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Capacity Improvement with Smart Antenna of TDSCDMA Base Station

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ABSTRACT:In this paper, the use of Smart Antenna with multiple directional beams employed at base station in a Time Division Synchronous Code Division Multiple Access (TDSCDMA) system standard is studied. To improve spatial resolution of the Antenna to BTS Link and BTS to Antenna link of the TD-SCDMA base stations, the proposed Adaptive capability of Smart antenna is tested. The time-varying weight coefficients along with the Matched Filter correlator and joint detection technique employedin the downlink beamformer are estimated by the feedback data from its uplink of the TD-SCDMA system. We present a physical layer design of TDSCDMA including the performance analysis for the 3G TD-SCDMA network with smart beamforming at the base station for both uplink & downlink & the results show that the implementation of the smart antenna for TD-SCDMA systems can improve the performance of the system capacity several fold.

KEYWORDS:TD-SCDMA, MAI, Scrambling, Handover, TDD, SDMA, Smart antenna, Joint detection, LMSE, BER

I.INTRODUCTION

The increasing demand for services viz. multimedia, data etc. without a corresponding increase in Radio Frequency spectrum allocation arouses the need for new techniques to improve spectrum utilization [1, 2]. One approach for better spectrum efficiency in digital cellular communication is the use of spread spectrum code division multiple access (CDMA) [3, 4, 5]. Despite the high capacity offered by CDMA, the expected demand likely to outstrip the projected capacity so the only option for substantial capacity enhancement is the use of spatial processing with smart Antenna array [6]. Using smart antenna technology, we could form multiple antenna beam to follow each user like spatial division multiple access (SDMA), and thus to enhance link budget. Subsequently the after CDMA & Multiple beamforming Antenna the technology has shifted to TDSCDMA Smart system to support more bandwidth for desired multimedia communication [7]. Due to TDD and CDMA, it can somewhat combine TDMA and CDMA so that the number of users in each time slot could be kept small to facilitate joint detection, which can significantly reduce multiple-access-interference (MAI) and can alleviate near-far problem to enhance system capacity [8]. TDSCDMA operates in TDD mode, using unpaired spectrum. TDD mode has inherent superiority in suiting asymmetric traffic. When traffic is asymmetric, TDSCDMA simply allocates different number of time slots to different direction so that the spectrum is always efficiently used. This time domain allocation can be easily realized by software programming and does not fall under any hardware limitation. Figure 1 shows the concept of TDSCDMA as discussed. TD-SCDMA applies dynamic channel allocation to adjust radio resource among time, frequency, code, and spatial domains. Baton handover is a special core technology in TD-SCDMA, between hard handover and soft handover. During the handover measurement period, uplink channel transmission time and power information are acquired in advance to reduce call drop rate. It is likely that multiple mobile operating on the same RF channel but different spatial channels at a particular cell which allows a reuse factor of unity, i.e. a single frequency can be used in all cells. This technology can increase the number of available voice channels through directional communication links [4,6]. It depends on the propagation environment, the number of antenna elements and it allows dynamic channel assignment. Transmission bit rate can be increased due to the improved SIR at the output of the Smart beamformer & allow RF channels to be adjusted through link power control to encounter the requirements of user-selective data transfer rates [7,9].

