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Adaptive resource allocation in downlink multi-user MC-CDMA systems

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Abstract: The joint channel and power allocation in the downlink transmission of multi-user multi-carrier code division multiple access(MC-CDMA) systems are investigated and the throughput maximization problem is considered as a mixed integer optimization problem. For simplicity of analysis, the problem is divided into two less complex sub-problems: power allocation and channel allocation, which can be solved by a suboptimal adaptive power allocation (APA) algorithm and an optimal adaptive channel allocation (ACA) algorithm, respectively. By combining APA and ACA algorithms, an adaptive channel and power allocation scheme is proposed. The numerical results show that the proposed APA algorithm is more suitable for MC-CDMA systems than the conventional equal power allocation algorithm, and that the proposed channel and power allocation scheme can significantly improve the system throughput performance.

Key words: code division multiple access (CDMA); multi-carrier transmission; multi-user; channel allocation; power allocation

Code division multiple access(CDMA) has been adopted as the major multiple access technique in third-generation (3G) communication systems. Meanwhile, in a wide bandwidth channel, multi-carrier transmission has become popular[1]. Many researchers have tried to combine CDMA and multi-carrier techniques and proposed multi-carrier CDMA(MC-CDMA) to exploit the benefits of the two techniques[2-3]. Therefore, MC-CDMA has become a hot research topic in recent years.

In multi-user MC-CDMA systems, channel fading differs at different sub-carriers or different users. This feature motivates researchers to investigate an adaptive channel allocation(ACA). Obviously, ACA can exploit multi-user diversity to significantly improve system performance. In Ref. [4], an ACA scheme was proposed for the downlink of the multi-user MC-CDMA system. However, in this conventional equal power allocation(EPA) algorithm, the transmit power is equally distributed to all sub-carriers without optimization. Thus, such EPA is inefficient. To improve the efficiency of power allocation, Zhu and Gunawan[5] proposed to turn off deeply-faded sub-carriers and uniformly distribute available transmit power among remaining sub-carriers to improve bit error ratio(BER) performance of MC-CDMA systems with a maximum-ratio combining(MRC) receiver. However, such a power allocation algorithm may result in outage (i. e., no transmission) when all sub-carriers suffer deep fading. In Ref. [6], Zhu and Bar-Ness further proposed a power allocation algorithm for MC-CDMA systems with a projection matrix-based receiver. Nevertheless, the algorithm proposed in Ref. [6] requires the knowledge of all the users' spreading codes, which increases the system complexity, especially for a large number of users and makes the implementation unfeasible in practical systems. In Ref. [7], Lee and Bar-Ness proposed a transmission power adaptation algorithm for uplink MC-CDMA transmissions with the MRC receiver. Unlike Ref. [7], Tan and Bar-Ness proposed an equal BER power control algorithm for the uplink of MC-CDMA systems with a minimum mean squared error successive interference cancellation (MMSE-SIC) detector[8]. Furthermore, Fu and Chen further investigated the sub-carrier and power allocation in the uplink of MC-CDMA systems with a linear minimum mean squared error(LMMSE) multi-user detector and proposed an iterative allocation algorithm[9]. However, combining ACA with adaptive power allocation(APA) has not been discussed in downlink MC-CDMA systems.

In this paper, we present joint channel and power allocation in order to maximize the total throughput in the downlink of a multi-user MC-CDMA system under the constraints of maximum transmit power, code channel(or simply channel) number and bit-error rate(BER). Particularly, this problem can be considered as a mixed integer optimization problem which has been proved to be nondeterministic polynomial time(NP)-complete without computational efficient algorithms to obtain the optimal solution. So, the problem is divided into two sub-problems: power allocation and channel allocation. Since the loss of orthogonality among spreading codes in frequency selective fading channels will cause serious inter-channel interferences(ICI), we propose a suboptimal APA algorithm which intends to keep the orthogonality by dynamically allocating transmit power to each sub-carrier of every channel according to the instantaneous channel state information(CSI). In addition, maximum ratio combining (MRC) and equal gain combining(EGC) are analyzed in the proposed APA algorithm. On the other hand, if the required amount of transmit power on every channel has been determined for all users before the channel allocation, the optimization problem can be simplified into a channel allocation problem which can be solved by an optimal ACA algorithm. By combining the proposed APA and ACA algorithms, we further propose an adaptive channel and power allocation scheme for the initial optimization problem.

