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PERFORMANCE ANALYSIS OF CELLULAR CDMA IN PRESENCE OF BEAMFORMING AND SOFT HANDOFF

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Abstract—The present paper proposes a scheme of combining soft handoff (HO) and beamforming in physical layer and automatic repeat request (ARQ) in link layer for improving the performance of data service in cellular CDMA. A stop and wait ARQ scheme has been assumed for data service. Joint effects of beamforming and soft handoff reduce delay, BER and increase throughput significantly. Impact of several parameters of soft handoff and beamforming on data performance has been evaluated. Both the cases of perfect and imperfect beamforming have been investigated. Effects of DOA (Direction of arrival) estimation error have also been indicated on data service.

1. INTRODUCTION

Wireless networks are evolving to support multimedia services such as voice, data and video. Code Division Multiple Access (CDMA) is a potential access technique for supporting multimedia traffic. Maintaining quality of service (QoS) of users is an important requirement for successful operation of cellular networks. Performance of a CDMA based system is limited by multiple access interference (MAI). The quality of radio link in cellular CDMA depends on signal to interference ratio (SIR). The fall of SIR below a threshold is defined as outage. This causes degradation of QoS (quality of service). Thus the cellular capacity of CDMA system is limited in the uplink by maximum tolerable interference at the base station (BS). The cellular capacity indicates that there are a practical number of admissible users which should not be exceeded in order to ensure QoS of the admitted users. A power based multi cell admission control for multimedia services with different QoS requirement is considered in [1]. One of the important features of CDMA is "soft HO" where the handoff mobile near a cell boundary transmits to and receives from two or more BSs simultaneously. Soft HO provides a seamless connectivity, reduces "ping-pong" effect as present in hard HO, lowers probability of lost calls and eases power control [2].

Several techniques have been proposed [3–5] to reduce interference such as space diversity technique, beam forming, soft handoff, multiuser detection etc. An interesting receiver structure in frequency domain is proposed for interference cancellation and analyzed in [6]. The suitable use of an antenna array at the base station of a wireless communication system can result in improvement in SIR [7]. SIR performance by using an antenna array is analyzed considering mutual coupling effect in [7]. Antenna arrays have also been used for interference suppression [8]. Further it is shown that antenna array is significant in improving the performance of MIMO (multiple input multiple output) wireless channel [9] and enhancing the performance of multi band-OFDM based UWB (ultra wide band) system [10]. Antenna arrays are also used in beamforming which could be used for improving cellular capacity [11, 12] and increasing the coverage [13].

Multi antenna can be used to enhance the system capacity [14]. Capacity improvement of CDMA with base station antenna array for both uplink and downlink has been studied in [15]. The outage probability was evaluated as a function of cell loading, array parameters, fading, shadowing effects and voice activity. Outage probabilities have been studied analytically in [5]. A simplified Beamforming model is used in deriving closed form outage probability expressions. The paper considers improvement due to beamforming only. However, the effects of soft handoff are not included in them.

In the present paper we consider data service in CDMA considering soft handoff as well as beamforming. Multiple antennas are assumed in BS only. By beamforming, BS can form specific beam for a specific user by calculating DOA (direction of arrival for EM wave). There are many techniques for DOA estimation such as Spectral Estimation Methods, MVDR method, Linear Prediction Method, MUSIC Algorithm and ESPRIT method etc. [3, 4]. DOA is used for steering beam by changing an angle. Main lobe of the antenna looks at the desired user and other users come under the null of the antenna beam.

The contribution of this paper is as follows. The present paper proposes a scheme of combining soft handoff (HO) and beamforming in physical layer and automatic repeat request (ARQ) in link layer for improving the performance of data service. The analysis presented in this paper evaluates the joint interactions of soft handoff and beamforming. Though the performance has been analyzed independently in presence of soft HO or beamforming in existing literature [2, 5], to the best of our knowledge, a joint interaction has not been proposed so far. The analyses available so far in the literature consider either effects of soft HO or beamforming in isolation. However, based on our model, parameters of one technique for e.g., beamforming could be adjusted depending on the given scenario and parameters of soft HO i.e., degree of soft HO, shadowing correlation, number of BSs involved, power control error. Effects of high power control error (pce), low shadowing correlation can be compensated by choosing appropriate parameters of beamforming following our model to achieve a given level of performance. Similarly, high DOA error associated with beamforming can be compensated by increasing degree of soft HO. Thus our results will help the system designer to choose appropriate values of parameters related to beamforming and soft handoff for an overall target data performance for e.g., BER, throughput etc.

