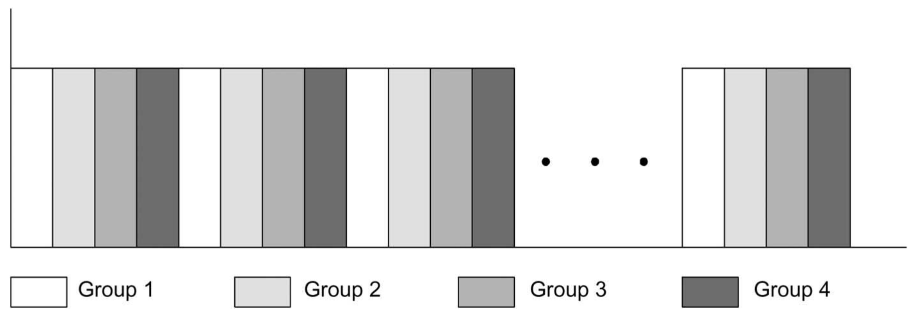

Fig. 1. Subcarrier allocation with four subcarrier groups.

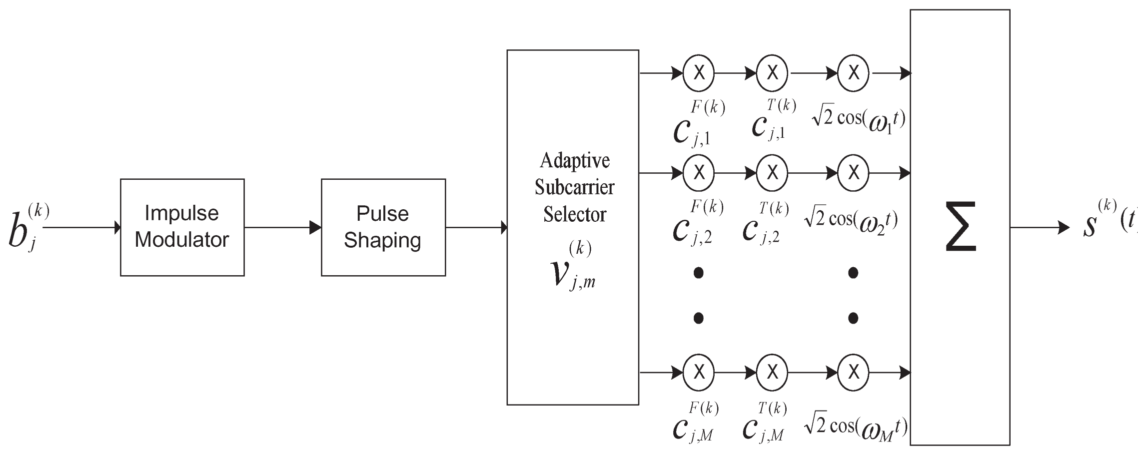

Fig. 2. Block diagram for the adaptive multicarrier CDMA system with time and frequency spreading.

allocates subcarriers for multicarrier CDMA systems with time and frequency spreading. Since the above system improves performance by simultaneously employing time- and frequency-domain spreading, we employ several findings from [8]–[14] to improve performance. Consequently, the subcarriers are separated into noncontiguous groups to maximize frequency diversity and minimize MAI. The users are recursively assigned to subcarrier groups that provide the highest possible level of SINR while simultaneously minimizing the amount of MAI to other users on the corresponding group. At each iteration, the interference power caused by the assigned user is utilized to recalculate the SINR for the subcarrier group, and the algorithm recursively continues until all users are assigned to the channel.

This paper is organized as follows. In Section II, we describe the subcarrier grouping strategy and present the adaptive multicarrier CDMA system model with time and frequency spreading. Section III describes the adaptive subcarrier allocation algorithm, and the numerical results are shown in Section IV for different spreading factors. Finally, Section V concludes this paper.

