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Forward Link Data Service with Beamforming and Soft Handoff in Cellular CDMA

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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 forward link of cellular CDMA. A stop and wait ARQ scheme has been assumed for forward link data service. Joint effects of beamforming and soft handoff via cross layer interaction reduce delay, bit error rate (BER) and increase throughput significantly. Impacts of several parameters of soft handoff and beamforming and their cross layer interaction on data performance have been evaluated. Both the cases of perfect and imperfect beamforming have been investigated. Effects of DoA (direction of arrival) estimation error associated with beamforming have also been indicated on data service.**

Index Terms—**Soft HO, Beamforming, ARQ, Throughput**

I. Introduction

High rate packet data transmission is becoming significantly important in wireless networks supporting multimedia services. Code Division Multiple Access (CDMA) is very promising to meet the demand for high data rate and quality of service (QoS) in wireless networks. CDMA uses soft handoff (HO) where the handoff mobile near a cell boundary transmits to and receives from two or more BS-s simultaneously. Soft HO provides a seamless connectivity in contrast to hard handoff by allowing a “make before break” connection. It reduces “ping-pong” effect as present in hard HO, probability of lost calls and eases power control [1]. Several techniques have been proposed [2, 3, 4] to improve capacity by reducing interference such as space diversity technique, beamforming, soft handoff, multiuser detection etc. Outage performance is shown to improve using antenna array [5]. Outage performance is investigated in presence of soft handoff and beamforming in [6]. Outage performance is studied with soft handoff only in [7]. An interference based call admission is analyzed in [8, 9] with soft handoff only without considering space diversity. BER analysis has been done in a new soft handoff scheme in forward link CDMA where each BS sends subset of main data stream [10]. Capacity improvement can be achieved with orthogonal code hopping multiplexing where number of allowable downlink channels in CDMA is increased [11]. Downlink data traffic models consists of FTP, HTTP (web browsing, WAP, video streaming model). Throughput and delay have been simulated for such downlink data traffic model [12]. Asymmetric transmission of traffic between reverse link and forward link (such as web browsing) has been considered in [13]. Analytical framework for balancing forward link and reverse link capacities using a cross layer model involving PHY, link and network layer has been presented [13]. Intercell interference experienced by a MS in a given sector is a function of network load on forward link of the neighboring sectors. A new scheme to estimate signal to noise interference ratio (SINR) at a MS has been proposed and throughput analysis shown in favor of their scheme in [14]. An overview of physical layer of forward link only (FLO) air interface has been presented in [15]. Adaptive BS power control strategies have been investigated for forward link data services. A few algorithms have been proposed on power control strategies and their impact on throughput and delay has been investigated [16].

Capacity improvement of CDMA with base station antenna array has been studied for both uplink and downlink [17]. The outage probability was evaluated as a function of cell loading, array parameters, fading, shadowing effects and voice activity. Different beamforming schemes, adaptive algorithms to adjust the required weighting on antennas, direction-of-arrival estimation method have been studied in [3]. The paper also provides their performance comparison and effects of errors on the performance of an array system, as well as schemes to alleviate them. Outage probabilities have been studied in presence of beamforming analytically in [5]. A simplified beamforming model is used in deriving closed form outage probability expressions. The above paper considers improvement due to beamforming only. However, the effects of soft handoff are not included in them. Beamforming can be applied both at transmit and receive side. Multiple antennas in MS are avoided to reduce complexity. Hence transmit beamforming (putting antenna elements at BS side) is preferred in the forward link. By transmit beam forming in forward link, 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]. DoA is used for steering beam by changing an angle. Main lobe of the transmitting antenna array looks at the desired user and other users come under the null of the antenna beam. Performance of data services has been analyzed for the reverse link in [18]. Real time multimedia services are gaining importance. Downlink data traffic e.g., web browsing, WAP, video streaming are becoming important. Thus performance analysis for data service in downlink is very important. This paper proposes a simulation study to

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evaluate performance of packet data encompassing the joint effects of beamforming and soft HO in the forward link of cellular CDMA. 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. An ARQ model for packet data in the downlink of an imperfect power controlled CDMA is considered. 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. Effects of beamforming parameters and soft handoff parameters on BER and data services are indicated. Influences of DoA errors have also been studied.

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 in the forward link. 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, 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. Our proposed scheme attempts to compensate the performance degradation caused by soft HO in forward link by using beamforming. 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 parameters of beamforming following our model to achieve a given level of performance. Similarly, high DoA error associated with beamforming can be compensated by varying other soft HO parameters. 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.

