PERFORMANCE ENHANCEMENT OF DS-CDMA SYSTEM FOR WIRELESS LOCAL LOOP*

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Resumo - Neste trabalho, investiga-se a melhoria do desempenho da wireless local loop (WLL) empregando múltiplo acesso por divisão espacial (SDMA) com CDMA ortogonal para o canal reverso quase-síncrono. A característica estática de canal da tecnologia WLL permite o uso eficiente de arranjos adaptativos de antenas nas estações de rádio-base e de antenas direcionais nos terminais dos usuários. Apresentam-se expressões explícitas para a capacidade do sistema. Neste cenário, setorização dinâmica é introduzida e um esquema simples de atribuição dinâmica de códigos é utilizado para distribuir códigos para usuários em diferentes regiões. Resultados de simulações mostram que o uso de CDMA ortogonal/SDMA com o esquema de distribuição de códigos proposto apresenta melhora significativa em relação a SDMA ou CDMA ortogonal puros.

Abstract - In this paper, performance enhancement of Wireless Local Loop (WLL) employing Spatial Division Multiple Access (SDMA) with orthogonal CDMA for the quasi-synchronous reverse link is investigated. The static channel characteristic of WLL allows base station adaptive antenna arrays and subscriber directional antenna to be used effectively. We give explicit expressions of the capacity to access their performance. In such an environment, dynamic sectorization is introduced and a simple dynamic spreading code assignment scheme is proposed to assign codes for users in different areas. Simulations results are presented which demonstrate that the use of orthogonal CDMA/SDMA with the proposed dynamic code assignment scheme yields a drastic improvement over using SDMA or orthogonal CDMA alone.

Keywords: Wireless local loop, spatial division multiple access, dynamic code allocation.

1. INTRODUCTION

Recently, there has been a growing interest in deploying WLL system to provide wireless telephone services for fixed subscribers, especially in sub-urban areas or developing countries. From a service provider's perspective, short network deployment time, low capital and operating costs are some attractive features of WLL over the wired telephone system. Also, WLL offers many engineering advantages over traditional mobile cellular system, such as larger coverage area, higher capacity, absent of hand-off and fast fading, etc. To achieve a further increase in capacity, SDMA can be easily employed in WLL, since it allows the use of highly directive antenna or adaptive antenna arrays at both base station and subscriber terminals. By exploiting the spatial filtering properties of adaptive antenna arrays, the amount of interference from co-channel users within the same cell and neighboring cells is reduced.

The choice of multiple access scheme is another important issue in studying WLL. CDMA is considered to be providing the highest capacity among other alternatives such as FDMA and TDMA [1]. This is more evident in WLL, since the main shortcoming of CDMA, being the power control error due to fast fading, is largely eliminated.

CDMA is a interference-limited scheme in the sense that the capacity depends critically on the signal-to-interference-plus-noise ratio(SINR). Two approaches may be used in WLL to minimize the co-channel interference and increase the capacity. The first is the use of quasi-synchronous reverse channel with orthogonal spreading code as the user's signature. Unlike the situation in mobile systems, fixed subscribers in WLL permit the reverse link to be synchronized. The second approach is the previously mentioned SDMA. Past researchers had focused on individual approach only [2] [3] [6]. In this paper , the capacity enhancement of WLL utilizing these two approaches together is investigated. We derive analytical expressions of the capacity for this CDMA/SDMA system. Also, with SDMA, the conventional fixed sectorization is no longer applicable and this invokes the problem of how to assign codes to users in different areas. A dynamic code assignment scheme is therefore proposed to overcome this problem and achieve high spectral efficiency.

The paper is organized as follows. Section 2 describes the details of CDMA/SDMA system model in WLL. The theoretical analysis of capacity for CDMA/SDMA system is presented in Section 3. In Section 4, we introduce the concept of dynamic spreading code allocation. Section 5 presents the simulations results and discussions. Finally, concluding remarks are given in Section 6.

2. SYSTEM MODEL

2.1. ADAPTIVE ANTENNA ARRAYS - SDMA

Adaptive antenna arrays comprise a set of sensors, or elements, the output of which are combined in a way such

