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Dynamic Space-Code Multiple Access (DSCMA) System: A Double Interference Cancellation Multiple Access Scheme in Wireless Communications System

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1. Introduction

It is well known that cellular mobile phone systems have evolved from 1G and 2G that use frequency and time division multiple access (FDMA and TDMA) systems respectively, to code division multiple access (CDMA) of third generation (3G) systems (Chen et al., 2006). Furthermore, the exploitation of spatial diversity from the emergence of advance antenna technologies such as smart antenna and space time signal processing have given rise to induce another multiple access scheme called space division multiple access (SDMA) systems (Fang, 2002). Among these schemes, the system capacity and spectrum efficiency are the key factors to compare the performances of various mobile communication systems.

Since radio frequency (RF) spectrum is a limited resource, these techniques have approached their fundamental limitations. Flexible utilization of such resources in space, time and code has led to great improvement in system capacity. For a given bandwidth, the system capacity for narrowband radio systems such as FDMA and TDMA is dimension or bandwidth limited. In contrast, the system capacity of CDMA and SDMA systems is interference limited. Any reduction in interference in CDMA and SDMA systems converts directly and linearly into increased capacity (Yu et al., 2004), (Chen et al., 2008).

Multiple access schemes such as FDMA and TDMA increase their system capacity and spectrum efficiency by dividing the different network planning phases more clearly into individual parts to allow different frequencies to be used at different time moments (Castaeda & Lara, 2008). In CDMA systems, the same frequency is used simultaneously in adjacent cells and the interference level should be taken into account in the coverage-planning phase (Niemela & Lempiainen, 2003). Furthermore, cell splitting and sectorisation to form SDMA systems with use of directional antenna could also result in increase of system capacity and spectrum efficiency over the omnidirectional antenna system (Godara,

1997). Although these approaches do significantly increase the system capacity and spectrum efficiency, each scheme basically is attempting a more efficient use of the same resource.

It is well known that CDMA system is characterized as being interference limited. Independent simultaneous transmissions by mobile users at different locations in a cell give rise to the near-far phenomenon. To combat the near-far problem, power control is used to ensure equal signal levels are received from all mobile users at different location (Hashem & Sousa, 1997). Therefore, power control is considered the most important system requirement for CDMA systems to increase the system capacity on the reverse link by overcoming the near-far problem (Cameron & Woerner, 1996), (Uthansakul, 2002). Since all the cells can operate with the same channel in CDMA cellular network, a significant source of interference apart from traffic in its own cell is the traffic from neighbouring cells. Thus, the system capacity of CDMA systems is determined by the amount of co-channel interference that it can tolerate, which is comprised of intra-cell interference and inter-cell interference (Wu et al., 1998). If the traffic load in neighbouring cells is reduced, more traffic can be accepted in the observed cell (Chatovich & Jabbari, 1999). However, because of power control from observed cell base station (BS), transmitting a high power level in reverse link may result in high interference to neighbouring cell BS (Hashem & Sousa, 1997). Therefore, in CDMA systems, if the capacity of a single cell increases it creates higher interference to its neighbouring cells and thus impacts their capacity.

Other approach that shows a promise for substantial capacity enhancement is the use of spatial filtering with exploitation of smart antenna at cell site BS (Zheng et al., 1996). Hence, the deployment of SDMA system has been recognised as one of the most promising techniques for controlling co-channel interference in cellular systems, leading to the required system capacity improvement (Liberti & Rappaport, 1998). The beamforming ability of smart antenna technology has been adapted to increase the gain of the desired signal while null interference sources resulting in the improvement of the system capacity (Huang et al., 2001). The narrow beams from smart antenna are steered toward desired users in order to filter out interference caused by co-channel users located in the same cell and from adjacent cells (Galvan-Tejada & Gardiner, 2001).

However, in order to achieve an ideal SDMA system, smart antenna must carefully form its radiation patterns to capture the desired user and to nullify sufficiently interfering users. Therefore, the smart antenna requires high accuracy in propagation channel response estimation (Cho et al., 2002). If there are N elements antenna array used in a smart antenna system, it is only possible to accommodate $N - 1$ users in reverse link (Rapajic, 1998), (Kim et al., 2001). Actually in the randomness of mobile users distribution, this is not always possible to eliminate interferers by null-steering in the corresponding arrival directions. Hence, there will be a probability of two or more mobile users located near to each other. This means that the co-channel interferences will occur among these mobile users when adaptive beams steering smart antenna are employed. On the other hand, the present of sidelobes from smart antenna system will further reduce the signal to interference ratio (SIR) performance of each mobile user. Hence, more sidelobes interferences are radiated in the direction of the desired user main lobe pattern. These sidelobes interferences can significantly reduce the system capacity if multiple beams are synthesized from smart antenna to accommodate the density of mobile users in a particular area.

The wireless channel usually characterized by the path loss, shadowing and fading (Feuerstein et al., 1994). In urban areas, multipath propagation is common, whereby the receiver observes a number of copies of the transmitted signal, each with a different time delay (Adachi et al., 2005). This provides a form of multipath fading. In a digital communication system, the delay-spread of multipath propagation could also cause inter-symbol interference (ISI) (Lien & Cherniakov, 1998). The characteristics of the spreading sequences in CDMA system provide a crucial effect on the performance of the whole communication systems. This signature sequences in general determine how much interference is received at a receiver from other mobile users and influence the extraction capability of the desired signal from noise-like spectrum (Xie & Rahardja, 2005). On the other hand, since the reverse link of a CDMA system is usually asynchronous, in the sense that the arrival times for each mobile user signal are different (Thompson et al., 1996), (Choi et al., 2007). Therefore, the spreading sequences of CDMA systems are characterized with ISI as well as multiple access interference (MAI) (Peterson et al., 1995), (Guo & Wang, 2008). In multipath propagation environment, multiple copies of transmitted signal arrive at receiver with different time delay will cause ISI. A MAI occurs if the orthogonality among spreading sequences is lost (Ishida et al., 2000). The MAI is caused by asynchronous in a CDMA system where each mobile user will observe interference from all other mobile users in the system, since the transmitted signal will not be orthogonal in delay-spread environment (Thompson et al., 1996). Traditional CDMA spreading sequences such as m-sequence (Golomb, 1992), Gold codes (Gold, 1967), and Kasami codes (Kasami, 1966), exhibit non-zero cross-correlation which results in high MAI in asynchronous reverse link transmission. Another family of orthogonal codes is constituted by Walsh codes (Harmuth, 1970) and orthogonal Gold codes (Popovic, 1997), do retain their orthogonality in the case of perfect synchronization, but also exhibit non-zero cross-correlation in asynchronous transmission (Wei et al., 2005). Recently, an attractive family of large area synchronized (LAS) CDMA spreading sequences is introduced in (Li, 2003) has exhibited zero correlation zone (ZCZ) or interference free window (IFW) near zero delay time offset, resulting in zero ISI and MAI within the IFW. The LAS spreading sequence is constituted by the combination of Large Area (LA) code (Li, 1999) and Loosely Synchronous (LS) code (Stańczak et al., 2001). More specifically, the interference-free in CDMA system only become possible when the maximum channel-induced delay-spread is within the designed IFW duration. However, in the system design especially using omnidirectional antenna, not all multipath signal components arrive within IFW time offset. Since the total duration of IFW expressed in terms of the number of chip intervals depend on the minimum zero padding implanted between non-zero pulses interval, thus the number of minimum zero padding must be increased to maximum delay-spread of the channel in LAS sequence in order to accommodate all multipath signal components. This implies that the duty ratio of LAS spreading sequences is low when the number of minimum zero padding is increased. Therefore, a specific drawback of LAS-CDMA is that its relatively efficient orthogonal codes demanded in wireless systems are limited, and hence reduce its spectrum efficiency. Besides that, the implementation of LAS sequences is very complex that additional components are necessary.

There have been many multiple access systems for the cellular system designed to improve its system performance. Several works have been carried out to show the improvement in the system capacity using the joint multiple access system. A careful selection of joints

multiple access from two or more individual systems can determine the fitness of the joint system. Interference-limited systems such as CDMA and SDMA are susceptible to time of arrival (TOA) and angle of arrival (AOA) of individual user signals. Thus, a non-uniform traffic can severely degrade the performance of CDMA and SDMA systems. In this chapter, a joint multiple access of CDMA and SDMA system is proposed. The performance of this joint multiple access system is also vulnerable to the non-uniform traffic. Although the performance of this joint multiple access system has been previously studied in several papers (Liberti & Rappaport, 1994), (Naquib et al., 1994), (Buracchini et al., 1996) and (Ng & Sousa, 1998), none of them considers to evaluate the most realistic of system performance in this joint multiple access.

In this chapter, a new approach called dynamic space-code multiple access (DSCMA) system arising from the combination of CDMA and SDMA systems is designed, and its system performances are then investigated. An innovative approach to eliminate the existing interferences in DSCMA system is introduced. The spreading sequences of Large Area Synchronous Even Ternary (LAS-ET), which exhibited an interference free window (IFW) in their correlation, are exploited here. The spatial signature from smart antenna narrower beam is exploited to drive all the multipath propagation signals to arrive within the IFW in reverse link transmission. The size of IFW is adaptable with the size of smart antenna beamwidth through dynamic space-code (DSC) algorithm. Therefore, the result of combined dominant signature from DSCMA system will yield a perfect interference cancellation so that the system capacity increases dramatically.

2. The Properties of Orthogonal CDMA Sequences

Traditional ways of separating multiple access signals in time or frequency such as TDMA and FDMA are relatively simple by making sure that the signals are orthogonal and non-interfering. However, in CDMA different mobile users occupy the same bandwidth at the same time. They are separated from each other through the use of a set of orthogonal sequences. Two waveforms x and y are said to be orthogonal to each other if their cross-correlation, $R_{xy}(0)$ over T period is zero in time shift τ (Lee, 1998), where

$$R_{xy}(\tau) = \lim_{T \to \infty} \frac{1}{2T} \int_{-T}^{T} x(t)y(t+\tau)dt \tag{1}$$

In discrete time, the two sequences x and y are orthogonal if their cross product $R_{xy}(0)$ over T period is zero (Wang et al., 2007). The cross product of $R_{xy}(\tau)$ is defined as

$$R_{xy}(\tau) = \sum_{\tau=-T}^{T} x(t)y(t+\tau) \tag{2}$$

As an example, the following two sequences or codes, x and y are orthogonal.

$$x = \begin{bmatrix} -1, -1, +1, +1 \end{bmatrix} \tag{3}$$
$$y = \begin{bmatrix} -1, +1, +1, -1 \end{bmatrix} \tag{4}$$

Hence, their cross-correlation is zero.

$$R_{xy}(0) = (-1)(-1) + (-1)(+1) + (+1)(+1) + (+1)(-1) = 0 \qquad (5)$$

In order for the set of codes to be used in a multiple access scheme, an additional property is needed. In addition to the zero cross-correlation property, each code in the set of orthogonal codes must have an equal number of +1s and –1s (Faruque, 1996). This second property gives that particular code the pseudorandom nature. A direct sequence CDMA (DS-CDMA) system spread the baseband data by directly multiplying the baseband data pulses with a peudorandom or PN sequence that is produced by a PN code generator. A single pulse or symbol of the PN waveform is called a chip, where the chip rate is much higher than the data bit rate (Lee, 1991).

2.1 Welch Bound in CDMA Systems

The CDMA system is a multiple access scheme in which several independent users access a common communication channel by modulating their data symbols with preassigned spreading sequences. The receiver observes the sum of the transmitted signals in additive white Gaussian noise (AWGN) channel. The decoder for a given mobile user treats the sum of the interfering signals from other mobile users as noise. The spreading sequences are chosen to create good single user channels for the individual coding systems. In fact, however, the channel created by the spreading sequences is susceptible to MAI (Rupf & Massey, 1994). In 1974, Welch in (Welch, 1974) had shown that the lower bound for the acceptable sidelobes of auto-correlation and cross-correlation functions are set around $SF^{-\frac{1}{2}}$, where SF is the spreading factor or processing gain of the system. This lower bound is called as Welch bound (Li, 2003). Signature sequences that maximize the sum capacity in the uplink of CDMA systems in AWGN channel are known to satisfy Welch's bound on the total squared correlation with equality (Heath et al., 2004).

2.2 LAS-ET Sequences

The original LAS codes proposed in (Li, 1999) are synthesized by seeding LS codes in LA codes to improve it spectrum efficiency. An N_p LA codes are synthesized in such a manner that the N_p non-zero ±1 pulses from m-sequences oriented are positioned as shown in Table 1. This arrangement forms a configuration of $LA(N_p, K_0, L_c)$ where K_0 is the minimum number of zero padding in pulse interval of non-zero pulses which determine the size of IFW delay-spread in term of chips, while having a total code length of L_c chips.