II. System Model

A. Subcarrier Grouping

Based on the results found in [8], the subcarriers are separated into noncontiguous groups that are equally spaced throughout the spectrum. These smaller groups are utilized to reduce the interference caused from frequency-domain spreading. The spacing of subcarrier groups also maximizes gains from frequency diversity because independent fading is likely to occur on each subcarrier. The subcarriers are separated into groups denoted as G_y, $y = \{1, 2, \ldots, Y\}$, where Y is the total number of groups. The subcarriers in group y are defined as

$$\begin{aligned} G_1 &= \left\{m_1, m_{1+\mu}, m_{1+2\mu}, \ldots, m_{1+(M_1-1)\mu}\right\} \\ G_2 &= \left\{m_2, m_{2+\mu}, m_{2+2\mu}, \ldots, m_{2+(M_2-1)\mu}\right\} \\ &\vdots \\ G_Y &= \left\{m_Y, m_{Y+\mu}, m_{Y+2\mu}, \ldots, m_{Y+(M_Y-1)\mu}\right\} \end{aligned} \tag{1}$$

where μ is the separation between subcarriers, and M_y is the number of subcarriers in group y. An example of the subcarrier grouping strategy is shown in Fig. 1 with four subcarrier groups.

B. Transmitter

A block diagram for the transmitter of the adaptive multicarrier CDMA system with time and frequency spreading is shown in Fig. 2.

The binary data stream for user k, $\mathbf{b}_j^{(k)} = \pm 1$, $j \epsilon \aleph$ is impulse modulated with BPSK and processed with a rectangular pulse-shaping filter with the response $p(t - jT_b)$, where T_b is the symbol duration. The resulting signal is copied to the subcarriers in the yth subcarrier group, where the group y is defined by the adaptive subcarrier allocation algorithm that occurs at

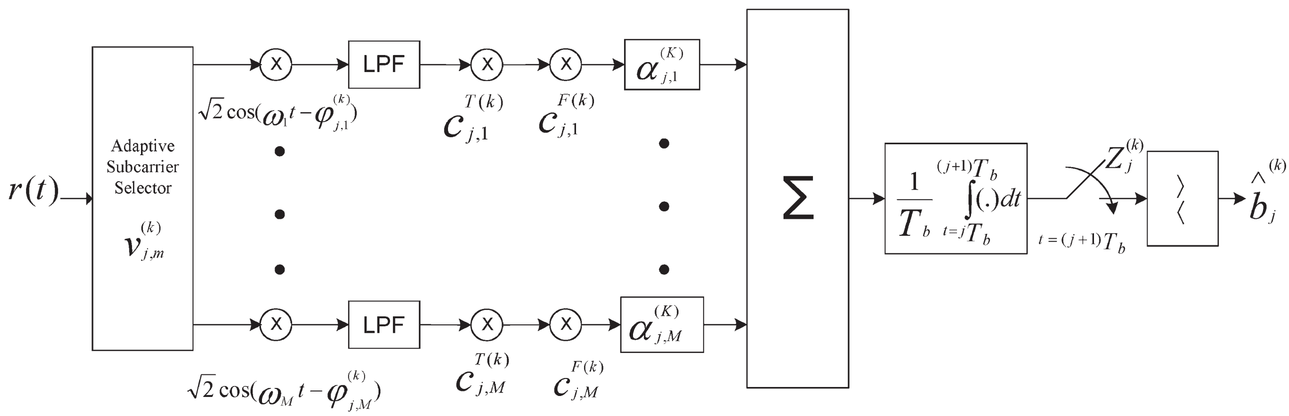

Fig. 3. Receiver block diagram for adaptive multicarrier CDMA system with time and frequency spreading.

the base station. Each subcarrier is multiplied by the frequency-domain pseudo-random (PN) chip $c_{j,m}^{F(k)}$ to provide frequency-domain spreading. Time-domain spreading is then performed by modulating the signal with the time-domain PN sequence $\mathbf{c}_{j,m}^{T(k)} = \sum_{n=1}^{N} c_{j,m,n}^{T(k)} p(t-(jN+n)T_c)$, where T_c is the PN chip duration, N is the length of the PN sequence, and $c_{j,m,n}^{T(k)}$ is the nth chip in the time-domain spreading sequence. Random sequences are assumed throughout this paper. The resulting signal is modulated to the frequency of the corresponding subcarrier ω_m. Each of these subcarrier frequencies is spaced by $1/T_c$ to ensure that the subcarriers are orthogonal. The result is finally summed to generate the transmitted signal for the kth user as

$$s^{(k)}(t) = \sqrt{2\varepsilon_c}\sum_j b_j^{(k)} \sum_{m=1}^{M} v_{j,m}^{(k)} c_{j,m}^{F(k)} \cos(\omega_m t) \times \sum_{n=1}^{N} c_{j,m,n}^{T(k)} p\left(t-(jN+n)T_c\right) \quad (2)$$

where ε_c is the chip energy, and the parameter $v_{j,m}^{(k)}$ is defined as

$$v_{j,m}^{(k)} = \begin{cases} 1, & \text{if } m\epsilon G_y \\ 0, & \text{otherwise.} \end{cases} \quad (3)$$

