Resource Allocation and Capacity in Wireless CDMA Networks using Adaptive Power Control and Antenna Array Multiuser Receiver

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Abstract

In this paper we developed a framework for resource allocation in multi-class traffic CDMA system using adaptive power control and antenna array multiuser receiver. We devised a new scheme in which both transmit power and receiver filter adapt to the time-varying channel state. An antenna array multiuser receiver that jointly processes received signal vectors from multiple antennas and maximizes the signal-to-interference ratio for each user is proposed. It is combined with adaptive power control based on target SIR for each user. Our scheme can support multi-class traffic with different SIR requirements and guarantee their quality of service in multipath fading environment. A theoretical bound is derived to characterize capacity of CDMA system using adpative power control and antenna array multiuser receiver in multipath fading environment. Simulations show that actual system capacity in multipath fading environment is close to the theoretical bound at large power constraint. Capacity at various power constraints can be characterized by a notion of bandwidth utility. It is also demonstrated that the antenna array multiuser receiver is quite effective in increasing capacity of users with higher SIR requirement and lower power constraint.

1. Introduction

Next generation wireless networks will provide a variety of multimedia services to transport voice, data, images, video, and other media. To enable these services it is essential that next generation wireless networks support multiple classes of traffic with diverse quality of service (QoS) requirements in terms of data rate, bit error rate, delay, throughput, etc. For example, voice traffic generally requires a data rate of 8 kbps and bit error rate (BER) less than 10^{-2} to 10^{-3}, while video traffic requires data rate of 64 kbps and up, with BER less than 10^{-6}. These are usually real time traffic which requires end-to-end delay to be less than 200 ms. On the other hand packet data traffic are non real time and usually there is no strict delay bound imposed on that. The packet data traffic requires a wide range of data rates (from less than 1 kbps to several Mbps) and bit error rate less that 10^{-6}. To satisfy the rapidly escalating demands for anytime, anywhere communications and provide users with much improved quality of service, next generation wireless networks must have significantly higher system capacity and enhanced performance, in terms of higher data rate, lower BER, lower latency, and higher throughput.

One of the viable technologies to meet these challenges is code division multiple access (CDMA). Due to its technical advantage in various aspects, like robustness to fading, flexibility in capacity and quality tradeoff, inherent statistical multiplexing of heterogeneous traffic, etc., CDMA has been selected as a major air interface standard of the third generation systems IMT-2000, such as wideband CDMA proposed by ETSI/ARIB and cdma2000 proposed by TIA. Current CDMA systems (e.g. IS-95) use a conventional matched filter receiver structure that treats other user's signal as noise and simply correlates the received signal with desired user's spreading codes. While easy to implement, this receiver suffers from performance degradation caused by severe multiple access interference when there are a large number of users accessing the system. To improve the performance and capacity it is desirable to apply so called "performance enhancing" techniques such as antenna array receiver in the next gereration wireless networks. Antenna array receiver jointly process signals received from multiple antennas to enhance the desired user's signal and reduce interference from other users. Previous works on antenna array receiver [7, 9, 8, 6, 5] focused on demonstrating the performance improvement in the physical layer in terms of lower bit error rate. They generally assume either no power control or some simple fixed power control scheme in which all the users' received power at the receiver is kept the same. Joint optimal power control and beamforming using antenna arrays are proposed in [12, 11, 10]. These

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works consider only single class traffic with the same SIR requirement. Issues like power control and resource allocation in multi-class traffic system are still unclear. There have not been a clear format for characterizing capacity of multi-class traffic system. In [3] the capacity of a power-controlled CDMA cell using multiuser receiver and antenna array is characterized in a theoretical format. A flat fading channel model was assumed and the paper focused on an asymptotic model in which the number of users goes to infinity.

Resource allocation and capacity in multi-class traffic CDMA system using adaptive power control and multirate multiuser receiver have been studied in [2, 1]. In this paper we developed a framework for resource allocation and capacity characterization in multi-class traffic CDMA system using adaptive power control and antenna array multiuser receiver. We devised a new scheme that can support multiple classes of traffic with different target SIRs and guarantee their quality of service requirements in multipath fading environment. In the scheme both transmit power and receiver filter adapt to the time-varying fading channel state. An antenna array multiuser receiver that jointly processes received signals from multiple antennas and maximizes the signal-to-interference ratio for each user is proposed. It is combined with adaptive power control based on required SIR for each user. A theoretical bound is derived to characterize capacity of CDMA system using the antenna array multiuser receiver. Simulations are carried out to study the actual system capacity in a multipath fading environment. Our approach is to establish an upper bound on system capacity which can be proved analytically. Then we compare the simulation results on system capacity with the theoretical bound.