A simulation study is carried out to evaluate performance of packet data encompassing the joint effects of beamforming and soft HO. Performance of data in terms of throughput and delay has been simulated with a fixed rate system for beamforming and different degrees of soft handoff. Two cases of beamforming perfect and imperfect have been simulated. Effects of beamforming parameters such as number of antenna elements, DOA error and soft handoff parameters such as degree of soft handoff, power control error, shadowing correlation on data services are indicated. Influences of DOA errors have also been studied. The interaction among those parameters has been highlighted.

The paper is organized as follows. Section 2 and 3 describes the cellular scenario and our simulation model. Results and discussions are presented in Section 4. Finally we conclude in Section 5.

2. SYSTEM MODEL

A cluster of three sectored cells with uniformly distributed mobile users (MS) and equal traffic intensity in all cells are considered. Here we assume that fixed beamforming has been used to cover all the users in a particular sector for paging, synchronization, call set up and adaptive beamforming has been used for traffic i.e. after call setup. During the call/data traffic, the desired user/MS will be tracked with a specific beam for optimum performance. All data users transmit at the same rate using a single code. For fixed rate system the user transmits on single code at a fixed rate R_b. The processing gain (pg) of all codes are equal; where $pg = W/R_b$; W is spread bandwidth. It is assumed

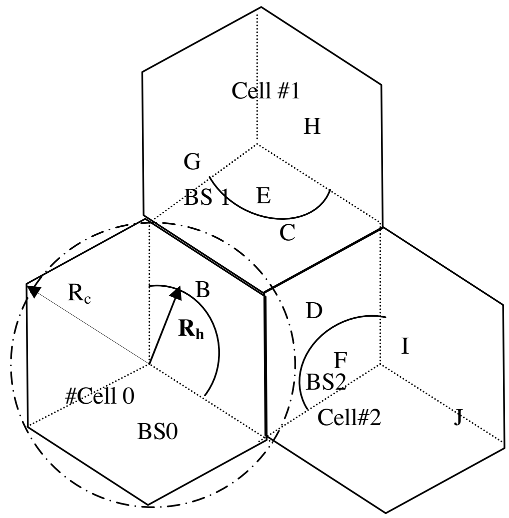

Figure 1. Cellular layout for soft HO. A, E, F are non HO region. B, C, D are soft HO region. Cell #0 is reference cell.

that number of simultaneous users 'm' in a cell is Poisson distributed with mean arrival rate λ:

$$P_m(l) = (\exp(-\lambda)\lambda^l)/l! \tag{1}$$

A "continuously active" data traffic model as in [16] is considered where each user generates a sequence of fixed length packets. A new packet is generated as soon as the preceding packet is delivered successfully. An ARQ model for packet data in the uplink of an imperfect power controlled CDMA is considered. The soft HO region is defined based on the distance from the base station (BS) as in Fig. 1. An MS located outside the handoff boundary R_h is considered to be under soft HO with three neighboring BS-s. Each sector is divided into two regions, soft HO regions (B, C, D) and non-HO region (A, E, F) of cell #0, 1 and 2 respectively in Fig. 1. BS_0, BS_1 and BS_2 are the BS-s of cell #0, 1 and 2 respectively. The propagation radio channel is modeled as in [17]. The link gain for a location (r, θ) is given as:

$$G_i(r, \theta) = d_i(r, \theta)^{-\alpha_p} 10^{\xi_s/10} \tag{2}$$

where $d_i(r, \theta)$ is the distance between the MS and BS_i, α_p is the path loss exponent and $10^{\xi_s/10}$ is the log-normal component with ξ_s normally distributed with 0 mean and variance σ_s^2. The shadow fading at i-th