More specifically, $v_{j,m}^{(k)} = 1$ if the mth subcarrier is assigned to user k. If the subcarrier is not allocated to user k during the jth signal element, $v_{j,m}^{(k)} = 0$.

C. Channel Model

In this analysis, the channel is assumed to be slowly varying with respect to the bit duration T_b. We also assume that the delay spread is smaller than the time-domain PN chip time T_c. Under this assumption, frequency-nonselective fading occurs on each subcarrier. This allows the frequency-domain channel model to be defined as

$$H_{j,m}^{(k)} = \alpha_{j,m}^{(k)} e^{i\phi_{j,m}^{(k)}} \quad (4)$$

where $i=\sqrt{-1}$. The term $\alpha_{j,m}^{(k)}$ is the Rayleigh fading gain for the mth subcarrier of the kth user during the jth transmitted bit. The phase is a uniformly distributed random variable over the interval $(0, 2\pi]$, which is independent for each bit, user, and subcarrier. Since the delay spread is less than the symbol duration, the fading amplitudes are approximated as being flat. In addition, since the algorithm uses subcarriers that are evenly spaced throughout the spectrum, each subcarrier is assumed to be independent since staggering the subcarriers ensures that the spacing is larger than the coherence bandwidth.

Since this algorithm operates in the reverse link, the transmitter is located at the mobile terminal. Consequently, the signal received at the base station consists of a summation of signals from K simultaneously transmitting users. The total received signal is written as

$$r(t) = \sqrt{2\varepsilon_c}\sum_{k=1}^{K}\sum_j b_j^{(k)} \sum_{m=1}^{M} v_{j,m}^{(k)} \alpha_{j,m}^{(k)} c_{j,m}^{F(k)} \times \cos\left(\omega_m t + \varphi_{j,m}^{(k)}\right) \times \sum_{n=1}^{N} c_{j,m,n}^{T(k)} p\left(t-(jN+n)T_c\right) + \eta(t) \quad (5)$$

where $\eta(t)$ is the additive white Gaussian noise (AWGN) signal with a double-sided power spectral density of $N_o/2$.

D. Receiver

The received signal $r(t)$ is recovered at the base station, as shown in Fig. 3. To recover the data from user 1, the $r(t)$ is copied to the subcarriers that are assigned to user 1. The signal on the mth subcarrier is restored to the baseband by multiplying with $\sqrt{2}\cos(\omega_m t - \varphi_{j,m}^{(1)})$ followed by low-pass filtering (LPF). The phase $\varphi_{j,m}^{(1)}$ is necessary to eliminate the phase shift produced by the channel. Each branch is multiplied by the synchronized time-domain spreading sequence $\mathbf{c}_{j,m}^{T(1)}$ and the frequency-domain PN chip $c_{j,m}^{F(1)}$. The despread signal is then multiplied by the fading gain $\alpha_{j,m}^{(1)}$ according to the maximal ratio combining algorithm. Finally, the subcarriers are summed, integrated over the bit period, and sampled to yield the decision variable for user 1, i.e.,

$$Z_j^{(1)} = D_j^{(1)} + I_j^{(1)} + \eta_j^{(1)} \tag{6}$$

where $D_j^{(1)}$ is the desired signal, $I_j^{(1)}$ is the interference from the other users on group y, and $\eta_j^{(1)}$ is the noise term.

We can determine the desired signal by considering the correlation between the time- and frequency-domain PN sequences with the transmitted signal for user 1. The desired signal is written as

$$D_j^{(1)} = N\sqrt{\varepsilon_c} b_j^{(1)} \sum_{m \epsilon G_y} \left(\alpha_{j,m}^{(1)}\right)^2 \tag{7}$$

where $m\epsilon G_y$ is the set of subcarriers in group y.