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1 System Model

Consider the downlink transmission of a synchronous MC-CDMA system with quadrature phase-shift keying (QPSK) modulation, N sub-carriers and K active users. The channel gain on each sub-carrier is assumed to be Rayleigh fading and constant for one MC-CDMA block but to vary independently from one block to another. In order to exploit frequency diversity, each data symbol modulates a number of sub-carriers in terms of frequency domain spreading. Since the spreading factor is L, all sub-carriers are further divided into $M = N/L$ contiguous groups. Each group has L channels and the L channels of each group are separated by their specific spreading codes. Moreover, each group can be allocated to at most one user. Assume that the perfect CSI from all users is available at the base station. Using this information, the adaptive channel and power allocation algorithm assigns the channels to the users with the best channel conditions, and determines the transmit power on each channel.

Without loss of generality, we concentrate on the k-th user. At the receiver of the k-th user, the channel allocation information is used to extract the signals of the desired channel. After the signal extraction, the output signals are combined at the frequency domain despreader to obtain the signals of the desired channel. If the number of the k-th user's channels on the m-th group is denoted as n_m^k, then after the frequency domain combining, the decision variable for the m-th group's i-th channel data symbols can be obtained as

$$R_m^{k,i} = \sum_{l=1}^{L} c_l^i c_l^i \omega_{m,l}^k h_{m,l}^k \sqrt{P_{m,l}^k} d_m^{k,i} + \sum_{j=1, j\neq i}^{n_m^k} \sum_{l=1}^{L} c_l^i c_l^j \omega_{m,l}^k h_{m,l}^k \sqrt{P_{m,l}^k} d_m^{k,j} + \sum_{l=1}^{L} c_l^i \omega_{m,l}^k \eta_{m,l}^k \quad (1)$$

where $\omega_{m,l}^k$ is the k-th user's frequency domain combining weight for the signal on the l-th sub-carrier of the m-th group; $h_{m,l}^k$ is the k-th user's channel fading on the l-th sub-carrier of the m-th group; $P_{m,l}^k$ is the signal power of one channel on the l-th sub-carrier of the m-th group; $d_m^{k,i}$ is the modulated data symbol with unitary power of the i-th channel on the m-th group; $c_l^i \in \{1, -1\}$ is the spreading code on the l-th sub-carrier of the i-th channel and the variance of the noise term $\eta_{m,l}^k$ is N_0.

Obviously, the first term on the right-hand side of Eq. (1) is the desired signal and the second term is the ICI. Thus, after some simple computations, the received signal power to interference-plus-noise power ratio (SINR) of the signal on the i-th channel of the m-th group, $\Gamma_m^{k,i}$, can be obtained as

$$\Gamma_m^{k,i} = \frac{\left| \sum_{l=1}^{L} \omega_{m,l}^k h_{m,l}^k \sqrt{P_{m,l}^k} \right|^2}{\sum_{j=1, j\neq i}^{n_m^k} \left| \sum_{l=1}^{L} c_l^i c_l^j \omega_{m,l}^k h_{m,l}^k \sqrt{P_{m,l}^k} \right|^2 + N_0 \sum_{l=1}^{L} \left| \omega_{m,l}^k \right|^2} \quad (2)$$

To meet the BER requirement, the SINR of each channel should be maintained no less than a target threshold γ; i. e., $\Gamma_m^{k,i} \geqslant \gamma$.

It should be noted that the frequency domain combining weights in Eqs. (1) and (2) are different for different combining schemes; i. e., $\omega_{m,l}^k$ is set to be $(h_{m,l}^k)^*$ for the MRC or $(h_{m,l}^k)^* / |h_{m,l}^k|$ for the EGC.