Performance of data in terms of throughput and delay has been simulated with a fixed rate system with 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 interactions among these parameters have been highlighted.

II. System Model

A cluster of three sectored cells with uniformly distributed mobile users (MS) and equal traffic intensity in all cells are considered. For fixed rate system the BS 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 that number of simultaneous users 'l' in a cell is Poisson distributed with mean arrival rate λ :

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

A "continuously active" data traffic model as in [19] is considered where each BS generates a sequence of fixed length packets. A new packet is generated as soon as the preceding packet is delivered successfully. 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 #0,1and 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 [7]. 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

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

where ζ and ζ_i are independent Gaussian random variables with zero mean and variance σ_S^2 . The reference user is located in non-HO region of reference sector i.e. in region 'A'. Two cases are investigated namely, with beamforming and without beamforming. Both the above cases are studied for perfect and imperfect power control.

A. *Without Beamforming*

PERFECT POWER CONTROL: Let P_{T_i} be the total forward transmit power by BS_i to the respective sector. Since the MSs are uniformly distributed throughout the system, we can assume that these total transmit powers are nearly equal to one another, where

$$P_{T\_R} \approx P_{T\_1} \approx P_{T\_2} \approx P_T \tag{4}$$

Then, given the location of a MS in the reference sector, the forward interference experienced by the MS can be approximated as:

$$\begin{aligned} I(r,\theta) &\approx G_R(r,\theta)P_{T\_R} + G_1(r,\theta)P_{T\_1} + G_2(r,\theta)P_{T\_2} \\ &\approx \left(G_R(r,\theta) + G_1(r,\theta) + G_2(r,\theta)\right)P_T \end{aligned} \tag{5}$$

Forward interference level experienced by each reference MS differs significantly depending on its location and associated shadow fading. Therefore, the forward transmit power for each MS needs to be controlled accordingly so that all MSs experience the uniform forward SIR level. Let us say that the forward transmit power for each MS is controlled in the following way [20]:

$$P(r,\theta)=\frac{\left(G_R(r,\theta)+G_1(r,\theta)+G_2(r,\theta)\right)}{G_i(r,\theta)}\times P_C \tag{6}$$

Given that the MS is connected to BS_i and P_C is the predetermined forward transmit power constant. Then, the forward CIR of the MS, regard less of its location and shadowing condition is

$$SIR_{forward}\approx\frac{P_C}{P_T} \tag{7}$$

With the given forward power control law, we compute the SIR to characterize the forward performance. Let us first consider the non handoff MSs in the reference sector (region A). According to the power control law discussed, the forward transmit power to a non handoff MS in the reference sector is

$$P_R(r,\theta)=\frac{\left(G_R(r,\theta)+G_1(r,\theta)+G_2(r,\theta)\right)}{G_R(r,\theta)}\times P_C \tag{8}$$

Now let us consider handoff MSs in regions B, C, and D. When a MS is in soft handoff mode, all BSs involved in soft handoff transmit to the MS and the MS can combine the signals for its advantage using a rake receiver. As multiple BSs transmit simultaneously during handoff for the MS in soft handoff zone, it can result increased forward interference at the same time. Based on the system model, the reference *BS*, BS_1, and BS_2 all transmit to MSs located in handoff region. Let us assume that each BS involved in soft handoff transmits P_C for each handoff MS when beamforming is not used; then the total forward transmit power by the reference sector is:

$$P_{T\_R}=\sum_{i=1}^{N_{nh}}P_R(i)+\left(N_{s,B}+N_{s,C}+N_{s,D}\right)\times P_C \tag{9}$$

Where, N_{nh} = number of users in non handoff region and N_s is number of users in soft handoff and $N_d = N_{nh} + N_s$, N_s is users soft HO region of reference and other sector, as reference BS transmit P_C for them too. $N_s=\left(N_{s,B}+N_{s,C}+N_{s,D}\right)$. Signal to interence ratio in the forward link without beamforming may be expressed as [7]

$$SIR_{forward}=\frac{P_C}{\sum_{i=1}^{N_{nh}}P_R(i)+\left(N_{s,B}+N_{s,C}+N_{s,D}\right)\times P_C} \tag{10}$$

IMPERFECT POWER CONTROL:

The forward transmit power with power control error is:

$$SIR_{forward}=\frac{P_C^{\ \varepsilon}}{P_{T\_R}^{\varepsilon}}\ \text{where}\ \ P_C^{\ \varepsilon}=P_C 10^{\xi/10} \tag{11}$$

ξ is a Gaussian random variable with zero-mean and variance σ_e^2. Equation (9) will be modified as below when imperfect power control is considered.

$$P_R^{\varepsilon}(r,\theta)=\frac{\left(G_R(r,\theta)+G_1(r,\theta)+G_2(r,\theta)\right)}{G_R(r,\theta)}\times P_C^{\ \varepsilon} \tag{12}$$

for non handoff MSs and $P_C^{\ \varepsilon}$ for handoff MSs.