The interference term is calculated by considering the correlation between the received signals from all K_y users on group y with the time- and frequency-domain spreading sequences for user 1. The resulting interference term is

$$I_j^{(1)} = \sqrt{\varepsilon_c} \sum_{k\epsilon G_y} b_j^{(k)} \sum_{m\epsilon G_y} \alpha_{j,m}^{(1)} \alpha_{j,m}^{(k)} c_{j,m}^{F(1)} c_{j,m}^{F(k)} \left(\varphi_{j,m}^{(k)} - \varphi_{j,m}^{(1)}\right) \times \frac{1}{T_c} \int_{t=jT_b}^{(j+1)T_b} \sum_{n=1}^{N} c_{j,m,n}^{T(1)} c_{j,m,n}^{T(k)} p\left(t-(jN+n)T_c\right) dt \tag{8}$$

where $k\epsilon G_y$ is the set of users that simultaneously transmit on subcarrier group y.

Finally, the noise term $\eta(t)$ is processed through the demodulator with the same steps as the desired and interference terms. The resulting noise term at the output of the correlator is

$$\eta_j^{(1)} = \sum_{m=1}^{M} \alpha_{j,m}^{(1)} c_{j,m}^{F(1)} \frac{1}{T_c} \int_{t=jT_b}^{(j+1)T_b} \sum_{n=1}^{N} c_{j,m,n}^{T(1)} p\left(t-(jN+n)T_c\right) \times \text{LPF}\left\{n(t)\sqrt{2}\cos\left(\omega_m t - \phi_{j,m}^{(1)}\right)\right\} dt. \tag{9}$$

E. SINR and BER Calculation

Based on the desired, interference, and noise terms determined in the previous section, we can calculate the SINR for user 1 during the jth bit ($\gamma_j^{(1)}$). The power of the desired signal is determined by finding the variance of the desired signal $D_j^{(1)}$. Since the bit stream $\mathbf{b}_j^{(1)}$ is zero mean, the power of the desired signal is written as

$$P_{d_j}^{(1)} = \text{Var}\left[D_j^{(1)}\right] = N^2 \varepsilon_c \left[\sum_{m\epsilon G_y} \left(\alpha_{j,m}^{(1)}\right)^2\right]^2. \tag{10}$$

The interference power can be approximated as a Gaussian random variable when the number of users is moderate to large, and the input data stream is random [6], [14]. The resulting interference power is

$$P_{i_j}^{(1)} = N\varepsilon_c (K_y - 1) E\left[(\alpha_y)^2\right] \sum_{m\epsilon G_y} \left(\alpha_{j,m}^{(1)}\right)^2 \tag{11}$$

where K_y is the number of users simultaneously occupying group y, and $E[(\alpha_y)^2]$ is the average fading gain for the K_y users and M_y subcarriers in group y.

Finally, the noise power is

$$P_{\eta_j}^{(1)} = \text{Var}\left[\eta_j^{(1)}\right] = N\, N_o \sum_{m\epsilon G_y} \left(\alpha_{j,m}^{(1)}\right)^2. \tag{12}$$

By substituting the power of the desired, interference, and noise terms into the SINR equation, the resulting SINR for user 1 on group y is

$$\gamma_{j,G_y}^{(1)} = \frac{N\varepsilon_c \sum_{m\epsilon G_y} \left(\alpha_{j,m}^{(1)}\right)^2}{(K_y-1)\varepsilon_c E\left[(\alpha_y)^2\right] + N_o}. \tag{13}$$

Based on this result, the probability of bit error can be determined for the jth bit as

$$P_{b_j}^{(1)} = Q\left(\sqrt{2\gamma_{j,G_y}^{(1)}}\right). \tag{14}$$

III. Adaptive Subcarrier Allocation

The goal of the proposed algorithm is to improve the overall BER performance for a multicarrier CDMA system with time and frequency spreading under various spreading factors. To improve the BER, we aim to maximize the average SINR of the system. To produce this effect, we utilize a recursive algorithm based on the algorithm utilized in [14], which uses the water-filling principle to assign users to subcarriers with a high SINR, while simultaneously reducing the interference to other users on the same subcarrier group.