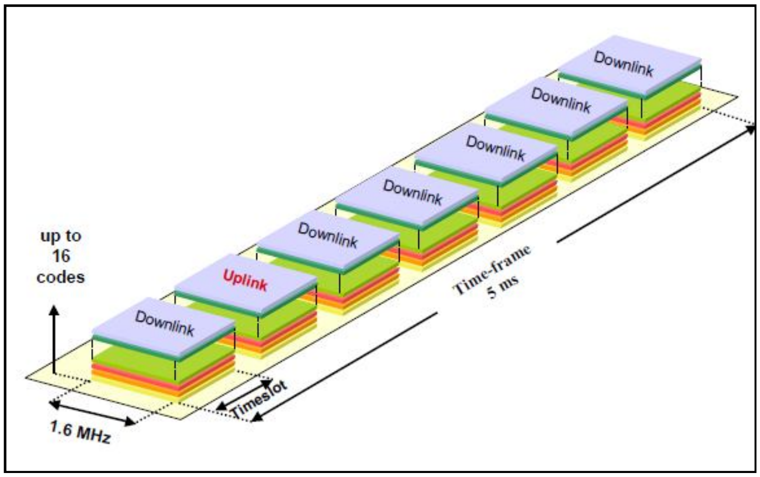

Fig. 1TD-SCDMA uses TDMA/TDD with CDMA to increase the capacity

II.MOBILE TO BTS LINK ANALYSIS

We are considering a scenario where there are N users randomly distributed around each cell site at varying ranges. Usually the receiver is code locked onto every user but does not know the direction of arrival (DOA) of these users. Each user has unique PN code modulated bit stream with a spreading factor which is known as processing gain, denoted as L. Let P be the received signal power at the cell site & the system noise power excluding interference from other in band users be σ^2 and M be the number of antenna elements. Assuming perfect instantaneous power control, the interference from a mobile within a given mobile's cell will arrive at cell sites, the interference power from such mobiles when active, at the desired user's cell site is given by

$$I_{i_k} = P\left(\frac{r_{ik}{}^{(k)}}{r_{ik}{}^{(o)}}\right)^4 \frac{\left\|\alpha_{ik}{}^{(o)}\right\|^2}{\left\|\alpha_{ik}{}^{(k)}\right\|^2} = P\beta_{ik}{}^2 \qquad (1)$$

Here $r_{ik}{}^{(k)}$ is the distance from the ik th user in the k th cell to its cell site, $\alpha_{ik}{}^{(k)}$ is a zero mean complex Gaussian variable that represents the corresponding amplitude fade along that path and combine both the Raleigh fading and lognormal shadowing effect means $\left\|\alpha_{ik}{}^{(k)}\right\|$ has a Raleigh distribution whose mean square value $E\left\{\left\|\alpha_{ik}{}^{(k)}\right\|^2\right\}$ is log normal i.e. $10\log_{10} E\left\{\left\|\alpha_{ik}{}^{(k)}\right\|^2\right\}$ is normally distributed with zero mean and variance $\sigma_s{}^2$. $r_{ik}{}^{(o)}$ is the distance between the same ik th mobile in the kth cell and desired user's cell site i.e. cell site o and finally $\alpha_{ik}{}^{(o)}$ is the corresponding amplitude fade. The mobile is controlled by the cell site that has minimum attenuation $\beta_{ik} < 1$. Adaptive beamforming with directional beams at BTS reduce the interference power and boast the SINR. To be able to use the technology of beamforming, we need to estimate the array response vectors or the spatial signature of the desired mobile user. Using the estimate of the array response vector, we can form a beam towards each mobile. Assuming a narrowband signal model the $M \times 1$ output of an array of M sensors at the cell site can be written as

$$x(t) = \sum_{i0=1}^{N} \psi_{i0}\sqrt{P} b_{i0}\left(\left[\frac{t-\tau_{i0}}{T}\right]\right) c_{i0}(t-\tau_{i0}) a_{i0} + \sum_{k=1}^{K}\sum_{ik=1}^{N} \psi_{ik}\sqrt{P}\beta_{ik} b_{ik}\left(\left[\frac{t-\tau_{ik}}{T}\right]\right) c_{ik}(t-\tau_{ik}) a_{ik} + n(t) \qquad (2)$$

Where K is the number of interfering cells, a_{ik} is the $M \times 1$ array response vector for signal arriving from the ik th mobile in the kth cell and we assume that $a_{ik}{}^{*}a_{ik} = 1$ and $c_{ik}(t)$ is the code used by that user, b_{ik} is the bit of duration T, τ_{ik} is the propagation delay, ψ_{ik} is a Bernoulli variable with probability of success v that models the velocity activity of the same user. N thermal noise vector with zero mean and covariance $E\left\{n(t)n^{*}(\tau)\right\} = \frac{\sigma^{2}}{M} I$ when $t = \tau$ or 0, when $t \neq \tau$. These equations imply that the noise is temporally & spatially white. For the desired user let a_0, τ_0, c_0, b_0 be the array response vector, the time delay, the used code and the transmitted bits, which are assumed to be binary random variables taking values ± 1 with equal probability respectively. The antenna outputs are correlated with the desired user's code c_0 to yield one sample vector for the desired users l^{th} bit is given by

$$Z_0(l) = \int_{t_1}^{t_2} x(t)c_0(t)dt = s_0(l)a_0 + \sum_{i0=2}^{N} \psi_{i0} I_{io}(l) a_{io} + \sum_{k=1}^{K}\sum_{ik=1}^{N} \psi_{ik} I_{ik}(l) a_{ik} + n_T(t) \quad (3)$$