2 Problem Formulation

Our objective is to optimize the channel and power allocation in order to maximize the throughput under several practical constraints. In this paper, the throughput maximization problem can be considered as the following optimization problem:

$$\max \sum_{k=1}^{K} \sum_{m=1}^{M} n_m^k \quad (3)$$

s. t.

$$\sum_{k=1}^{K} \phi(n_m^k) \leqslant 1 \qquad \forall m \quad (3a)$$

$$\sum_{k=1}^{K} \sum_{m=1}^{M} \sum_{l=1}^{L} n_m^k P_{m,l}^k \leqslant P_{\mathrm{T}}^{\max} \quad (3b)$$

$$\Gamma_m^{k,i} \geqslant \gamma \qquad \forall k, m, i \quad (3c)$$

$$P_{m,l}^k \geqslant 0 \qquad \forall k, m, l \quad (3d)$$

$$n_m^k \in \{0, 1, \ldots, L\} \qquad \forall k, m \quad (3e)$$

where $P_{\mathrm{T}}^{\max}$ is the maximum transmit power, and $\phi(n_m^k)$ is the sign function which is defined as

$$\phi(n_m^k) = \begin{cases} 1 & n_m^k > 0 \\ 0 & n_m^k = 0 \end{cases} \quad (4)$$

Note that constraint (3a) imposes the restriction that at most one user can be allocated to each group simultaneously. Constraints (3b) and (3c) are the transmit power and the SINR constraints, respectively. Moreover, constraints (3d) and (3e) ensure the correct values for the channel number and the transmit power, respectively.

3 Proposed Adaptive Channel and Power Allocation Scheme

Obviously, the optimization problem (3) is a mixed integer programming problem which has been known to be NP-complete[10]. Thus, the initial problem can be divided into two sub-problems: power allocation and channel allocation. In the following, the two sub-problems are discussed respectively. Then, an adaptive channel and power allocation scheme will be presented.

3.1 APA

In this paper, the optimality criterion of power allocation is to minimize the total transmit power while satisfying the SINR constraints. Without loss of generality, assuming the m-th group is assigned to the k-th user, the optimal power allocation can be obtained by solving the following optimization problem:

$$\min \sum_{i=1}^{L} P_m^{k,i} \quad (5)$$

s. t.

$$\Gamma_m^{k,i} \geqslant \gamma \qquad \forall i \quad (5a)$$

$$P_{m,l}^k \geqslant 0 \qquad \forall l \quad (5b)$$

However, we can find that the optimal solution cannot be obtained analytically. In addition, the loss of orthogonality among spreading codes in the frequency selective fading channels will cause serious ICI. If the ICI can be eliminated by maintaining the orthogonality among spreading codes, the transmit power consumption of each channel will be reduced significantly. Thus, let the term $h_{m,l}^{k}\,\omega_{m,l}^{k}\sqrt{P_{m,l}^{k}}$ in Eq. (2) be a constant for all sub-carriers, the term of ICI will become zero and Eq. (2) can be rewritten as

$$\frac{\left|\sum_{l=1}^{L}\omega_{m,l}^{k}\,h_{m,l}^{k}\sqrt{P_{m,l}^{k}}\right|^{2}}{N_0\sum_{l=1}^{L}\left|\omega_{m,l}^{k}\right|^{2}}\geqslant\gamma \tag{6}$$

Therefore, one channel's minimum transmit power on the l-th sub-carrier of the m-th group can be obtained as

$$P_{m,l}^{k}=\frac{\gamma N_0\sum_{l=1}^{L}\left|\omega_{m,l}^{k}\right|^{2}}{L^{2}\left|\omega_{m,l}^{k}\,h_{m,l}^{k}\right|^{2}} \tag{7}$$

Moreover, for one channel on the m-th group, the required transmit power is expressed as

$$S_m^k=\sum_{l=1}^{L}P_{m,l}^{k}=\gamma N_0L^{-2}\sum_{l=1}^{L}\left|\omega_{m,l}^{k}\right|^{2}\sum_{l=1}^{L}\left|\omega_{m,l}^{k}\,h_{m,l}^{k}\right|^{-2} \tag{8}$$

It should be noted that different combining schemes will lead to different results of power allocations. The corresponding results can be obtained by substituting the value of $\omega_{m,l}^{k}$ into Eq. (7) and Eq. (8).