It is evident from (13) that the SINR is dependent on the fading gains for user 1 and the interference power on group y. It may seem logical to allocate each user to the subcarrier group that provides the best fading characteristics. While this may maximize the SINR for the intended user, it increases the interference to other users in the same subcarrier group and reduces the average SINR.

As a result, this algorithm recursively assigns users to subcarriers with the highest possible SINR while simultaneously minimizing the amount of MAI to other users in the same subcarrier group. This algorithm searches for the group with the largest SINR for each user. From this set, the user is assigned what is expected to produce the lowest amount of interference. The SINR is then recalculated for the subcarrier group based on the anticipated interference caused by the user. This process recursively continues until all users are assigned.

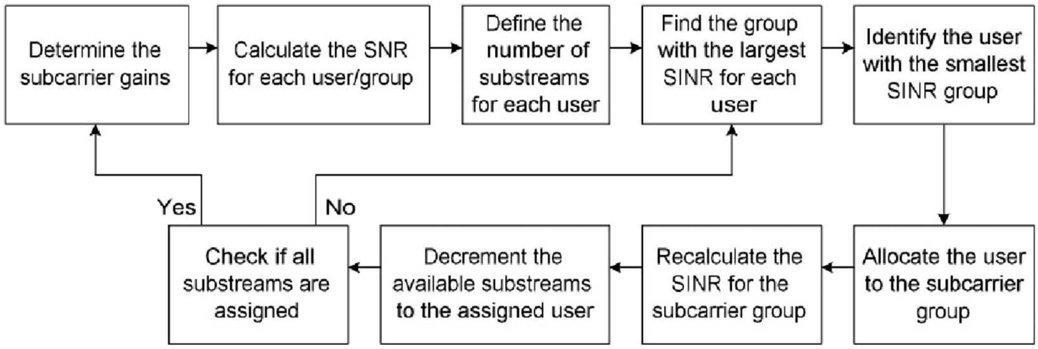

Fig. 4. Adaptive subcarrier allocation flowchart.

A. Algorithm

Step 1) Define the set $Q = \{\beta^{(1)}, \beta^{(2)}, \ldots, \beta^{(K)}\}$, where $\beta^{(k)}$ is the maximum number of substreams that can be transmitted by the kth user.

Step 2) Determine the fading gain of each subcarrier for all k users. These gains are expressed as

$$\lambda = \begin{bmatrix} \alpha_1^{(1)} & \alpha_2^{(1)} & \cdots & \alpha_M^{(1)} \\ \alpha_1^{(2)} & \alpha_2^{(2)} & \cdots & \alpha_M^{(2)} \\ \vdots & \vdots & & \vdots \\ \alpha_1^{(K)} & \alpha_2^{(K)} & \cdots & \alpha_M^{(K)} \end{bmatrix} \tag{15}$$

where $\alpha_m^{(k)}$ is the gain of the mth subcarrier for the kth user.

Step 3) Calculate the SNR on each group for all k users as

$$\gamma_y^{(k)} = \frac{N\varepsilon_c \sum_{m\epsilon G_y} \left(\alpha_{j,m}^{(k)}\right)^2}{N_o}. \tag{16}$$

This process yields the SNR for each user–group combination as

$$\zeta = \begin{bmatrix} \gamma_1^{(1)} & \gamma_2^{(1)} & \cdots & \gamma_Y^{(1)} \\ \gamma_1^{(2)} & \gamma_2^{(2)} & \cdots & \gamma_Y^{(2)} \\ \vdots & \vdots & & \vdots \\ \gamma_1^{(K)} & \gamma_2^{(K)} & \cdots & \gamma_Y^{(K)} \end{bmatrix}. \tag{17}$$

Step 4) Find the subcarrier group that has the largest $\gamma_y^{(k)}$ for all k users. The group with the maximum SINR for user k is found as

$$\gamma_{\max}^{(k)} = \max\left\{\gamma_1^{(k)}, \gamma_2^{(k)}, \ldots, \gamma_Y^{(k)}\right\} \tag{18}$$

for all k, where $\beta^{(k)} \neq 0$. We record the index denoted $y_{\max}^{(k)}$.

Step 5) From the result in Step 4, find the subcarrier group with the smallest SINR as

$$\gamma_{\min} = \min\left\{\gamma_{\max}^{(1)}, \gamma_{\max}^{(2)}, \ldots, \gamma_{\max}^{(K)}\right\}. \tag{19}$$

Record the index of the user with the lowest SINR value (denoted $k_{\min}$).