Where $t_1 = (l-1)T; t_2 = lT$ &

$$s_0(l) = \int_{t_1}^{t_2} \sqrt{P} b_0 \left(\left[\frac{t}{T}\right]\right) c_0(t) c_0(t) dt \quad (4)$$

$$I_{io}(l) = \int_{t_1}^{t_2} \sqrt{P} b_{io} \left(\left|\frac{t-\tau_{io}}{T}\right|\right) c_{io}(t-\tau_{io}) c_0(t) dt \quad (5)$$

$$I_{ik}(l) = \int_{t_1}^{t_2} \sqrt{P} \beta_{ik} b_{ik} \left(\left|\frac{t-\tau_{ik}}{T}\right|\right) c_{ik}(t-\tau_{ik}) c_0(t) dt \quad (6)$$

$$n_T(l) = \int_{t_1}^{t_2} c_0(t) n(t) dt \quad (7)$$

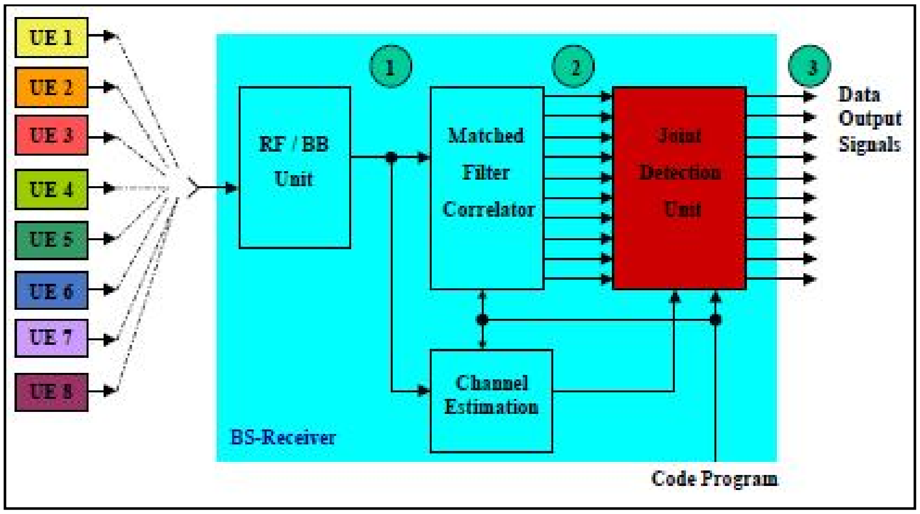

Fig. 2 Joint detection minimizes Multiple Access Interference & increases loading factor

Array outputs has been combined to estimate the desired signal, we need to determine the array response vector for the wave front arriving from each individual mobile station (MS) as depicted in figure 2.Figure 3 depicts the single channel of a TDSCDMA transmitter. In TDSCDMA systems, the number of user's will far exceed the number of antenna therefore subspace methods of DOA estimation may not be a good choice. The array response vector of the desired MS a_0 can be estimated from the pre-correlation and post correlation array covariance R_{xx} and R_{z0z0} respectively where $R_{xx} = E\left\{xx^*\right\}$ & $R_{z_0z_0} = E\left\{z_0 z_0^*\right\}$. Using the estimation of a_0, the post correlation antenna outputs are combined via beamforming to estimate the signal from desired user. The decision variable, which is the output of the beam former, is given by

$$d_0(l) = a_0^* z_0(l) = s_0(l) + n_1(l) + n_2(l) + n_T(l)$$
$$= L\sqrt{P} b_0(l) + \sum_{io=2}^{N} \psi_{io} I_{io} a_0^* a_{io} + \sum_{k=1}^{K}\sum_{ik=1}^{N} \psi_{ik} I_{ik} a_0^* a_{ik} + a_0^* n_T(l) \quad (8)$$

