Performance of Voice / Data Integrated Services in Cellular CDMA in Presence of Soft Handoff

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Abstract **:-Effects of soft- handoff (HO) on voice/data integrated services have been presented in this paper. Outage of voice is considered while performance of packet data transmission using multi-code (MC) CDMA is evaluated on basis of throughput and delay in integrated CDMA in presence of soft HO. Influence of physical layer issues like soft HO parameters, shadowing correlation, power control error (pce) on voice/ data performance has been investigated. The impact of higher data rate and voice user on data performance is indicated.**

Key words : **Soft handoff, Multicode (MC)-CDMA, delay throughput**

I. Introduction

Wireless networks are evolving to support multimedia services such as voice, data and video. 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. The QoS of radio link is often determined by SIR (signal to interference ratio). The fall of SIR below a threshold causes an 'outage' of the radio link and hence degrades the QoS [1,2]. It is important to evaluate the probability of such event in order to estimate the cellular capacity [1]. The demand for high rate packet data in wireless networks is growing at a rapid pace [3]. Variable spreading gain (VSG) CDMA and Multi-code (MC) CDMA [2,3,4] are two interesting schemes for increasing data rate. In VSG-CDMA scheme, the spreading ratio is reduced as the data rate is increased. In contrast, several codes are allocated to a single user for parallel transmission in MC-CDMA as data rate is increased [2,11].

One of the important features of CDMA is soft handoff (HO) where the HO mobiles near a cell boundary transmits to and receives from two or more BS-s simultaneously [5]. Soft HO provides a seamless connectivity in contrast to hard HO by allowing a "make before break approach" connection [5,6]. It reduces "ping-pong" effect as present in hard HO, probability of lost calls and eases power control [5]. Since a mobile (MS) is power controlled by the BS requiring the least power, soft HO extends the coverage and increases the reverse link capacity by providing base station diversity and reducing overall interference [7,8]. Soft HO has been shown to improve outage performance in [6].

Since soft HO affects the generated interference at physical layer, it is expected to have significant impact on outage performance of voice and successful transmission of data. Effects of soft HO on outage is analyzed in [6, 9] where only one kind of user is considered. However for integrated services in CDMA, it is necessary to consider the joint performance of both voice and data.

In this present paper we carryout simulation studies to evaluate the effects of soft HO on integrated voice/ data services in an imperfect power control CDMA. Voice users transmit on a single code while data users transmit on multiple codes using MC-CDMA. Influences of soft HO parameters, shadowing correlation, pce are studied on outage of voice and throughput and delay performance of data. The impact of higher data rates (multiple codes) is also indicated.

The paper is organized in the following manner. Section II and III describe system model and simulation model respectively. Results and discussion are presented in section IV. Finally we conclude in section V.

II. System Model

A hexagonal cellular layout with three sectors per cell supporting equal number of voice (N_v) and data users (N_d) per sector is considered. A basic transmission rate of R_b is considered for a voice user transmitting on a single code, where as a data user can transmit at a higher rate $r_d R_b$ using r_d number of codes for parallel transmission in MC-CDMA. The processing gain (pg) of all codes are equal; where $pg = W/R_b$; W is spread bandwidth. A "continuously active" data traffic model as in [10] 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. The activity variable φ_v for voice is modeled as binomially distributed r.v. with $P(\varphi_v = 1) = \alpha_v$. The reverse link of a cell 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 regions (A, E, F) of cell #0,1and 2 respectively in Fig.1. BS_o, BS_1 and BS_2 are the BS-s of cell #0, 1 and 2 respectively. The propagation radio channel is modeled as in [6]. The link gain for a location (r,θ) is

$$G_i(r,\theta) = d_i(r,\theta)^{-\alpha_p} 10^{\xi_S/10} \quad (1)$$

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 as normally distributed with 0 mean and variance σ_s^2. The shadow fading at i-th BS is [6,7]

$$\xi_{s-i} = a\zeta + b\zeta_i \quad \text{with } a^2 + b^2 = 1 \quad (2)$$

ζ and ζ_i are independent Gaussian random variables with zero mean and variance σ_s^2. Out-cell interference is assumed to consists of interference due to MS-s from region (E,C,) of cell #1 and (D,F) of cell # 2. The reference user (voice or data) is located in non-HO region of reference sector i.e. in region 'A'. Total in-cell interference in cell # 0 is $I_{in} = I_1 + I_2$ *(3)*

where I_1 is due to all MS-s in A and I_2 is due to MS-s in B. The out-cell interference is

$$I_{out} = 2(I_E + I_{c1} + I_{c2} + I_{co}) \quad (4)$$

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 controlled by BS_0. A multiplication factor of two is used in eqn (4) to include contribution of cell #2. The actual received power from a desired user is $U = S_i e^S$, where S is a Gaussian r.v. with mean 0 and variance σ_e^2. Expressing σ_e in dB, $\sigma = \sigma_e/\lambda$, $\lambda = \ln(10)/10$ where and σ is pce in dB. Let be the required received power level at a reference BS, where $i = v$ or d depending on voice or data user respectively. A simplifying assumption of $S_v = S_d = S_R$ is made.