BS is [2, 17] $\xi_{s-i} = a\zeta + b\zeta_i$ with as:

$$a^2 + b^2 = 1 \tag{3}$$

where ζ and ζ_i are independent Gaussian random variables with zero mean and variance σ_s^2. Out-cell interference consists of interference due to MS-s from region (E, C, G, H) of cell #1 and (D, F, I, J) of cell #2. MS-s in furthest sectors (G, H, I, J) are assumed to be power controlled by respective BS-s. The reference user is located in non-HO region of reference sector, i.e., in region 'A'. Total in-cell interference in cell #0 is:

$$I_{in} = I_1 + I_2 \tag{4}$$

where I_1 is due to all MS-s in A and those in B connected to BS_0, I_2 is due to MS-s in B but connected to BS_1 and BS_2. The out-cell interference is:

$$I_{out} = 2\left(I_E + I_{c1} + I_{c2} + I_{co} + I_G + I_H\right) \tag{5}$$

I_E is the interference due to MS-s in E and connected to BS_1. Similarly $I_{c1}$and I_{c2} are due to MS-s in region C and power controlled by BS_1 and BS_2 respectively. I_{co} is due to MS-s in C and power controlled by BS_0. I_G and I_H are the interference due to MS-s in G and H. MS-s in these farthest sectors are assumed to be power controlled by respective BS, i.e., BS_1. A multiplication factor of two is used in Eq. (5) to include contribution of cell #2. The actual received power from desired user is $U = S_d e^S$, where S is a Gaussian r.v. with mean 0 and variance $\sigma_S^2 = \sigma_e^2$.

2.1. Perfect Beamforming

Next we consider beamforming at BS. The distance between the elements of the Linear Equally Spaced (LES) array is assumed to be 0.5λ, where λ is the carrier wavelength. In the LES array system, a combining network could generate an antenna pattern [3], with gain

$$G(\phi, \theta) = \left|\frac{\sin\left(0.5M\pi\left(\sin\theta - \sin\phi\right)\right)}{M\sin\left(0.5\pi\left(\sin\theta - \sin\phi\right)\right)}\right|^2 \tag{6}$$

where M is the number of antenna elements and θ is a variable. The beam could be steered to a desired direction, ϕ by varying θ. In this paper, we shall use the antenna pattern specified in (6) to evaluate the impact of beamforming on the CDMA reverse link capacity. Desired user is generated with proper (r, θ_d) at region A. If any user other than desired user subtends an angle, θ_i with cell #0 then interference power will be multiplied by antenna gain, $G(\theta_i,\ \theta_d)$.

$$G(\theta_i, \theta_d) = \left| \frac{\sin\left(0.5M\pi\left(\sin\theta_i - \sin\theta_d\right)\right)}{M\sin\left(0.5\pi\left(\sin\theta_i - \sin\theta_d\right)\right)} \right|^2 \tag{7}$$

This beamforming gain is very less compared to one for small difference between two angles, the gain becomes lesser with increasing difference in θ_i and θ_d. In general, θ_i and θ_d differ by large margin as θ_d is the desired angle whereas θ_i is a direction towards the null of the antenna. Further $G(\theta_i,\ \theta_d)$ could be reduced by increasing M. Thus interference could be reduced further. The interference generation considering the beamforming gain has been shown in later section.

2.2. Imperfect Beamforming

Imperfect beamforming may result due to DoA estimation error, angle spread, array perturbation or mutual coupling. DoA estimation error may be due to an error in measured arrival angle of the wave which is normally done by using some estimation algorithm. Angle spread may be caused due to obstacle around the transmitter. Array perturbation is due to position change of the array elements. Array perturbation may cause change in beamforming gain even with perfect DoA estimation. DoA error has been considered to capture imperfection in beamforming [5]. We have considered DoA error that may be caused either due to DoA estimation or due to angle spread, in our simulation to show its effects on performance. DoA error may be simulated either by considering it as normally distributed or as uniformly distributed. DoA error has been simulated considering it as uniformly distributed and Gaussian distributed. If $\hat{\theta}$ is the estimate of θ then these estimates are used for estimating received signal power for desired user and interferers [5].

$$\Delta_{\max} = \frac{\arcsin\left(\frac{2}{M}\right)}{\sqrt{3}} \tag{8}$$

We have considered Δ as 75% of $\Delta_{\max}$ for analysis.

$$f\left(\hat{\theta}\right) = \frac{1}{2\sqrt{3}}\Delta; \quad -2\sqrt{3}\Delta \le \hat{\theta} - \theta \le 2\sqrt{3}\Delta \tag{9}$$

for uniform distribution as in [5].

$$f\left(\hat{\theta}\right) = \frac{1}{\sqrt{2\pi\Delta^2}} \exp\left\{ -\frac{\left(\hat{\theta} - \theta\right)^2}{2\Delta^2} \right\} \tag{10}$$

for normal distribution, i.e., $\hat{\theta} \sim N(\theta, \Delta^2)$.

Considering these distributions, estimates of angles are simulated and steps in (3.2) to (3.3) of later section are repeated for getting results with DoA error.