	0	38	78	120	164	210	258	308	360	414	470	530	592	660	732	808	847
C1	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
C2	+	+	+	+	-	-	-	-	+	-	+	-	-	+	+	-	+
C3	+	+	+	-	-	-	-	+	-	+	-	-	+	+	-	+	+
C4	+	+	-	-	-	-	+	-	+	-	-	+	+	-	+	+	+
C5	+	-	-	-	-	+	-	+	-	-	+	+	-	+	+	+	+
C6	+	-	-	-	+	-	+	-	-	+	+	-	+	+	+	-	+
C7	+	-	-	+	-	+	-	-	+	+	-	+	+	+	-	-	+
C8	+	-	+	-	+	-	-	+	+	-	+	+	+	-	-	-	+
C9	+	+	-	+	-	-	+	+	-	+	+	+	-	-	-	-	+
C10	+	-	+	-	-	+	+	-	+	+	+	-	-	-	-	+	+
C11	+	+	-	-	+	+	-	+	+	+	-	-	-	-	+	-	+
C12	+	-	-	+	+	-	+	+	+	-	-	-	-	+	-	+	+
C13	+	-	+	+	-	+	+	+	-	-	-	-	+	-	+	-	+
C14	+	+	+	-	+	+	+	-	-	-	-	+	-	+	-	-	+
C15	+	+	-	+	+	+	-	-	-	-	+	-	+	-	-	+	+
C16	+	-	+	+	+	-	-	-	-	+	-	+	-	-	+	+	+

Table 1. The arrangement of 16 $LA(16,38,847)$ sequences

In order to exploit the characteristics of LA sequences proposed in (Li, 1999) without altering the size of its IFW, a modified version of the sequence such LAS-ET sequences (Ng et al., 2009) is employed in DSCMA instead of LAS-CDMA sequences proposed in (Li, 2003) which exhibit a small IFW. Figure 1 shows the correlation properties of the $LAS - ET(16,38,818)$ sequences. As can be seen in these figures, the correlation properties of $LAS - ET(16,38,818)$ sequences are similar to the original proposed $LA(16,38,847)$ sequences which exhibited a large IFW around the origin. The cross-correlation value of $LAS - ET(16,38,818)$ sequence in zero delay spread is 4.03 x 10^-17.

(a)

(b)
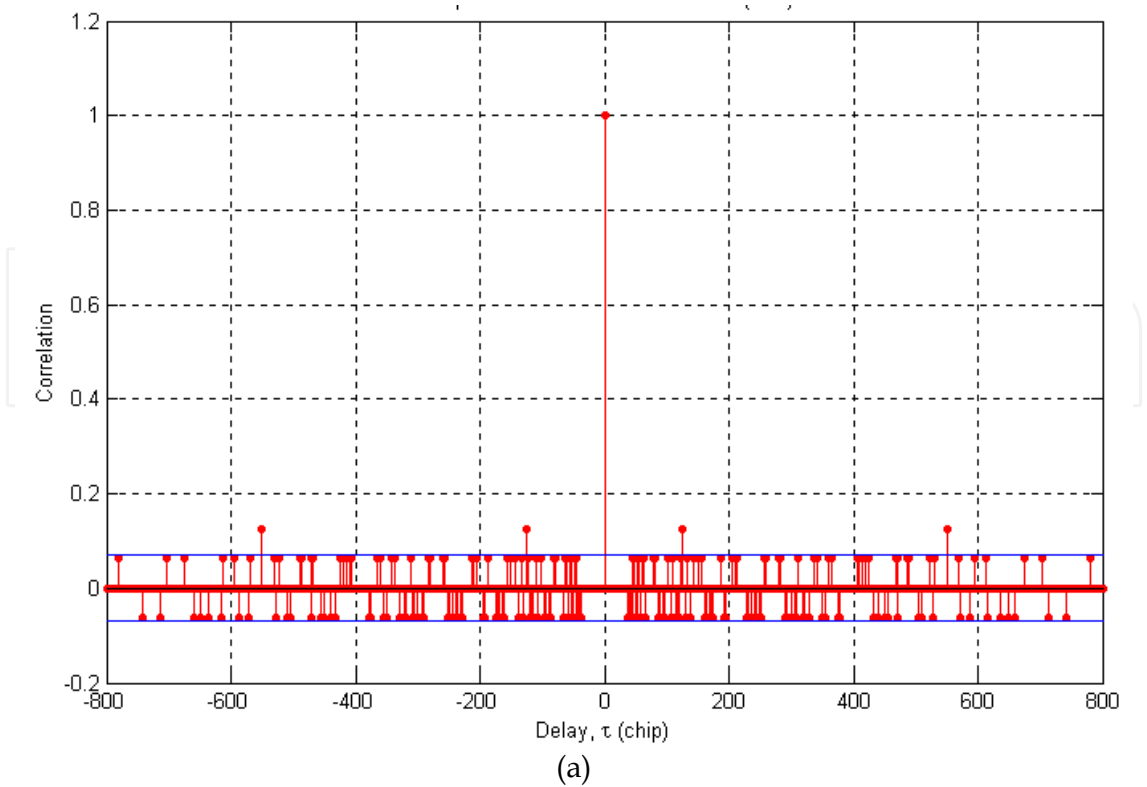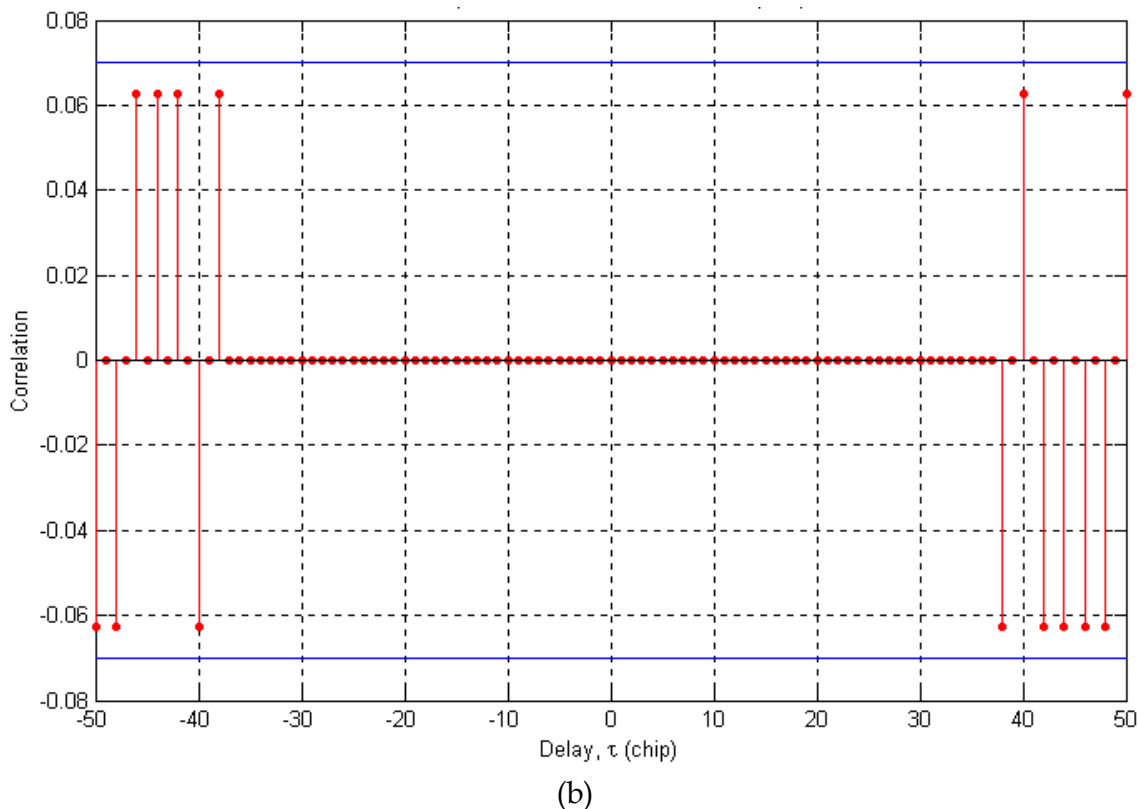
Fig. 1. Correlation properties of $LAS - ET(16,38,818)$ sequence; (a) auto-correlation and (b) cross-correlation.

3. Reverse Link Capacity of SDMA System

The conventional SDMA systems increase its capacity by spatial filtering the interferences. The system continuously adapts its narrower beam from smart antenna system to steer each mobile user with the main lobe while isolating interferences with nulls. Hence, SDMA is allowed to reuse the limited radio resources (frequency, time and code) within a cell. From Equation (1) in (Ng et al., 2008), the nulls' AOA, ψ_{nulls} of the SDMA radiation pattern occur at

$$\psi_{nulls} = \cos^{-1}\left[2\left(\frac{h}{N_e} - \frac{\alpha}{2\pi}\right)\right] \qquad (6)$$

where N_e is the number of elements in smart antenna system, α is progressively phase shift, and h is any integer but not equal to 0, n, $2n$, …..

Figures 2a and 2b show the typical SDMA system for N_e = 8 and 32 respectively with 90º AOA of the desired user. For N_e = 8, the nulls to accommodate interfering users are occurred at 41.41º, 60º, 75.52º, 104.48º, 120º and 138.59º, while the nulls for N_e = 32 are occurred at 20.36º, 28.96º, 35.66º, 41.41º, 46.57º, 51.32º, 55.77º, 60º, 64.06º, 67.98º, 71.79º, 75.52º, 79.19º, 82.82º, 86.42º, 90º, 93.58º, 97.18º, 100.81º, 104.48º, 108.21º, 112.02º, 115.94º, 120º,

124.23º, 128.68º, 133.43º, 138.59º, 144.34º, 151.05º and 159.64º. These figures show that the system capacity, *K* of SDMA system is direct proportional to the number of antenna elements in smart antenna with expression below (Rapajic, 1998)

$$K = N_e - 1 \qquad (7)$$

The interfering users are only allowed to be located at null AOAs, otherwise co-channel interferences between mobile users will occur. Any additional mobile user into this system after the limited nulls are fully occupied will also cause co-channel interference to other mobile users.

(a)

(b)
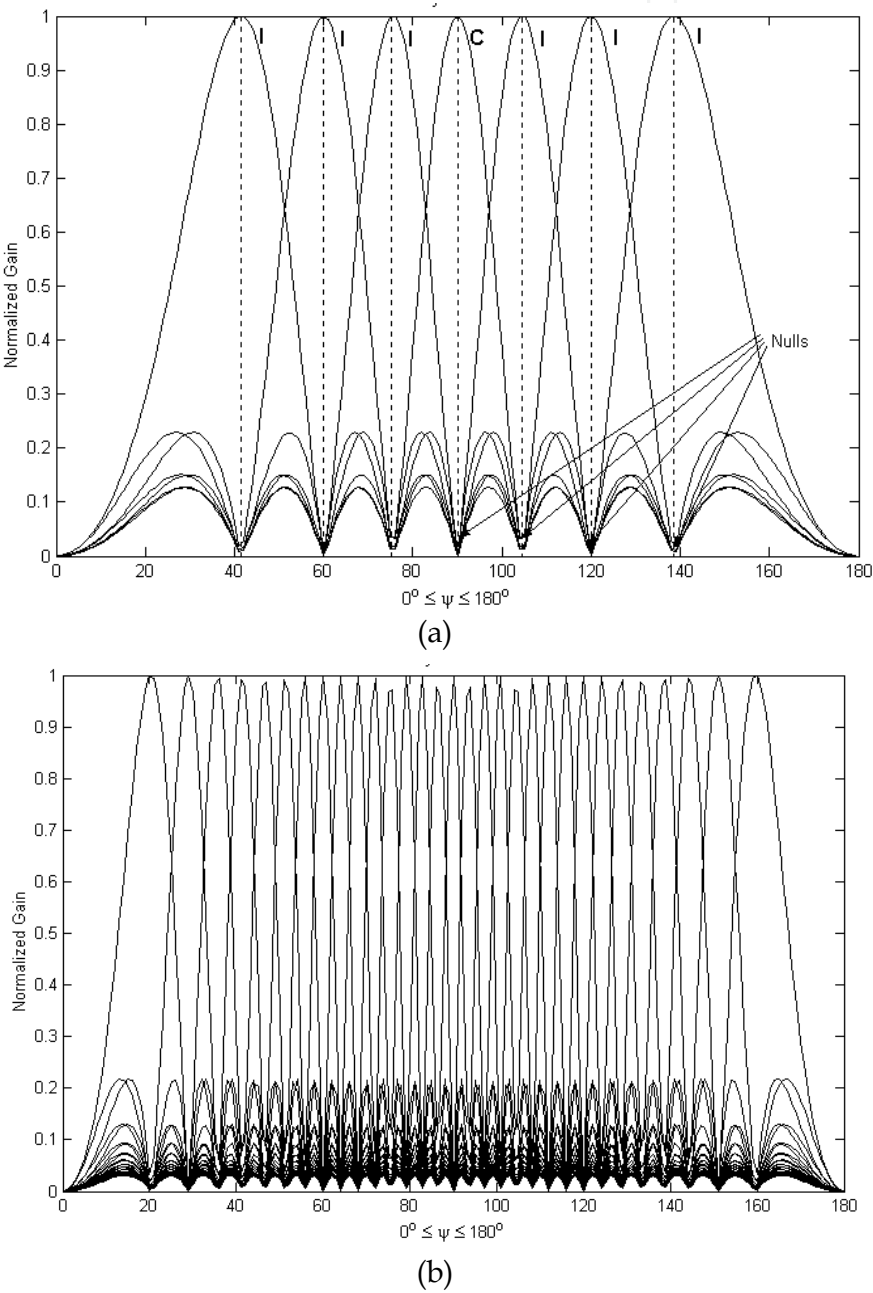
Fig. 2. Radiation pattern of SDMA system for (a) $N_e = 8$ and (b) $N_e = 32$.