B. With Beamforming

There are two situations depending on nature of beamforming such as perfect and imperfect beamforming as discussed below.

PERFECT BEAMFORMING:

Next we consider transmit beamforming at reference *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 [4], with gain

$$G(\phi,\theta)=\left|\frac{\sin\left(0.5M\pi(\sin\theta-\sin\phi)\right)}{M\sin\left(0.5\pi(\sin\theta-\sin\phi)\right)}\right|^2 \tag{13}$$

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 (13) to evaluate the impact of beamforming on the CDMA forward link. 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 transmit power from the reference *BS* for that user will be multiplied by antenna gain, $G(\theta_i, \theta_d)$.

$$G(\theta_i,\theta_d)=\left|\frac{\sin\left(0.5M\pi(\sin\theta_i-\sin\theta_d)\right)}{M\sin\left(0.5\pi(\sin\theta_i-\sin\theta_d)\right)}\right|^2 \tag{14}$$

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 array antenna. Further $G(\theta_i, \theta_d)$ could be reduced by increasing M. Thus forward interference could be reduced further. The forward interference generation considering the beamforming gain has been shown below. For a user at non handoff region transmit power from reference *BS* will be:

$$P_{R,withbeamform}(r,\theta)=\frac{\left(G_R(r,\theta)+G_1(r,\theta)+G_2(r,\theta)\right)}{G_R(r,\theta)}\times P_C\times G(\theta_i,\theta_d) \tag{15}$$

Accordingly, signal to interference ratio in the forward link with beamforming may be expressed as below (eqn. 16) by modifying eqn. (10). $\theta_{i,sho}$ is the corresponding angle for the users in different soft HO regions. $\theta_{i,shoC}$ and $\theta_{i,shoD}$ are the angles of the users at region 'C' and region 'D' with respect to reference *BS*.

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 other users [5].

$$\Delta_{\max} = \frac{\arcsin\left(\frac{2}{M}\right)}{\sqrt{3}} \tag{17}$$

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

$$f\left(\hat{\theta}\right) = \frac{1}{2\sqrt{3}}\Delta \;\; ; -2\sqrt{3}\Delta \le \hat{\theta} - \theta \le 2\sqrt{3}\Delta \tag{18}$$

for uniform distribution as in [5].

$$f\left(\hat{\theta}\right) = \frac{1}{\sqrt{2\pi\Delta^2}} \exp\left\{ -\frac{\left(\hat{\theta} - \theta\right)^2}{2\Delta^2} \right\} \tag{19}$$

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

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. Further, performance has been analyzed for without beamforming and with beamforming cases considering both perfect and imperfect power control separately.

C. BER, Throughput, Delay analysis

The BER (P_e) for a 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 [19]

$$P_r = 1 - (1 - P_e)^{L_p r_c} \tag{20}$$

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 BS transmitting at a rate of R_b is:

$$T_i = \frac{L_p}{R_b} = \frac{L_p \;\; pg}{R_c} \tag{21}$$

We assume that acknowledgement from the receiver is instantaneous and perfectly reliable. The average delay [21]

$$D = \frac{T_i}{(1 - P_r)} = \frac{L_p \;\; pg}{R_c(1 - P_r)} \tag{22}$$

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

$$G = \frac{L_p r_c}{D} = \frac{r_c R_c (1 - P_r)}{pg} \tag{23}$$

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

III. 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.

A. Generation of Users' location and interference

1. The number of users (N) is generated by generating a Poisson distributed random variable with mean λ .

$$SIR_{forward} = \frac{P_C}{\sum_{i=1}^{N_{nh}} P_R(i) \times G(\theta_i, \theta_d) + \left(N_{s,B} \times G(\theta_{i,shoB}, \theta_d) + N_{s,C} \times G(\theta_{i,shoC}, \theta_d) + N_{s,D} \times G(\theta_{i,shoD}, \theta_d)\right) \times P_C} \tag{16}$$

2. Locations (r,θ) of all (N) 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 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 regions (N_s), the forward transmitted power has been calculated as per equations (9) and (11). Again N_d users are generated for cell#1 and cell#2. However, only users in soft HO region 'C' and 'D' are considered to determine the forward interference powers from reference BS, separately considering no beamforming case and beamforming cases. Angles for the users in region 'C' and 'D' with respect to cell #0 are calculated accordingly using the cell geometry when forward interference power is determined using beamforming.