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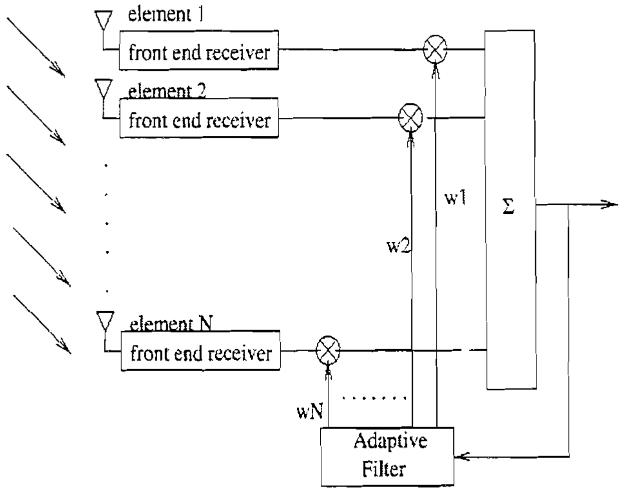
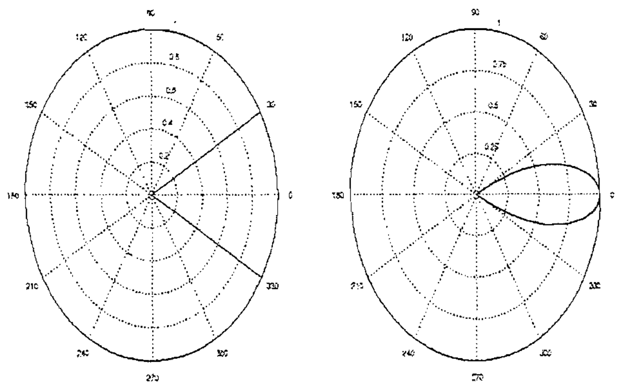


Figure 1. Basic structure of adaptive antenna array.



(a) "pie" shape, (b) "parabola" shape

Figure 2. Ideal antenna patterns.

Antenna	*Directivity*
Omni-directional	0 dB
Static "pie"	7.78 dB
Adaptive "pie"	7.78 dB
Adaptive "parabola"	9.70 dB

Table 1. Directivity of different antenna patterns

that their directional patterns will maximize the signal-to-noise ratio of a desired signal (Figure 1). An optimum directional pattern usually consists of beams steered toward signal components from the desired terminal and nulls steered towards those of the undesired terminals. To be able to form such pattern, the array weight vector must be determined adaptively to cope with signal or interference changes. However, in WLL, the motions of subscriber terminals are restricted and the computational burden required is reduced significantly. In this paper, we assume that there exists a line of sight(LOS) signal path and also the angular spread of multipath is small. Thus, the adaptation algorithm can utilize the information of direction of arrival (DOA), which is known a priori, for adaptation [4]. For simplicity, the following analysis of adaptive antenna arrays is based upon the assumption that steering the main beam towards the desired terminal is the optimum radiation pattern.

2.2. ANTENNA PATTERN

Figure 2a depicts the directional antenna pattern which is used at the subscriber terminal in all simulated scenarios. The main lobe is 60° wide with uniform gain and side lobes are assumed to be negligible. The center of the main lobe is directed towards the base station with which the terminal is operating. Next, for the sake of comparison, we considered 5 different ideal configurations for the base station antenna. The first configuration is simply the traditional omni-directional antenna with uniform gain. The second is 60° 6-sector/cell fixed sectorization. We assume the ideal "pie" shape pattern, as shown also in Figure 2a. The third configuration is the adaptive antenna with ideal "pie" shape pattern having the center directed towards the desired terminal. This configuration is the adaptive version of the second case and it will serve the purpose of comparing dynamic sectorization and fixed sectorization. The forth configuration is an adaptive antenna with "parabola" shape as illustrated in Figure 2b. In all the above cases, users in the reverse channel are synchronized and orthogonal spreading codes are employed. But in the final configuration, adaptive antenna with "parabola" shape is used with asynchronous reverse channel employing pseudo-random codes.

A metric used to assess the effectiveness of the antenna is directivity [6], which is defined below:

$$D = \frac{2\pi}{\int_0^{2\pi} G(\varphi)\, d\varphi} \tag{1}$$

where $G(\varphi)$ is the beam pattern or the antenna gain as a function of signal impinging angle φ. As shown in [6], if users are uniformly distributed and no subscriber antenna is used, the amount of interference power reduced is approximately equal to the directivity. Table 1 lists the directivity for all 4 antenna patterns.

2.3. CDMA CELLULAR MODEL

We proceed by defining a typical hexagonal cell arrangement, as shown in Figure 3. It consists of a center cell (0th cell), for which the capacity is derived, and the surrounding two tiers of interfering cells. We also classify the interfering cells into 3 groups, A, B and C, as shown in Figure 3. The base station is located at the center of each cell. To simplify the following calculations, we will use circular cell to approximate hexagonal cell by replacing a circle having the same area as the corresponding hexagon, hence the radius of the cell R is given as,

$$\pi R^2 = 6 \cdot \frac{1}{2} \cdot T \cdot \frac{2T}{\sqrt{3}} \Rightarrow 1.05T \tag{2}$$

where T is shortest distance from the center to the edge of hexagon.

