# Performance of Data Services in Cellular CDMA in Presence of Soft Handoff and Packet Combining

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***Abstract.*** *Performance analysis of data services is studied in CDMA network in presence of soft handoff (HO) and packet combining. Packet combining in conjunction with soft handoff is found to enhance throughput, reduce delay and packet delay variation (PDV) significantly. A stop and wait automatic repeat request (ARQ) scheme has been assumed. Two different packet combining schemes for packet data service, one based on log likelihood ratio (LLR) and another based on equal gain combining (EGC) have been studied. A cross layer interactions between ARQ and packet combining at link layer and soft HO in physical layer has been shown.*

## Keywords

Packet Combining, LLR, ARQ.

## 1. Introduction

The 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. 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 [1]. Soft HO provides a seamless connectivity, reduces "ping-pong" effect as present in hard handoff, lowers probability of lost calls and eases power control [1], [2]. Since a mobile (MS) is power controlled by the base station (BS) requiring the least power, soft HO extends the coverage and increases the reverse link capacity by reducing overall interference [3]. Further packet combining can reduce number of retransmission of packet when packet is in error; it is expected to have significant impact on resultant throughput. Retransmission is needed when packet was not received correctly. There are two types of ARQ schemes namely type 1 and type 2 [4]. Some literature uses type 3 ARQ scheme which is a special case of type 2 ARQ, where repetition codes are used for incremental redundancy. Same copy of the previously transmitted packet is retransmitted in case of type 1 ARQ. In case of type 2 ARQ protocol, different encoded packets are transmitted in an incremental redundancy. When the ARQ schemes work in conjunction with forward error correction (FEC), it is called hybrid ARQ. Hybrid ARQ (HARQ) has both forward (due to FEC) and backward (due to ARQ) error correction capabilities. In case of packet combining, receiver extracts the information by linearly combining current packet and previously transmitted copies of the packet for different slots. There are two types of packet combining [5], [6], code combining and diversity combining. Code combining is a technique for combining the number of repeated packets with a code rate, R to obtain a lower rate. Diversity combining is related to packet combining technique based on diversity such as equal gain combining (EGC). Throughput depends on physical layer receivers (Multi User Detection algorithms and channel coding schemes) and Media Access Control (MAC) layer protocols (packet combining, ARQ technique) [5]. Packet combining is also well suited for multi hop wireless sensor network applications where overhead packets may be used for reducing number of retransmissions. Thus packet combining is expected to improve the network performance while reducing the number of retransmissions. LLR based packet combining have been used in [7], [8]. Three types of hybrid ARQ schemes are studied for Multiple Input Multiple Output – Orthogonal Frequency Division Multiplexing (MIMO-OFDM) viz., repetition coded HARQ, the Low Density Parity Check (LDPC) coded Type-I and Type-II HARQ [7]. Different HARQ schemes for soft adaptive Interleaved Division Multiple Access (IDMA) were proposed in [8]. If a packet is in error then the same packet is retransmitted from transmitter but errored packet is kept in buffer at the receiver.

This paper presents a simulation study to evaluate performance of packet data encompassing the joint effects of packet combining and ARQ in link layer and soft HO at physical layer. Here we studied two different types of packet combining, one based on LLR combining of different bits in a packet and another based on Equal gain combining. An ARQ model for packet data in the uplink 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 LLR based and EGC based packet combining. The performance is compared with scenario of no packet combining in presence of soft handoff.

The paper is organized as follows. Section 2 and 3 describe 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. 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 that number of simultaneous users '$m$' in a cell is Poisson distributed with mean arrival rate $\lambda$ as:

$$P_m(l) = (\exp(-\lambda)\lambda^l)/l! \quad (1)$$

A "continuously active" data traffic model as in [9], [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 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 [11], [12]. The link gain for a location ($r$, $\theta$) is given as:

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

where $d_i(r, \theta)$ is the distance between the MS and $BS_i$, $\alpha_p$ is the path loss exponent and $10^{\xi_s/10}$ is the log-normal component with $\xi_s$ normally distributed with 0 mean and variance $\sigma_s^2$. The shadow fading at $i$-th BS is [11]

$$\xi_{s-i} = a\zeta + b\zeta_i \text{ with } a^2 + b^2 = 1 \quad (3)$$

$\xi$ and $\xi_i$ are independent Gaussian random variables with zero mean and variance $\sigma_s^2$.