$s_0(l)$ is the term due to desired user, n_1 is due to interference from users within its own cell, the third term n_2 is due to interference from users outside the cell, both zero mean and n_T is due to additive thermal noise, which is normal with zero mean and variance equal to $\frac{L\sigma^2}{M}$. With asynchronous transmission, random sequence codes give approximately same result for randomly chosen codes. The faded energy per bit to interference plus noise densities ratio can be written as

$$\frac{E_b}{N_0 + I_0} = \frac{L}{\frac{\sigma^2}{MP} + I_1 + I_2} \quad (9)$$

Here I_1 & I_2 are the interference to signal power ratio due to own cell and outer cell users respectively

$$I_1 = \sum_{i0=2}^{N} \psi_{i0} \left\| a_0^* a_{i0} \right\|^2 \quad (10)$$

$$I_2 = \sum_{k=1}^{K}\sum_{ik=1}^{N} \psi_{ik} \beta_{ik}^2 \left\| a_0^* a_{ik} \right\|^2 \quad (11)$$

The probability of outage is defined as the probability of the bit error rate exceeding a certain threshold P_0 required for acceptable performance. By using efficient modems and powerful convolutional codes adequate BER (BER<10^{-3}) may be achieved with $\frac{E_b}{N_0 + I_0} < 7dB$.

$$P_{out} = P_r(BER > P_0) = P_r\left(\frac{E_b}{N_0 + I_0} < S\right)$$
$$= P_r\left(I_1 + I_2 > \frac{L}{S} - \frac{\sigma^2}{MP}\right) \quad (12)$$

This expression gives outage probability as a function of random variable I_1 & I_2. The distribution of random variables depends on the number of active users, their relative distances, their array response vectors, array parameter, fading and also in shadowing effects. The capacity of the system in terms of maximum cell loading can be determined by finding the maximum N such that for the BER P_{out} will not exceed the threshold.

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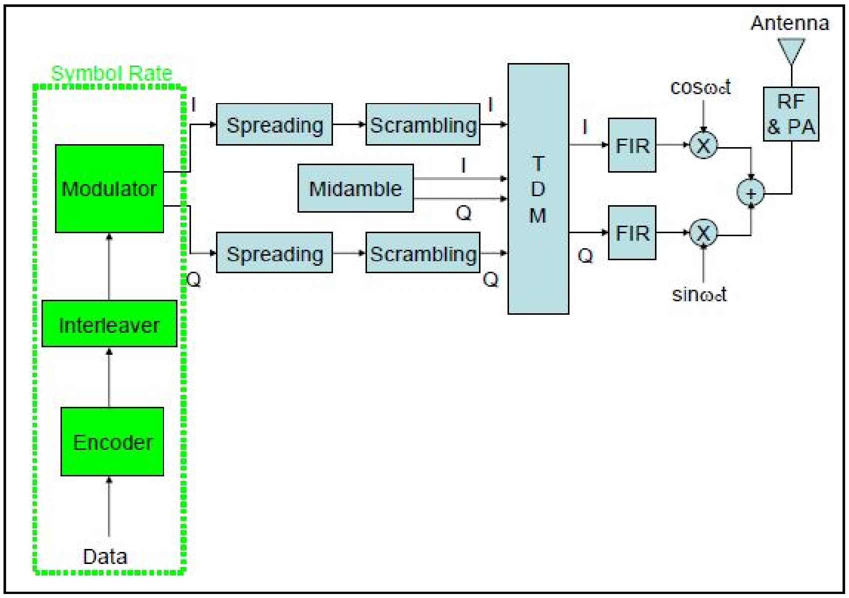

Fig. 3 TDSCDMA Transmitter for Physical Layer

III.BTS TO MOBILE LINK

All signals received at the mobile from the same base station has propagated over same path & experience same fading & path loss. Here we assume the BTS transmits the same power to all mobile controlled by the BTS. The power of each signal arriving at the desired mobile from the kth cell is

$$P_k = P\frac{\left\|\alpha_k{}^{(o)}\right\|^2}{(r_k{}^{(o)})^4} = P\beta_k{}^2 \qquad (13)$$