We assumed that ideal power control is employed, fast fading is neglected due to the existence of LOS. The path loss

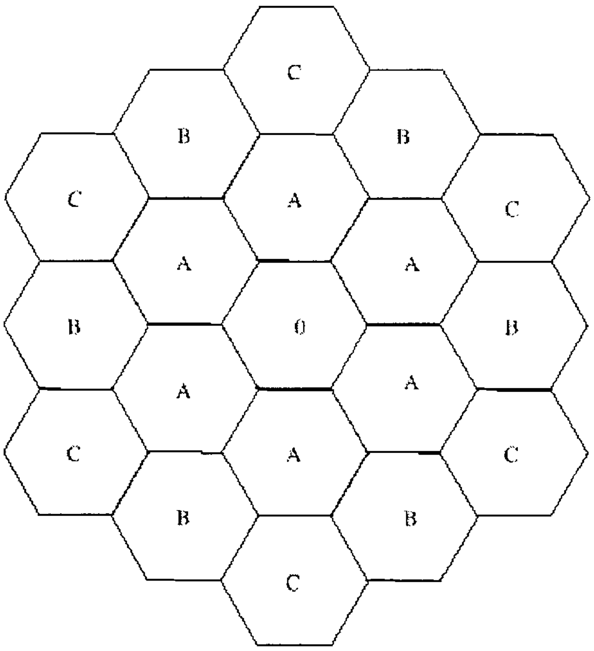


Figure 3. Cellular Environment in WLL.

between the subscriber and the base station is proportional to $10^{(\xi/10)}d^{-n}$ where n is the path loss exponent, d is the distance between them and ξ is a Gaussian random variable with standard deviation σ. For the reverse link, all users within the same cell are received with power P_u and the amount of interference power received by base station 0 from user i in neighboring cell j is given by:

$$P_{0,j,i} = 10^{\frac{\chi}{10}} P_u \left(\frac{d_{i,j}}{d_{i,0}}\right)^n \tag{3}$$

where $d_{i,0}$ is the distance between user i and base station 0, $d_{i,j}$ is the distance between user i and base station j, and $\chi = \xi_{d_{i,0}} - \xi_{d_{i,j}}$ is a Gaussian with zero mean and variance $2\sigma^2$. In this paper, n is assumed to be 3.

We assume the number of users is large and multiple access interference is modeled as Gaussian noise. Thus, in a 1/2 chip quasi-synchronous DS-CDMA WLL system employing sinc chip pulse and QPSK modulation, the SINR of a single user for reverse link is given below:

$$\text{SINR} = \frac{G}{\gamma I_1 + I_2 + \eta} \tag{4}$$

where I_1 is the intracell interference power, I_2 is the intercell interference power η is background noise density and γ is the interference reduction factor which is found as [7]:

$$\gamma = \begin{cases} 1, & \text{asynchronous system.} \\ 0.1158, & \frac{1}{2}\text{ chip quasi-synchronous system.} \end{cases} \tag{5}$$

3. THEORETICAL ANALYSIS OF CAPACITY

3.1. OMNI-DIRECTIONAL ANTENNA AT BASE STATION AND DIRECTIONAL ANTENNA AT SUBSCRIBER

We now confine our focus on the reverse link. First, we consider the capacity when 60° "pie" shaped fixed-directional antenna is deployed at the subscriber and omni-directional antenna at is deployed at the base station. The intercell interference from users of other cells to a user in the $0th$ cell is first calculated.

During the site planning, the existence of LOS is enforced between subscribers and their nearest base stations. As slow fading occurs, some terminals may experience temporary deep fades. Due to the fixed set-up of directional subscriber antenna, the pointing direction is not allowed to change with time. Hence, all the subscribers are operating with their nearest base stations, instead of the best stations which provide the highest reception quality. As the directional antenna is used at the subscriber terminal with main beam pointing at the desired base station, some users in the neighboring cells do not cause intercell interference to those in the center cell. Note that the intercell interference is only contributed by users in certain areas, according to their the positions and distances from their own base stations. Only those with radiation pattern covering the center cell base station are included as intercell interference. Figure 4 shows the geometry for calculating intercell interference. D denotes the distance between the 0th base station and jth base station with which interferer i is communicating. r_{ij} denotes the distance between subscriber i to its base station j. d_{i0} represents the distance between the subscriber i and $0th$ base station. Assuming that the received power at jth base station form subscriber i is 1, the transmitting power of subscriber i is equal to $r_{ij}^3 \cdot 10^{-\xi_{r_{i,j}}/10}$. Assume that users are uniformly distributed over each cell and let N_S denote the number of subscribers in each cell, the total interference I_{cell} caused by users in one neighbouring cell is,

$$I_{cell} = \rho \int_0^R \int_0^{2\pi} 10^{\frac{\chi}{10}} \left(\frac{r}{d_{i0}}\right)^3 \cdot G_S(\theta)\, r\, d\beta\, dr \tag{6}$$

where $\rho = \frac{N_S}{\pi R^2}$ the subscriber density and $G_S(\theta)$ is the subscriber antenna gain given by,

$$G_S(\theta) = \begin{cases} 1, & \text{if } |\theta| \le \pi/6, \quad \text{where } \theta = \sin^{-1}\left(\frac{D}{d_{i0}}\sin\beta\right) \\ 0, & \text{otherwise} \end{cases} \tag{7}$$