4. Next forward transmit power of BS_0 for MS-s in non_HO region (A) of reference cell is obtained utilizing the formulas derived in Section 2.

5. Signal from desired BS is, P_C or P_C^{ε} and SIR_d is as in equation (11) and (16) for without beamforming and with beamforming cases respectively.

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

C. 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 as in B(2) with processing gain (pg) 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 B(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 number of retransmissions for 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): All packets will not have same delays. Delay of an individual packet (e.g. i th packet),* $D(i)$ *is recorded.* Thus, variations in packet delay with respect to an average delay (D) have been observed for large number of packets. PDV is evaluated as: $E[\{D(i) - D\}^2]/D^2$

IV. Results and Discussions

Table I

SIMULATION PARAMETERS

Spread bandwidth, W	5 MHz
Chip rate, R_c	5 Mcps
R_b = W/pg; processing gain, pg	128, 64
Packet length, L_p	1024
Power control error, σ	2 dB
Path loss exponent, α_p	4
Standard deviation of shadow fading, σ_s	6 dB
FEC code rate, r_c	0.5
Shadowing correlation, a^2	0.6 and 0.3
Degree of soft HO, PR_h	0.3, 0.7
No. of antenna elements, M	5, 7
DoA error, Δ_{max}	10 degree.

Fig.2 shows the effects of beamforming with soft HO on BER performance. Higher degree of soft HO increases BER in fixed pg case as seen in curves due to increased level of interference when beamforming is not considered. A higher value of PR_h means more MS-s are in soft HO mode. Thus increase in PR_h is found to degrade forward link performance significantly by increasing the interference. BER decreases to large extent when beamforming is considered with a number of antenna elements at BS_0. *BER is seen to increase by 16 % as* PR_h *is increased from 0.3 to 0.7 while* λ *=11 in absence of beamforming.*

Fig.3 shows the effects of beamforming, processing gain, degree of soft HO and power control error on packet error rate. PER reduces as PR_h is increased from 0.3 to 0.7 in presence of beamforming at reference BS site although PER is increased with higher degree of soft HO if beamforming is not used [22]. Interference will be reduced with beamforming even in presence of higher degree of soft HO. This is expected as more users in region 'B', 'C' and 'D' mean BS_0 needs to transmit very less for those users as $G_t(\theta_i, \theta_d)$ becomes very less. Transmit antenna beamforming gain, $G_t(\theta_i, \theta_d)$ is less for users' at large distances (region 'B', 'C' and 'D') with more differences in θ_i and θ_d angles. Further in presence of beamforming, lower pce improves the performance due to reduction in forward link interference. *It is seen that PER reduces by 92% for beamforming case with 5 antenna elements and* λ = 9 *as compared to without beamforming while other parameters are same.*

Fig.4 shows the effects of beamforming, degree of soft HO on throughput. Throughput will increase with an increase in number of antenna elements from M_t = 5 to 7. *Throughput* *increases by 10% as M_t is increased from 5 to 7 for λ =15 while other parameters remain fixed.* In presence of beamforming improvement in throughput due to lowering of pce is more as compared to the improvement achievable by increasing degree of soft HO. Interference reduces to large extent in presence of beamforming as explained earlier with higher degree of soft HO, thus throughput becomes very high.

Fig. 5 shows delay versus arrival rate under different conditions with shadowing correlation, number of antenna elements at cell site. Higher shadowing correlation lowers interference and hence reduces delay with shadowing correlation. *Delay is increased by 9.5 % for λ = 9 as shadowing correlation (a^2) is changed from 0.6 to 0.3.* Beamforming gain towards the users other than the desired user transmitting data become very less with more number of array elements at the cell site. Hence interference gets reduced and delay goes lower with increase in M_t.. However, the effects of shadowing correlation are more significant than the effects of increasing M_t.