3.2 ACA

If the required amount of transmit power of each channel has been determined for all users before the channel allocation, then the constraints (3b), (3c) and (3d) in the optimization problem (3) can be substituted by one constraint as

$$\sum_{k=1}^{K}\sum_{m=1}^{M}n_m^k\,S_m^k\leqslant P_{\mathrm{T}}^{\max} \tag{9}$$

Obviously, the optimization problem (3) can be further simplified into a channel allocation problem as

$$\max\sum_{k=1}^{K}\sum_{m=1}^{M}n_m^k \tag{10}$$

subject to the constraints (9), (3a) and (3e).

Without loss of generality, we denote μ_m as the user whose transmit power for one channel on the m-th group is the minimum among all users. Thus, we have the following proposition 1.

Proposition 1 There exists one optimal solution to the optimization problem (10) satisfying that each group is assigned to the user who requires the minimum transmit power for one channel of that group; i. e., for $m=1,2,\ldots,M$, the m-th group is allocated to the μ_m-th user.

Proof Assume that one optimal solution of the optimization problem (10) is denoted as $(n_m^{\pi_m})_{m=1,2,\ldots,M}$, where π_m is the user for whom the m-th group is assigned and $n_m^{\pi_m}\in\{0,1,\ldots,L\}$. The corresponding objective value is $\sum_{m=1}^{M}n_m^{\pi_m}$ and $\sum_{m=1}^{M}n_m^{\pi_m}S_m^{\pi_m}\leqslant P_{\mathrm{T}}^{\max}$. For $m=1,2,\ldots,M$, if $\mu_m\neq\pi_m$, then let $n_m^{\mu_m}=n_m^{\pi_m}$. Obviously, we have $\sum_{m=1}^{M}n_m^{\mu_m}=\sum_{m=1}^{M}n_m^{\pi_m}$ and $\sum_{m=1}^{M}n_m^{\mu_m}S_m^{\mu_m}\leqslant P_{\mathrm{T}}^{\max}$. Thus, $(n_m^{\mu_m})_{m=1,2,\ldots,M}$ is also one optimal solution to the optimization problem (10).

After the group assignment, each group is associated with a transmit power, i. e., for $m=1,2,\ldots,M$, the associated transmit power of the m-th group is $S_m^{\mu_m}$. If the associated transmit powers for all groups is sorted according to the increasing order, we can obtain an order $\{v(i)\}_{i=1,2,\ldots,M}$, where $v(i)$ is the group whose associated transmit power is the i-th minimum among the associated transmit powers of all groups. Without loss of generality, we denote the associated transmit power according to the increasing order, i. e., $S_{v(1)}^{\mu_{v(1)}}<S_{v(2)}^{\mu_{v(2)}}<\ldots<S_{v(M)}^{\mu_{v(M)}}$. Then, we have the following proposition 2.

Proposition 2 Under the constraints of any given maximum transmit power $P_{\mathrm{T}}^{\max}$ and the maximum channel number of every group L, if the transmit power is not enough to be allocated to all channels of all groups simultaneously, that is $\sum_{i=1}^{M}LS_{v(i)}^{\mu_{v(i)}}>P_{\mathrm{T}}^{\max}$, then the throughput is maximized by selecting the groups and allocating channels according to the increasing order of the associated transmit power; i. e., one optimal channel allocation for the optimization problem (10) owns the following form:

$$\tilde{N}\triangleq(\tilde{n}_{v(i)}^{\mu_{v(i)}})_{i=1,2,\ldots,M}=(\underbrace{L,\ldots,L}_{\alpha},l,\underbrace{0,\ldots,0}_{\beta}) \tag{11}$$

where $l\in\{0,1,\ldots,L\}$; $\alpha,\beta\in\{0,1,\ldots,M-1\}$ and $\alpha+\beta+1=M$.