The rest of the paper is organized as follows: Section 2 describes the CDMA system model. In Section 3 a theoretical bound is derived for characterizing capacity of CDMA system using antenna array multiuser receiver. In Section 4 simulations in multipath fading environment are described. In Section 5 numerical results and discussion are presented. Conclusions are given in Section 6.

2. System Description

We consider a direct-sequence CDMA system with BPSK modulation and coherent detection, and focus on synchronous transmission in the uplink. The received signal at the antenna array receiver is a superposition of multiple copies of attenuated and delayed signals transmitted by all the K users. The signal at the mth antenna is given by

$$r^{(m)}(t)=\sum_{k=1}^{K}\sum_{l=1}^{L_k}A_k\alpha_{k,l}\rho_{k,l}^{(m)}b_k s_k(t-iT-\tau_{k,l})+n^{(m)}(t), \tag{1}$$

where L_k is the number of paths associated with user k, A_k, b_k and $s_k(t)$ are the received amplitude, the transmitted bit, and the spreading waveform for user k respectively, $\tau_{k,l}$ and $\alpha_{k,l}$ are the delay and the complex coefficient associated with path l for user k respectively, $\rho_{k,l}^{(m)}$ is the array response factor at the mth antenna associated with path l for user k, and $n(t)$ is the additive white gaussian noise (AWGN). The received vector sampled at chip rate in a symbol period can be written as

$$\begin{aligned}\mathbf{r}_i^{(m)} &= \sum_{k=1}^{K}(A_k[\sum_{l=1}^{L_k}\alpha_{k,l}\rho_{k,l}^{(m)}\mathbf{s}_k^{+}(l)]b_{i,k} \\ &\quad +A_k[\sum_{l=1}^{L_k}\alpha_{k,l}\rho_{k,l}^{(m)}\mathbf{s}_k^{-}(l)]b_{i-1,k})+\mathbf{n}_i^{(m)},\end{aligned} \tag{2}$$

where $\mathbf{s}_k^{+}(l)$ and $\mathbf{s}_k^{-}(l)$ contain the chip matched-filter output samples of $s_k(t-\tau_{k,l})$ and $s_k(t+T-\tau_{k,l})$, respectively. Notice that $\mathbf{s}_k^{+}(l)$ and $\mathbf{s}_k^{-}(l)$ are vectors of dimension $N\times 1$, where N is the spreading factor. We can rewrite (3) as

$$\mathbf{r}_i^{(m)}=\sum_{k=1}^{K}(A_k\mathbf{a}_k^{+(m)}b_{i,k}+A_k\mathbf{a}_k^{-(m)}b_{i-1,k})+\mathbf{n}_i^{(m)}, \tag{3}$$

where

$$\mathbf{a}_k^{\pm(m)}\equiv\sum_{l=1}^{L_k}\alpha_{k,l}\rho_{k,l}^{(m)}\mathbf{s}_k^{\pm}(l). \tag{4}$$

In the case of synchronous transmission, the ith bits of all the users are aligned. Also for DS-CDMA applications, it is typically assumed that the path delays $\tau_{k,l}$ span at most a few chips, the intersymbol interference (ISI) due to multipath vectors $\mathbf{a}_k^{-}$ (i.e. $i-1th$ bit) is then quite small and is therefore ignored [4]. The received signal vector can be written as

$$\mathbf{r}^{(m)}=\sum_{k=1}^{K}A_k b_k\mathbf{a}_k^{(m)}+\mathbf{n}^{(m)}. \tag{5}$$

The subscripts i and superscripts $+$ are dropped since the detection window overlaps with the ith bit and ISI from the $i-1th$ bit is ignored. The received signal vectors of M antennas are processed jointly in the antenna array multiuser receiver. Concatenating signal vectors $\mathbf{r}^{(m)}, m=1,\cdots,M$ we can define a joint signal vector $\mathbf{r}\equiv[(\mathbf{r}^{(1)})^H,\cdots,(\mathbf{r}^{(M)})^H]^H$. According to (5)

$$\mathbf{r}=\sum_{k=1}^{K}A_k b_k\mathbf{a}_k+\mathbf{n}, \tag{6}$$

where $\mathbf{a}_k\equiv[(\mathbf{a}_k^{(1)})^H,\cdots,(\mathbf{a}_k^{(M)})^H]^H$ is an $MN\times 1$ vector. One can think $\mathbf{a}_k$ as the "effective spatial-spreading signature" of user k which is the sum of spatial-spreading signatures of the L_k paths of user k. In the receiver a spatial-spreading filter with coefficients $\mathbf{c}_k$ is used to demodulate user k and the receiver statistic is given by

$$\mathbf{c}_k^H \mathbf{r} = A_k \mathbf{c}_k^H \mathbf{a}_k b_k + \sum_{k' \neq k} A_{k'} \mathbf{c}_k^H \mathbf{a}_{k'} b_{k'} + \mathbf{c}_k^H \mathbf{n}. \quad (7)$$