Step 6) Assign user $k_{\min}$ to the subcarrier group $y_{\max}^{(k_{\min})}$.

Step 7) Recalculate the SINR for the subcarrier group that corresponds to $y_{\max}^{(k_{\min})}$. The SINR for the entire column representing the group of ζ is recalculated according to the SINR equation

$$\gamma_y^{(k)} = \frac{N\varepsilon_c \sum_{m\epsilon G_y} \left(\alpha_m^{(k)}\right)^2}{(K_y - 1)\varepsilon_c E\left[(\alpha_y)^2\right] + N_o} \tag{20}$$

for $k\epsilon\{1, 2, \ldots, K\}$. If $K_y \times M_y$, the number of users and subcarriers is large enough. Based on the law of large numbers, the term $E[(\alpha_y)^2]$ is updated as

$$E\left[(\alpha_y)^2\right] = \frac{1}{K_y M_y} \sum_{k\epsilon G_y} \sum_{m\epsilon G_y} \left(\alpha_m^{(k)}\right)^2. \tag{21}$$

Step 8) Decrement the number of substreams for user $k_{\min}$, $\beta^{k_{\min}} = \beta^{k_{\min}} - 1$. If the set $Q = 0$, return to Step 1. Otherwise, return to Step 4.

The above steps are summarized in a flowchart in Fig. 4.

IV. Results and Discussion

The performance of the proposed system is evaluated with a Monte Carlo analysis. The reverse link bandwidth is assumed to be 20 MHz, with a total of 128 subcarriers. We assume that the delay spread is 6.4 μs, which is common in urban areas [14]. There are 32 users assigned to the channel by the subcarrier allocation algorithm. Each of the users is assumed to be travelling at a velocity of 5 km/h, which corresponds to a Doppler frequency of 23.14 Hz. This corresponds to a coherence time of approximately 18 μs. The update period of the algorithm is identical to the coherence time in this simulation to ensure that the algorithm adapts to the current channel conditions.

Since the multicarrier CDMA system with time and frequency spreading is capable of providing different performance characteristics by altering the spreading factor, we consider four different configurations and compare these results with those generated by You *et al.* in [6]—which is denoted as *Non-adaptive*, and the proposed algorithm is denoted as *Adaptive*, in the figures. In Fig. 5(a), the performance of the adaptive subcarrier allocation algorithm is evaluated when time-domain spreading is prioritized. A time-domain spreading factor of 16