It has been reported that smart antenna can synthesize a high directive beam toward the desired user while nulling the interfering users to increase capacity. However, fully nulling the interfering users in SDMA system do not take place because there are two major interference sources, which are side-lobes and co-channel interferences. The interfering users will not always locate at the nulls of the desired user radiation pattern especially in randomly distributed traffic environment as shown in Figure 3.
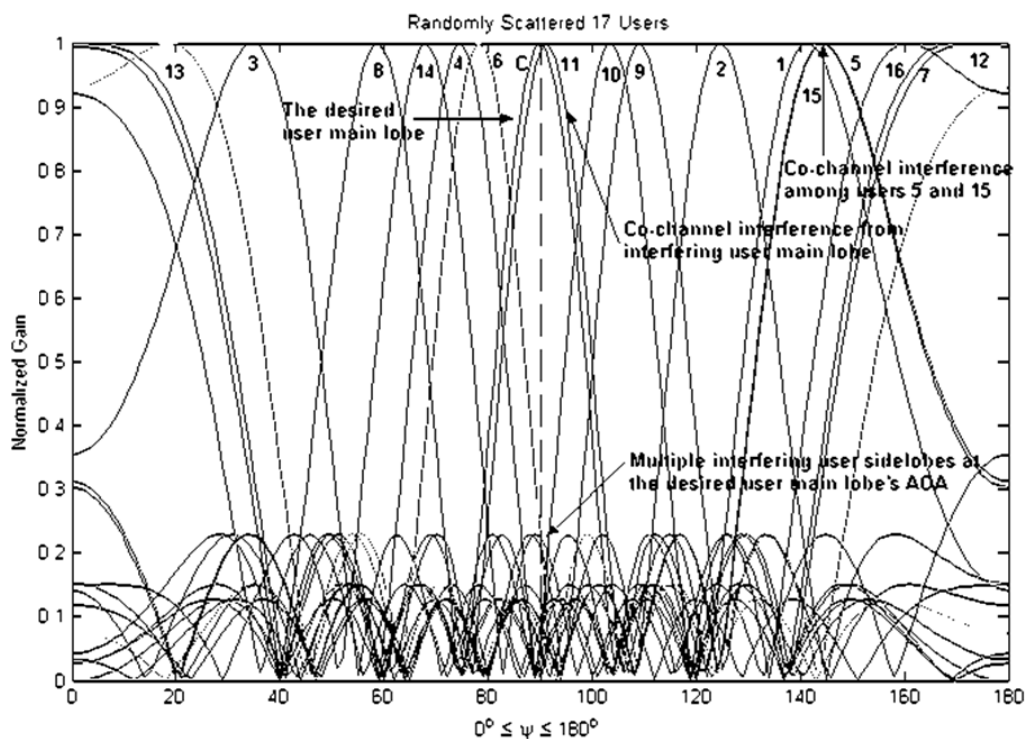
Fig. 3. Co-channel and side-lobes interferences to the desired user, C from randomly located interfering users of 1, 2, 3, 4,….., 16

4. Dynamic Space Code Multiple Access (DSCMA) System

Non-uniformly distributed traffic usually degrades the performance of CDMA and SDMA systems severely in the reverse link. The imperfect correlation properties of the traditional CDMA spreading sequences result in ISI and MAI at non-zero delay spread. The random positions of mobile users will cause MAI among them in the SDMA system, where positions at nulls of the desired user radiation pattern are rarely achieved. Therefore, the non-uniform traffic causes loss of orthogonality to distinguish each mobile user in the conventional interference limited systems.

Here, a promising solution to deploy the BS with smart antenna system to perform the joint multiple access of CDMA and SDMA systems is proposed. The CDMA and SDMA systems are adapted to each other dynamically to form DSCMA system. This proposed multiple access scheme is a novel interference cancellation scheme that employ the spreading sequences of CDMA system into spatial signatures of SDMA system through DSC algorithm. In DSC algorithm, the size of dedicated IFW from LAS-ET spread sequence is

adapted dynamically to the size of half power synthesized beamwidth from smart antenna beamforming system as shown in Figure 4. In this joint multiple access scheme, each user is assigned an LAS-ET sequence within a high directivity beam. Hence, the integration of these two signature schemes, spatial filtering and spreading sequence, creates a dominant signature scheme called DSC signature. Therefore, by using this dominant signature scheme, the inherent interferences in CDMA and SDMA systems environment can be eliminated.
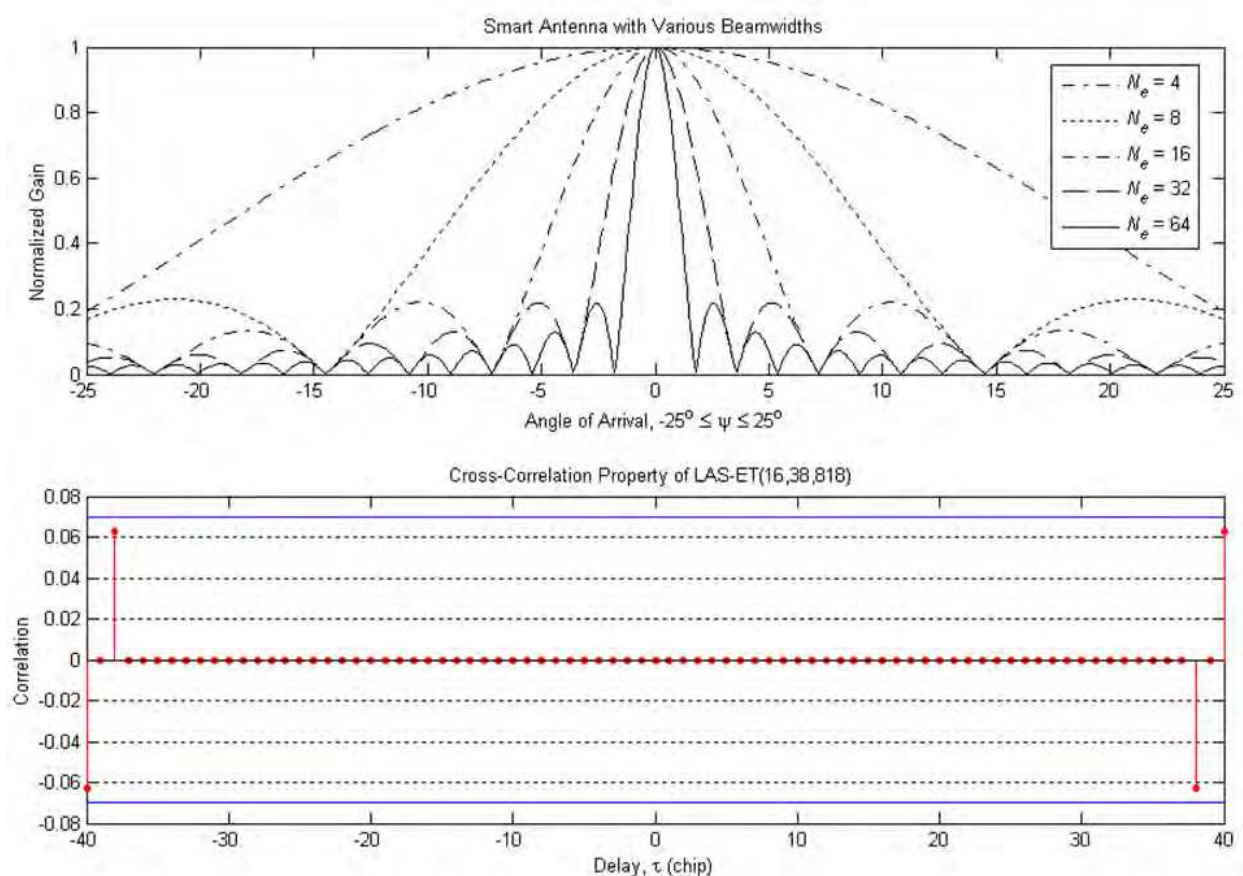
Fig. 4. Performance of various beamwidths in smart antenna system over IFW region from correlation property of $LAS-ET(16,38,818)$ sequences.

As shown in previous section, the co-channel interference between two mobile users in SDMA system occurs when both of them are located close to each other. For example, assuming that the desired user, C is located at AOA of 90° to the smart antenna axis while other mobile users are randomly located within the AOA of 0° to 180° as shown in Figure 3. It is observed that the 11th user's beam is located very near to C with only 0.6^o separation. This phenomenon causes co-channel interference between them while other mobile users also contribute interferences to C through their sidelobes radiation pattern. It is possible to mitigate these co-channel interferences by CDMA spreading sequences. However, all traditional CDMA spreading sequences are self-interference systems when all signals from each mobile user arrive at the BS in asynchronous manner. The auto-correlation and cross-correlation properties of traditional CDMA sequences are not orthogonal at non-zero delay

spread, $\tau > 0$. Thus, it shows that interference occur among the mobile users in asynchronous transmission environment.

Therefore, it is necessary to prefer spreading sequences that exhibit zero correlation between each other to drive all the asynchronous signal components to drop within the smart antenna's narrow beam maximum propagation delay spread. Hence, a spreading sequence that exhibits large size of IFW is required to accommodate large beamwidth of smart antenna radiation pattern. Considering Figure 3 again, there is group of beams with theirs AOA respectively to accommodate 17 randomly distributed mobile users. Each beam is assigned to different mobile user with an LAS sequence order, C1, C2, C3, C4, C5,…, Cm, where m is the maximum number of total available sequence. These sequences are assigned to mobile users in chronological order upon their arrival and can be reused dynamically whenever needed.

To illustrate how directive beam can improve the reverse link in a single cell of DSCMA system, consider the case in which each mobile user has an omnidirectional antenna, and the BS tracks each mobile user in the cell using a directive beam. Assume that the beam pattern, $G(\psi)$ in formed such that the pattern has a maximum gain in the AOA of the desired user. Such a directive pattern can be formed using an N_e elements smart antenna array. Assume that K users in the single cell of DSCMA system are non-uniformly distributed throughout a cell. On the reverse link, the power received from the desired user signal is $P_{r,0}$ with maximum gain of $G_0(\psi_0)$. The received powers from $K-1$ interfering users are given by $P_{r,i}$ for $i = 1,2,\ldots,K-1$. Then the average total received interference power, I seen at the desired user AOA, ψ_0 at the BS is given by

$$I = E\left\{\sum_{i=1}^{K-1} G_i(\psi_0)P_{r,i}\right\} \tag{8}$$

where $G_i(\psi_0)$ is the ith interference gain level of smart antenna radiation pattern seen at the AOA of the desired user. The value of $G_i(\psi_0)$ can be obtained from Equation (1) in (Ng et al., 2008) and is given as

$$G_i(\psi_0) = \frac{1}{N_e}\left|\frac{\sin N_e(\pi k \cos\psi_0 + \alpha_i/2)}{\sin(\pi k \cos\psi_0 + \alpha_i/2)}\right| \tag{9}$$

where k is given as 0.5 for half wavelength spacing between elements to avoid the appearance of grating lobe in the system, and parameter α_i is the phase shift of the smart antenna to steer the beam in ψ_i direction of ith interfering user. If the perfect power control is applied such that the received power at the BS antenna from each mobile user is the same, then $P_{r,i} = P_c$ for each of K users, and hence the average interference power seen by the desired user is given by

$$I = P_c E\left\{\sum_{i=1}^{K-1} G_i(\psi_0)\right\} \tag{10}$$

5. Reverse Link Interferences in DSCMA System

In DSCMA system, a BS equipped with smart antenna transmits signal to each mobile user in forward link transmission using a synthesized narrow beam and a dedicated spreading sequence. The signal is perfectly synchronized at transmission so that it arrives at mobile receiver in synchronism with zero delay spread. Consequently, due to the orthogonalities of both spatial signature and spreading sequence in zero delay spread among the K users in a cell, each mobile receiver can demodulate its own signal without interference from other transmitted signals that share the same channel.