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

$$I_{in} = I_1 + I_2 \quad (4)$$

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

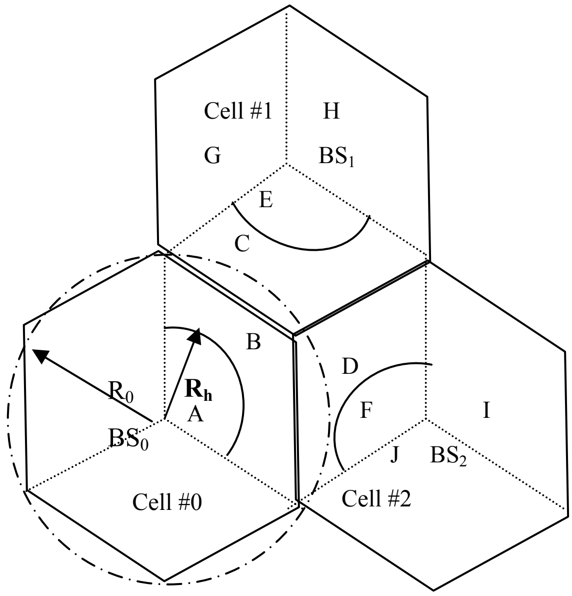


**Fig. 1.** Cellular Layout for soft HO. A, E, F are non HO region. B, C, D are soft HO region. Cell # 0 is reference cell.

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

$I_E$ 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. $I_{c0}$ 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 (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 $\sigma_s^2 = \sigma_e^2$.

The Bit Error Rate, BER ($P_e$) for data user can be simulated as described in [12] in the above soft HO environment considering direct sequence spreading and BPSK data modulation having spread b.w W in AWGN channel. Next we consider packet combining at BS.

Three types of detection schemes for the received signal have been considered here, viz., without packet combining, LLR based detection and another based on EGC. The packet retransmission probability for no packet combining case, $P_{r\_nc}$ is given as [12].

$$P_{r\_nc} = 1 - (1 - P_e)^{L_p r_c} \quad (6)$$

where $L_p$ is the length of the packet in bits and $r_c$ is the FEC code rate. Probability of receiving a packet correctly in its first attempt is $p$ (where $p = 1 - P_{r\_nc}$) in case of packet combining. However, the probabilities of receiving a packet correctly in its subsequent attempts are different from $p$, depending on combining strategies. In case of packet combining, probabilities of receiving the packet correctly ($p_j$) in its subsequent attempts are different; where $j$ = 1, 2, 3,... in case of infinite ARQ. 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:

$$T_i = \frac{L_p}{R_b} = \frac{L_p \quad pg}{R_c}. \quad (7)$$

We assume that acknowledgement from the receiver is instantaneous and perfectly reliable. The average delay [12] for no combining case,

$$D = \frac{T_i}{(1-P_{r\_nc})} = \frac{L_p \; pg}{R_c(1-P_{r\_nc})} \; . \quad (8)$$

As the retransmission probabilities for a packet in subsequent attempts are different, expression of (8) does not capture the situation of packet combining cases. Delay and throughput for packet combining cases have been found by simulation as discussed in simulation model. The average throughput ($G$) is defined as the average number of information bits successfully transferred per second and for no combining case is given as

$$G = \frac{L_p r_c}{D} = \frac{r_c R_c (1-P_{r\_nc})}{pg} \; . \quad (9)$$

In the next section, we briefly describe our simulation model, which is used to evaluate throughput, delay, packet delay variation, packet error rate and average number of retransmissions.

# 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

$$R_h = R_0 \sqrt{1 - PR_h}$$

where $R_0$ is the radius of the cell, normalized to unity and hexagonal cell is approximated by a circular one with radius $R_0$. Users are assumed to be uniformly distributed.

## 3.1 Generation of Users' Location and Interference

Step 1. The number of users ($N_d$) is generated by generating a Poisson distributed r.v with mean $\lambda$.

Step 2. Locations ($r, \theta$) 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 interfering users in non_HO are ($N_h$ - 1) . Number of users in soft HO region: $N_s = N - N_h$.