Note that θ and β are both defined in Figure 4. And d_{i0} is given by,

$$d_{i0} = \sqrt{r^2 + D^2 - 2rD\cos\beta} \tag{8}$$

where

$$\begin{array}{ll} D = 2T, & \text{Group A cell} \\ D = 2\sqrt{3}T, & \text{Group B cell} \\ D = 4T, & \text{Group C cell} \end{array} \tag{9}$$

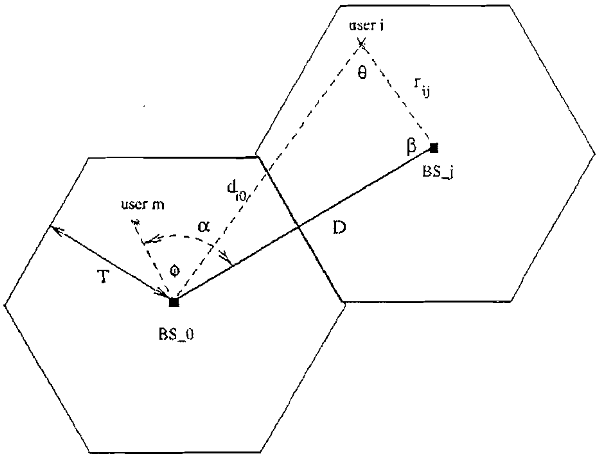


Figure 4. Reverse Link Calculation Geometry.

After some mathematical manipulations, (6) can be rewritten as,

$$I_{cell} = 10^{\frac{\chi}{10}} \cdot \Lambda \qquad (10)$$

where

$$\Lambda = \rho \int\limits_{0}^{R} \int\limits_{u(r)}^{\pi} \left(\frac{r}{d_{i0}}\right)^3 \cdot r \, d\beta \, dr \qquad (11)$$

and

$$u(r) = \sin^{-1}\left[\frac{0.5}{D}\left(0.866r + \sqrt{D^2 - \frac{r^2}{4}}\right)\right] \qquad (12)$$

As in [5], Icell is modeled as Gaussian random variable, assuming the spatial independence or whiteness of the blockage variable. The mean or first moment of Icell is given by,

$$E(I_{cell}) = E\left(10^{\frac{\chi}{10}}\right) \cdot \Lambda \qquad (13)$$

Due to the complexity of integral, we resort to numerical integration. And the mean of total intercell interference, which comprises of interference from cells of type A, B, and C, is given by,

$$E(I_2) = 6\left(E(I_A) + E(I_B) + E(I_C)\right) \qquad (14)$$

The variance of I_{cell} is given by,

$$\operatorname{var}(I_{cell}) = \operatorname{var}\left(10^{\frac{\chi}{10}}\right) \rho \int\limits_{0}^{R} \int\limits_{u(r)}^{\pi} \left(\frac{r}{d_{i0}}\right)^6 \cdot r \, d\beta \, dr \qquad (15)$$

Likewise, the variance of total intercell interference is,

$$\operatorname{var}(I_2) = 6\left(\operatorname{var}(I_A) + \operatorname{var}(I_B) + \operatorname{var}(I_C)\right) \qquad (16)$$

3.2. ADAPTIVE ANTENNA AT BASE STATION AND DIRECTIONAL ANTENNA AT SUBSCRIBER

The adaptive antenna array at the base station is now considered. Recall that the radiation pattern of base station adaptive antenna array $G_B(\phi)$ will be adjusted such that its maximum is directed towards the desired user. Both "pie" and "parabola" antenna (Figure 2) can be used as adaptive radiation patterns.