Fig. 6 shows the effects of beamforming with soft HO on packet delay variation (PDV). Higher degree of shadowing correlation reduces PDV as seen in curves due to reduced level of interference. Thus increase in a^2 is found to improve forward link performance similar to reverse link case. If pg is decreased from 128 to 64 then PDV increases considerably due to increased level of interference. *PDV is reduced by 82% as pg is increased from 64 to 128. Lower PDV implies a reduction in packet jitter which is desired for delay constrained services.*

Fig. 7 shows the average number of retransmission versus mean arrival rate for different degrees of soft handoff and beamforming. It is important to note that both throughput (TP) and delay depend on number of retransmission in practice. However, number of retransmissions depends on channel condition and multiple access interference at a particular time. Lower degree of soft HO as well as less number of array elements increases number of retransmissions. *Lower degree of soft HO indicates less number of users in B, C and D regions. BS_0 needs to transmit less power for them because transmit antenna beamforming gain, $G_t(\theta_i, \theta_d)$ is reduced for users' at large distances (i.e. in region 'B', 'C' and 'D') due to large differences in θ_i and θ_d angles. However, there will be more users at non HO region requiring more power to be transmitted in that region. This will increase the overall interference. Lowering number of antenna elements decreases transmit antenna gain thereby increasing interference. Retransmission increases by a factor of 107% if pce is increased from 1 dB to 2 dB and it is reduced by 75 % if PR_h is increased from 0.3 to 0.7 in presence of beamforming for λ =15.*

Impact of DoA estimation error on data performance is depicted via Fig. 8 to Fig. 13 considering pg = 128, PR_h =0.3 or 0.7, pce=2dB, a^2 =0.3 and M_t = 5. Two cases of DoA error distribution namely Uniform distribution and Gaussian distribution are investigated. Effects of DoA error on BER, PER, retransmission count are shown in Fig. 8, 9 and 13 respectively. Fig 10, 11 and 12 shows effects of DoA error on throughput, Delay and PDV. We observed that DoA estimation error change BER, PER, throughput, delay and others significantly for both types of distribution considered.

Fig. 14 shows radiation pattern of the antenna array used for beamforming at the BS site. It can be noticed that increasing number of array elements, (M_t) beam becomes more directive which provides very high gain at a particular direction. Considerable amount of energy will be lost due to side lobes if M_t (e.g. M_t = 3) is reduced.

V. Conclusions

A scheme of combining beamforming and soft HO in forward link data service is proposed and evaluated. The joint effects of beamforming and soft handoff on data services in the forward link are investigated. Soft handoff parameters, shadowing correlation and PR_h are found to have significant impact on data service. Performance is enhanced due to incorporation of beamforming. Performance degradation in forward link caused by higher degree of soft HO could be compensated by suitable choice of beamforming. Number of antenna elements at base station for beamforming has significant impact on BER and throughput. Increase in number of elements improves the performance which can be used to compensate the performance degradation due to increase in pce, higher shadowing and higher degree of soft HO. Higher shadowing correlation in presence of beamforming 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 beamforming parameters and soft handoff parameters for performance improvement which is helpful for overall system design.

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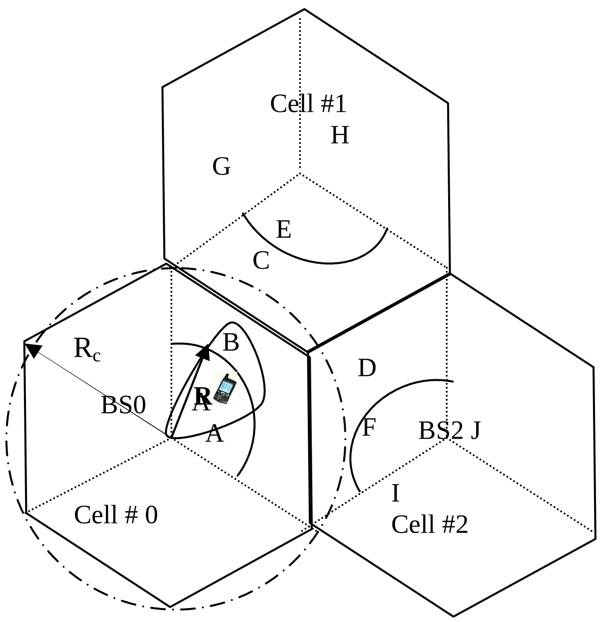

Fig.1 Cellular Layout for soft HO. A,E,F are non HO region. B,C,D are soft HO region. Cell #0 is reference cell. Adaptive transmit beamforming at BS_0 has been applied for the MS (shown in figure). Other users are also present (but not shown in the figure). The desired user is tracked by the specific beam during the call.