Proof Assume that the optimal channel allocation owns the form (11), then the residual transmit power P_{R} can be obtained as

$$P_{\mathrm{R}}=P_{\mathrm{T}}^{\max}-\sum_{j=1}^{m}\tilde{n}_{v(j)}^{\mu_{v(j)}}S_{v(j)}^{\mu_{v(j)}} \tag{12}$$

where $m=\alpha+1$. Obviously, for $i=1,2,\ldots,M$, the residual transmit power P_{R} is less than $S_{v(i)}^{\mu_{v(i)}}$.

Suppose that there exists some channel allocation $N=(n_{v(i)}^{\mu_{v(i)}})_{i=1,2,\ldots,M}$, whose objective value is greater than the one achieved under $\tilde{N}$, i. e., $\sum_{i=1}^{M}n_{v(i)}^{\mu_{v(i)}}>\sum_{i=1}^{M}\tilde{n}_{v(i)}^{\mu_{v(i)}}$. Moreover, for $i=1,2,\ldots,M$, $n_{v(i)}^{\mu_{v(i)}}\in\{0,1,2,\ldots,L\}$, $\sum_{i=1}^{M}n_{v(i)}^{\mu_{v(i)}}S_{v(i)}^{\mu_{v(i)}}\leqslant P_{\mathrm{T}}^{\max}$ and $(n_{v(i)}^{\mu_{v(i)}})_{i=1,2,\ldots,M}\neq(\tilde{n}_{v(i)}^{\mu_{v(i)}})_{i=1,2,\ldots,M}$.

Case 1 $(n_{v(i)}^{\mu_{v(i)}})_{i=1,2,\ldots,m-1}=(\tilde{n}_{v(i)}^{\mu_{v(i)}})_{i=1,2,\ldots,m-1}$, $n_{v(m)}^{\mu_{v(m)}}<\tilde{n}_{v(m)}^{\mu_{v(m)}}$, $n_{v(i)}^{\mu_{v(i)}}\geqslant0$ where $i=m+1,m+2,\ldots,M$ and at least one inequality strictly holds. To eliminate the difference between $n_{v(m)}^{\mu_{v(m)}}$ and $\tilde{n}_{v(m)}^{\mu_{v(m)}}$, we transfer transmit power $(\tilde{n}_{v(m)}^{\mu_{v(m)}}-n_{v(m)}^{\mu_{v(m)}})S_{v(m)}^{\mu_{v(m)}}$ to the $v(i)$-th group where $i\in\{m+1,m+2,\ldots,M\}$. Since $S_{v(i)}^{\mu_{v(i)}}>S_{v(m)}^{\mu_{v(m)}}$ and $S_{v(m)}^{\mu_{v(m)}}>P_{\mathrm{R}}$, we can obtain that

$$n_{v(i)}^{\mu_{v(i)}}=\tilde{n}_{v(i)}^{\mu_{v(i)}}+\left\lfloor\frac{P_R+(\tilde{n}_{v(m)}^{\mu_{v(m)}}-n_{v(m)}^{\mu_{v(m)}})S_{v(m)}^{\mu_{v(m)}}}{S_{v(i)}^{\mu_{v(i)}}}\right\rfloor<\left\lfloor\frac{(\tilde{n}_{v(m)}^{\mu_{v(m)}}-n_{v(m)}^{\mu_{v(m)}}+1)S_{v(m)}^{\mu_{v(m)}}}{S_{v(i)}^{\mu_{v(i)}}}\right\rfloor<\tilde{n}_{v(m)}^{\mu_{v(m)}}-n_{v(m)}^{\mu_{v(m)}}+1 \tag{13}$$

where $\lfloor x\rfloor$ denotes the integer part of x. Since $n_{v(i)}^{\mu_{v(i)}}$ is a non-negative integer, Eq. (13) leads to a contradiction $\sum_{i=1}^{M}n_{v(i)}^{\mu_{v(i)}}$

$\leqslant \sum_{i=1}^{M} \tilde{n}_{v(i)}^{\mu_{v(i)}} < \sum_{i=1}^{M} n_{v(i)}^{\mu_{v(i)}}$. Thus, N cannot outperform $\tilde{N}$ in case 1.