2.3. Throughput and Delay Analysis

The BER (P_e) for data user is simulated as described in later section in the above soft HO environment considering direct sequence spreading and BPSK data modulation having spread b.w W. The retransmission probability P_r is given as [18]

$$P_r = 1 - (1 - P_e)^{L_p r_c} \tag{11}$$

where L_p is the length of the packet in bits and r_c is the FEC code rate. For continuously active data users, the average packet delay is the same as the packet transfer time T_p as there is no waiting delay in the queue. The time required for transmitting a packet of length L_p by a data user transmitting at a rate of R_b is:

$$T_i = \frac{L_p}{R_b} = \frac{L_p\ pg}{R_c} \tag{12}$$

We assume that acknowledgement from the receiver is instantaneous and perfectly reliable. The average delay [18]

$$D = \frac{T_i}{(1 - P_r)} = \frac{L_p\ pg}{R_c(1 - P_r)} \tag{13}$$

The average throughput (G) is defined as the average number of information bits successfully transferred per sec and is given as

$$G = \frac{L_p r_c}{D} = \frac{r_c R_c (1 - P_r)}{pg} \tag{14}$$

In the next section, we briefly describe our simulation model, which is used to evaluate outage, bit error rate (BER), throughput, delay.

3. SIMULATION MODEL

The simulation is developed in MATLAB using the following parameters: PR_h indicates the degree of soft HO, shadowing correlation (a^2), power control error (pce). The soft HO region boundary R_h given as $R_h = R_c\sqrt{1 - PR_h}$ where R_c is the radius of the cell, normalized to unity and hexagonal cell is approximated by a circular one with radius R_c. Users are assumed to be uniformly distributed.

3.1. Generation of Users' Location and Interference

1. The number of users (N) is the input variable for outage analysis. The number of users (N_d) is generated by generating a Poisson distributed r.v with mean λ for BER, TP and delay analysis.

2. Locations (r, θ) of all users are generated and users are divided into non-HO (N_h) and soft HO (N_s) region based on their location. Assuming the desired user in non-HO region, let the remaining interfering users in non_HO are $(N_h - 1)$. Number of users in soft HO region: $N_s = N - N_h$.

3. For each of those in soft HO region (N_s), the link gains corresponding to each of three BS-s involved in soft HO are generated as

$$G_i(r,\theta) = r_i^{-\alpha_p} e^{\xi_i}, \qquad i = 0, 1, 2$$

where ξ_i is a Gaussian r.v with mean 0 and variance $b^2\sigma_s^2$, r_i is the distance from i-th BS. The user is power controlled by the BS for which the link gain is maximum, i.e., it is power controlled by BS_i if G_i is maximum; $i = 0, 1, 2$.

4. Beamforming gain is generated for each user considering perfect beamforming as in Eq. (7) and the interference received at reference BS is:

$$I = S_R \exp(r_n) \left(\frac{G_0}{G_i}\right) G\left(\theta_i, \theta_d\right) \tag{15}$$

if connected to BS_i , where $i = 0, 1, 2$. Here r_n is a normal r.v. with 0 mean and standard deviation σ_e. S_R is the required received power at the respective BS which is normalized to unity in the simulation since SIR is unaffected by assigning $S_R = 1$.

5. Next interference due to $(N_h - 1)$ MS-s in non_HO region (A) of reference cell each power controlled by BS_0 is considered as

$$I_2 = S_R G\left(\theta_i, \theta_d\right) \sum_{i=1}^{N_h-1} e^{r_{n,i}} \tag{16}$$

Now the interference due to MS-s in adjacent sectors, i.e., (region E, C, D and F) of cell#1 and #2 are found in similar manner. The number of MS-s in E and F are $(N_d - N_s)$ each. Let $I_3 = I_E + I_C$ and $I_4 = I_D + I_F$.

6. Interference from MS-s in G, H, I and J regions are generated. Let $I_5 = I_G + I_H$ and $I_6 = I_I + I_J$.

7. Total interference

$$I = \sum_{k=1}^{6} I_k \tag{17}$$

8. Signal from desired user is,

$$U = S_d e^x, \qquad SIR = U/I \tag{18}$$

x is Gaussian with mean '0' and variance σ_e^2.