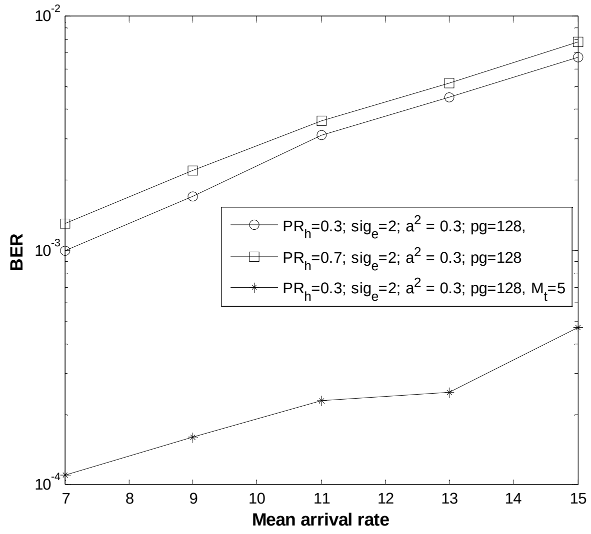

Fig. 2. Effects of beamforming and soft handoff on BER.

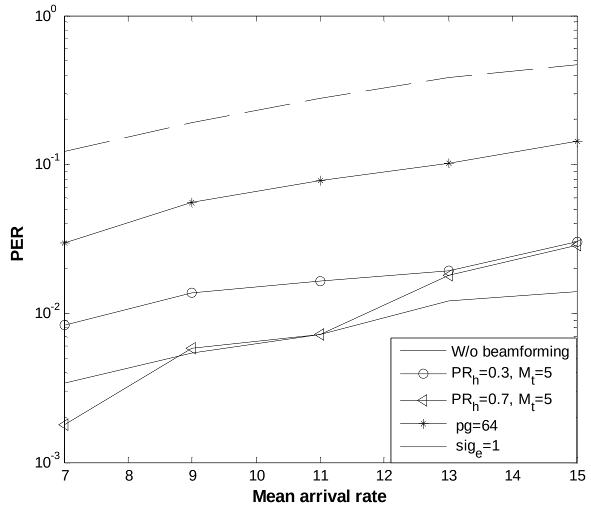

Fig. 3. PER vs. mean arrival rate

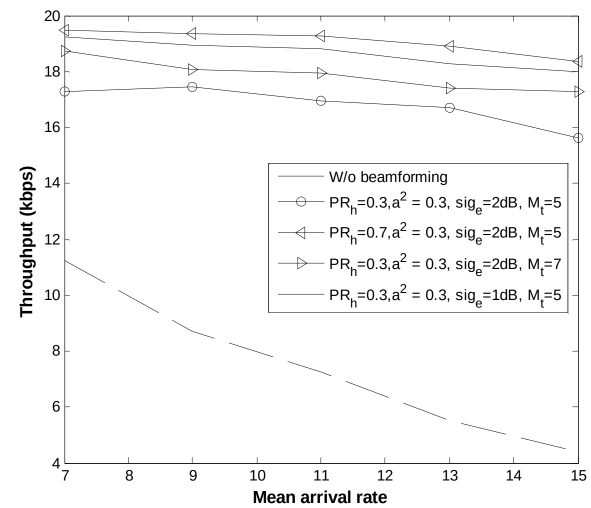

Fig. 4. Throughput vs. mean arrival rate under different beamforming and soft handoff conditions

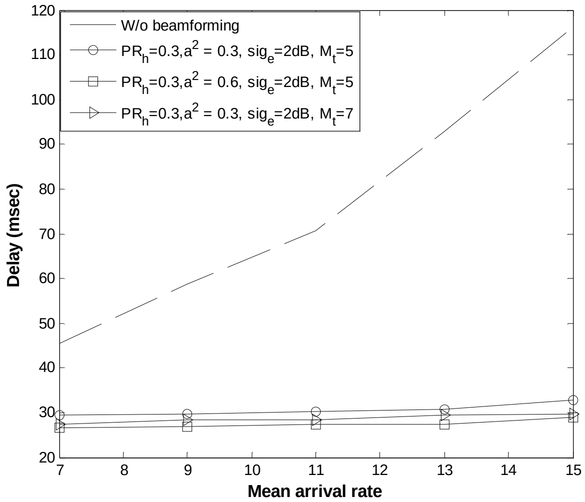

Fig. 5. Delay vs. mean arrival rate under different beamforming and soft handoff conditions.