For a desired voice user, the in-cell interferes I_{in} consists of $(N_v - 1)$ voice and N_d data interferers. The SIR of a desired voice user is $SIR = U/I$. The probability of outage for a desired voice user $P_{out} = P(SIR < \gamma_{th}')$ (5)

where $\gamma_{th}' = \gamma_{th}/pg$, γ_{th} is the threshold for SIR. A correlation receiver in the uplink is assumed. 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 with spread band width (b.w) W. For this case the in-cell interference consists of voice and data interferers. The retransmission probability is given as

$$P_r = 1 - (1 - P_e)^{L_p r_c} = \quad (6)$$

where L_p is the length of the packet in bits and 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 $r_d R_b$ is :

$$T_i = \frac{L_p}{r_d R_b} = \frac{L_p\, pg}{R_{ch} r_d} \quad (7)$$

R_{ch} is chip rate. We assume that acknowledgement from the receiver is instantaneous and perfectly reliable. The average delay [11]

$$D = \frac{L_p\ pg}{R_{ch}(1-P_r) r_d} \quad (8)$$

The average throughput (G) is defined as the average number of information bits successfully transferred per sec and is given as [11]

$$G = \frac{L_p r_c}{D} = \frac{r_c R_{ch}(1-P_r) r_d}{pg} \quad (9)$$

In the next section we briefly describe our simulation model which is used to evaluate BER, delay and throughput of data and outage for voice in described soft HO environment.

III. Simulation Results

The simulation is developed in MATLAB. 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.

PR_h indicates the degree of soft HO. Users are assumed to be uniformly distributed.

A. Generation of users location and interference

1. The number of voice and data users (N_v, N_d) is input variable.
2. Locations (r,θ) of all (N_v, N_d) users are generated and users are divided into non-HO (N_{vh}, N_{dh}) and soft HO region (N_{vs}, N_{ds}) based on their locations. Here N_{vh} and N_{dh} are voice and data users in non-HO region, N_{vs} and N_{ds} are voice and data users in soft HO region respectively.

   MS-s in non-handoff region : $N_h = N_{vh} + N_{dh}$ and

   MS-s in soft HO region: $N_s = N_{vs} + N_{ds}$
3. For each MS in soft HO region (N_s), the link gains corresponding to each of three Bs-s involved in soft HO are generated as

$G_i(r,\theta) = r_i^{-\alpha_p} e^{\xi_i}$, i = 1, 2,3. where ξ_i are Gaussian r.v-s 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

(i) BS_0 if $G_R > G_1$ and $G_R > G_2$

(ii) BS_1 if $G_1 > G_R$ and $G_1 > G_2$

(iii) BS_2 if $G_2 > G_R$ and $G_2 > G_1$ (10)

4. The interference received at reference BS due to an active voice user

$$I = S_R \exp(r_n) \quad \text{if connected to } BS_0 \text{ (i)}$$

$$= S_R \exp(r_n)\left(\frac{G_R}{G_1}\right) \quad \text{if connected to } BS_1 \text{ (ii)}$$

$$= S_R \exp(r_n)\left(\frac{G_R}{G_2}\right) \quad \text{if connected to } BS_2 \text{ (iii)} \quad (11)$$

r_n is a normal r.v. with 0 mean and standard deviation σ_e. For data user, above eqns (i) to (iii) is multiplied by r_d. S_R is normalized to unity in the simulation since SIR is unaffected by assigning $S_R = 1$. Total interference due to all Ms-s in soft HO (N_s) is I_2.

5. Next interference due to N_h MS-s in non-HO region (A) of reference cell, each power controlled by BS_0. For a desired voice user :

$$I_{1,v} = S_R \sum_{i=1}^{N_{vh}-1} \varphi_v e^{r_{n,i}} + r_d S_R \sum_{j=1}^{N_{dh}} e^{r_{n,j}} \quad (12)$$

while for a desired data user

$$I_{1,d} = S_R \sum_{i=1}^{N_{vh}} \varphi_v e^{r_{n,i}} + r_d S_R \sum_{j=1}^{N_{dh}-1} e^{r_{n,j}} \quad (13)$$

6. 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 $(N_{vh} + N_{dh})$ each. The interference is found following step 3 and 4.