Case 2 $(n_{v(i)}^{\mu_{v(i)}})_{i=1,2,\dots,m-1} \leqslant (\tilde{n}_{v(i)}^{\mu_{v(i)}})_{i=1,2,\dots,m-1}$ and at least one inequality strictly holds. Assume the k-th inequality strictly holds, i. e., $n_{v(k)}^{\mu_{v(k)}} < \tilde{n}_{v(k)}^{\mu_{v(k)}}$, where $1 \leqslant k < m$. To eliminate the difference between $n_{v(k)}^{\mu_{v(k)}}$ and $\tilde{n}_{v(k)}^{\mu_{v(k)}}$, we transfer transmit power $(\tilde{n}_{v(k)}^{\mu_{v(k)}} - n_{v(k)}^{\mu_{v(k)}}) S_{v(k)}^{\mu_{v(k)}}$ to the $v(i)$-th group where $i \in \{m, m+1, \dots, M\}$. Similar to case 1, we can obtain $n_{v(i)}^{\mu_{v(i)}} \leqslant \tilde{n}_{v(i)}^{\mu_{v(i)}} + \tilde{n}_{v(k)}^{\mu_{v(k)}} - n_{v(k)}^{\mu_{v(k)}}$ which also leads to a contradiction $\sum_{i=1}^{M} n_{v(i)}^{\mu_{v(i)}} \leqslant \sum_{i=1}^{M} \tilde{n}_{v(i)}^{\mu_{v(i)}} < \sum_{i=1}^{M} n_{v(i)}^{\mu_{v(i)}}$. Thus, N cannot outperform $\tilde{N}$ in case 2.

Combining cases 1 and 2, proposition 2 is proved.

According to propositions 1 and 2, an optimal ACA algorithm is proposed as follows:

Initialize $P_{\mathrm{R}} = P_{\mathrm{T}}^{\max}$, $C = \{1, 2, \dots, M\}$, $n_m^k = 0$, $k = 1, 2, \dots, K$ and $m = 1, 2, \dots, M$.

For each group $m = 1, 2, \dots, M$, do % Group Assignment

$\mu_m = \arg \min_{1 \leqslant k \leqslant K} \{S_m^k\}$

End For

While $C \neq \varnothing$ do % Channel Allocation

$t = \arg \min_{\forall m \in C} \{S_m^{\mu_m}\}$;

$n_t^{\mu_t} = \min\left(\left\lfloor \frac{P_R}{S_t^{\mu_t}} \right\rfloor, L \right)$;

$P_{\mathrm{R}} = P_{\mathrm{R}} - n_t^{\mu_t} S_t^{\mu_t}$;

$C = C \backslash \{\mu_t\}$;

If $n_t^{\mu_t} = 0$

Break the loop;

End If

End While

3.3 ACA

By combining the proposed APA and ACA algorithms, an adaptive channel and power allocation scheme can be proposed for problem (3). The stepwise procedures are described as follows:

Step 1 According to the obtained CSI, for all users, the required amount of transmit power to be allocated to one channel of every group S_m^k is determined by Eq. (8).

Step 2 Based on the results obtained in step 1, the channels are allocated to different users by using the proposed ACA algorithm described in section 3.2.

Step 3 The transmit power is allocated to all sub-carriers of all allocated channels using Eq. (7).

4 Numerical Results

To evaluate the performance of the proposed scheme, two comparisons are considered in this section. First, the proposed APA algorithm is compared with the conventional EPA algorithm in terms of BER. Secondly, the proposed adaptive channel and power allocation scheme is compared to the static channel allocation (SCA) algorithm with the APA algorithm in terms of throughput. Note that with the SCA algorithm, all groups are equally distributed to all users and the group assignment cannot be adjusted with the variations of instantaneous CSI. Two simulation environments are considered which are shown in Tab. 1. Referring to Ref. [11], we can obtain the target SINR value for the given BER requirement.