However, this synchronism in forward link transmission cannot be maintained in reverse link transmission where all the signals from K users are rather arrived at BS in asynchronized manner. Thus, the signals from the other mobile users appear as additive interference to the desired user signal if the orthogonalities of both spatial signature and spreading sequence among them are loss in non-zero delay-spread. The reverse link interferences are twofold: the interference arising from $K-1$ users in the same cell or can be known as intra-cell interference, and the interference arising from mobile users in neighbouring cells or also called as inter-cell interference. Hence, the system capacity of DSCMA is examined by considering both intra-cell and inter-cell interference environments in reverse link transmission.

5.1 Intra-cell Interference

Suppose that each cell has K randomly distributed mobile users. With the use of perfect instantaneous power control, all K user signals are arriving at the BS with the same power level S within the same cell. Therefore, the intra-cell interference, $I_{int\,ra}$ from $K-1$ interfering users is given as

$$I_{int\,ra} = (K-1)S \tag{11}$$

In DSCMA system, the $K-1$ interferences power level are not same in the AOA of the desired user, ψ_0. Nevertheless, the interfering signals from $K-1$ users are still received at the same power level S from theirs respective AOA through perfect power control. Most of these interfering signals contribute merely side-lobe interferences with $G_i(\psi_0) < S$ in ψ_0 direction. Some of the interfering signals are also received at the same power level, $G_i(\psi_0) = S$ when they are at the same AOA of the desired user.

The arbitrarily interferences level, $G_i(\psi_0)$ as shown in Figure 3 with 16 interfering users can be analogously as multiple dots along the line of radiation pattern as shown in Figure 5. This is assuming that all radiation patterns for all mobile users are same. Hence, from (9) and (11), the intra-cell interference in AOA of mobile user C, $I_{int\,ra}(\psi_0)$ yields to

$$I_{int\,ra}(\psi_0) = S \cdot \sum_{i=1}^{K-1} G_i(\psi_0) = \frac{S}{N} \cdot \sum_{i=1}^{K-1} \left| \frac{\sin N(\pi k \cos(\psi_0) + \alpha_i / 2)}{\sin(\pi k \cos(\psi_0) + \alpha_i / 2)} \right| \tag{12}$$
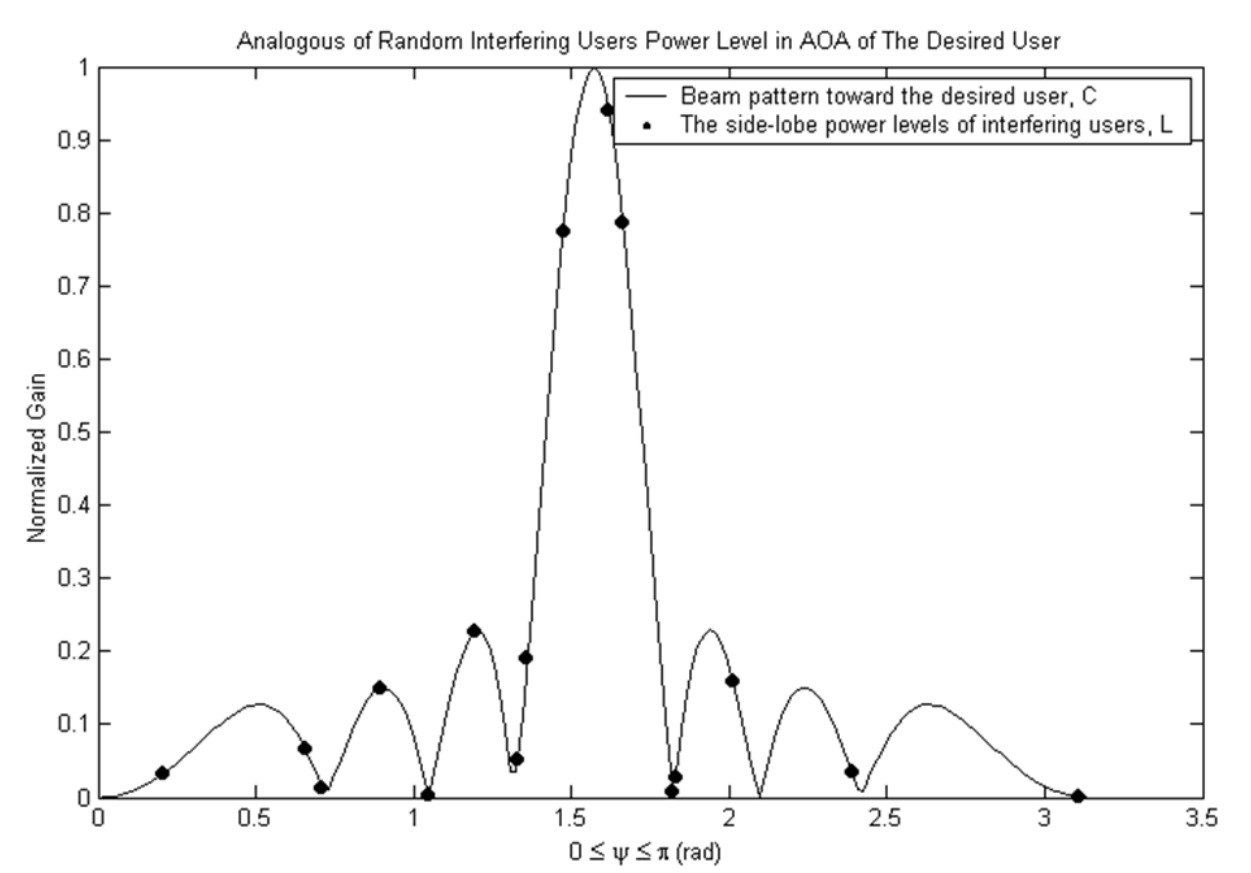
Fig. 5. The analogously random side-lobes interferences from 16 interfering users in AOA of the desired user

5.2 Inter-cell Interference

In the multi-cell of DSCMA system, the interference analysis in reverse link becomes complicated. This is because the mobile users are power controlled by their own cell BS. The membership of the user is determined by the maximum pilot signal power among the cells and not the minimum distance from a cell BS. The mobile users are connected to a BS that offers the lowest signal attenuation rather than the closest BS (Gilhousen et al., 1991). Because of power control, the interference level received from mobile users in neighbouring cells depends on two factors: attenuation in the path to the desired user's cell BS, and attenuation in the path to the mobile user's cell BS. Thus, in the fourth power law of distance, the user's transmitted power P_t can be expressed as (Chatovich & Jabbari, 1999)

$$P_t = P_r r^4 10^{(\zeta/10)} \tag{13}$$

where P_r is the received signal power at its BS, ζ is the log-normal Gaussian random variable with zero mean and standard deviation, σ of 8 dB, and r is the distance from the mobile user to BS. Since only average power levels are considered, the effects of multipath fading are ignored. To evaluate inter-cell interference, $I_{inter}(\psi_0)$ in DSCMA, consider an

interfering user located in mth neighbouring cell at a distance r_m from its base station BS_m and r_0 from the desired user base station BS_0 as shown in Figure 6.
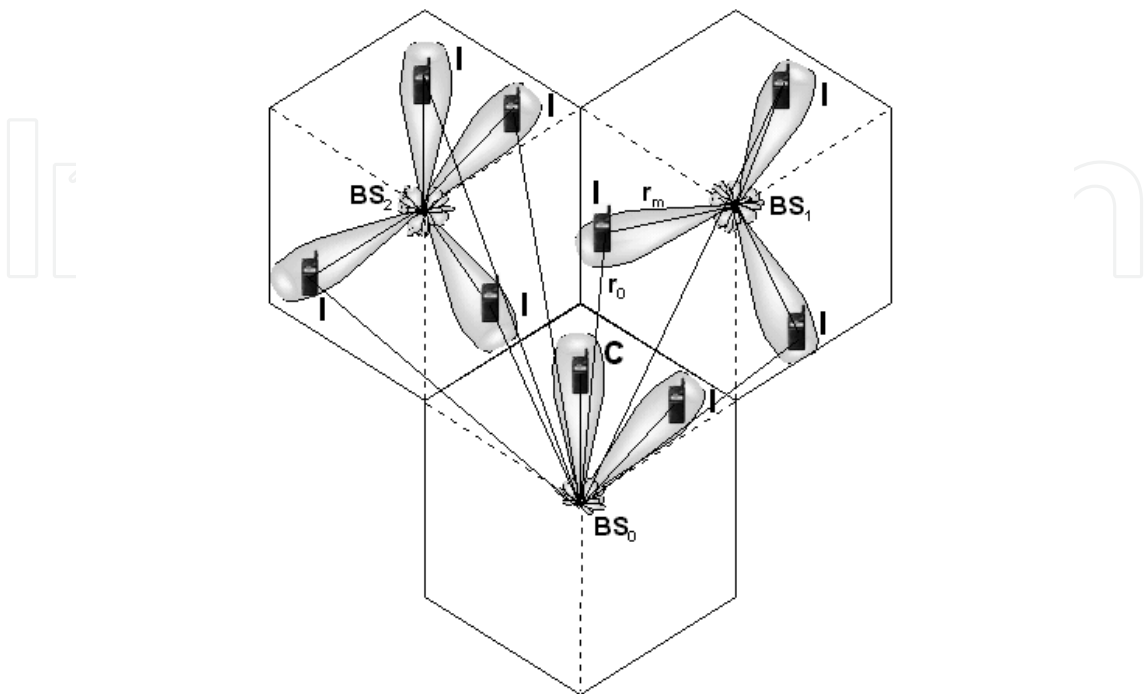
Fig. 6. Inter-cell interference environment model.

If P_t is its transmit power, the received power S at its BS is given by

$$S = \frac{P_t G_m(\psi_m)}{10^{(\zeta_m/10)} r_m^4} \tag{14}$$

where $G_m(\psi_m)$ is the antenna gain in the AOA of the interfering user to its cell BS_m, and ζ_m is the Gaussian random variable representing the shadowing process in its cell. Then the interference I received at BS_0 is given by

$$I = \frac{P_t G_0(\psi_{mi})}{10^{(\zeta_0/10)} r_0^4} \tag{15}$$

where $G_0(\psi_{mi})$ is the antenna gain of BS_0 in the AOA of the ith interfering user from mth neighbouring cell to BS_0, and ζ_0 is the Gaussian random variable representing the shadowing process in the desired user cell.

Hence, from (14) and (15), the interference to signal ratio, I/S is given by

$$\frac{I}{S} = \left(\frac{r_m}{r_0}\right)^4 \cdot \left(\frac{G_0(\psi_{mi})}{G_m(\psi_m)}\right) \cdot 10^{(\zeta_m - \zeta_0)/10} \tag{16}$$

where the first term is due to the attenuation caused by distance and blockage to the given BS, while the third term is the effect of power control to compensate for the corresponding attenuation to its BS. Since ζ_m and ζ_0 are independent their difference has zero mean and variance $2\sigma^2$ (Cooper & Nettleton, 1978). The second term reveals the total antenna gain received in the AOA of the interfering user to the BS_0, and its value is less than unity. In DSCMA, this second term will only has a maximum value when an interfering user from a neighbouring cell is located at the same AOA of the desired user, ψ_0. Then $G_0(\psi_{mi})$ in (16) will become

$$G_0(\psi_{mi}) = \frac{1}{N_e} \cdot \sum_{m=1}^{6} \sum_{i=1}^{K-1} \left| \frac{\sin N_e(\pi k \cos(\psi_{mi}) + \alpha_0/2)}{\sin(\pi k \cos(\psi_{mi}) + \alpha_0/2)} \right| \tag{17}$$

For all values of the parameters in (16), I/S is less than unity. If its value is not less than unity then the user would switch to the other cell BS. Therefore, $I_{inter}(\psi_0)$ in DSCMA is found by summing (16) for all mobile users in the first tier neighbouring cells

$$I_{inter}(\psi_{mi}) = \sum_{m=1}^{6} \sum_{i=1}^{K-1} S \cdot \left(\frac{r_{mi}}{r_{0i}} \right)^4 \cdot \left(\frac{G_0(\psi_{mi})}{G_m(\psi_m)} \right) \cdot 10^{(\zeta_{mi} - \zeta_{0i})/10} \tag{18}$$

where $G_m(\psi_m) = 1$ which the gain to theirs mobile user is 1.