The signal-to-interference-ratio (SIR) for user k can be written as

$$\gamma_k = \frac{P_k |\mathbf{c}_k^H \mathbf{a}_k|^2}{\sum_{k' \neq k} P_{k'} |\mathbf{c}_k^H \mathbf{a}_{k'}|^2 + (\mathbf{c}_k^H \mathbf{c}_k)\sigma^2}, \quad (8)$$

where $P_k = A_k^2$ is the received power for user k and σ^2 is the noise spectral density. In conventional antenna array matched-filter receiver the spatial-spreading filter is chosen to be the same as the effective spatial-spreading signature for user k, i.e. $\mathbf{c}_k = \mathbf{a}_k$. In the antenna array multiuser receiver the filter coefficients $\mathbf{c}_k$ is selected to maximized the SIR of each user. Using the method similar to that in [13] it is derived that

$$\mathbf{c}_k = \frac{\mathbf{Z}_k^{-1} \mathbf{a}_k}{\mathbf{a}_k^H \mathbf{Z}_k^{-1} \mathbf{a}_k}, \quad (9)$$

where $\mathbf{Z}_k$ is the covariance matrix of the interference to user k defined as

$$\mathbf{Z}_k \equiv \sum_{k' \neq k} P_{k'} \mathbf{a}_{k'} \mathbf{a}_{k'}^H + \sigma^2 \mathbf{I}. \quad (10)$$

The SIR for user k at the antenna array multiuser receiver is given by

$$\gamma_k = P_k (\mathbf{a}_k^H \mathbf{Z}_k^{-1} \mathbf{a}_k). \quad (11)$$

The adaptive power control algorithm adjusts the transmit powers so that the SIR at the receiver exceeds or equals to the required SIR for all the users,

$$\gamma_k \geq \gamma_k^*, \quad (12)$$

where γ_k^* is the required SIR for user k.

3. Theoretical Bound on Capacity

The question of system capacity can be stated as: for a set of users with required SIR $\gamma_k^*, k = 1, \cdots, K$, how to characterize the number of users whose SIR requirements can be simultaneously met via appropriate power control? We derived the following result: The SIR requirements of all the users can be met only if

$$\sum_{k=1}^{K} \frac{\gamma_k^*}{1 + \gamma_k^*} < MN, \quad (13)$$

where N is the spreading factor and M is the number of antennas in the antenna array. Due to the limited space the proof is not given here. An analytical proof of (13) can be found in [1].

The result in (13) can be interpreted using the notion of "effective bandwidth". The effective bandwidth of user k is defined as

$$EB_k \equiv \frac{\gamma_k^*}{1 + \gamma_k^*}. \quad (14)$$

The users' SIR requirements can be met only if the sum of the effective bandwidths for all the users is less than the degree of freedom. The degree of freedom in a CDMA system using antenna array multiuser receiver is the *product* of the number of antennas and the spreading factor. Inequality (13) provides a theoretical bound on the capacity of CDMA system with antenna array multiuser receiver.

4. Simulation

In the previous section it is proved that capacity of CDMA system with antenna array multiuser receiver can be characterized by a theoretical bound given in (13).

Given a set of users with required SIR, it is necessary to find out whether the users' SIR requirements can be met simultaneously or not. If yes, what are the power assignments so that the SIR requirements are met and transmit powers are minimized. To minimize the transmit power, it is required that equality in (12) holds, i.e. the SIR at the receiver is equal to the required SIR. The power assignment can be solved by running an iterative power control algorithm:

```
$P_k' = P_k^i$
$\gamma_k = 0$
$while(\gamma_k < \gamma_k^*) and (P_k' \leq P_k^c)$
    $P_k = P_k'$
    $\gamma_k = f(P_k)$
    $P_k' = P_k \cdot \frac{\gamma_k^*}{\gamma_k}$
$end$
```

where $k = 1, \cdots, K$, P_k^i and P_k^c are the initial power assignment and power constraint (maximum power allowed) of user k, respectively, and $f()$ is a function given in (11). For a set of users the iterative power control algorithm is run. After the algorithm stops the condition $P_k' \leq P_n^k$ is examined. If it holds, i.e. power assignment is less than or equal to the power constrait for all the users, then this set of users is said to be feasible. There exists valid power assignment P_k that the SIR requirements of all the users can be met. If it does not hold, i.e. power assignment of at least one user is larger than the power contraint, then this set of users is not feasible. In the simulation we consider a system with several classes of users. Required SIR are the same for users in a class. Capacity is expressed as a set of number of users in each class. The maximum set of number of users for which SIR requirements of all the users can be met is said to be the actual system capacity.