Tab. 1 Simulation parameters

Parameters	Environment 1	Environment 2
Bandwidth/MHz	1	100
Sub-carrier number	16	1 024
User number	1	8
BER requirement		10^{-3}
Spreading factor	16	8
Multipath delay spread/μs	1	
Channel model	Uncorrelated Rayleigh fading channel[12]	
Spreading code	OVSF	
Modulation	QPSK	

In the first comparison, we adopt environment 1 in the simulations and define the transmit SNR per channel (ChSNR) as the ratio of the transmit power per channel to the noise power. Fig. 1 shows the BER versus the ChSNR for different combining schemes and power allocation algorithms when all 16 code channels are used for transmitting data. With the EPA algorithm, the EGC scheme outperforms the MRC scheme significantly. Meanwhile, since the APA algorithm maintains frequency-domain orthogonality which results in the decrease of ICI, the performance of the EGC scheme has been improved significantly when the EPA algorithm is substituted by the APA algorithm. In addition, the performance of the MRC scheme has also been improved for higher ChSNR. Considering that the uncoded BER requirement usually ranges from 10^{-2} to 10^{-6} in real operations, the APA algorithm is obviously more suitable for the practical MC-CDMA systems.

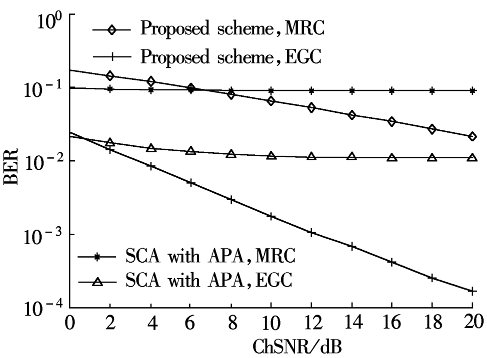

Fig. 1 BER versus ChSNR

In the second comparison, environment 2 is applied in the simulations and the throughputs in bit per MC-CDMA block are depicted for various scenarios. Here, the maximum transmit power is measured by $\mathrm{SNR}_{\max} = P_{\mathrm{T}}^{\max}/(N_0 N)$. Fig. 2 shows the throughput performance with different values of maximum transmit power. It can be seen from Fig. 2 that due to the insufficient use of frequency diversity, the performance obtained by the SCA algorithm with the APA algorithm is lower than that obtained by the proposed channel and power allocation scheme. Fig. 3 further shows the throughput performance with different numbers of users. In Fig. 3, with the increase in the number of users, the throughput of the proposed channel and power allocation scheme increases as well, while the throughput for the SCA algorithm with the APA algorithm remains constant. The differences between the proposed scheme and the SCA algorithm with the APA algorithm result from the effects of multi-user diversity. In summary, the proposed adaptive channel and power allocation scheme outperforms the SCA algorithm with the APA algorithm and can significantly improve system performance in throughput.

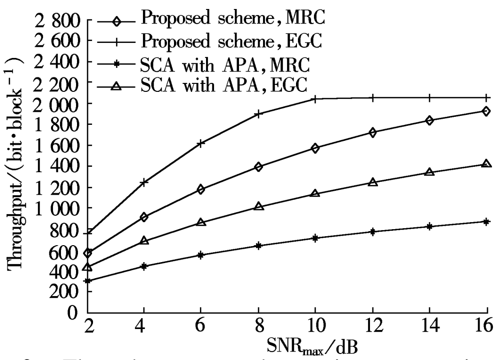

Fig. 2 Throughput versus the maximum transmit power (measured by SNR_{max})