$\alpha_k{}^{(o)}$ Represents fading and shadowing experienced by all signals arrived at desired mobile from kth cell site and $r_k{}^{(o)}$ is the distance between the desired mobile from its cell site. Assuming N users per cell randomly distributed around each cell site at varying ranges the received signal at mobile under test

$$x_0(t) = \sum_{i0=1}^{N} \psi_{i0}\sqrt{P}b_{i0}\beta_0\left(\left[\frac{t-\tau_{i0}}{T}\right]\right)c_{i0}(t-\tau_{i0})a_{i0}{}^{*}a_0{}^{(o)}$$
$$+\sum_{k=1}^{K}\sum_{ik=1}^{K}\sigma_{ik}\sqrt{P}\beta_k b_{ik}\left(\left[\frac{t-\tau_{ik}}{T}\right]\right)c_{ik}(t-\tau_{ik})a_{ik}{}^{*}a_0{}^{(k)} + n(t) \qquad (14)$$

$a_0{}^{(k)}$ is the transmit array response vector of the desired mobile as seen by the k th cell site and $n(t)$ is the background noise received by the mobile. The decision variable is considered as

$$d_0 = L\beta_0\sqrt{P}b_0(l) + \sum_{io=2}^{N}\psi_{io}I_{io}a_0{}^{(o)}a_{io}{}^{*} +$$
$$\sum_{k=1}^{K}\sum_{ik=1}^{N}\sigma_{ik}I_{ik}a_0^{(k)}a_{ik}{}^{*} + n_T(l) \qquad (15)$$

Where, $n_T(l) = \int_{t_1}^{t_2} c_0(t)n(t)dt$ (16)

The energy per bit to interference plus noise density can be represented by

$$G_1 = \sum_{i0=2}^{N} \psi_{io} \left\| a_{io}{}^{*} a_0{}^{(o)} \right\|^2 \qquad (17)$$

$$G_2 = \sum_{k=1}^{K} \sum_{ik=1}^{N} \psi_{ik} \frac{P_k}{P_0} \left\| a_{ik}{}^{*} a_0{}^{(k)} \right\|^2 \qquad (18)$$

The corresponding outage probability may be written as

$$P_{out} = P_r(BER > P_0) = P_r\left(\frac{\sigma^2}{P_0} + G_1 + G_2 > \frac{L}{S} \right) \qquad (19)$$

Here it is assumed that each antenna array is made up of M array elements and $N = N_e + N_i$ is the total received users. N_e is expected users from the chosen sectors and the N_i, the interference users from the other sectors, hence antenna output signals in down link may be stacked in vectors notation

$$y_d(t) = \sum_{k=1}^{N_e} w_{dk}{}^{*}(t) s_{dk}(t) \qquad (20)$$

Here $w_{dk}{}^{*}$ is the time varying weight vectors for the antenna array. By adjusting the weight coefficients appropriately the antenna can achieve the spatial beamforming in downlink and point to the expected user. Hence the downlink beamforming problem should minimize the radiated array power while coupling energy from the array to the mobile and suppressing MAI. Here mean square error scheme is adopted to compute weight vectors

$$w_{d_k} = \arg\min_{w} w^H R_{dk}{}^{[i]} w$$

$$\xi_k = w^H R_{d_k}{}^{[s]} w = \frac{1}{M} a_{u_k}{}^{H} a_{u_k} = \frac{1}{MP_{u_k}} tr(R_{u_k}{}^{[s]}) \qquad (21)$$

Received signal power of the k th user in downlink is equal to the average power of the same user in uplink

$$R_{d_k}^{[s]} = R_{dk} ; R_{d_k}^{[i]} = \sum_{\substack{q=1 \\ q \neq k}}^{N} R_{d_q}$$

$$R_{d_k} = a_{d_k} a_{d_k}^{H} ; k \in \{1, 2, ..., N_e\} \qquad (22)$$

$R_{d_k}^{[s]}$ and $R_{d_k}^{[i]}$ denotes correlation matrix of the expected kth user and the correlation matrix of the interference user. These are defined by the kth user spatial signature vector

$$a_{d_k}(t) \alpha_k v\left(\theta_k(t)\right) \text{ in downlink} \qquad (23.a)$$

$$a_{u_k}(t) \alpha_k v\left(\theta_k(t)\right) \text{ in uplink} \qquad (23.b)$$

$v\left(\theta_k(t)\right)$ is array response vector & α_k is the complex attenuation factor

$$v\left(\theta_k(t)\right) = \left[1, w_1(t) e^{\frac{j2\pi d \sin\theta(t)}{\lambda}}, .., w_{M-1}(t) e^{\frac{i2\pi d (M-1) \sin\theta(t)}{\lambda}} \right]^T \qquad (24)$$