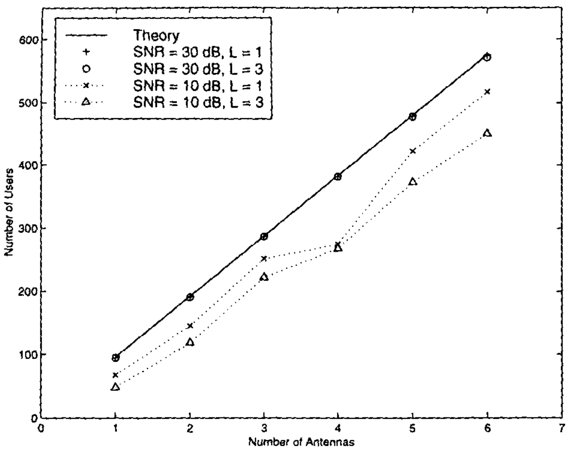

Figure 1. Capacity of CDMA system with antenna array multiuser receiver vs. power constraint.

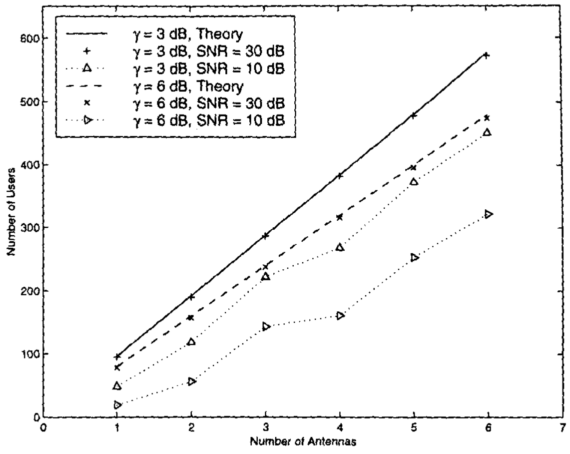

Figure 2. Capacity of CDMA system with antenna array multiuser receiver vs. required SIR.

5. Numerical Results and Discussion

Assume a bandwidth of $W = 4.096$ MHz is allocated for wideband CDMA system. The transmit symbol rate is 64 kbps, corresponding to a spreading factor of $N = 64$. The users' spreading sequences are independently and randomly chosen [13]. There are K users uniformly distributed in a cell, and the antenna array multiuser receiver is located at the base station in the center of the cell. Power constraints are expressed in terms of signal-to-noise ratio (SNR) at the receiver, instead of modeling the constraint on users' transmit power and path loss.

Multipath is modeled as L paths, each delayed at $l = 0, \cdots, L-1$ chips, and the coefficient $\alpha_{k,l}$ a complex random variable with $|\alpha_{k,l}| = 1/\sqrt{L}$, i.e. power is divided equally among the L paths. The angle of arrival (AOA) of these paths are uniformly distributed within $[\theta_k - \theta_d/2, \theta_k + \theta_d/2]$, where θ_k is the AOA of user k and θ_d is the dispersion angle of the multipaths for each user. In the simulation a uniform circular array (UCA) is used in the receiver [7]. The array response factor is given by

$$\rho_{k,l}^{(m)} = exp[j\pi cos(2\pi(m-1)/M - \theta_{k,l})], \qquad (15)$$

where $\theta_{k,l}$ is the angle of arrival of path l of user k. We consider a dual-class system in which the required SIR for users in class I and II are denoted as γ_1^* and γ_2^*, respectively.