3.2. BER Simulation

1. A sequence of random data bits +1 or −1 is generated which indicates the transmitted bits.

2. A Gaussian noise sample n_g is generated with variance $\sigma_g^2 = 1./(2.pg.SIR_d)$ and added to each transmitted bit, where SIR_d is found following steps 3.1(1) to 3.1(8) for a given pg.

3. The received bit is first detected as +1 or −1 after comparing with a threshold of 0. Then each received bit is compared with corresponding transmitted bit and an *error_count* is incremented in case they disagree.

4. Steps 3.2(1) to 3.2(3) are repeated for a large N_{total} number of times to yield estimate of BER as $P_e = error\_count/N_{total}$.

3.3. Packet Error, Delay and Throughput Simulation

1. A packet consisting of $L(= r_c L_p)$ information bits are generated. A sample of Gaussian noise with processing gain (pg) as in 3.2(2) is added to each transmitted bit of a packet.

2. The received L bits of a packet are checked with their corresponding transmitted bits to assess packet error.

3. If the received packet is incorrect, the same packet (i.e., same bit pattern as in 3.3(1)) is retransmitted until the packet is received correctly finally.

4. Total number of erroneous packet is counted out of a large number of transmitted packets to estimate the PER.

5. Average delay (D) is estimated as: $((N_p + retx\_count)./N_p)T_i$ where T_i is as in (12), N_p: number of transmitted packets, *retx_count*: total retransmissions of N_p packets.

6. The throughput is: $G = L_p r_c/D$

7. Total number of erroneous packet is counted out of a large number of transmitted packets to estimate the packet error rate (PER).

8. *Packet delay variation (PDV)*: Delay of individual packet $D(i)$ is recorded for all packets. PDV is evaluated as: $E[\{D(i) - D\}^2]/D^2$

4. RESULTS AND DISCUSSIONS

The following parameters are used in simulation. Spread b.w W = 5 MHz, chip rate $R_{ch} = 5$ Mcps, $R_b = W/pg$, $pg = 128$ and 312, $L_p = 1024$, pce $\sigma = 2$ dB, $\alpha_p = 4$, $\sigma_s = 6$ and 8 dB, and $r_c = 0.5$. SIR threshold $\gamma_{th} = 6$ dB. Three cases of shadowing correlation $a^2 = 0$, 0.6 and 0.3 are considered. Similarly two values of $PR_h = 0.3$ and 0.7 are assumed. Two values of $M = 3$ and 5 have been considered. $\Delta_{\max}$ is considered as 10 degree.

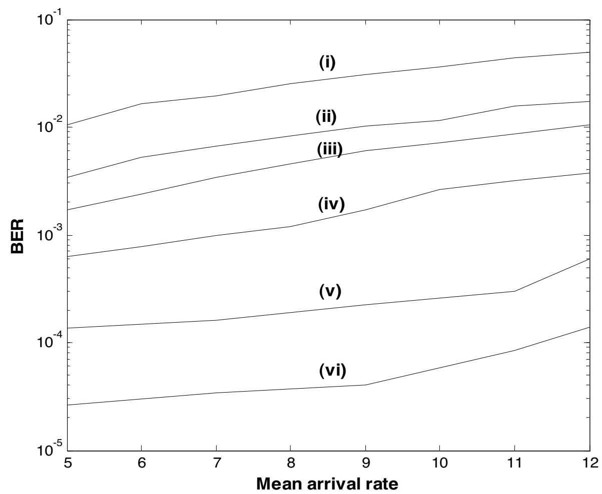

Figure 2. Effects of beamforming and soft handoff on BER. (i) $PR_h = 0.3$; $\sigma_e = 2$; $a^2 = 0.3$; $pg = 128$; (ii) $PR_h = 0.3$; $\sigma_e = 2$; $a^2 = 0$; $pg = 312$; (iii) $PR_h = 0.3$; $\sigma_e = 2$; $a^2 = 0.3$; $pg = 312$; (iv) $PR_h = 0.3$; $\sigma_e = 2$; $a^2 = 0.3$; $pg = 128$; $M_r = 5$; (v) $PR_h = 0.3$; $\sigma_e = 2$; $a^2 = 0.6$; $pg = 312$; (vi) $PR_h = 0.3$; $\sigma_e = 2$; $a^2 = 0.3$; $pg = 312$; $M_r = 5$.