The maximal normalized Eigen vector $e_{u_k}{}^{[\max]}$ of the expected user $R_{d_k}^{[s]}$ and interference users $R_{d_k}^{[i]}$. Hence beamforming weight in downlink

$$w_{d_q} = \left(\frac{\xi_k}{e_{d_k}{}^{[\max]^H} R_{d_k}^{[s]} e_{d_k}^{[\max]}} \right)^{\frac{1}{2}} e_{d_k}^{[\max]} \qquad (25)$$

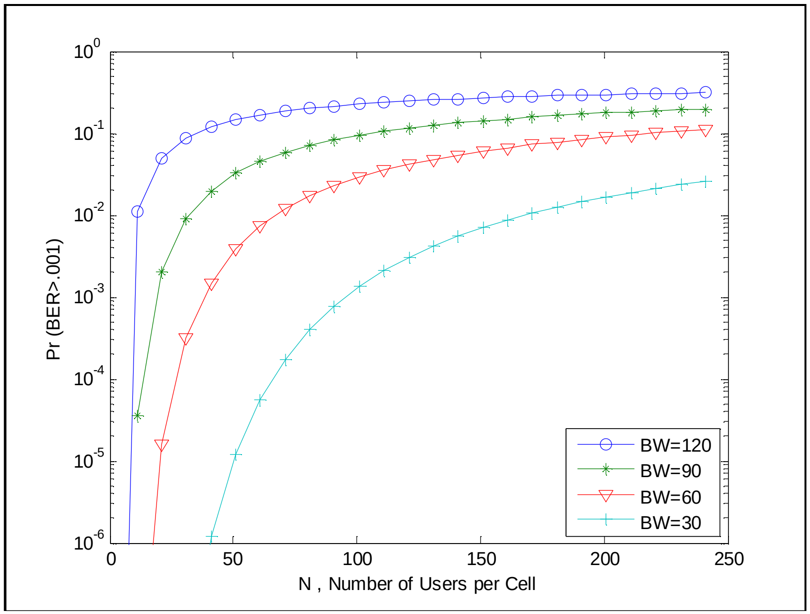

Fig. 4 Uplink outage probability as a function of beam width

IV.SIMULATION RESULT

In our simulations and numerical results, we consider only the first two tiers of interfering cells which means that K=18 Cells. We assume that for adequate performance, the required BER is 10^{-3} which corresponds to of $E_b/(N_0+I_0)$ of 7 dB. Here L=128 (processing gain) & σ_s=8 dB. From Figure 4 it can be concluded that by using antenna array to form narrow beams towards desired mobile, a many fold increase in system capacity can be achieved. For .01 outage probability, the uplink system capacity goes up from 5 users per cell for single antenna case to 200 users per cell cite Linear antenna array with 8 elements, beam width was taken corresponding to half power beam width to account for the interference energy picked up through the side lobes of the antenna pattern. Figure 5 shows the actual array pattern. Figure 6 shows multiple element smart arrays with OVSF code used on downlink may increase system capacity. In figure 7 upper curve denotes SINR of the sectored cell and the below curve denotes SINR of non-sectored cell. It can be said that performance of the sectored cell is much better than the non-sectored cell. The sectored TDSCDMA system is capable to enlarge capacity of the system.