We first study a case in which class I and class II users have the same SIR requirement γ^*. This is actually a single class system and capacity can be expressed as total number of users in the system. The actual system capacity for antenna array multiuser receiver with different number of antennas is depicted in Figure 1. The required SIR $\gamma^* = 3$ dB and $\theta_d = 60°$. For comparison theoretical bound given by (13) is also plotted. The actual system capacity in multipath fading environment is always upper bounded by the theoretical bound. At large power constraint (SNR = 30 dB) the actual system capacity for $L = 1$ and $L = 3$ are almost the same. They are all quite close to the theoretical bound. At lower power contraint (SNR = 10 dB) capacity is reduced. Notice that the percentage of reduction is much lower with larger number of antennas, e.g. for $L = 3$ the reduction in capacity is about 1/2 for $M = 1$ while the reduction is only about 1/5 for $M = 6$. This shows that using multiple antennas increases the bandwidth utility at lower power constraint. Capacity of multipath channel ($L = 3$) is less than that of single path channel ($L = 1$), due to interference caused by the nonzero cross-correlation between the multiple path components of the same user. These results suggest that given relatively large power constraint, multipath diversity can be fully exploited such that actual system capacity approaches the theoretical bound. Therefore theoretical bound in (13) is quite useful for characterizing capacity of CDMA system with antenna array multiuser receiver.

We now study capacity of CDMA system using antenna array multiuser receiver with higher SIR requirement, $\gamma^* = 6$ dB. The actual system capacity for $L = 3$, $\theta_d = 60°$ and the theoretical bound are plotted in Figure 2. At large power constraint (SNR = 30 dB) the actual system capacity is quite close to the theoretical bound. At lower power constraint (SNR = 10 dB) capacity is reduced. For $M = 1$ the reduction is about 3/4, while for $M = 6$ the reduction is about 1/3. This shows that using multiple antennas

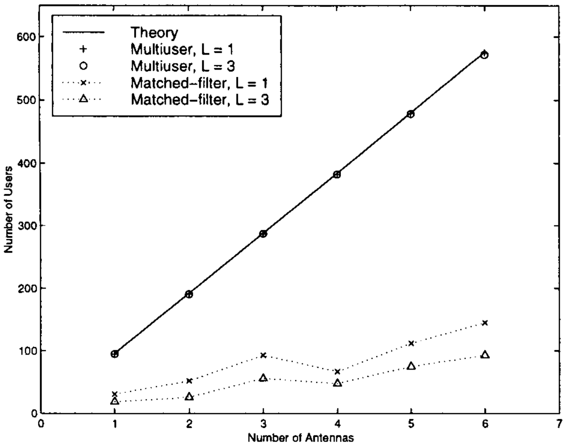

Figure 3. Capacity of CDMA system with antenna array multiuser receiver and matched-filter receiver.

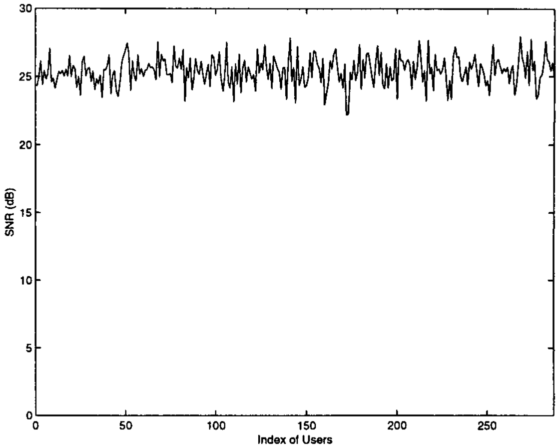

Figure 4. Power assignment of all the users. $K = 287$.

increases the bandwidth utility at lower power constraint. Considering that required SIR $\gamma^* = 6$ dB is close to the power constriant SNR $= 10$ dB, it is significant that system with 6 antennas can still support 320 users.We can compare capacity in this case to that in the previous case ($\gamma^* = 3$ dB, also plotted). While the SIR requirement is twice that of the previous case, capacity is about $5/6$ that of the previous case at large power constraint (SNR $= 30$ dB). Capacity is about $7/10$ of that in the previous case for $M = 6$ at lower power constraint (SNR $= 10$ dB). These results show that the antenna array multiuser receiver can support users with higher SIR requirement and achieve high capacity in CDMA system.

We now compare the capacity of CDMA system using antenna array multiuser receiver and antenna array matched-filter receiver. The actual system capacity for $\gamma^* = 3$ dB, $\theta_d = 60°$ and power constraint SNR $= 30$ dB as well as the theoretical bound are plotted in Figure 3. Capacity of system using antenna array matched-filter receiver is considerably lower than that of antenna array multiuser receiver. For example capacity of matched-filter receiver with 6 antennas is less than that of multiuser receiver with 2 antennas. Therefore using the antenna array multiuser receiver provides significantly higher system capacity than antenna array matched-filter receiver.