Figure 2 shows the effects of beamforming with soft HO on BER performance. Higher degree of shadowing correlation reduces BER in fixed pg case as seen in curves due to reduced level of interference Thus increase in a^2 is found to improve reverse link performance significantly by limiting the interference [(ii), (iii) and (v) for $pg = 312$]. For example, with $a^2 = 0.6$ BER is less compared to that with $a^2 = 0$ or 0.3. Bit error probability decreases to large extent when beamforming considered with a number of antenna elements at reference BS [(i) and (iv)].

Figure 3 shows the curves for variation of throughput with respect to mean arrival rate for different degrees of soft handoff, beamforming and for different values of processing gain. If pg is fixed at 312 then R_b is less than that of with $pg = 128$. But interference is less with $pg = 312$. Hence, we see that throughput is not very large with $pg = 312$ compared to the case with $pg = 128$. Using beamforming throughput could be improved even with higher pg of 312. As seen from the curves, throughput is very less even with $M = 5$ for $pg = 312$. Throughput increases with higher degree of soft handoff. We find maximum throughput with $pg = 128$, $PR_h = 0.7$ and $M = 5$.

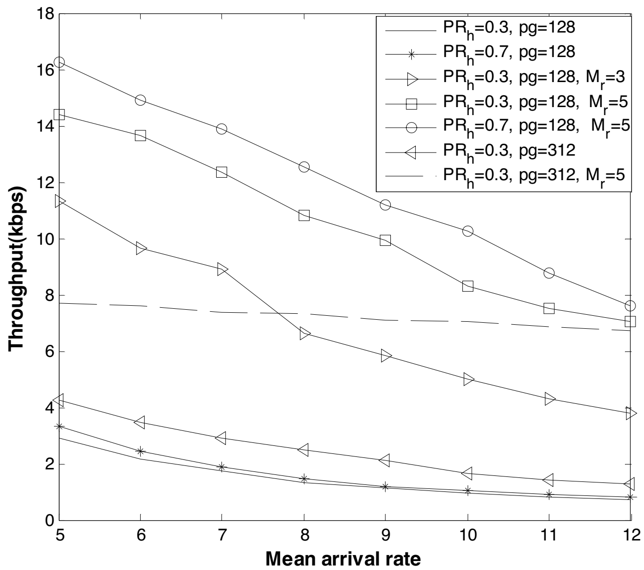

Figure 3. Throughput vs. mean arrival rate under different beamforming and soft handoff conditions.

Beamforming provides better performance with less delay. From Fig. 4, we see that delay is very less when beamforming is applied at base station. It also shows the effects of number of antenna elements at the BS. It shows that $M = 5$ gives lower delay than with $M = 3$.

Figures 5 and 6 show the effects of beamforming and soft handoff on packet error rate and packet delay variation. It is noticed that both of them reduce if M is increased.

Figures 7, 8 and 9 show the effects of DoA estimation error with $pg = 128$, $PR_h = 0.3$ or 0.7, pce = 2 dB, $a^2 = 0.3$, $M = 5$ on BER, TP and delay respectively. DOA error has been considered to follow uniform distribution and Gaussian distribution respectively. We observed that DoA estimation error does not change BER, throughput, delay considerably after considering both types of distribution. It is

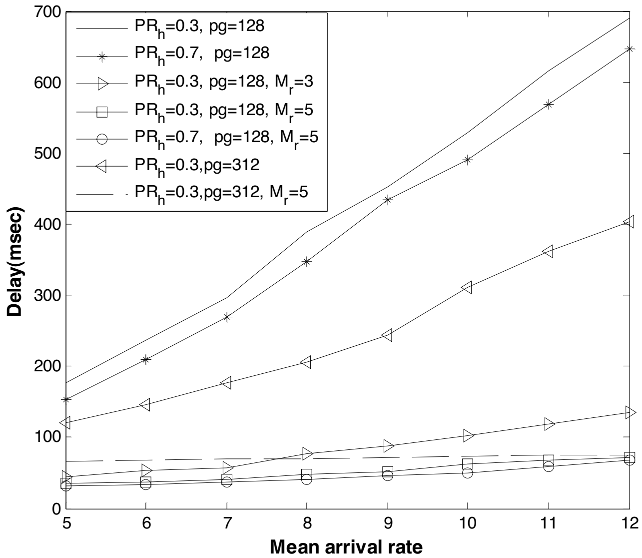

Figure 4. Delay vs. mean arrival rate under different beamforming and soft handoff conditions.