6. DSCMA System Signalling

To simplify the derivation, only the baseband signal of transmitted signal is being considered. Hence, in DSCMA system, the transmitted signal from the ith user, $s_i(t)$ that occupies the ith spreading sequence for $i = 1, 2, \ldots, K-1$ can be written as

$$s_i(t) = \sqrt{P} d_i(t) c_i(t) \qquad\qquad 0 \le t \le T \tag{19}$$

Assuming that the desired user is user 0 and all the other $K - 1$ users are interfering users. The received signal, $r(t)$ is a sum of the transmitted signals from all K users and corrupted by its additive complex Gaussian thermal noise, $n(t)$ in an AWGN channel. The signal of each mobile user arrives at a different propagation delay, τ_i. Thus, the received signal at the BS equipped with smart antenna beamforming network in the AOA of user 0 can be expressed as

$$r(\psi_0, t) = \sum_{i=0}^{K-1} s_i(t - \tau_i) \sqrt{G_i(\psi_0)} + n(t) = \sum_{i=0}^{K-1} \sqrt{P} \sqrt{G_i(\psi_0)} d_i(t - \tau_i) c_i(t - \tau_i) + n(t) \tag{20}$$

where $G_i(\psi_0)$ denotes as ith radiation pattern gain of ith user in the AOA of user 0. This equation signifies the combination of CDMA and SDMA by the terms $G_i(\psi_0)$. When

$G_0(\psi_0)$ is normalized to 1, the generated $G_i(\psi_0)$ will be less than 1 if the ith interfering user is not located at the same AOA as user 0. For a conventional CDMA system, $G_i(\psi_0)$ will take the value of 1. This signal is then despread with the spreading sequence of user 0 at the receiver. A correlation-based detector is used to obtain the appropriate decision, z_0 which can be derived as

$$z_0 = \int_0^T r(\psi_0, t) c_0(t - \tau_0 - \tau_e) dt \tag{21}$$

where τ_e is the sequence synchronization error, which degrades the auto-correlation properties. If prefect synchronization is assumed as in the case of directional antenna, where the multipath fading effect is neglected, then $\tau_0 = \tau_e = 0$. Thus, Equation (21) leads to

$$\begin{aligned}
z_0 &= \int_0^T r(\psi_0, t) c_0(t) dt \\
&= \int_0^T \left[\sqrt{P}\sqrt{G_0(\psi_0)} d_0(t) c_0^2(t) + \sum_{i=1}^{K-1} \sqrt{P}\sqrt{G_i(\psi_0)} d_i(t - \tau_i) c_i(t - \tau_i) c_0(t) \right. \\
&\quad \left. + n(t) c_0(t) \right] dt \\
&= S + I + \eta
\end{aligned} \tag{22}$$

7. Probability of Error Evaluation in DSCMA System over AWGN Channel

A bit error rate (BER) expression for DSCMA is derived over MAI from the other $K – 1$ users in an AWGN channel. The derivation is performed at the baseband level, which will simplify the analysis. From the previous section, the first term of (22), S is the transmitted signal of user 0, where

$$S = \int_0^T \sqrt{P}\sqrt{G_0(\psi_0)} d_0(t) c_0^2(t) dt \tag{23}$$

Considering that $G_0(\psi_0) = 1$, $c_0^2(t) = 1$ and $d_0 = \pm 1$, thus Equation (23) becomes

$$S = \pm\sqrt{PT} \tag{24}$$

The term η in (22) is the noise component due to $n(t)$ in AWGN channel, which corresponds to the despread term of $n(t)$ attributes to

$$\eta = \int_0^T n(t) c_0(t) dt \tag{25}$$

Since $n(t)$ is the zero mean AWGN having a variance of $\sigma^2 = N_0/2$, thus η is also a zero mean Gaussian variable and a variance of $Var[\eta]$, which is derived as

$$
\begin{aligned}
Var[\eta] &= E[\eta^2] \\
&= E\left[\int_0^T n(t)c_0(t)dt \int_0^T n(u)c_0(u)du\right] \\
&= \int_0^T \int_0^T E[n(t)n(u)]c_0(t)c_0(u)dtdu
\end{aligned}
\tag{26}
$$

But $E[n(t)n(u)]$ is the auto-correlation of $n(t)$, where

$$
E[n(t)n(u)] = \frac{N_0}{2}\delta(t-u)
\tag{27}
$$

Therefore, the variance of (26) becomes

$$
\begin{aligned}
Var[\eta] &= \frac{N_0}{2}\int_0^T \int_0^T \delta(t-u)c_0(t)c_0(u)dtdu \\
&= \frac{N_0}{2}\int_0^T c_0^2(u)du \\
&= \frac{N_0 T}{2}
\end{aligned}
\tag{28}
$$

The term I in (22) is the MAI component of the $K-1$ interferers, which is given by

$$
I = \sum_{i=1}^{K-1}\sqrt{P}\sqrt{G_i(\psi_0)}\int_0^T d_i(t-\tau_i)c_i(t-\tau_i)c_0(t)dt
\tag{29}
$$

Since $\int_0^T c_i(t-\tau_i)c_0(t)dt$ is cross-correlation between sequences c_i and c_0, thus

$$
\int_0^T c_i(t-\tau_i)c_0(t)dt = R_{i,0}T
\tag{30}
$$

and $d_i(t-\tau_i) = \pm 1$, therefore I is reduced to

$$
I = \pm\sqrt{PT}\sum_{i=1}^{K-1}\sqrt{G_i(\psi_0)}R_{i,0}
\tag{31}
$$

The signal to interference plus noise ratio (SINR) is then given as

$$
SINR = \frac{S^2}{Var[\eta]+I^2}
\tag{32}
$$

Therefore, from (24), (28) and (31), the SINR for the DSCMA system can be expressed as

$$
\begin{aligned}
SINR &= \frac{PT^2}{\dfrac{N_0 T}{2} + PT^2 \displaystyle\sum_{i=1}^{K-1} G_i(\psi_0) R_{i,0}^2} \\[2em]
&= \left[\frac{\dfrac{N_0 T}{2} + PT^2 \displaystyle\sum_{i=1}^{K-1} G_i(\psi_0) R_{i,0}^2}{PT^2} \right]^{-1} \\[2em]
&= \left[\frac{N_0}{2PT} + \sum_{i=1}^{K-1} G_i(\psi_0) R_{i,0}^2 \right]^{-1}
\end{aligned}
\tag{33}
$$

Since the amplitude of each mobile user's signal is $\sqrt{P}$, then the energy per bit is $E_b = PT$. The Equation (33) leads to

$$
SINR = \left[\frac{1}{2\,E_b/N_0} + \sum_{i=1}^{K-1} G_i(\psi_0) R_{i,0}^2 \right]^{-1}
\tag{34}
$$

Assuming that the combining noise and interference components have a Gaussian distribution, then the BER is given as

$$
BER = Q\left(\sqrt{SINR}\right) = Q\left(\left[\frac{1}{2\,E_b/N_0} + \sum_{i=1}^{K-1} G_i(\psi_0) R_{i,0}^2 \right]^{-\frac{1}{2}} \right)
\tag{35}
$$

where Q(x) is the Gaussian Q-function.
For the interference limited of DSCMA system where thermal noise is not a factor due to

$$
\frac{E_b}{N_0} = SF \frac{E_c}{N_0}
\tag{36}
$$

where the resultant of E_b/N_0 is large enough to cause the thermal noise become negligible. Therefore, Equation (35) is reduced to

$$
BER = Q\left(\left[\sum_{i=1}^{K-1} G_i(\psi_0) R_{i,0}^2 \right]^{-\frac{1}{2}} \right)
\tag{37}
$$

which is a expression of BER performance in DSCMA over AWGN channel.

8. BER Performance and System Capacity in DSCMA System

Two different types of BS antenna, omnidirectional antenna and smart antenna are exploited for BER performance comparison through simulation. The system simulation will evaluate the BER performance of DSC algorithm in DSCMA by considering interference from both intra-cell and inter-cell interferences. The BER expressions over these interferences have been derived in the previous section. From these BER expressions the system capacity in DSCMA can be estimated by looking at the number of mobile users that the system can support at 0.001 BER (BER < 10^{-3}). Since the cell is split into three sectors, the inter-cell interference sources are only considered from two neighbouring cells for each sector. The system chip rate is 1.2288 Mcps resulting at a data rate of 4.8 Kbps for sequence length of about 256 chips per bit. This data rate is used to transmit the multimedia type data. The data transmission will go through a wireless channel with fourth power of distance loss and 8 dB shadowing. The voice activity factor is not taken into consideration in this simulation. The system parameters for the system simulation are summarised in Table 2.

Cell radius, R	Unity
Number of sectors per cell	3
Number of interfering neighbouring cells per sector	2
Type of data	Multimedia
Spreading factor, SF	About 256
System chip rate, W	1.2288 Mcps
Data rate, R	4.8 Kbps
Path loss exponent, μ	4.0
Standard deviation of shadowing, ζ	8 dB

Table 2. Summary of the system parameters

The radiation pattern of a smart antenna represents gains of different AOA along a 120º azimuth span sector. It is assumed that K separate narrow beams and K different spreading sequences can be generated from BS and directed to each of K users within a sector of interest. Assume that a sector antenna beamwidth is 120º in the three sectors per cell configuration. This beamwidth size attributes to a maximum excess delay, τ_{max} of 142 chips for chip rate, R_c of 1.2288 Mcps in separation of 10 Km. Thus, the correlation property, $R_{i,0}$ of the spreading sequences between ith interfering user and the desired user is randomly taken within 142 chips delay spread. Nevertheless, when the smart antenna is exploited, the beamwidth becomes narrower as a function of the number of elements, N_e. Hence, the maximum excess delay, τ_{max} of this narrower beam will be reduced. The maximum excess delay, τ_{max} for the smart antenna system with different number of elements, N_e has been shown in Table 3.

Number of elements, N_e	Beamwidth, BW (°)	Maximum angular spread, γ_{max} (°)	Maximum excess delay, τ_{max}	
			(μs)	(chip)
1	120	60	115	142
4	25.5	12.75	15.1	18.5
8	12.75	6.375	7.45	9.15
16	6.375	3.19	3.7	4.56
32	3.19	1.59	1.85	2.27
64	1.59	0.8	0.93	1.14