   Let $I_3 = I_E + I_C$ and $I_4 = I_D + I_F$ (14)
7. Total interference to a desired user

$$I_i = I_{1,i} + I_2 + I_3 + I_4 \quad (15)$$

   where i = *v* or *d* for a desired voice or data user.
8. Signal from desired user $U = S_d e^S$, SIR for voice: $SIR_v = U / I_v$ and for data : $SIR_d = U / I_d$

B. Outage Simulation

1. Activity of a voice user is checked. A random number u_n uniformly distributed in (0,1) is generated. If $u_n < \alpha_v$, user is active i.e. $\varphi_v = 1$ else it is inactive and $\varphi_v = 0$.
2. SIR_v for a desired voice user is generated and compared with γ'_{th} where $\gamma'_{th} = \gamma_{th} / pg$.
3. If SIR_v falls below, an outage counter (*outage_count*) is incremented.
4. Steps B(2) and B(3) are repeated large (number of times to yield an estimate of as $P_{out} = outage\_count / N_t$

C. BER simulation of data

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

D. 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 C(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 and in case they disagree, a counter (*error_count*) is incremented. If (*error_count)* is zero for any packet, the packet is received correctly else the packet is in error.
3. If the received packet is incorrect, the same packet (i.e. same bit pattern as in D (1)) is retransmitted and a counter (retx_count) is incremented. This is repeated until the packet is received correctly.
4. Steps D (1) to D (3) are repeated for N_p packets and retx_count is recorded.
5. Average delay (D) is estimated as : $((N_p + retx\_count)./ N_p)T_i$ where T_i is as in eqn (7).
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).

The simulations are carried out ensuring 95% confidence limit.

IV. Results and Discussions

The effects of parameters PR_h and $_a{}^2$ on outage of voice and delay and throughput of data are investigated. The following parameters are used in simulation. Spread b.w W = 4.096 MHz, chip rate $R_{ch} = 4.096$ Mcps, R_b=16Kbps, pg =256, L_p = 1024, pce σ = 1 and 2 dB, SIR threshold γ_{th} = 7 dB, α_p = 4, σ_s = 6 dB, r_d = 1or 2 and r_c =0.5.Two cases of shadowing correlation $_a{}^2 = 0$ and 0.3 are considered. Similarly two values of =0.3 and 0.7 are assumed.

Fig.2 shows the effects of PR_h and $_a{}^2$ on outage of voice user while $N_d = 2$. A higher value of means more MS-s are in soft HO mode. Thus increase in is found to improve reverse link performance significantly by limiting the interference. For example at 5, reduces from 3.6e-02 to 2.7e-03 as increases from 0.3 to 0.7 curves (i,iii). Increasing shadowing correlation () has the same effect as reducing for the assumed correlation model [6]. Thus for a given , as increases from 0 to 0.3, outage performance improves i.e. reduces [curves(iii,iv)]. Further effects of higher data rate on voice outage are also depicted. More allocated codes (increases due to higher data interference as in curves (ii, iii).

Fig.3 shows the effects of PR_h , pce and voice users on BER of data while $_a{}^2$ =0.3 and r_d =2. Higher degree of soft HO reduces BER by reducing the overall interference. Thus as increases from 0.3 to 0.7, BER reduces from 4.7e-03 to 4.1e-04 for [curves (i,iv)]. As the number of voice users is increased from 4 to 8 while other conditions are same, the data BER is increased due to increased voice interference curves (ii, iii). A higher pce of 2 dB increases BER as compared to pce of 1 dB while other factors are same [curves (iii,iv)]. Since BER is affected by PR_h, pce and voice interference, these factors will influence data throughput and delay.

Fig.4 shows the packet error rate (PER) or retransmission probability (P_r) vs number of data users. PER is affected in a similar manner as BER by PR_h. Higher shadowing correlation ($_a{}^2$) reduces PER [curves (iii,iv)]. Higher number of allocated codes increases PER due to increased interference, for example P_r increases from 4.3e-02 to 1.5e-01 as r_d increases from 1 to 2 at $N_d = 5$ [curves (ii,iv)].