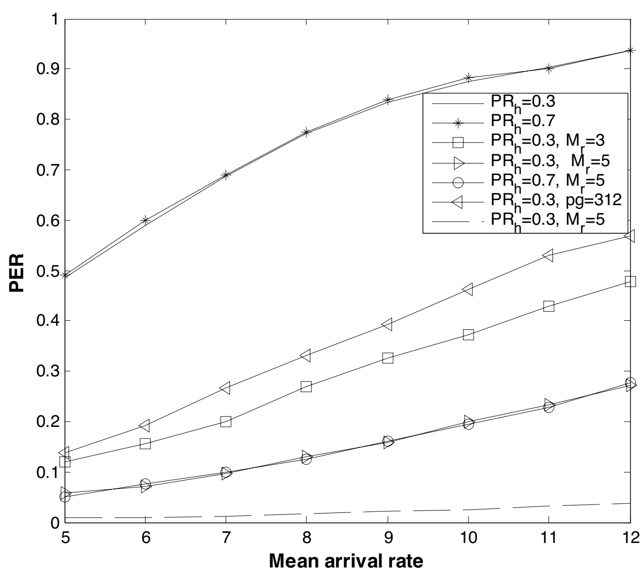

Figure 5. PER vs. mean arrival rate for different beamforming and soft handoff conditions.

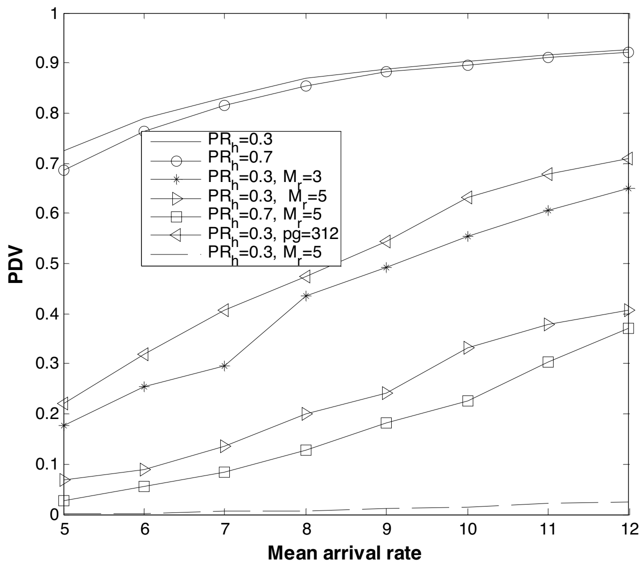

Figure 6. PDV vs. mean arrival rate for different beamforming and soft handoff conditions.

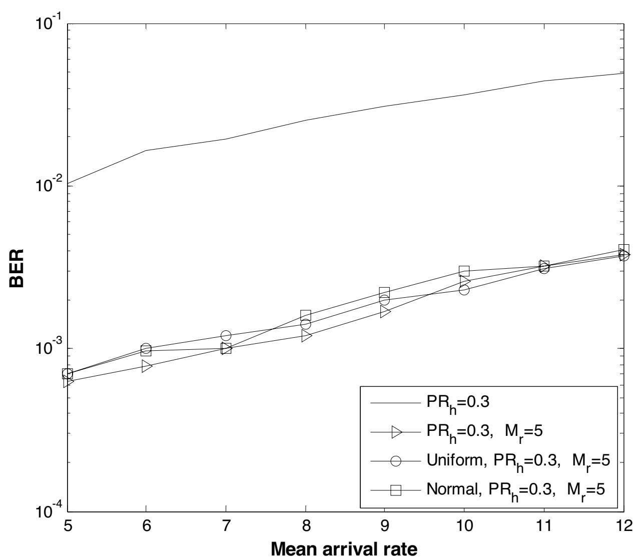

Figure 7. Effects of DOA error on BER.

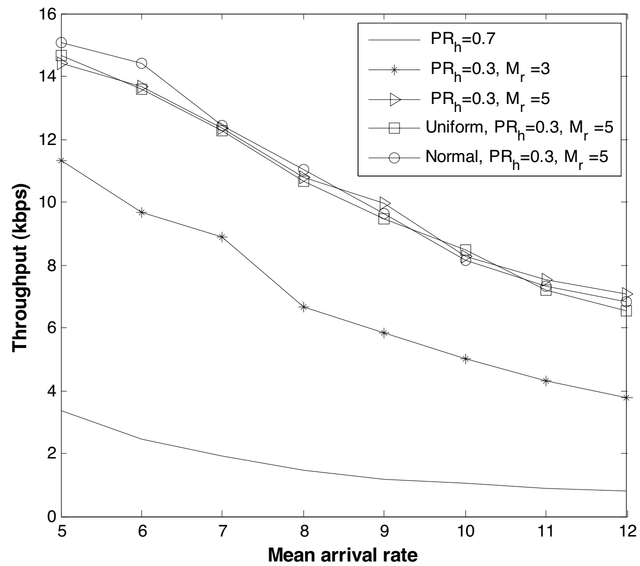

Figure 8. Effects of DOA error on throughput.