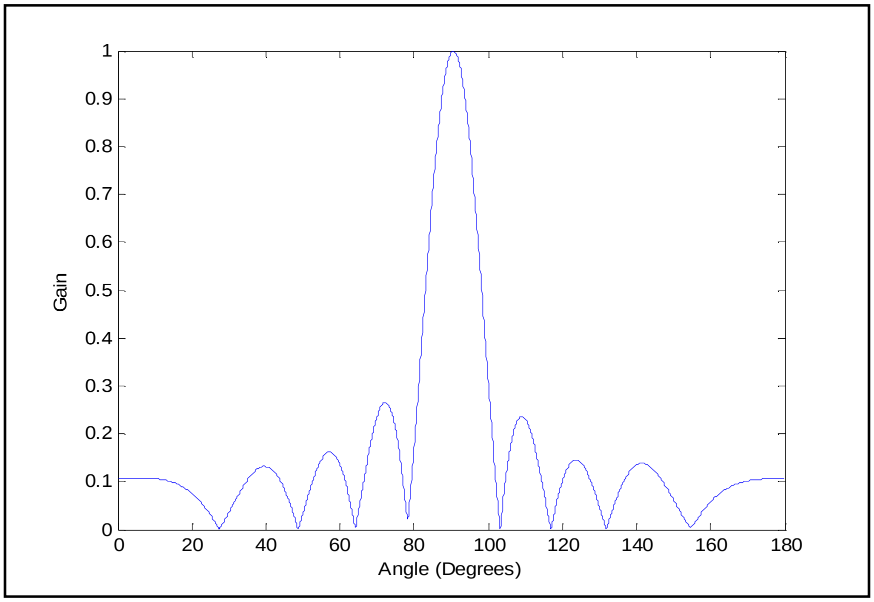

Fig. 5 Actual beam pattern

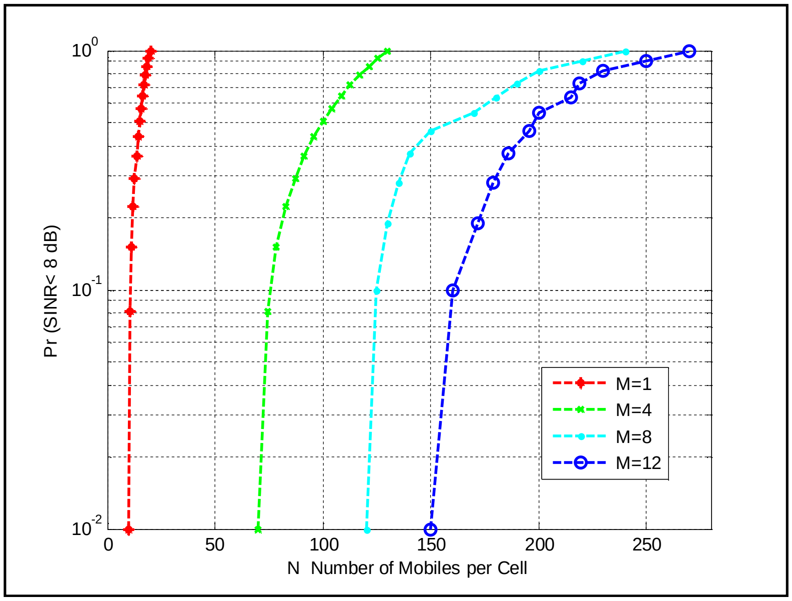

Fig. 6 Downlink outage probablity versus number of array sensors

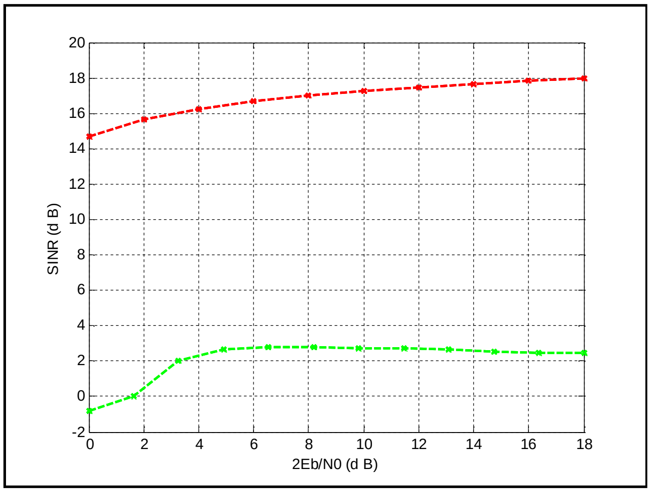

Fig. 7 SINR curves versus $2E_b/N_0$ for sectored and non-sectored system

V. CONCLUSION

We have studied the capacity improvement for TDSCDMA cellular communication system with smart antenna installed at base station. The model for uplink and downlink both taken under consideration to study the outage probability & capacity of the system as a function of cell loading, array parameters, weight update algorithms. The simulated results show that there can be significant increase in system capacity by incorporation of smart antenna array at BTS. The spatial processing approach & LMSE algorithm to control the weight of the array constructs a robust beamforming for TDSCDMA base station.

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