Fig.5 and Fig.6 show the effects of soft HO on average delay (msec) and throughput (Kbps) of data respectively. Since higher PR_h reduces BER of data, average delay reduces as increases from 0.3 to 0.7, [curves (i,iv)] in Fig.5 and correspondingly throughput increases as seen in curves (ii,iv) of Fig.6. Increase in shadowing correlation ($_a{}^2$) from 0 to 0.3 reduces delay and increases throughput for moderate traffic ($N_d = 6$ onwards) due to lowering of interference of MS-s in non HO region as observed in curves (iii,iv) of Fig.5 and curves (ii,iii) of Fig.6 respectively. Effects of multi-codes are also depicted. Up to a certain number of users, $N_d = 6$; higher rate (r_d=2) leads to higher throughput and lower delay due to reduction in average packet transfer time.

However interference also increases with higher number of codes, which tends to increase packet error. This second effect dominates with increase in traffic and results in higher delay [curves (ii,iv)] in Fig.5 and lower throughput [curves (i,ii)] in Fig.6.

V. Conclusions

Performance of packet data transmission using MC-CDMA in presence of voice is evaluated under influence of soft HO. Higher degree of soft handoff reduces outage of voice and BER of data. Thus throughput and delay performance of data improves with increase in level of soft HO. Higher shadowing correlation also reduces outage and improves delay and throughput of data by reducing packet error. Higher pce as well as more voice users increase data BER. Higher number of allocated codes degrades data performance beyond a range of traffic. Thus soft HO parameters, shadowing correlation, number of allocated codes and pce significantly influence the system design for integrated services in cellular CDMA.

References

[1] Sumit Kundu and Saswat Chakrabarti, "Outage and BER analysis of cellular CDMA for integrated services with correlated signal and interference", *pp-478-480, vol-7, No-10, October 2003, IEEE Communications Letters.*

[2] Deepak Ayyagari and Anthony Ephremides, "Cellular multicode CDMA capacity for integrated (voice and data) services", *IEEE J.Select. Areas. Commun., vol-17, No-5, May 1999, pp 928 – 938.*

[3] Sarath Kumar and Sanjeev Nanda, "High data rate packet communication for cellular network using CDMA: Algorithms and Performance", *IEEE Journal on selected Areas in Commun, vol-17, No-3, pp 472-491, March 99.*

[4] Rath Vamithamby and E.S.Sousa, "Performance of multi- rate data traffic using variable spreading gain in reverse link under wide band CDMA", *pp 1155-59, IEEE Vehivular Technol Conference VTC-2000.*

[5] D.Wong, T.Lim, "Soft handoff in CDMA mobile system", *IEEE Personal Commun pp 6 –17, Dec 1997.*

[6] J.Y.Kim and G.L.Stuber," CDMA soft HO analysis in the presence of power control error and shadowing correlation", *IEEE Trans on wireless Comm, vol-1, No-2, pp245-255, April 02.*

[7] A.Viterbi, A.M. Viterbi, Gilhousen, Zehavi, "Soft handoff extend CDMA cell coverage and increases the reverse link apacity", *IEEE J. Select Areas in Commun , vol 12, No-8, pp1281 –1287, Oct,1994.*

[8] Hai Jiang,C.H.Davis, " Coverage expansion and capacity improvement from soft handoff for cellular CDMA", *IEEE Trans on Wireless Comm,vol-4,No-5, Sept 2005, pp-2163-2171.*

[9] Sumit Kundu and Saswat Chakrabarti, " Outage and call blocking analysis in cellular CDMA with soft handoff", *pp-300-304, IEEE ICPWC 2005.*

[10] J.Kim and M.Honig, "Resource allocation for multiple class of DS-CDMA traffic", *pp 506- 518, IEEE Trans on Vehicular Technol, Vol49, N02, March-2000.*

[11] Sumit Kundu and Saswat Chakrabarti," Performance of high rate data in wideband CDMA with correlated interferers", *in GESTS International Transactions on Communication & Signal Processing, Vol-7, No-1, June 2006, pp 53-64.*

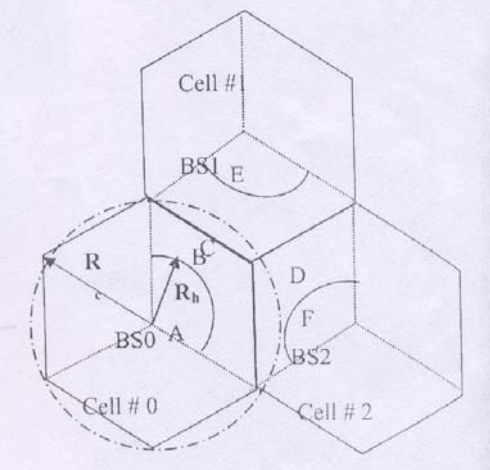

Fig.1 Cellular Layout for soft HO. A, E, F are non HO region. B, C, D are soft HO region. Cell # 0 is reference cell