Step 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 $G_i(r,\theta) = r_i^{-\alpha_p} e^{\xi_i}$ , $i$ = 0, 1, 2. where $\xi_i$ is a Gaussian r.v with mean 0 and variance $b^2\sigma_s^2$, $r_i$ is the distance from the $i$-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; $i = 0,1,2$.

Step 4. 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

$$I_2 = S_R \sum_{i=1}^{N_h-1} e^{r_{n,i}} \; . \quad (10)$$

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 $I_4 = I_D + I_F$.

Step 5. Interference from MS-s in G, H, I and J regions are generated. Let $I_5 = I_G + I_H$ and $I_6 = I_I + I_J$ .

Step 6. Total interference

$$I = \sum_{k=1}^{6} I_k \; . \quad (11)$$

Step 7. Signal from desired user is

$$U = S_d e^x, SIR = U / I \quad (12)$$

However, in case of EGC based packet combining, $SIR$ value after $l$-th retransmission, ($SIR_l$) is given as [5] $SIR_l = l{\cdot}SIR_{noARQ}$. $SIR_{noARQ}$ is $SIR$ with no ARQ. $x$ is Gaussian with mean '0' and variance $\sigma_e^2$.

## 3.2 Packet Error, Delay and Throughput Simulation

Step 1. A packet consisting of $L$ (= $r_cL_p$) information bits (a sequence of random +1 or -1) are generated. Gaussian noise sample $n_g$ is generated with variance $\sigma_g^2$ = 1./(2.$pg$.$SIR$) for no combining and LLR based cases and added to each transmitted bit. For EGC based case, Gaussian noise sample is generated as $\sigma_s^2$ = 1./(2.$pg$.$SIR_l$).

Step 2. The received $L$ bits of a packet are checked with their corresponding transmitted bits to assess packet error. The interference scenario is assumed to remain unchanged for the duration of transmission for any particular packet.

Step 3. If the received packet is incorrect, the same packet (i.e. same bit pattern as in 3.2 (1)) is retransmitted entirely until the packet is received correctly.

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

Step 5. Average delay ($D$) is estimated as (($N_p$ + $retx\_count$)./ $N_p$) $T_i$ where $T_i$ is as in (7), $N_p$ number of transmitted packets, $retx\_count$: total retransmissions of $N_p$ packets.

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

Step 7. *Packet delay variation (PDV):* Delay of individual packet $D(i)$ is recorded for all packets. PDV is evaluated as: $E[\{D(i) - D\}^2]/D^2$.

### 3.3 Average LLR Based Packet Combining

LLR values are computed for all bit positions of the packet [13].

$$LLR = \frac{2x_k}{\sigma^2} \tag{13}$$

where $x_k$ is a received sample value at $k$-th bit position. (i) If a packet is received incorrectly, LLR values of the packet are computed, saved in buffer and retransmission of the entire packet is requested. (ii) If retransmitted packet is still incorrect, LLR value is computed and added to old LLR(s). Average LLR values are computed and the values are checked with respect to a threshold of 0. If LLR value for $k$-th bit position is less than 0, that $k$-th bit is detected as -1 else it is considered as +1, based on average LLRs, the bits are determined as -1 and +1s in similar way. This process will continue till the packet is received correctly. Once correct reception is made, ACK signal sent to transmitter and LLR storing buffer is cleared.

### 3.4 EGC Based Packet Combining

After the $l$-th ARQ transmission, the SIR is $l$ times that without ARQ [5],

$$SIR_l = l \times SIR_{noARQ} \tag{14}$$

Retransmission is continued i.e., (infinite ARQ) till packet is received correctly. Now these combining techniques are simulated to obtain throughput, delay, packet delay variation and retransmission rate.

## 4. Results and Discussions

The following parameters are used in simulation [14], [15]. Spread b.w $W = 5$ MHz, chip rate $R_c = 5$ Mcps, $R_b = W/pg$, $pg = 128$, $L_p = 1024$, pce $\sigma = 2$ dB, $\alpha_p = 4$, $\sigma_s = 6$ dB, and $r_c = 0.5$. Three cases of shadowing correlation $a^2 = 0.3$ and 0.6 are considered. Similarly, $PR_h = 0.7$ and 0.3 are assumed. All simulation results assume $PR_h = 0.7$, $a^2 = 0.3$, $\sigma_s = 6$ dB, $\sigma = 2$ dB, unless otherwise specified.