Table 3. Performance of smart antenna for various N_e

This table showed that the narrower beam of a smart antenna will reduce the TOA of a transmitted signal. This implies that the maximum excess delay of a channel can be reduced when more elements in a smart antenna system is exploited. To analyse the system performance in DSCMA, all the simulations are executed by considering smart antenna systems with N_e = 4, 8, 16, 32, 64 in the channel models of AWGN, Rayleigh fading, and fading with diversity gain. The simulations also consider spreading sequences such as m-sequence, Gold, Walsh-Hadamard and LAS-ET for performance comparison in DSCMA system. For the simulation in AWGN channel, Equation (37) from previous section is used to analyse the BER performance in DSCMA system.
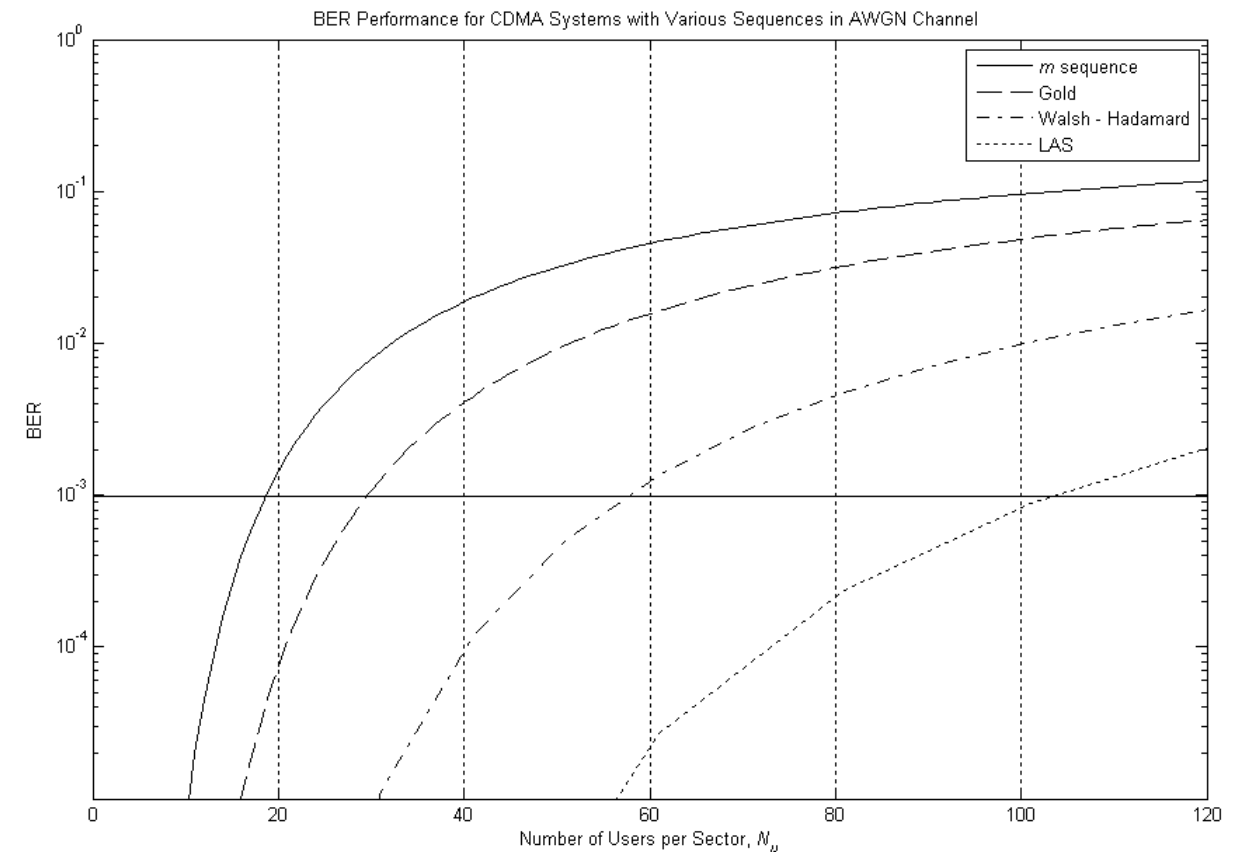
Fig. 7. BER performance of CDMA system for various spreading sequences

For comparison purposes, the BER of conventional CDMA and SDMA systems will be the first to be evaluated. In the CDMA system, the omnidirectional antenna gain, $G_i(\psi_0)$ for all mobile users are normalized to one in the whole sector. Therefore, the BER of the CDMA system is evaluated based on the correlation property of the spreading sequences. Figure 7 shows the BER performance of CDMA system for various spreading sequences. The system capacity of the CDMA system for these spreading sequences for BER < 10⁻³ are shown in Table 4.

Sequences	Capacity, N_u (BER < 10⁻³)
m-sequence	18
Gold	29
Walsh-Hadamard	58
LAS-ET	104

Table 4. System capacity of CDMA system for various spreading sequences

On the other hand, in the SDMA system, the correlation property, $R_{i,0}^2$ is normalized to one because it is not a factor of improvement in the conventional SDMA system. The only parameter that is used to evaluate BER performance of SDMA system is the antenna gain of interfering users, $G_i(\psi_0)$ in the direction of the desired user. These antenna gains of interfering users are taken randomly from the radiation pattern of smart antenna within the 120° sector. Figure 8 shows the BER performance of the conventional SDMA for various antenna beamwidths. The SDMA system capacity of BER < 10⁻³ for various beamwidths is given in Table 5.
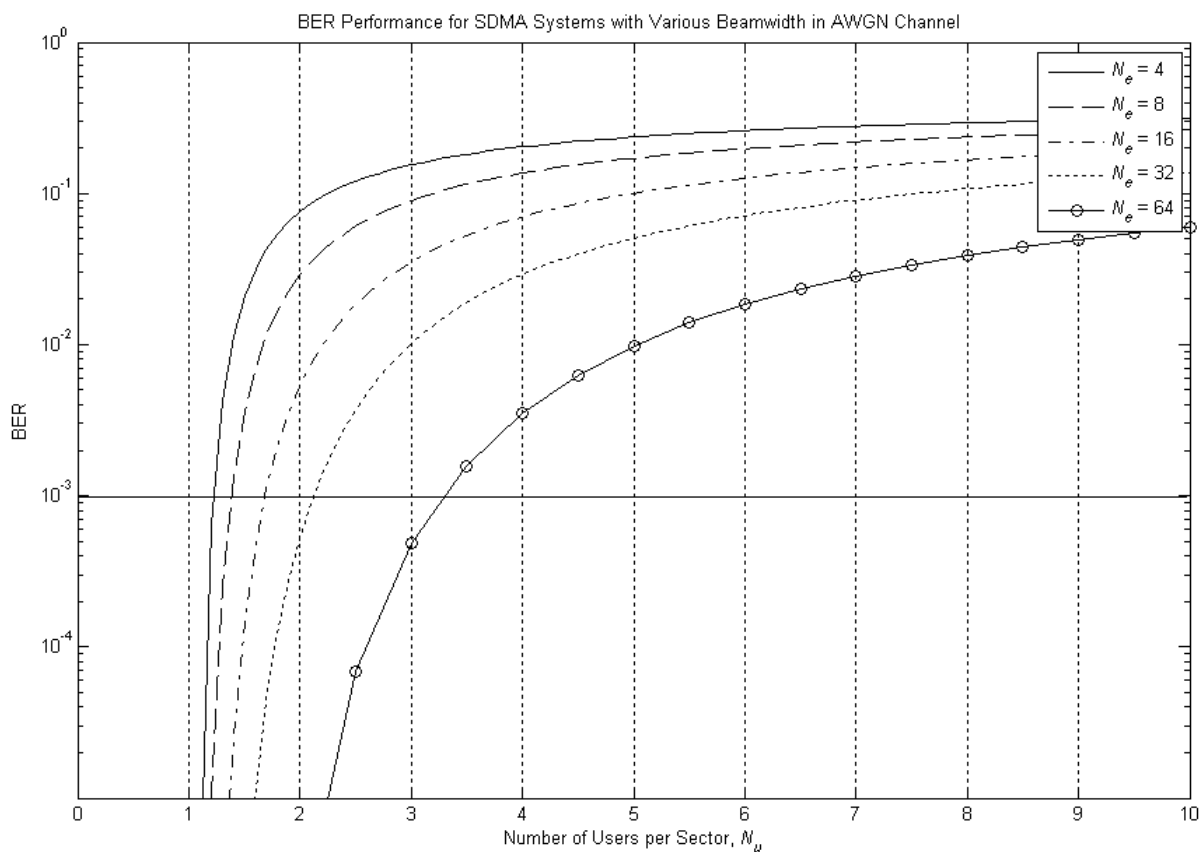
Fig. 8. BER performance of SDMA system for various numbers of elements

Number of elements, N_e	Capacity, N_u (BER < 10^{-3})
4	1
8	1
16	1
32	2
64	3

Table 5. System capacity of SDMA system for various numbers of elements

In the AWGN channel, it is necessary for DSCMA to perform in perfect synchronous manner to obtain the orthogonality among the mobile users in zero delay spread. However, perfect synchronisms rarely exist because each mobile user signal arrives at BS receiver with different delay. Therefore, the orthogonality between spreading sequences is no longer held in non-zero delay spread.

The BER performance of the DSCMA system in AWGN channel for various spreading sequences, vis m-sequence, Gold, Walsh-Hadamard and LAS-ET sequences are shown in Figures 9a - 9d respectively. In each figure, the BER performance is evaluated by exploiting the smart antenna with different number of elements, N_e = 4, 8, 16, 32 and 64 elements. Additionally, the system capacity of the DSCMA system based on BER < 10^{-3} for these spreading sequences are shown in Tables 6a - 6d respectively.

Fig. 9a. DSCMA system BER performance for m-sequence with different number of antenna elements, N_e in AWGN channel

Number of elements, N_e	Capacity, N_u (BER < 10^{-3})
4	48
8	25
16	173
32	374
64	420

Table 6a. DSCMA system capacity of BER < 10^{-3} for *m*-sequence with different number of antenna elements, N_e in AWGN channel

Fig. 9b. DSCMA system BER performance for Gold sequence with different number of antenna elements, N_e in AWGN channel

Number of elements, N_e	Capacity, N_u (BER < 10^{-3})
4	69
8	119
16	194
32	259
64	530

Table 6b. DSCMA system capacity of BER < 10^{-3} for Gold sequence with different number of antenna elements, N_e in AWGN channel

Fig. 9c. DSCMA system BER performance for Walsh-Hadamard sequence with different number of antenna elements, N_e in AWGN channel

Number of elements, N_e	Capacity, N_u (BER < 10^{-3})
4	1147
8	6.85×10^3
16	2.75×10^4
32	8×10^4
64	2.4×10^5