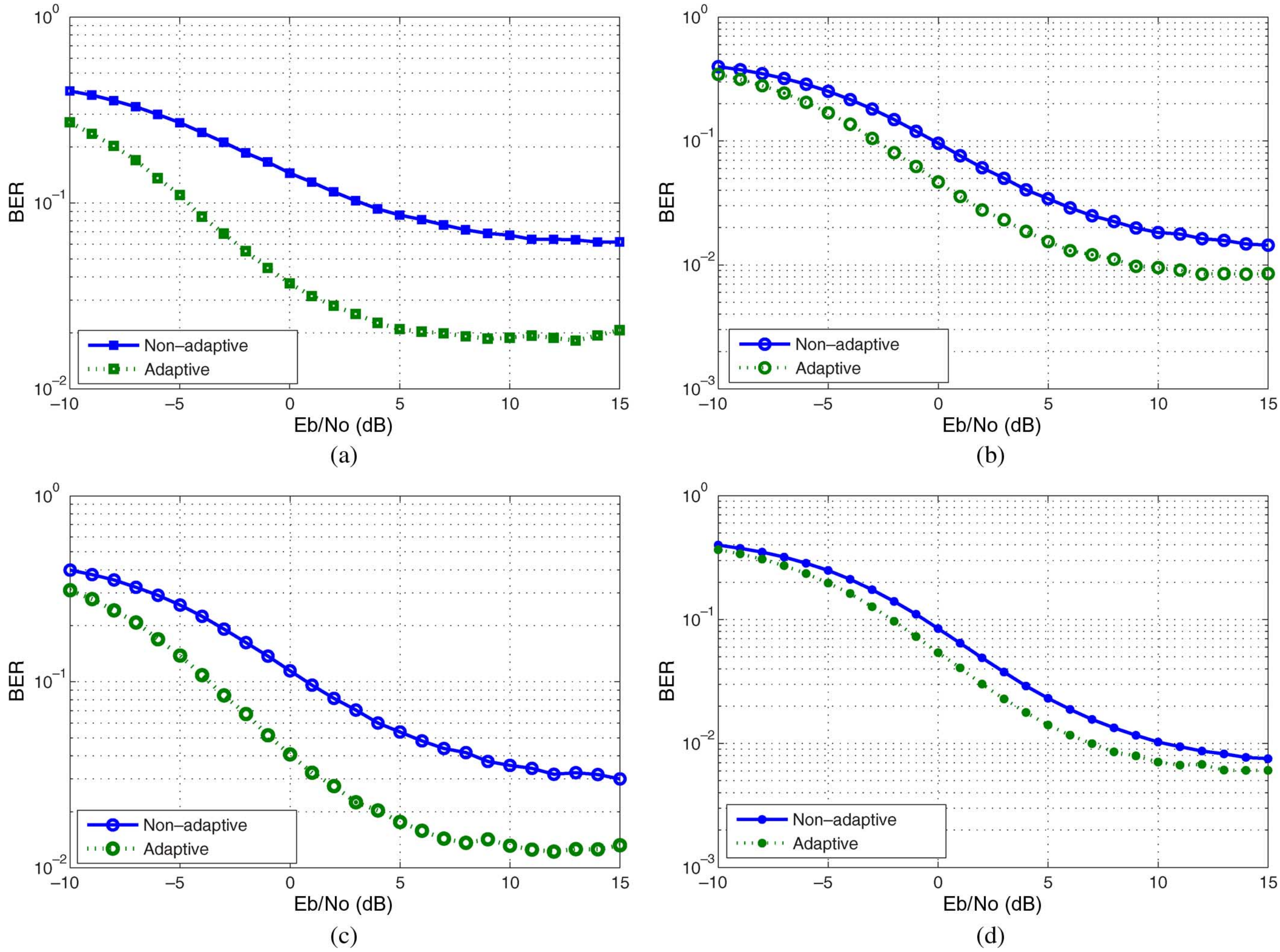

Fig. 5. BER versus E_b/N_o with (a) 16×2, (b) 8×4, (c) 4×8, and (d) 2×16.

is utilized, with a frequency-domain processing gain of 2. This configuration is denoted 16×2. These results show that the proposed algorithm is able to significantly outperform a non-adaptive multicarrier CDMA system with time and frequency spreading. An improvement of approximately 7 dB is achieved in the noise-limited region of the curve, and the BER floor is improved.

In Fig. 5(b) and (c), the BER versus E_b/N_o curve for the 8×4 and 4×8 spreading is shown, respectively. The results indicate that for both spreading configurations, the proposed algorithm reduces the BER floor and improves performance in the noise-limited region of the BER curve. More specifically, a 4-dB gain is achieved with 8×4 spreading, whereas a 2.5-dB gain is achieved with 4×8 spreading.

In Fig. 5(d), we plot the BER versus E_b/N_o curve for the adaptive and nonadaptive multicarrier CDMA system with time and frequency spreading with 2×16 spreading. This represents a case where frequency-domain spreading is prioritized to maximize gains from frequency diversity. The results indicate that the adaptive system is able to improve the BER performance by approximately 1.5 dB and maintain the BER floor.

Finally, in Fig. 6, we plot the BER versus E_b/N_o curve for the adaptive multicarrier CDMA system with different spreading factors. This figure presents an interesting characteristic of the adaptive subcarrier allocation algorithm. At small values of E_b/N_o, the absolute performance is superior when a high time-domain spreading factor is utilized. This result is expected