Although with perfect power control, the received SINR will vary from user to user due to the adaptive beam pattern. Let's first consider the effect on the intercell interference due to one interfering cell. Referring Figure 4 for calculation geometry, it becomes clear that the amount of intercell interference depends on the DOA (α) of desired signal from subscriber m in cell 0. Hence,

$$I_{cell} = \rho \int\limits_{0}^{R} \int\limits_{0}^{2\pi} G_B(\phi) \cdot 10^{\frac{\chi}{10}} \left(\frac{r}{d_{i0}}\right)^3 \cdot G_S(\theta) \, r \, d\beta \, dr \qquad (17)$$

and

$$\phi = \alpha - (\pi - \beta - \theta) \qquad (18)$$

I_{cell} is a function of two random variables α, χ, where the random variable α is uniformly distributed between $[0, 2\pi)$. The mean of I_{cell} is given by,

$$\begin{aligned} E(I_{cell}) &= \rho \int\limits_{0}^{R} \int\limits_{0}^{2\pi} E\left(G_B(\phi) \cdot 10^{\frac{\chi}{10}}\right) \left(\frac{r}{d_{i0}}\right)^3 \\ &\quad \cdot G_S(\theta) \, r \, d\beta \, dr \\ &= E\left(10^{\frac{\chi}{10}}\right) \frac{1}{2\pi} \int\limits_{0}^{2\pi} \rho \int\limits_{0}^{R} \left(\frac{r}{d_{i0}}\right)^3 G_S(\theta) \\ &\quad \cdot G_B(\alpha + \beta + \theta - \pi) \, r \, d\beta \, dr \, d\alpha \qquad (19) \end{aligned}$$

We have used the fact that G_B is a function of a uniformly distributed random variable (between $[0, 2\pi)$) independent of the values of β, θ. Using the definition of directivity (1), (19) becomes,

$$E(I_{cell}) = E\left(10^{\frac{\chi}{10}}\right) \mathcal{D}^{-1} \Lambda \qquad (20)$$

where Λ is given by (11) Thus we see that directivity indicates the amount of interference reduced by using the adaptive antenna over omni-directional antenna.

Likewise, the variance of I_{cell} is given by (assuming spatial whiteness),

$$\begin{aligned} \operatorname{var}(I_{cell}) &= \operatorname{var}\left(G_B(\phi) \cdot 10^{\frac{\chi}{10}}\right) \\ &\quad \cdot \rho \int\limits_{0}^{R} \int\limits_{0}^{2\pi} \left(\frac{r}{d_{i0}}\right)^6 \cdot G_S(\theta) \, r \, d\beta \, dr \qquad (21) \end{aligned}$$

where,

$$\begin{aligned}\operatorname{var}\left(G_B(\phi)\cdot 10^{\frac{x}{10}}\right) &= E\left(\left(G_B(\phi)\cdot 10^{\frac{x}{10}}\right)^2\right) - \\ &\quad E\left(G_B(\phi)\right)^2 E\left(10^{\frac{x}{10}}\right)^2 \\ &= E\left(G_B(\phi)^2\right) E\left(10^{\frac{x}{5}}\right) - \\ &\quad D^{-2} E\left(10^{\frac{x}{10}}\right)^2 \qquad (22)\end{aligned}$$

By computing the above numerically, we may obtain the variance of I2. Next, the intracell interference received when using base station adaptive antenna is given by,

$$\begin{aligned} I_1 &= \frac{N_S - 1}{\pi R^2} \int_0^R \int_0^{2\pi} G_B(\alpha)\, r\, d\alpha\, dr \\ &= (N_S - 1)\,\mathcal{D}^{-1} \qquad (23)\end{aligned}$$

Therefore the SINR can be expressed as,

$$\mathrm{SINR} = \frac{G_p}{\mathcal{D}^{-1}\gamma(N_S - 1) + I_2 + \eta} \qquad (24)$$

Now, we need to access the performance by the outage probability $\Pr(\mathrm{SINR} \leq \mathrm{SINR}_{\mathrm{req}})$. We assume that with a powerful convolutional code and e_cient modem, the $\mathrm{SINR}_{\mathrm{req}} = 6\,\mathrm{dB}$. Hence,

$$\Pr(\mathrm{SINR} \leq 6\,\mathrm{dB}) = \Pr(I_2 > \delta) \qquad (25)$$

where

$$\delta = \frac{G_p}{3.17} - D^{-1}\gamma(N_S - 1) - \eta \qquad (26)$$

4. DYNAMIC SPREADING CODE ASSIGNMENT

For the orthogonal CDMA reverse link, the intracell interference is minimized and a significant increase of SINR is achieved. In conventional fixed sectorization, all codes are reused in every sector. However, when each terminal establishes its own link with the base station via the adaptive antenna at the base station, we can define dynamic sector. Each terminal is located at the center of the sector as if it defines its own sector. For the analysis in the last section, we assume that the orthogonal code is available whenever a new subscriber requests a connection. However, the fact that the number of codes is limited must be taken into account and the issue of code allocation must be considered. Hence, we now propose a simple dynamic code assignment scheme to achieve high spectral efficiency while maintaining the required orthogonality between co-channel users. The scheme works as follows:

We introduce a parameter called minimum reuse angular separation (MRAS), which is de_ned as the required angular separation between two terminals which use the same code. MRAS thus determines the size of a user's sector. Obviously, narrow beam width with small side lobes' gain corresponds to a small MRAS and high reuse efficiency. In addition, a lookup table is used which contains the active terminals' locations with the corresponding codes which they are currently using. The simple allocation algorithm is summarized stepwise below:

1. When a new call request arrives, information about its location is sent to the base station.
2. Use the lookup table to check whether the angular separation between the new user and other active users is below the MRAS. If yes, go to 3. Otherwise go to 5.
3. The codes currently used by those terminals within the new call's MRAS are restricted from use by the new call. Compose a list of the possible codes for the new call. If no code is possible, the call is blocked. Otherwise, proceed to 4.
4. For each possible code, _nd out from the lookup table which users are currently using it. The new call would select the code which is currently used by the nearest[1] terminal.
5. Select a code randomly.

5. SIMULATION RESULTS

Performance analysis is conducted through simulations and they will be compared with the theoretical results. N subscriber terminals were uniformly generated in each cell. (N ranges from 100 to 1500 in simulations).

Dynamic code assignment is only used when using adaptive antenna. For simplicity, after N terminals are placed in each cell, the assignment scheme will assign codes to N terminals in random order, i.e. codes are assigned on a first come first serve basis, but the order of arrival of calls is random. The number of orthogonal codes is equal to the processing gain which is assumed to be 128. Also, we assume that the MRAS is 30° for both adaptive "pie" and "parabola" antenna.

5.1. NO SHADOWING ($\sigma = 0\,\mathrm{DB}$)

For the reverse link, the SINR was calculated in the center cell according to (4) for each user and the resulting bit error rates were averaged. The results for all con_gurations are summarized in Figure 5. Note that the x-axis shows the number of successful users, not the number of users requesting a call (N). There is a maximum hard limit of users that the system can accept, since the capacity is limited by the number of available codes. Users with no codes assigned are considered dropped. Note that the hard limit of capacity is different for different configurations, except for the case with asynchronous reverse channel which has no capacity hard limit. SINR comparison among various configurations is drawn from the region in which all hard limits have not been attained. As illustrated in Figure 5, the "parabola" adaptive antenna with synchronous channel

[1] Nearest here means smallest angular separation.

shows the most promising SINR performance and manyfold improvement over the same antenna with asynchronous channel or the omni-directional antenna with synchronous channel. This shows the benefit of utilizing both SDMA and orthogonal CDMA. The "pie" adaptive antenna shows comparable performance to the "pie" static antenna(60° sectorization), as their SINR curves overlap each other. In other words, with same directivity and uniformly distributed users, adaptive antenna in WLL does not produce significant SINR improvement over static antenna. However, a careful examination shows that with "pie" static antenna, system reaches the code's hard limit before it reaches unacceptable SINR (e.g. SINR = 6 dB). Under this circumstance, the system is now code- limited instead of interference-limited. Thus, the main benefit of using adaptive antenna comes from the use of dynamic code assignment, which increases the maximum number of users allowed. As shown in Figure 5 the hard limit of adaptive antenna is higher than that of static antenna, therefore achieving higher spectral efficiency through the use of SDMA with dynamic code assignment.

The average SINR calculation does not show whether individual link is able to maintain its connection and the required quality of service. This suggests another Figure of merit, the outage probability, which is defined below:

$$\Pr(\text{outage}) = \Pr(\text{SINR} < 6dB) + \Pr(\text{blocking}) \quad (27)$$

Note that users with no code assigned, i.e. blocking, are also considered as outage. Thus we assume that unacceptable SINR can be treated as blocking and vice versa. The results of all configurations are summarized in Figure 6. Now the x-axis shows the number of users requesting calls. Table 2 summarizes the capacities of all configurations when the required probability of outage must be less than 0.05. With the same directivity, "pie" adaptive antenna can achieve 1.4 times the capacity of "pie" static antenna. This improvement is the result of employing dynamic code assignment. To illustrate this fact further, Figure. 7 shows how many users are assigned the same code within the same cell, when "pie" adaptive antenna is used and number of users is large. Note that all codes are reused more than 8 times and some even 11 times. In comparison, codes are reused at most 6 times(6 sectors/cell) for the "pie" static antenna. Therefore higher spectral efficiency is achieved through the use of dynamic code assignment. Finally, the "parabola" adaptive antenna, combining the advantages of orthogonal CDMA and SDMA, achieves the lowest probability of outage. It is able to support 1260 users, whereas the "parabola" adaptive antenna with asynchronous channel supports 220 users and omni-directional with synchronous channel supports 130 users.