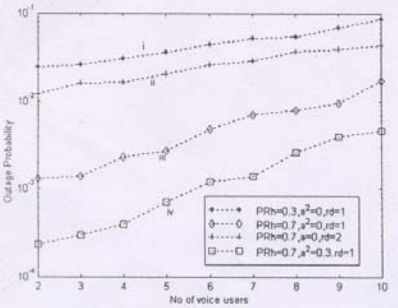

Fig.2 Outage probability vs number of voice users, N_d =2, pce =2 dB.

(i) $a^2=0$, $PR_h=0.3$, $r_d=1$ (ii) $a^2=0$, $PR_h=0.7$, $r_d=2$

(iii) $a^2=0$, $PR_h=0.7$, $r_d=1$ (iv) $a^2=0.3$, $PR_h=0.7$, $r_d=1$

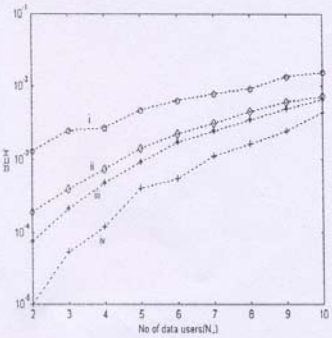

Fig.3 BER of data vs number of data (N_d) users;

$r_d=2$, $a^2=0.3$ (i), $PR_h=0.3$, $N_v=4$, pce = 1dB

(ii) $PR_h=0.7$, $N_v=8$, pce = 2dB

(iii) $PR_h=0.7$, $N_v=4$, pce = 2dB

(iv) $PR_h=0.7$, $N_v=4$, pce = 1dB

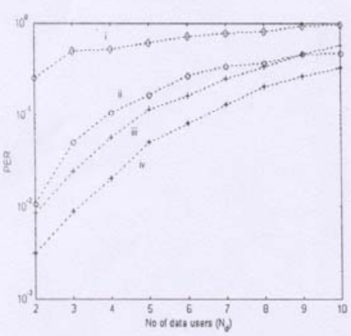

Fig.4 Packet error rate vs number of data (N_d) users;

pce = 2 dB, $N_v=4$ (i) $a^2=0.3$, $PR_h=0.3$, $r_d=1$

(ii) $a^2=0.3$, $PR_h=0.7$, $r_d=2$

(iii) $a^2=0$, $PR_h=0.7$, $r_d=1$

(iv) $a^2=0.3$, $PR_h=0.7$, $r_d=1$

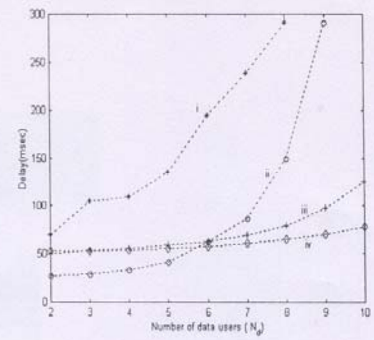

Fig.5 Delay (msec) vs number of data users;

$N_v=4$, pce = 2 dB. (i) $a^2=0.3$, $PR_h=0.3$, $r_d=1$

(ii) $a^2=0.3$, $PR_h=0.7$, $r_d=2$

(iii) $a^2=0$, $PR_h=0.7$, $r_d=1$

(iv) $a^2=0.3$, $PR_h=0.7$, $r_d=1$

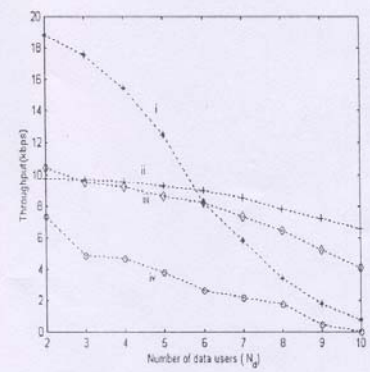

Fig.6 Throughput(Kbps) of data vs number of data (N_d) users; $N_v=4$, pce = 2dB

(i) $a^2=0.3$, $PR_h=0.7$, $r_d=2$

(ii) $a^2=0.3$, $PR_h=0.7$, $r_d=1$

(iii) $a^2=0$, $PR_h=0.7$, $r_d=1$

(iv) $a^2=0.3$, $PR_h=0.3$, $r_d=1$