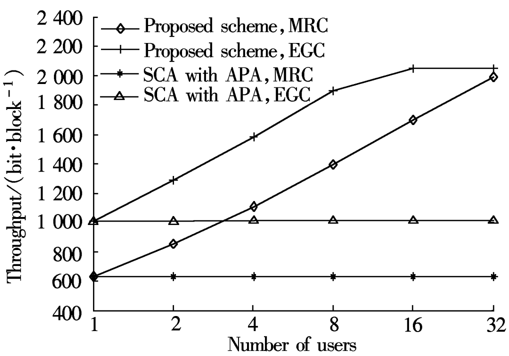

Fig. 3 Throughput versus the number of users

5 Conclusion

This paper studies the problem of joint channel and power allocation in order to maximize the total throughput in the downlink multi-user MC-CDMA system under the constraints of maximum transmit power, channel number and BER. The problem is divided into two sub-problems: power allocation and channel allocation. Furthermore, a suboptimal APA algorithm and an optimal ACA algorithm are proposed to solve the two sub-problems, respectively. By combining the APA and ACA algorithms, an adaptive channel and power allocation scheme is presented to solve the initial optimization problem. The numerical results show that the proposed APA algorithm is more suitable for MC-CDMA systems and the proposed channel and power allocation scheme can significantly improve the throughput performance.

References

[1] Jamalipour A, Wada T, Yamazato T. A tutorial on multiple access technologies for beyond 3G mobile networks [J]. *IEEE Communications Magazine*, 2005, **43**(2): 110 − 117.

[2] Hara S, Prasad R. Overview of multi-carrier CDMA [J]. *IEEE Communications Magazine*, 1997, **35**(12): 126 − 133.

[3] Yee N, Linnartz J P, Fettweis G. Multi-carrier CDMA in indoor wireless radio networks [J]. *IEICE Transactions on Communications*, 1994, **77**(7): 900 − 904.

[4] Li C, Wang X. Adaptive subchannel allocation in multiuser MC-CDMA systems [C]//*Proc of IEEE Global Telecommunications Conference*. Dallas, Texas, USA, 2004: 2503 − 2507.

[5] Zhu Y, Gunawan E. Performance of MC-CDMA system using controlled MRC with power control in Rayleigh fading channel [J]. *Electronics Letter*, 2000, **36**(8): 752 − 753.

[6] Zhu J, Bar-Ness Y. Power allocation algorithm in MC-CDMA [C]//*Proc of IEEE International Conference on Communications*. New York, USA, 2002: 931 − 935.

[7] Lee Y H, Bar-Ness Y. Transmission power adaptations in MC-CDMA communications over Rayleigh fading channels [C]//*Proc of Wireless Communications and Networking Conference*. Atlanta, USA, 2004: 1589 − 1594.

[8] Tan M, Bar-Ness Y. Equal BER power control for uplink MC-CDMA with MMSE successive interference cancellation [J]. *IEEE Communications Letters*, 2004, **8**(6): 348 − 350.

[9] Fu P-W, Chen K-C. Rate, sub-carrier, and power allocations for multi-carrier CDMA with LMMSE multiuser detection [J]. *IEEE Transactions on Wireless Communications*, 2007, **6**(5): 1574 − 1580.

[10] Nemhauser G L, Wolsey L A. *Integer and combinatorial optimization* [M]. New York: Addison Wiley, 1988.

[11] Goldsmith A J, Chua S-G. Variable-rate variable-power MQAM for fading channels [J]. *IEEE Transactions on Communications*, 1997, **45**(10): 1218 − 1230.

[12] Sorooshyari S, Daut D G. On the generation of correlated Rayleigh fading envelopes for accurate simulation of diversity channels [J]. *IEEE Transactions on Communications*, 2006, **54**(8): 1381 − 1386.

下行多用户 MC-CDMA 系统中的自适应资源分配

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摘要:研究了多用户场景下多载波码分多址系统(MC-CDMA)的下行信道和功率分配,并将吞吐最大化问题建模成一个混合整数优化问题. 为了简化分析,将问题分成 2 个低复杂度的子问题:功率分配和信道分配. 这 2 个子问题可分别被一个次最优自适应功率分配算法(APA)和一个最优自适应信道分配算法(ACA)解决. 通过联合 APA 和 ACA 算法,进一步提出了一个自适应信道和功率的分配方案. 仿真结果表明:与传统的均匀功率分配算法相比,提出的 APA 算法更加适用于 MC-CDMA 系统;此外,提出的自适应信道和功率分配方案可以显著地提高系统吞吐量性能.

关键词:CDMA; 多载波传输; 多用户; 信道分配; 功率分配

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