The effects of packet combining with soft HO on throughput performance have been shown in Fig. 2. Throughput increases with higher degree of soft handoff. It is observed that throughput is higher with $PR_h = 0.7$ as compared to $PR_h = 0.3$ in case of LLR based detection. Further it is seen that EGC based detection achieves highest throughput amongst all three cases. This is because the *SIR* in each retransmission in case of EGC improves by a factor of $l$ (where $l$ is number of retransmissions).

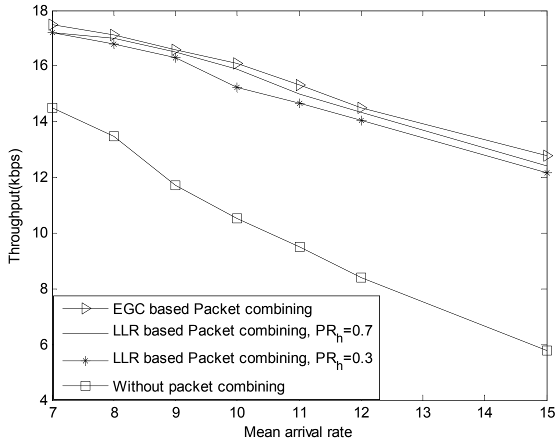


**Fig. 2.** Throughput vs. mean arrival rate ($\lambda$) for different cases of packet combining.

Effects of packet combining on delay are shown in Fig. 3. Packet combining yields better performance with less delay. We see that delay is almost the same for LLR and EGC based detection. They provide very less delay compared to no combining case. Further it is seen that delay increases at much higher rate in case of no combining with mean arrival rate. This is due to high interference for large number of users. The increase in interference does not increase number of retransmission significantly for packet combining case as effects of previously received packets are also considered for decoding a packet. Higher shadowing correlation ($a^2 = 0.6$) yields less delay in case of LLR based packet combining. This is expected as higher shadowing correlation decreases interference to improve delay performance.

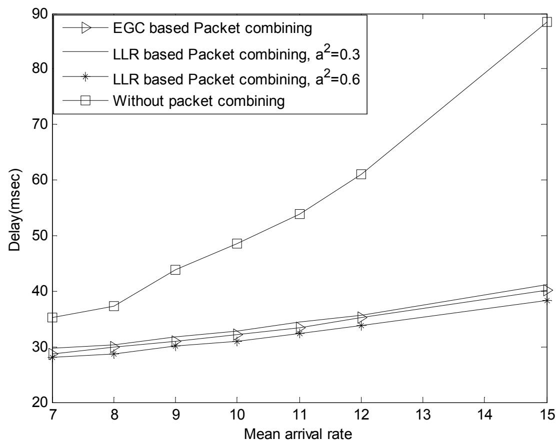


**Fig. 3.** Delay vs. mean arrival rate ($\lambda$) for different cases of packet combining.

The plots for packet delay variation vs. mean arrival rate are shown in Fig. 4. Packet delay variation is always less than 0.1 for LLR based and EGC based detection. The variations are appreciably less than the variations in case of no packet combining case as number of retransmissions reduce considerably for packet combining cases. PDV increases considerably even for LLR based packet combining case if degree of soft handoff is reduced from $PR_h = 0.7$ to 0.3. This is due to more users being inside hard handoff region and creating more reverse link interferences for desired user at region A of $BS_0$.