Table 6c. DSCMA system capacity of BER < 10^{-3} for Walsh-Hadamard sequence with different number of antenna elements, N_e in AWGN channel
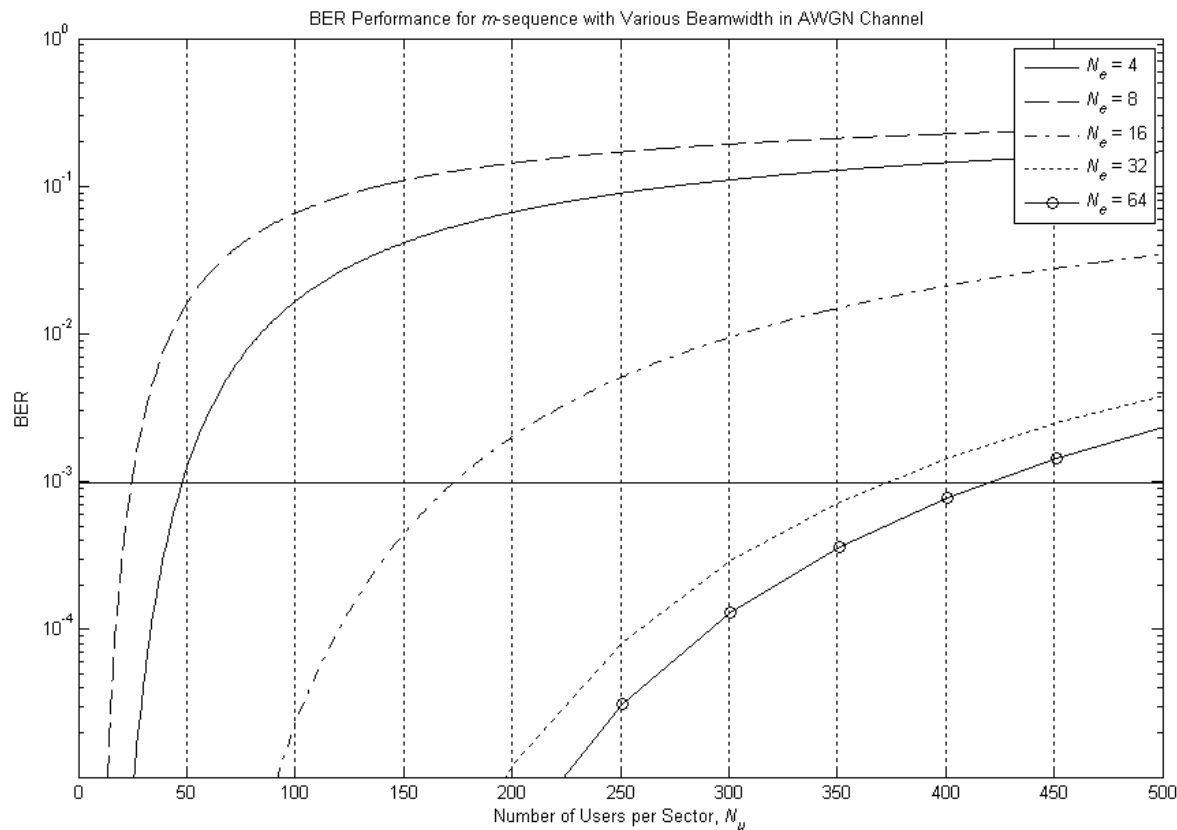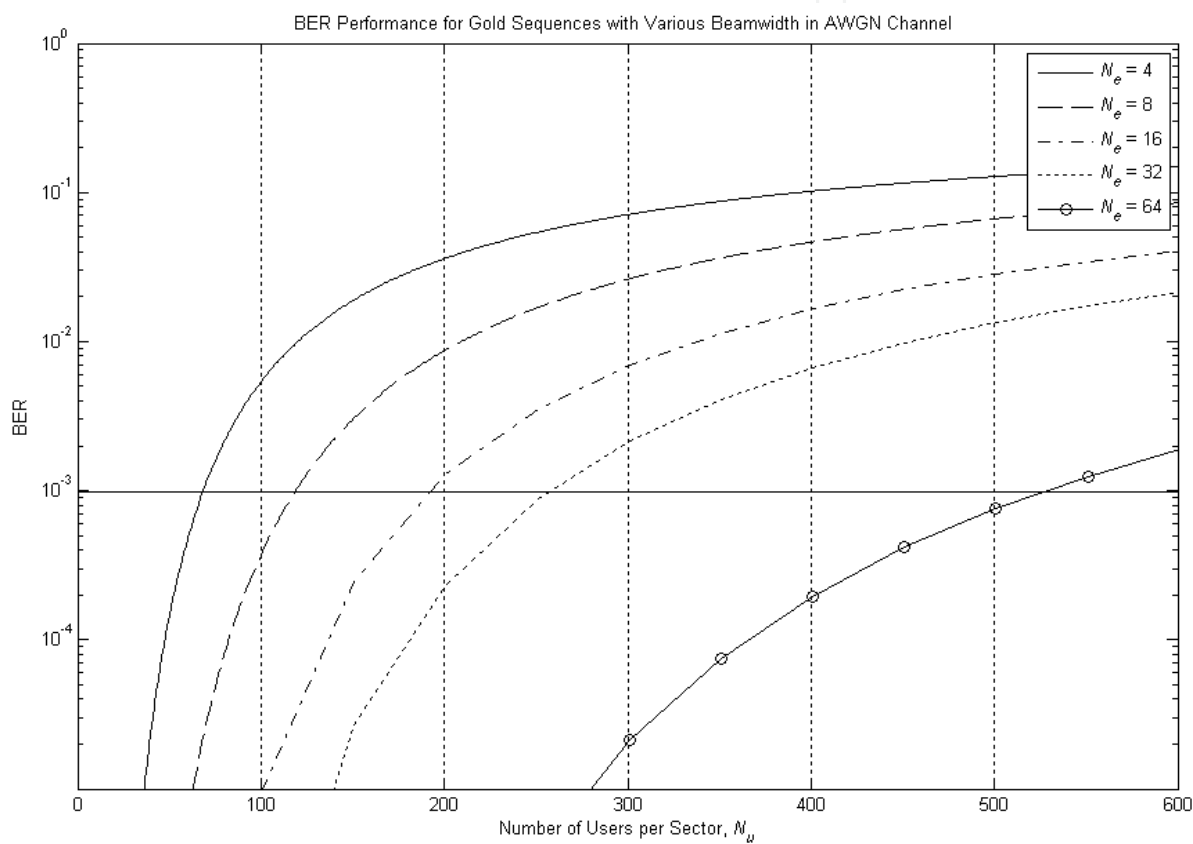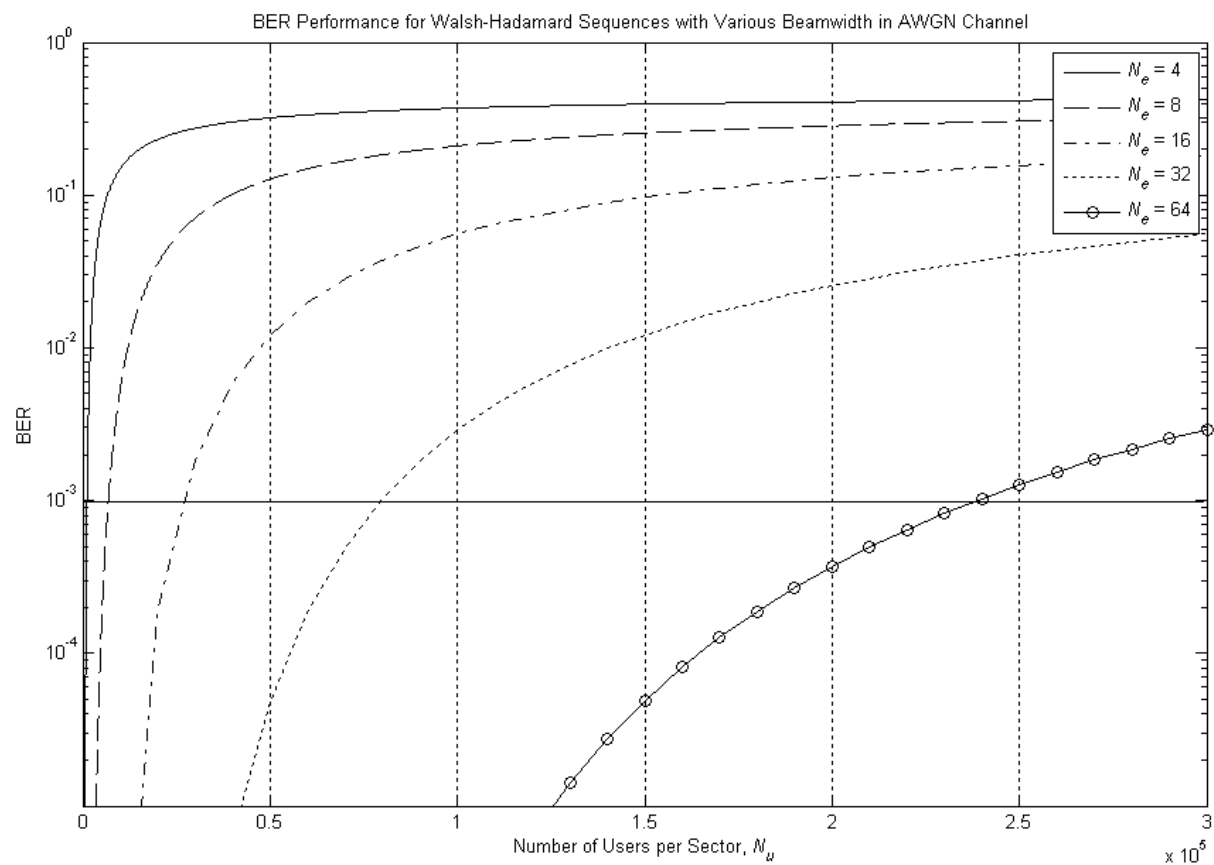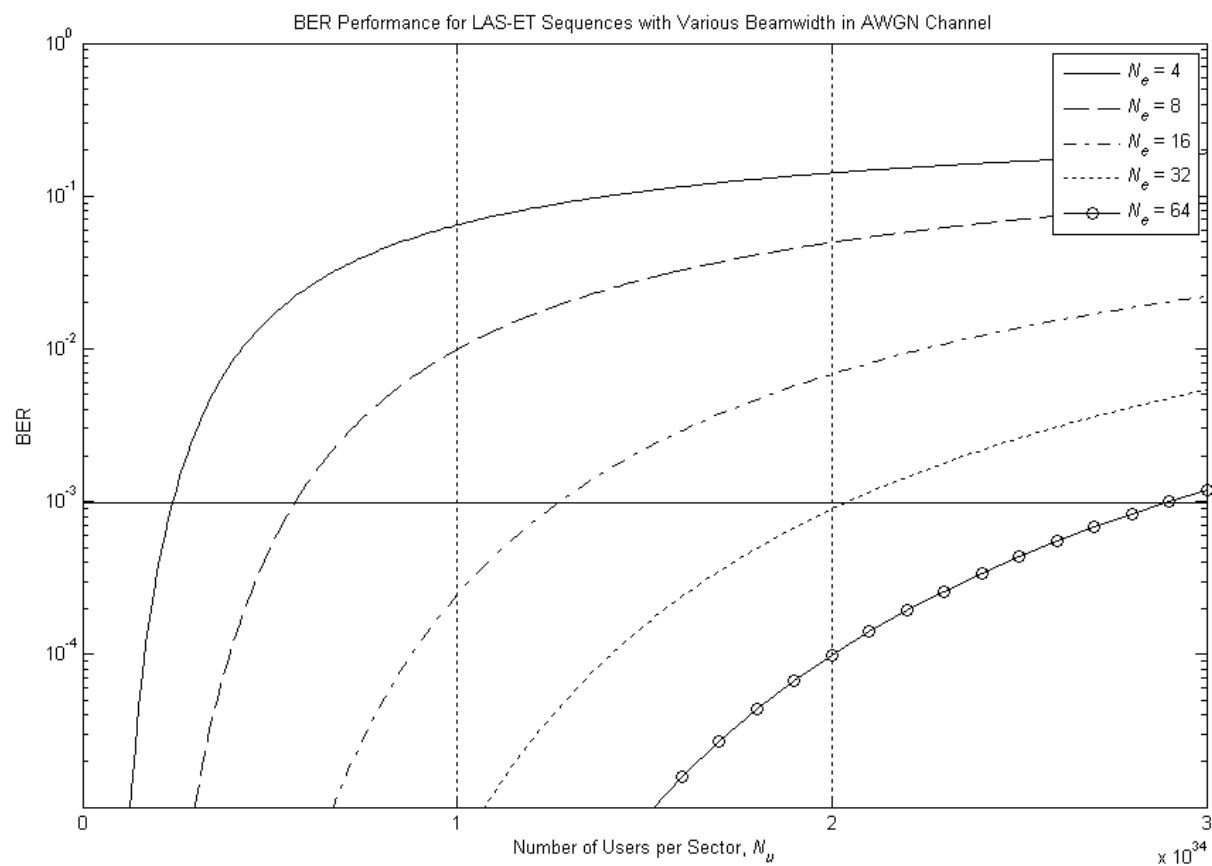
Fig. 9d. DSCMA system BER performance for LAS-ET sequence with different number of antenna elements, N_e in AWGN channel

Number of elements, N_e	Capacity, N_u (BER < 10^{-3})
4	2.4×10^{33}
8	5.67×10^{33}
16	1.27×10^{34}
32	2.04×10^{34}
64	2.9×10^{34}

Table 6d. DSCMA system capacity of BER < 10^{-3} for LAS-ET sequence with different number of antenna elements, N_e in AWGN channel

All the evaluated system capacities in DSCMA system here are based on the interference level that the system can tolerant. Hence, these attained results are not the ideal system capacity performance. There are some other factors need to be considered in conforming to this issue such as the totally bandwidth available, the number of spreading sequences that can be synthesized, and the limitation of system signal processing. Therefore, all the attained results are only suited for the comparison purpose and are not representing the real scenario.

In general, it shows that the DSCMA system performance is improved with spreading sequences of *m*-sequence, Gold, Walsh-Hadamard and LAS-ET in ascending order as in

conventional CDMA system. This is because the mean square correlation property, $E\left(R_{i,0}^2\right)$ for $i = 1,2,3,......,K-1$ between ($K-1$) interfering users and the desired user are decreased in ascending order from these spreading sequences. Further improvement is exhibited when the number of elements, N_e in smart antenna is increased as in conventional SDMA system. This is because the interference gain factor, $G_i(\psi_0)$ for $i = 1,2,3,......,K-1$ in the direction of the desired user, ψ_0 is reduced due to the fact that the sidelobe levels of interfering users radiation pattern presented in ψ_0 direction is decreased while the number of nulls is increase when the number of elements in smart antenna is increase.

All the energies from higher number of antenna elements, N_e are transformed into high gain in the main lobe of smart antenna. It can be seen that there is considerable improvement when the beamwidth of the smart antenna become narrower. The narrower beam from higher number of antenna elements, N_e also contributes to the interference reduction due to the fact that the probability of users' beam interfere to each other is low in narrower beam compared to wider beam. Therefore, higher system capacity can be observed in DSCMA when number of elements, N_e is increased. And this improvement can achieve as high as 2.9 x 10³⁴ users per sector when LAS-ET sequences together with DSC algorithm are used. On the other hand, this is interesting to find that in traditional spreading sequences, their system performances suppose to be appeared in randomness because of non-uniform distribution in their correlation property within the concerned delay-spread. This is obviously occurred in *m*-sequences.

9. Conclusion

It can be concluded that non-uniform traffics can severely degrade the performance of CDMA and SDMA cellular systems. The DSCMA system described in this chapter is a double signatures system that can distinguish more users by cancelling the existing interference in multipath environment. This multiple access system uses LAS-ET sequences to create IFW near zero delay spread in its cross-correlation function. In order to ensure all the signal components drop within the IFW, a narrow beam with higher directivity smart antenna system is exploited. The size of IFW is adapted to the smart antenna half-power beamwidth using DSC algorithm. Therefore, all the interferences induced in non-uniform traffics can be dramatically reduced in DSCMA system and thus resulting in higher system capacity.