5.2. WITH SHADOWING ($\sigma = 2\,\text{DB}$)

Due to relatively static nature of WLL's radio channel and the existence of LOS, shadowing has less impact on the overall capacity. Hence, a smaller value of standard deviation is used compared with mobile channels (typical 6 to 8 dB). By introducing shadowing, the SINR performance decreases significantly (e.g. Figure 9). However, due to the perfect power control, the loss is mainly contributed by intercell interference, which is significantly mitigated by the subscriber directional antenna. Hence, base station antenna with high directivity still exhibits the code-limit behavior, that is, the outage is mainly due to loss for blocking. This can be shown by comparing the two "pie" configurations. The one with dynamic code allocation outperforms its counterparts significantly. When adaptive "parabola" antenna is used with orthogonal codes, as shown in Table 2, shadowing seems to have no impact on the outage performance. This is because the outage is due to blocking for such high directivity antenna, the loss in SINR due to shadowing does not contribute to the loss in outage. If the shadowing is much severe, the outage would be affected and antenna with higher directivity is required. On the other extreme, if the antenna's beam width is large, such as omni-directional antenna, the outage performance is also not affected by shadowing (Table 2). This is because the system quickly reaches the code-limit and outage due to blocking occurs, even for small number of subscribers.

Config.	*Antenna pattern and type of code*	$\sigma = 0\,\text{dB}$	$\sigma = 2\,\text{dB}$
1	Omni-directional, ortho.	130	130
2	Static "pie," ortho.	798	790
3	Adapt. "pie," ortho.	1135	990
4	Adapt. "parabola," ortho.	1260	1260
5	Adapt. "parabola," non-ortho.	220	200

Table 2. The maximum number of users which can be supported at an outage probability of 5% for various configurations

In Figure 9, we compare the results obtained from theoretical analysis and simulations for Configuration 4 employing orthogonal codes. For fair comparison, the code-limit is neglected during the simulations since the theory assumes that the number of orthogonal codes is not limited. The theoretical results agree closely with the simulations results, as shown by the mean of SINR.

6. CONCLUSION

The capacity improvement of CDMA WLL system had been studied. To achieve substantial improvement, two approaches had been examined: 1) realize SDMA by employing base station adaptive antenna arrays and subscriber directional antenna, 2) use orthogonal spreading codes for the quasi-synchronized reverse link. We have shown analytically the capacity equation of such CDMA/SDMA system. Due to the absent of fixed sectors, the issue of dynamic code allocation is introduced and a dynamic code assignment scheme is proposed to efficiently reuse the limited spreading codes.

For comparison, we considered 5 different ideal antenna configurations in a multicell, WLL system with LOS. Simulations results demonstrated that using SDMA with orthogonal CDMA shows the most promising improvement

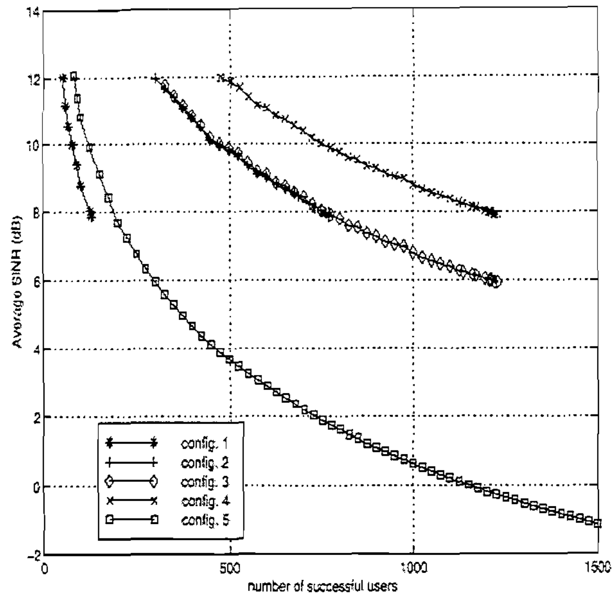


Figure 5. SINR performance of various con gurations (no shadowing).

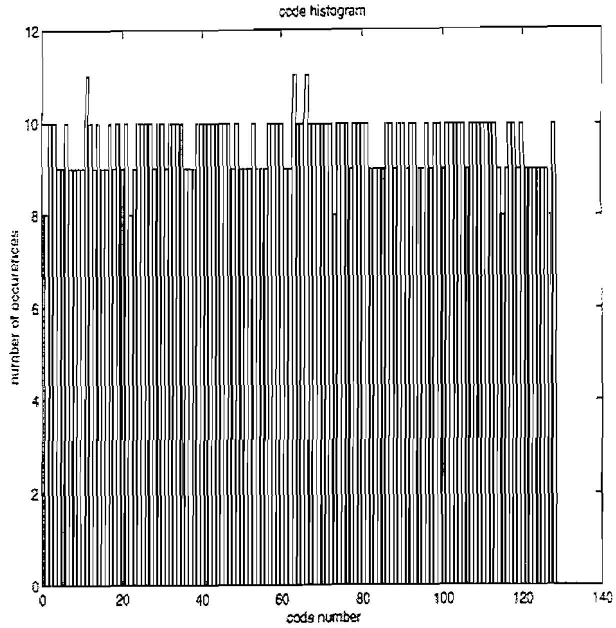


Figure 7. Number of occurrence versus code number.