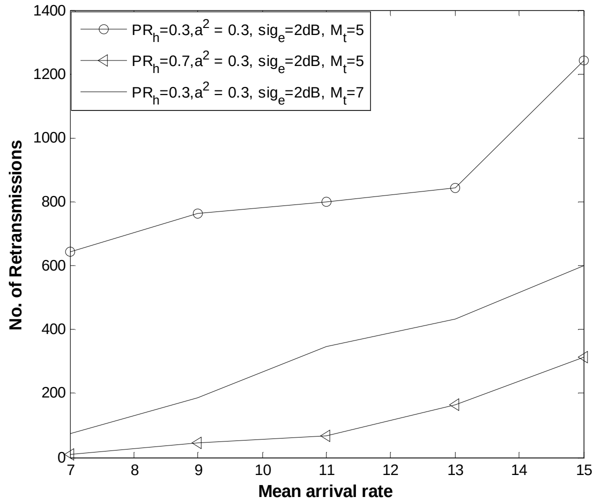

Fig. 7. Retransmission count vs. mean arrival rate for different beamforming and soft handoff conditions.

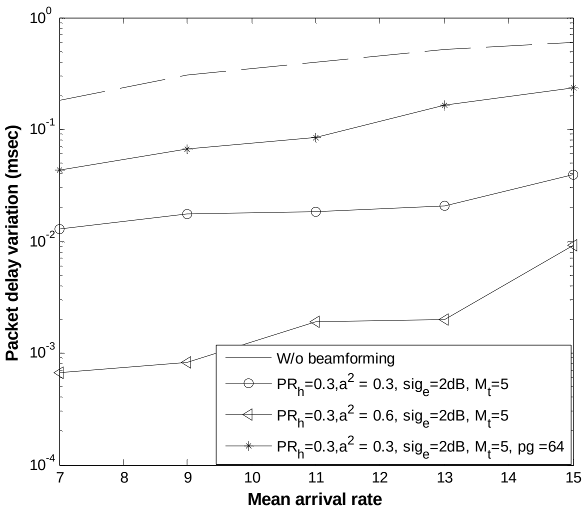

Fig. 6. PDV vs. mean arrival rate for different beamforming and soft handoff conditions.

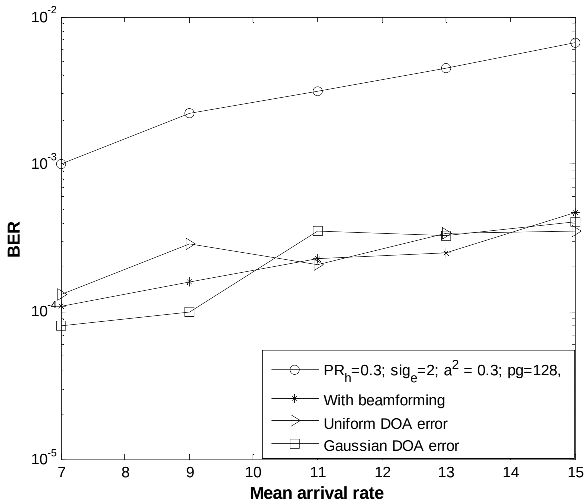

Fig. 8. Effects of DOA error on BER.

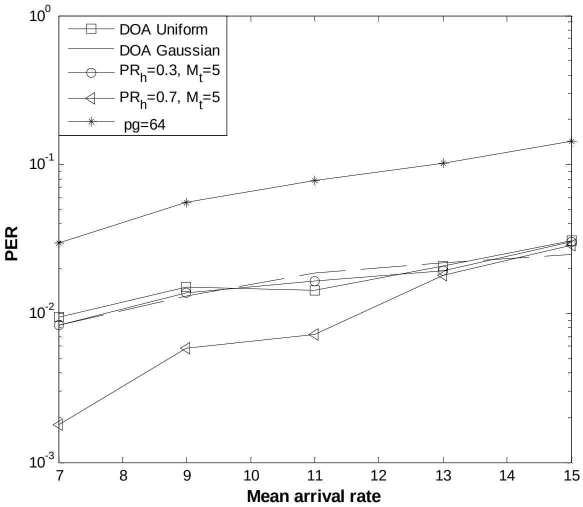

Fig. 9. Effects of DoA error on PER.

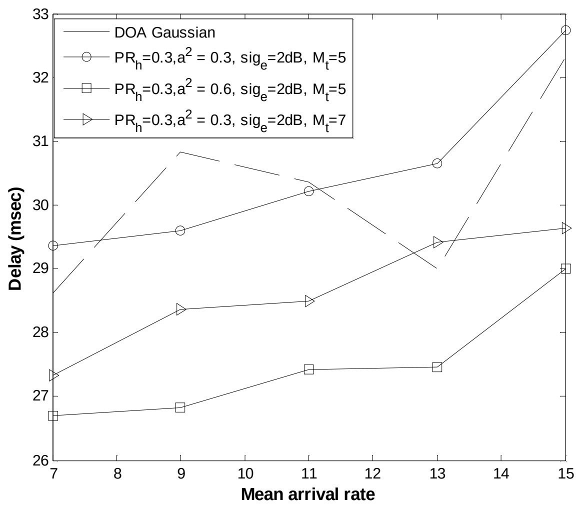

Fig. 11. Effects of DoA error on delay.