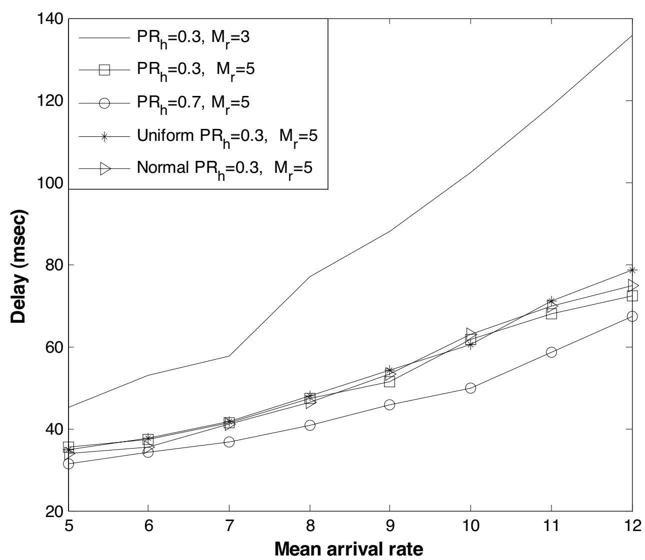

Figure 9. Effects of DOA error on delay.

found that particularly throughput is not changed significantly for DoA estimation error. BER changes to some extent if $\lambda < 11$ and after that BER does not change significantly.

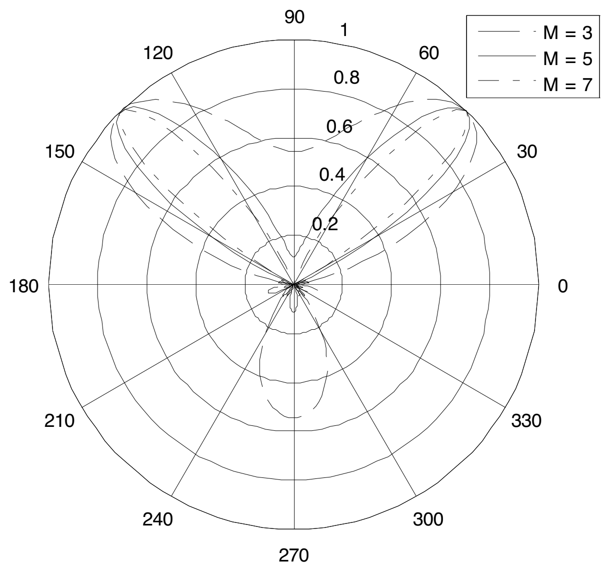

Figure 10. Radiation pattern of the beamformer.

Figure 10 shows radiation pattern of the antenna array used for beamforming at the BS site. It can be noticed that for increasing number of array elements, M beam becomes more directive providing very gain at a particular direction. Considerable amount of energy will be lost due to side lobes if M (e.g., $M = 3$) is reduced.

5. CONCLUSIONS

A scheme of combining beamforming with soft handoff in cellular CDMA for improving performance of data services has been proposed and evaluated. Soft handoff parameters, shadowing correlation and PR_h are found to have significant impact on data service. Performance is further enhanced due to incorporation of beamforming. Number of antenna elements at base station for beamforming has significant impact on BER and throughput. Increase in number of elements increases throughput and reduce delay significantly. Beamforming and higher shadowing correlation increase throughput and reduce BER. DOA error has been found to have effects on BER and throughput but its impact is not very significant. The above study reveals the interactions among soft handoff parameters and beamforming parameters for performance improvement which is helpful for overall system design. Further, data services with delay constraint will require truncation on ARQ. Our present model could easily be extended to capture such situation where it will help to choose parameters of soft HO and beamforming considering a constraint on maximum allowable retransmissions. Our present simulation model could also be extended to capture a practical situation where more BSs are involved in soft HO process. The number of BSs will further affect the parameters of beamforming and soft HO for achieving a desired performance level.

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