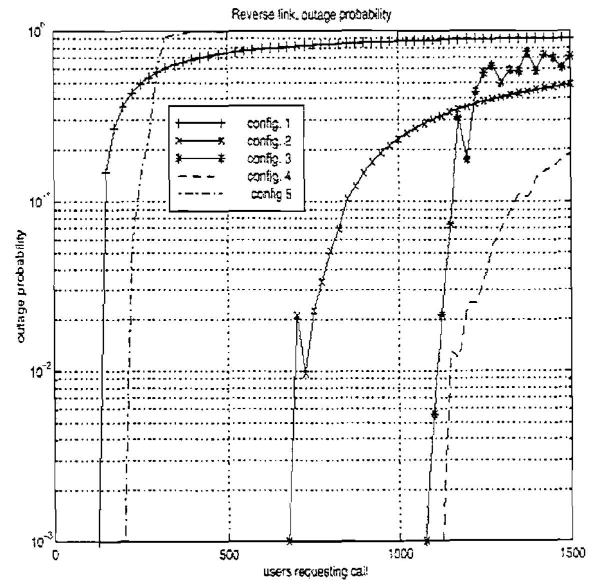


Figure 6. Outage probability of various con gurations (no shadowing).

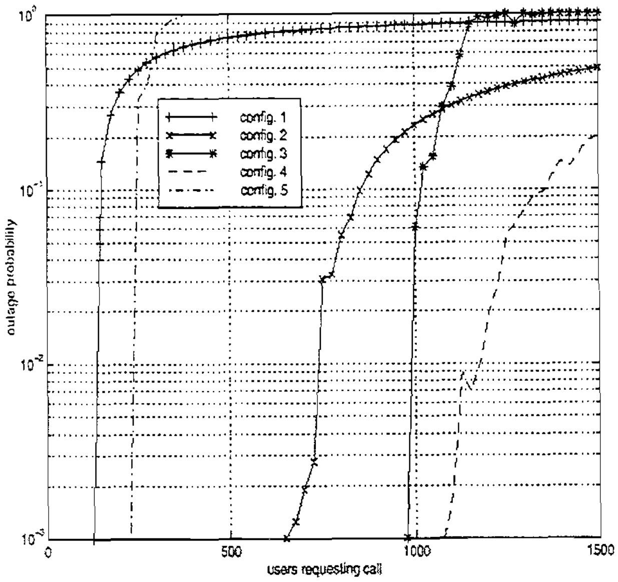


Figure 8. Outage probability of various con gurations (shadowing 2dB).

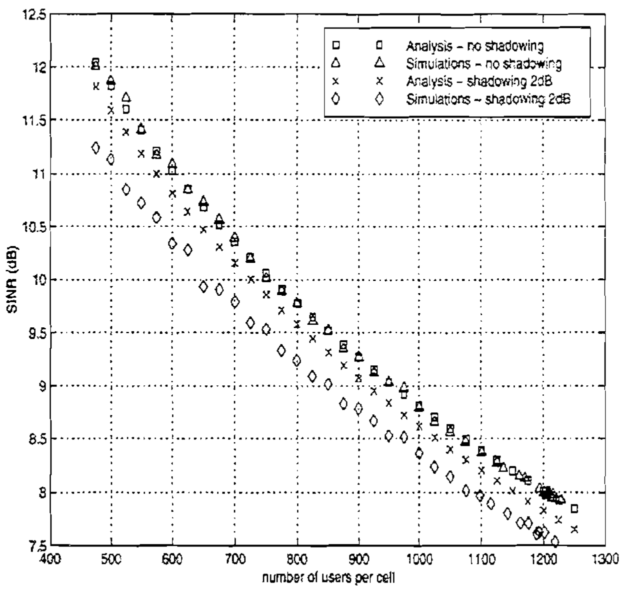


Figure 9. Mean SINR performance of con guration 4 (theory vs. simulations).

in capacity. It was found that such substantial improvement came partly from the reduction of interference due to orthogonal CDMA/SDMA and partly from the high spectral efficiency achieved by the proposed code assignment scheme.

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