We now study the effect of adaptive power control on capacity. The following results are for $\gamma_1^* = 3$ dB, $\gamma_2^* = 3$ dB, $M = 3$, $L = 3$, $\theta_d = 60°$ and power constraint of $SNR = 30$ dB. Consider an example $K = 287$ which is quite close to the theoretical bound on capacity. The power assignment of all the users solved by the iterative power control algorithm is depicted in Figure 4. The average SNR of all the users is about 25 dB, and the range of SNRs is about 5 dB. The variance of SNR among the users is due to the different fading condition in channel and different cross-correlation of random codes. In fixed power control the received SNR is kept the same for all the users, clearly this would cause a large variance in SIR among the users. This degrades quality of service and/or reduces system capacity. In contrast to fixed power control, adaptive power control dynamically adjust the SNR according to the fading condition in the channel and cross-correlation of codes such that SIR at the receiver is equal to the required SIR.

Figure 5 depicts dynamics of adaptive power control for $K = 270$. The power assignment and SIR of user 1 during iteration are plotted, where τ_c is the time period in which the channel is nearly static, and t_{PC} is the time period between power updates. Assume channel variation caused by fading is slow that $\tau_c = 20 \cdot t_{PC}$. In the first channel state all the users start power iteration from initial power assignment of $SNR = 10$ dB, and SIR converges to the target level during iteration. After that power assignment is adjusted according to the change of fading condition in the channel. Notice that after the channel state changes it only takes a few iterations for the SIR to converge to the target level. This demonstrates that adaptive power control is able to maintain the SIR at the target level in multipath fading channel.

The relation of average power level and bandwidth utility is depicted in Figure 6. Bandwidth utility is defined as

$$\eta \equiv \frac{1}{MN} \sum_{k=1}^{K} \frac{\gamma_k^*}{1 + \gamma_k^*}, \qquad (16)$$

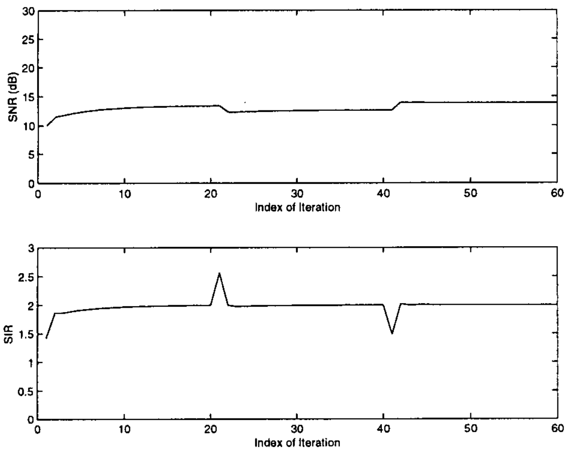

Figure 5. Power assignment and SIR for user 1 during iteration. $\tau_c = 20 \cdot t_{PC}$.

which indicates the load in CDMA system. The average power increases monotonically as the bandwidth utility increases. For antenna array multiuser receiver ($M = 3$) the average power is low ($SNR < 10$ dB) when load is light ($\eta < 0.87$). The average SNR is larger than 20 dB only when η is quite close to 1 ($\eta > 0.98$). The plot shows that a relatively low power level is sufficient for CDMA system with antenna array multiuser receiver to achieve reasonably high bandwidth utility. For the same bandwidth utility, the average SNR is 5 dB lower than of single antenna multiuser receiver ($M = 1$), since more energy is received using multiple antennas in the antenna array receiver.

We now study another case in which class II users have higher SIR requirement, $\gamma_1^* = 3$ dB and $\gamma_2^* = 6$ dB. The actual system capacity for $L = 3, \theta_d = 60°$ and the theoretical bound are plotted in Figure 7. For antenna array multiuser receiver ($M = 3$), at large power constraint (SNR = 30 dB) the actual system capacity is quite close to the theoretical bound. This again demonstrates that the theoretical bound is quite useful. At lower power constraint (SNR = 10 dB) capacity is reduced. The reduction when all users are in class I is about 1/5, while the reduction when all users are in class II is about 2/5. This is due to the higher SIR requirement (6 dB) for class II users and the lower power constraint (SNR = 10 dB). For single antenna multiuser receiver ($M = 1$), at large power constraint (SNR = 30 dB) the actual system capacity is quite close to the theoretical bound. At lower power constraint (SNR = 10 dB) capacity the capacity reduction when all users are in class I is about 1/2, while the reduction when all users are in class II is about 3/4. Therefore using multiple antennas helps to increase the bandwidth utility at lower power constraint.