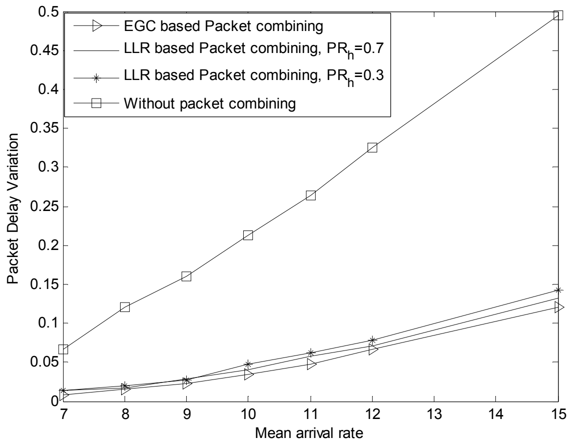


**Fig. 4.** Packet delay variation vs. mean arrival rate (λ) for different cases of packet combining.

The effects of packet combining and soft handoff on number of retransmissions per packet have been shown in Fig. 5. Number of retransmission for erroneous packet reduces significantly after employing packet combining case. Number of retransmissions/packet is less than 0.5 for mean arrival rate more than 15 i.e., $\lambda > 15$ in case of both types of packet combining whereas required transmission rate is greater than 2.3 for $\lambda > 15$ in case of no packet combining. This reduction results in higher throughput and lower delay for detection with packet combining. Higher shadowing correlation reduces reverse link interference and decreases number of retransmissions. Fig. 5 reflects retransmission probability for all three detection schemes. Retransmission probability is significantly less for packet combining cases compared to no combining cases.

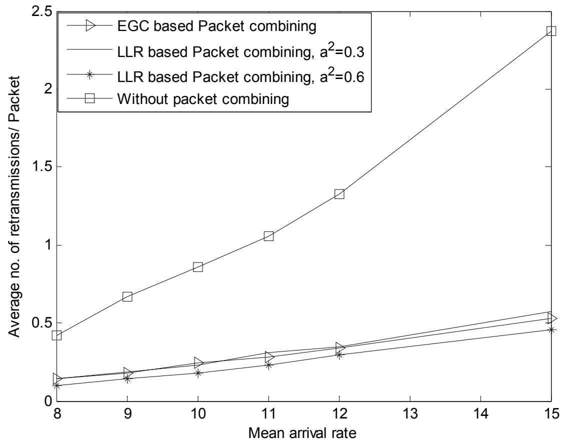


**Fig. 5.** Average number of retransmissions/packet vs. mean arrival rate (λ) for different cases of packet combining.

Packet error rate (PER) due to MAI in the channel for all three detection schemes is shown in Fig. 6. It realizes packet error whenever first packet is not received correctly. Packet error rate is almost same for all cases. This is expected as packet error is dependent on channel condition. However, degree of soft handoff and shadowing correlation has significant impact on packet error rate since they affect interference significantly. Retransmission probability is same as PER in case of no combining since any erroneous received packet is retransmitted. However retransmission probability is less than PER in case of packet combining. The decision of retransmission depends on correct detection of the packet using packet combining.

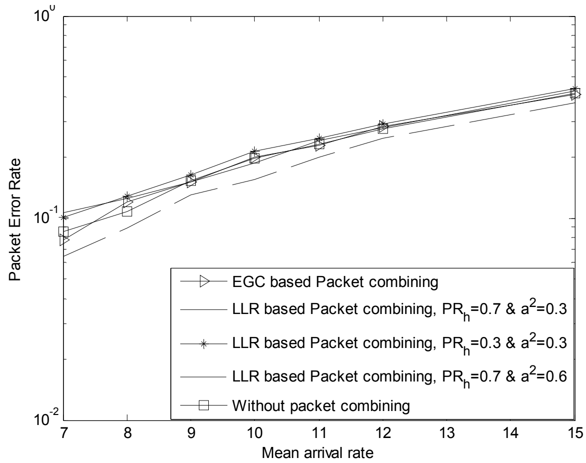


**Fig. 6.** Packet error rate vs. mean arrival rate (λ) for different cases of packet combining.

# 5. Conclusions

The joint effects of packet combining, ARQ and soft handoff on data services are evaluated. Soft handoff parameters such as $PR_h$ and shadowing correlation are found to have significant impact on data service. ARQ in conjunction with soft HO improves performance. Performance is further enhanced due to incorporation of packet combining. Throughput is increased whereas delay, packet delay variation are decreased by utilizing packet combining schemes such as LLR, EGC etc. Average number of retransmission is decreased for packet combining schemes. Packet combining technique reduces number of retransmissions because old copies of the packet are not neglected. Rather, they are taken into consideration for reducing packet error probability. Increase in shadowing correlation improves throughput and delay performance. Increase in $PR_h$ reduces interference and thus improves performance of the network. LLR based and EGC based packet combining schemes provide similar performance.

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