10. References

Adachi, F., Garg, D., Takaoka, S. & Takeda, K. (2005). Broadband CDMA techniques, *IEEE Wireless Communications*, vol. 12, no. 2, pp. 8 - 18.

Buracchini, E. et al. (1996). Performance Analysis of A Mobile System Based on Combined SDMA/CDMA Access Technique, *IEEE 4th International Symposium on Spread Spectrum Techniques and Applications Proceedings*, vol. 1, pp. 370 - 374.

Cameron, R. & Woerner, B. (1996). Performance Analysis of CDMA with Imperfect Power Control, *IEEE Transactions on Communications,* vol. 44, pp. 777 - 781.

Castaeda-Camacho, J. & Lara-Rodriguez, D. (2008). Teletraffic Analysis of an Overlaid System Using CDMA and TDMA With Cell Coverage Area Restriction, *IEEE Transactions on Vehicular Technology*, vol. 57, no. 2, pp. 828 - 846.

Chatovich, A. & Jabbari, B. (1999). Effect of Non-uniform Traffic Load on Erlang Capacity of CDMA, *IEEE 49th Vehicular Technology Conference Proceedings*, vol. 1, pp. 816 - 820.

Chen, H. H., Chiu, H. W. & Guizani, M. (2006). Orthogonal Complementary Codes for Interference-Free CDMA Technologies, *IEEE Wireless Communications*, vol. 13, no. 1, pp. 68 - 79.

Chen, H. H., Chiu, H. W. & Guizani, M. (2008). On Next Generation CDMA Technologies: The REAL Approach for Perfect Orthogonal Code Generation, *IEEE Transactions on Vehicular Technology*, vol. 57, no. 5, pp. 2822 - 2833.

Cho, K. et al. (2002). Novel Smart Antennas for Applying SDMA to Cellular Mobile Communication Systems, *IEEE Antennas and Propagation Society International Symposium Proceedings*, vol. 4, pp. 652 - 655.

Choi, W., Andrews, J. G. & Heath, R. W. (2007). Multiuser Antenna Partitioning for Cellular MIMO–CDMA Systems, *IEEE Transactions on Vehicular Technology*, vol. 56, no. 5, Part 1, pp. 2448 - 2456.

Cooper, G. R. & Nettleton, R. W. (1978). A Spread Spectrum Technique for High Capacity Mobile Communications, *IEEE Transactions on Vehicular Technology*, vol. VT-27, pp. 264 - 275.

Fang, X. (2002). More Realistic Analysis for Blocking Probability in SDMA Systems, *IEE Proceedings Communications*, vol. 149, no. 3, pp. 152 - 156.

Faruque, S. (1996). *Cellular Mobile Systems Engineering*, Norwood, MA, Artech House.

Feuerstein, M. et al. (1994). Path Loss, Delay Spread, and Outage Models as Functions of Antenna Height for Microcellular System Design, *IEEE Transactions on Vehicular Technology*, vol. 43, no. 3, pp. 487 - 498.

Galvan-Tejada, G. M. & Gardiner, J. G. (2001). Theoretical Model to Determine the Blocking Probability for SDMA Systems, *IEEE Transactions on Vehicular Technology*, vol. 50, no. 5, pp. 1279 - 1288.

Gilhousen, K. S. et al. (1991). On The Capacity of A Cellular CDMA System, *IEEE Transactions on Vehicular Technology*, vol. 42, no. 2, pp. 303 - 312.

Godara, L. C. (1997). Applications of Antenna Arrays to Mobile Communications, Part I: Performance Improvement, Feasibility, and System Considerations, *Proceedings of the IEEE*, vol. 85, no. 7, pp. 1031 - 1060.

Gold, R. (1967). Optimal Binary Sequences for Spread Spectrum Multiplexing, *IEEE Transactions on Information Theory*, vol. 13, no. 4, pp. 619 - 621.

Golomb, S. W. (1992). Shift Register Sequences, *Aeqean Park Press*.

Guo, D. & Wang, C. C. (2008). Multiuser Detection of Sparsely Spread CDMA. *IEEE Journal on Selected Areas in Communications*, vol. 26, no. 3, pp. 421 - 431.

Harmuth H. F. (1970). Transmission of Information by Orthogonal Functions, *Springer-Verlag*.

Hashem, B. & Sousa, E. (1997). On the Capacity of a Cellular DS/CDMA System under Slow Multipath Fading and Fixed Step Power Control, *IEEE 6th International Conference on Universal Personal Communications Record*, vol. 2, pp. 352 - 355.

Heath, R. W. et al. (2004). Construction of Equiangular Signatures for Synchronous CDMA Systems, *IEEE 8th International Symposium on Spread Spectrum Techniques and Applications Proceeding,* pp. 708 - 712.

Huang, C. et al. (2001). A Joint Multiple Access Scheme for Uplink Channels of CDMA Systems, *International Conferences on Info-tech and Info-net (ICII 2001) Proceedings,* vol. 2, pp. 323 - 328.

Ishida, Y. et al. (2000). Wideband CDMA Base Station with Co-channel Interference Canceller, *IEEE 51st Vehicular Technology Conference (VTC 2000-Spring) Proceedings,* vol. 1, pp. 293 - 297, Tokyo.

Kasami T. (1966). Weight Distribution Formula for Some Class of Cyclic Codes, *Technical Report R-285 (AD 632574),* Coordinated Science Laboratory, Univ. of Illinois, Urbana.

Kim, S. W. et al. (2001). Performance of Smart Antennas with Adaptive Combining at Handsets for the CDMA2000 System, *International Conference on Third Generation Wireless and Beyond Proceeding,* San Francisco, pp. 882 - 887.

Lee, W. C. Y. (1991). Overview of Cellular CDMA, *IEEE Transactions on Vehicular Technology,* vol. 40, no. 2, pp. 291 - 302.

Lee, W. C. Y. (1998). *Mobile Communications Engineering,* McGraw Hill.

Li, D. (1999). A High Spectrum Efficient Multiple Access Code, *Fifth Asia-Pacific Conference on Communications and Fourth Optoelectronics and Communications Conference (APCC/OECC '99) Proceedings,* vol. 1, pp. 598 - 605.

Li, D. (2003). The Perspectives of Large Area Synchronous CDMA Technology for the Fourth-Generation Mobile Radio, *IEEE Communications Magazine,* vol. 41, no. 3, pp. 114 - 118.

Liberti, J. C. Jr. & Rappaport, T. S. (1994). Analytical Results for Capacity Improvements in CDMA, *IEEE Transactions on Vehicular Technology,* vol. 43, no. 3, pp. 680 - 690.

Liberti, J. C. Jr. & Rappaport, T. S. (1998). *Smart Antennas for Wireless Communications,* Prentice Hall PTR, Upper Saddle River, NJ.

Lien, S. Y. & Cherniakov, M. (1998). Analytical Approach for Multipath Delay Spread Power Distribution, *IEEE Global Telecommunications Conference (GLOBECOM 98) Proceedings,* The Bridge to Global Integration, vol. 6, pp. 3680 - 36858.

Naguib, A. F. et al. (1994). Capacity Improvement with Base-Station Antenna Arrays in Cellular CDMA, *IEEE Transactions on Vehicular Technology,* vol. 43, no. 3, pp. 691 - 698.

Ng, B. & Sousa, E. S. (1998). Performance Enhancement of DS-CDMA System for Wireless Local Loop, *IEEE International Telecommunications Symposium (ITS) Proceedings,* vol.1, pp. 78 - 82.

Ng, C. K., Noordin, N. K., Khatun, S., Mohd Ali, B., Jamuar, S. S. & Ismail, M. (2008). Directional Diversity of Smart Antenna in LAS CDMA Systems, *Wireless Personal Communications,* Springer Netherlands, vol. 46, pp. 305 – 316.

Ng, C. K., Noordin, N. K., Mohd Ali, B., Jamuar, S. S. & Ismail, M. (2009). Spectrum Efficiency Enhancement in Dynamic Space Coded Multiple Access (DSCMA) System, *Wireless Personal Communications,* Springer Netherlands, 0929-6212 (Print) 1572-834X (Online), DOI 10.1007/s11277-009-9682-7.

Niemela, J. & Lempiainen, J. (2003). Impact of the Base Station Antenna Beamwidth on Capacity in WCDMA Cellular Networks, *The 57th IEEE Semiannual Vehicular Technology Conference (VTC 2003-Spring) Proceedings*, vol. 1, pp. 88 - 84.

Peterson, R. L. et al. (1995). *Introduction to Spread Spectrum Communications*, Prentice Hall International Edition.

Popovic, B. M. (1997). Efficient Despreaders for Multi-code CDMA Systems, *IEEE 6th International Conference on Universal Personal Communications Record*, vol. 2, pp. 516 - 520.

Rapajic, P. B. (1998). Information Capacity of The Space Division Multiple Access Mobile Communication System, *IEEE 5th International Symposium on Spread Spectrum Techniques and Applications Proceedings*, vol. 3, pp. 946 - 950.

Rupf, M. & Massey, J. L. (1994). Optimum Sequence Multisets for Synchronous Code-Division Multiple-Access Channels, *IEEE Transactions on Information Theory*, vol. 40, no. 4, pp. 1261 - 1266.

Stańczak, S. et al. (2001). Are LAS-Codes a Miracle?," *IEEE GLOBECOM '01 Proceedings*, vol. 1, (San Antonio, Texas), pp. 589 - 593, November 2001.

Thompson, J. S. et al. (1996). Smart Antenna Arrays for CDMA Systems, *IEEE Personal Communications*, pp. 16 - 25.

Uthansakul, P. & Uthansakul M. (2002). Number of Elements in Smart Antenna System Effects on Both Perfect and Imperfect Power Control for Reverse Link of CDMA Cellular System, *The International Technical Conference on Circuits/Systems, Computer and Communications Proceedings*, Thailand.

Wang, X., Ahonen, T. & Nurmi, J. (2007). Applying CDMA Technique to Network-on-Chip, *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, vol. 15, no. 10, pp. 1091 - 1100.

Wei, H. et al. (2005). Interference-Free Broadband Single and Multicarrier DS-CDMA, *IEEE Communications Magazine*, vol. 43, no. 2, pp. 68 - 73.

Welch, L. R. (1974). Lower Bounds on the Maximum Cross Correlation of Signals, *IEEE Transactions on Information Theory*, vol. IT-20, pp. 397 - 399.

Wu, J. S. et al. (1998). Hot-Spot Traffic Relief with A Tilted Antenna in CDMA Cellular Networks, *IEEE Transactions on Vehicular Technology*, vol. 47, no. 1, pp. 1 - 9.

Xie, S. & Rahardja, S. (2005). Performance Evaluation for Quaternary DS-SSMA Communications with Complex Signature Sequences over Rayleigh-Fading Channels, *IEEE Transactions on Wireless Communications*, vol. 4, no. 1, pp. 266 - 277.

Yu, J. et al. (2004). Reverse-Link Capacity of Power-Controlled CDMA Systems with Beamforming, *IEEE Transactions on Vehicular Technology*, vol. 53, no. 5, pp. 1423 - 1433.

Zheng, Z. et al. (1996). Capacity Improvement with Base Station Antenna Arrays in Cellular CDMA, *IEEE 46th Vehicular Technology Conference, Mobile Technology for the Human Race Proceedings*, vol. 2, pp. 1303 - 1306.

Trends in Telecommunications Technologies

Edited by Christos J Bouras

The main focus of the book is the advances in telecommunications modeling, policy, and technology. In particular, several chapters of the book deal with low-level network layers and present issues in optical communication technology and optical networks, including the deployment of optical hardware devices and the design of optical network architecture. Wireless networking is also covered, with a focus on WiFi and WiMAX technologies. The book also contains chapters that deal with transport issues, and namely protocols and policies for efficient and guaranteed transmission characteristics while transferring demanding data applications such as video. Finally, the book includes chapters that focus on the delivery of applications through common telecommunication channels such as the earth atmosphere. This book is useful for researchers working in the telecommunications field, in order to read a compact gathering of some of the latest efforts in related areas. It is also useful for educators that wish to get an up-to-date glimpse of telecommunications research and present it in an easily understandable and concise way. It is finally suitable for the engineers and other interested people that would benefit from an overview of ideas, experiments, algorithms and techniques that are presented throughout the book.

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