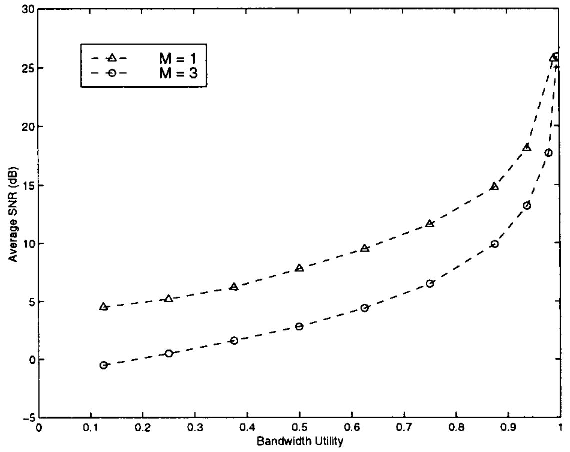

Figure 6. Average power vs. bandwidth utility, single class traffic.

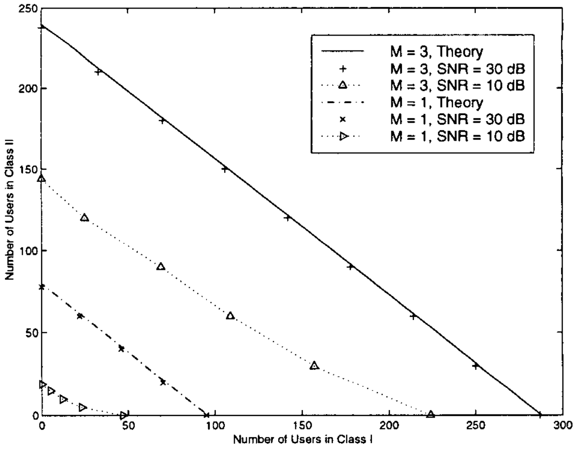

Figure 7. Capacity of dual-class CDMA system with antenna array multiuser receiver, single power constraint.

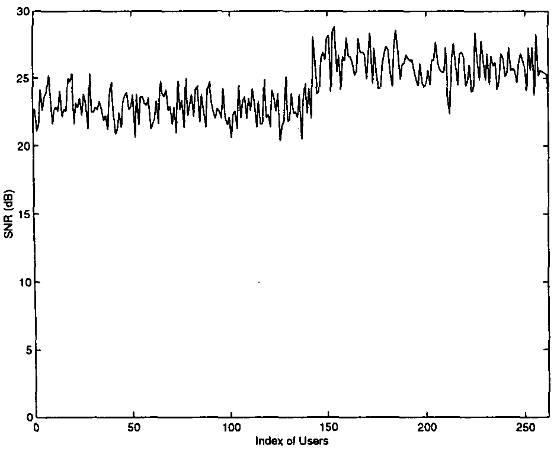

Figure 8. Power assignment of all the users. $K_1 = 142, K_2 = 120$.

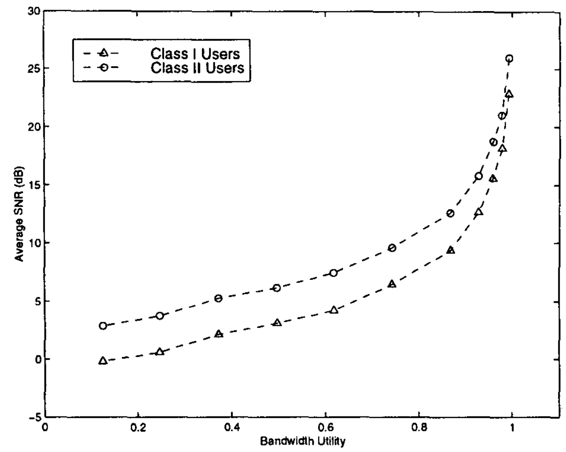

Figure 9. Average power vs. bandwidth utility, dual-class traffic.

We now study the power assignment for multiple classes of traffic. Consider an example $K_1 = 142$ and $K_2 = 120$ which is quite close to the theoretical bound on capacity. The power assignment of all the users solved by the iterative power control algorithm is depicted in Figure 8. The average SNR of class-I users is about 23 dB, and the average SNR of class-II users is about 26 dB. This is consistent with the fact that the required SIR for class II users ($\gamma_2^* = 6$ dB) is 3 dB higher than that of class I users ($\gamma_1^* = 3$ dB). The range of SNRs in each class is about 5 dB. The variance of SNR among the users within each class is due to the different fading condition in channel and different cross-correlation of random codes. In fixed power control the received SNR is kept the same for all the users in each class, clearly this would cause a large variance in SIR among the users. This degrades quality of service and/or reduces system capacity. In contrast to fixed power control, adaptive power control dynamically adjust the SNR according to the fading condition in the channel and cross-correlation of codes such that SIR at the receiver is equal to the required SIR.