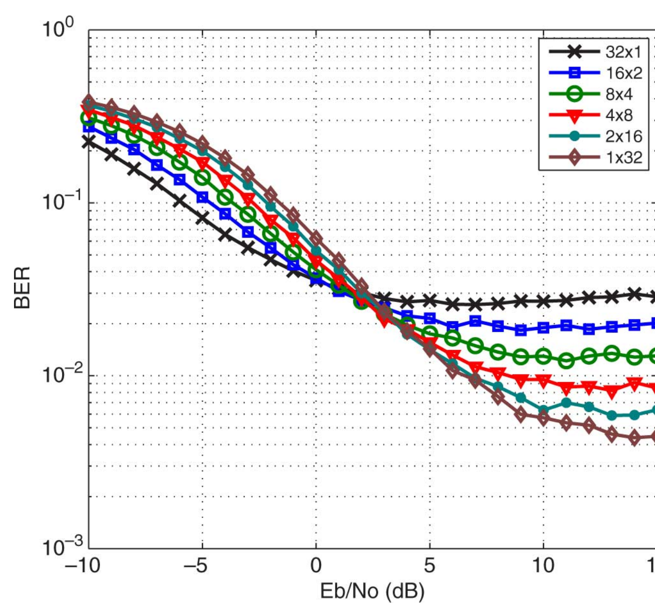

Fig. 6. BER versus E_b/N_o for adaptive multicarrier CDMA system with various spreading factors.

because there are more subcarrier groups available to maximize the average SINR of the system. The opposite result occurs at high E_b/N_o values. To explain this phenomenon, we refer to the results provided in [14], where the performance of the water-filling algorithm is originally evaluated for single subcarrier allocation. In that paper, it is found that the algorithm is suboptimal at higher values of E_b/N_o. This occurs because the system performance is limited by MAI, and selecting subcarriers with large SINR values provides a negligible gain with respect to the AWGN noise power. In addition, since more substreams are utilized for higher time-domain spreading factors, several substreams are assigned to less-favorable subcarriers. The number of substreams simply changes the system capacity. Other simulations could be done with either a different number of users or a different number of substreams, and the results and subsequent conclusions would be similar. Our results indicate that the frequency diversity gained by transmitting over independently faded subcarriers produces a more favorable result at high levels of E_b/N_o. It is evident from this curve that there is a distinct threshold above 2.5 dB, where a higher frequency-domain spreading factor is superior. This represents the transition of the multicarrier CDMA time and frequency spreading system from being limited by thermal noise to being interference limited. As a result, when high bit energies are employed, a high frequency-domain spreading factor should be employed to maximize the absolute performance. At lower levels of E_b/N_o, time-domain spreading should be prioritized to improve performance. These results suggest that the adaptive subcarrier allocation algorithm is more effective with lower frequency-domain spreading factors. This occurs because there are more available subcarrier groups, allowing the system to locate the subcarrier group that has the best SINR characteristics, while simultaneously minimizing the amount of interference. It is also found that frequency diversity moderates the SINR on each subcarrier, which minimizes the improvement from selecting subcarriers with favorable fading gains.

V. Conclusion

In 4G wireless communications, users will require access to high-data-rate applications such as streaming video, multimedia, and Internet access. Since these applications require a large bandwidth, a multicarrier CDMA system with time and frequency spreading is a viable option to support these demanding requirements. This technology is also able to outperform MC-CDMA and MC-DS-CDMA systems by simultaneously utilizing time- and frequency-domain spreading. The proposed adaptive subcarrier allocation algorithm is shown to further improve the BER performance for a multicarrier CDMA system with time and frequency spreading. The BER performance improvement ranges from 1.5 dB with 2×16 spreading to 7 dB with 16×2 spreading. The BER floor is also reduced or maintained in each of these configurations. Overall, this algorithm is an excellent method of improving the BER performance of a multicarrier CDMA system with time and frequency spreading with minimal implementation complexity.

The adaptive subcarrier allocation algorithm proposed in this paper utilizes a spreading factor that can be changed based on the conditions that exist in the cell. This includes characteristics such as the Doppler frequency and delay spread of the channel. In a practical environment, users may each travel at a different velocity or experience a different delay spread. As a result, an adaptive subcarrier allocation can be developed with groups that utilize different spreading factors. This would accommodate users with different fading characteristics. In this paper, adaptive subcarrier allocation is utilized only with BPSK modulation. A further improvement to the proposed system would be to simultaneously incorporate adaptive modulation and coding and adaptive subcarrier allocation. This would allow the system to experience higher throughput while experiencing better BER performance. In a continuing work, we investigate the performance analysis using adaptive modulation and coding in multicarrier CDMA systems with time and frequency spreading, as well as the difference in performance when using different combiners at the receiver.

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