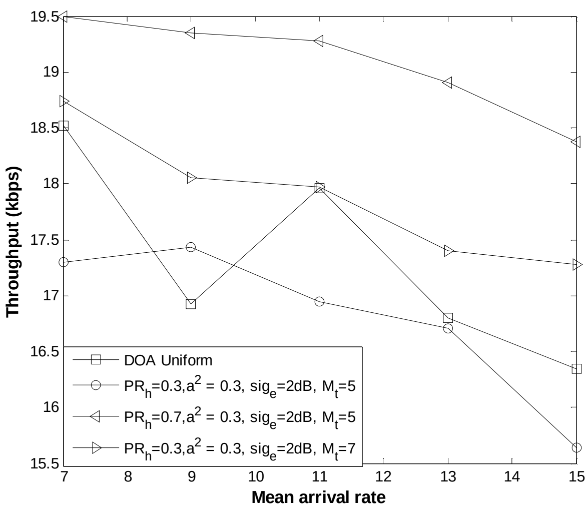

Fig. 10. Effects of DoA error on throughput.

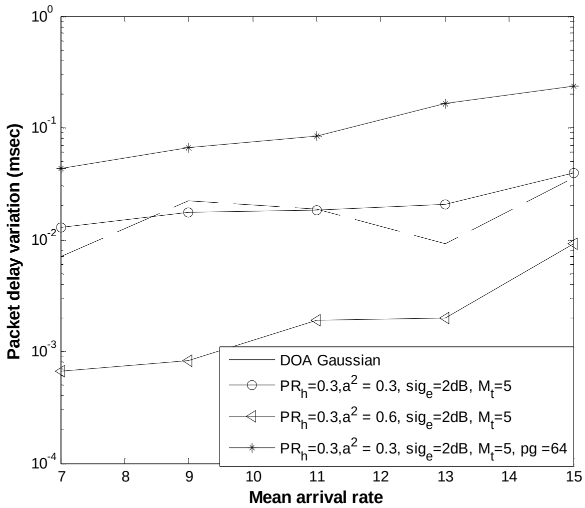

Fig. 12. Effects of DOA error on Packet delay variation.

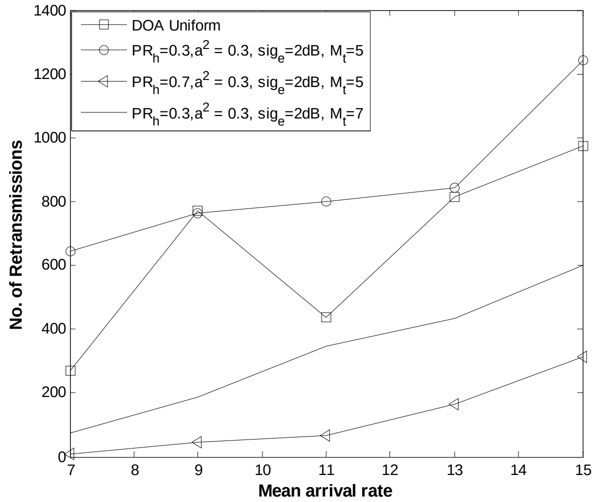

Fig. 13. Effects of DoA error on retransmission count.

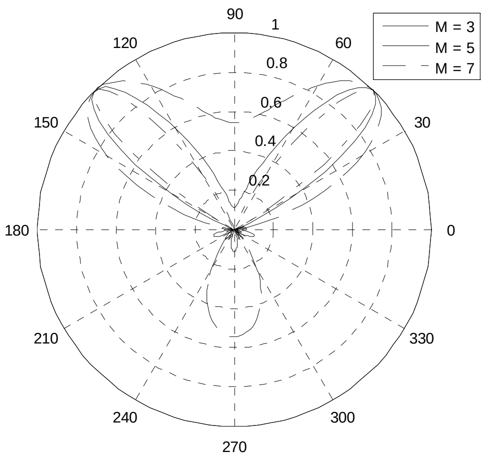

Fig. 14. Radiation pattern of the beamformer

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