We now study the power vs. load in system with multiple classes of traffic. The relation of average SNR for each class and bandwidth utility is depicted in Figure 9. Bandwidth utility is defined in (16). The average SNR for each class increases monotonically as the bandwidth utility increases. The average SNR of class-II users is about 3 dB higher than that of class-I users, which reflects the fact that the required SIR for class II users ($\gamma_2^* = 6$ dB) is 3 dB higher than that of class I users ($\gamma_1^* = 3$ dB). The plot shows that a relatively low power level ($SNR < 10$ dB) is sufficient for CDMA system with antenna array multiuser receiver to achieve reasonably high bandwidth utility ($\eta > 0.75$).

In the above we have shown that the average SNR of class-II users is 3 dB higher than that of class-I users. This suggests using different power constraints for each class of users in a multi-class traffic system. The actual system capacity with dual power constraint and the theoretical bound are plotted in Figure 10. The power constraint for class I users are $SNR_1 = 30$ dB and $SNR_1 = 10$ dB respectively, and power constraint class II users are 3 dB higher than that of class I users. For antenna array multiuser receiver ($M = 3$), at large power constraint ($SNR_1 = 30$ dB, $SNR_2 = 33$ dB) the actual system capacity is quite close to the theoretical bound. At lower power constraint ($SNR_1 = 10$ dB, $SNR_2 = 13$ dB) capacity is reduced. The reduction is about 23% and it is the same for different proportion of class I and class II users. Therefore using dual power constraint capacity can be simply described in terms of bandwidth utility. For example in this case bandwidth utility is about 0.77 for power constraint of $SNR_1 = 10$ dB and $SNR_2 = 13$ dB. For single antenna multiuser receiver ($M = 1$), at large power constraint ($SNR_1 = 30$ dB, $SNR_2 = 33$ dB) the actual system capacity is quite close to the theoretical bound. At lower power constraint ($SNR_1 = 10$ dB, $SNR_2 = 13$ dB) capacity is reduced by about 50% and bandwidth utility is about 0.5. Therefore using multiple antennas helps to increase the bandwidth utility at lower power constraint. The results here show that using dual power constraint the number of class II users that can be accommodated by the system is about 5/6 that of class I users for various power constraints, while the required SIR of class II users is twice that of class I users. Therefore using the antenna array multiuser receiver can increase the

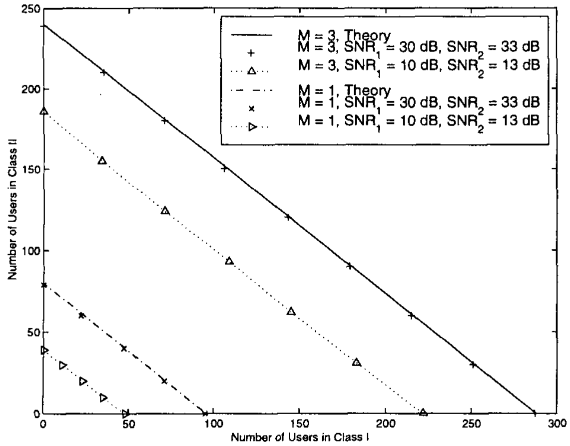

Figure 10. Capacity of dual-class CDMA system with antenna array multiuser receiver, dual power constraint.

capacity of users with higher SIR requirement.

6. Conclusions

In this paper we developed a new resource allocation scheme for wireless CDMA system using adaptive power control and antenna array multiuser receiver. The scheme can support multiple classes of traffic with different target bit error rate and guarantee their quality of service requirements in multipath fading environment. Our approach is that both transmit power and receiver filter adapt to the time-varying fading channel state. An antenna array multiuser receiver that jointly processes received signals from multiple antennas and maximizes the signal-to-interference ratio for each user is proposed. It is combined with adaptive power control based on required SIR for each user. A theoretical bound is derived to characterize capacity of CDMA system using the antenna array multiuser receiver. Simulations show that actual system capacity in multipath fading environment is close to the theoretical bound at large power constraint. Capacity at various power constraints can be characterized by a notion of bandwidth utility. It is also demonstrated that the antenna array multiuser receiver is quite effective in increasing capacity of users with *higher* SIR requirement and *lower* power constraint.

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