RAN Working Group 1 #13 **R1(00)0917**
Tokyo, Japan
22 – 26 May 2000

Agenda:	**6, AH28**
Source:	**GBT**
Title:	**Forward Link CDMA Packet Data Capacity**
Document for	**Discussion**

---

1. Introduction

In order to justify the use of CLPC on FACH, we need to probe the CDMA downlink capacity for packet data applications and show the capacity gain in the context of a system analysis that examines the dynamics of the BER operation point, limited power control dynamic range, interleaving depth, bursty-ness of packet data, random-ness of CDMA downlink capacity, impact of higher layers on the physical layer performance. In this document we examine the downlink capacity for packet data and show the dependencies on various parameters such as received Eb/N0 and the transmitted power to determine the capacity gain achieved by introduction of CLPC on FACH in slow fading environment. So this document is complementary to R1-00-0625 where the second set of simulation results have been presented. **In short the main aim of this document is to show why the Eb/N0 gain at link level simulations results in a downlink capacity gain.**

This documents also entails some more simulation results that were necessitated as a result of AH28 reflector discussions.

In this contribution, we address the issue of the forward link capacity of the CDMA system for non real time packet data. The challenges in such analysis are:

1. Orthogonality and spillover in the downlink direction.
2. Statistical nature and location dependence of the spillover factor.
3. Bursty nature of the packet data traffic
4. Impact of Hybrid ARQ and FER operating point on downlink throughput
5. Impact of power control and interleaving on downlink throughput
6. Impact of Various RNC resource allocation methods on downlink throughput

7. dynamics of required transmit power, required received Eb/N0 and CDMA downlink capacity.

In the following sections, we address these issues in a non-sequential manner. In **section 2**, the uplink and downlink capacity formulas for N equal power mobiles are developed to isolate the impact of orthogonality and spillover. In **section 3**, the downlink capacity is further formulated as a function of base node transmit power. In **section 4**, the impact of bursty-ness on capacity is explored. This section is included to justify the capacity gains achieved by using common channel approach for bursty data. We have compared DCH/DCH+DSCH with the FACH method to provide further motivation for a potential change on operation of FACH. In **section 5**, the impact of HARQ on capacity is analyzed to the extent of establishing what the potential BER before HARQ could be. It is also of interest to put the impact of HARQ on downlink capacity in conjunction with other parameters. In **section 6**, we present some simulation results to bring out the effect of interleaving, fading rate and limited dynamic range on the required Eb/N0 in the two cases of OLPC and CLPC. And finally in **section 7**, we present more simulation results and establish the impact of these results on the overall downlink capacity.

2. CDMA Uplink and Downlink Capacity formulation

The CDMA system capacity for the downlink and uplink directions can be written as follows:

$N_{dl} = S \text{ x } PG/ \{ (f_{spill} + r_{orth}) \text{x } SNR_{req\text{-}DL}\}$
$N_{ul} = S \text{ x } PG/ \{ (f_{spill} + 1) \text{x } SNR_{req\text{-}UL}\}$

These formulas apply to N mobiles with equal allocated power. The case of CDMA downlink capacity for packet data and random transmit power allocation is given in the next section. However, this section is useful in showing the dependency of capacity to orthogonality and spillover both of which are random variable and location dependent.

Where PG is the processing Gain, SNR is the required Eb/N0 in the downlink and uplink directions, f_{spill} is the spill over from adjacent cells or sectors, and r_{orth} is the orthogonality factor.

The orthogonality factor is different for various environments. Using the ITU channel model A, we derive the following numbers for this factor:

r_{orth}= .1/.9 (indoor) = (power in other paths)/ (power in the Main path) =.11
r_{orth}= .4/.6 Vehicular = .67
r_{orth}= .06/.94 Pedestrian = .067

We also assume the spillover to be 50% for both uplink and downlink directions:

f_{spill}= .5 for both uplink and downlink cases

$\alpha 1 = N_{dl} / N_{ul} = (1.5\ SNR_{req\text{-}UL})/ (.61\ SNR_{req\text{-}DL}) = 2.46\ SNR_{req\text{-}UL} / SNR_{req\text{-}DL}$

$\alpha 2 = N_{dl} / N_{ul} = (1.5\ SNR_{req\text{-}UL})/ (1.17\ SNR_{req\text{-}DL}) = 1.28\ SNR_{req\text{-}UL} / SNR_{req\text{-}DL}$

$\alpha 3 = N_{dl} / N_{ul} = (1.5\ SNR_{req\text{-}UL})/ (.567\ SNR_{req\text{-}DL}) = 2.65\ SNR_{req\text{-}UL} / SNR_{req\text{-}DL}$

SNR imbalance depends on the performance of macro and micro diversity gains in uplink and downlink directions. Macro diversity is the soft handover gain and micro diversity is the antenna diversity gain (transmit diversity versus receive diversity). STTD transmit diversity functions identical to the receiver diversity. Note that in the micro-cellular environment, power limitation is not a factor, so we can assume that the diversity gain is the same in the uplink and downlink directions. The overall implementation loss in the UE can be assumed to be worse by a small margin. The RAKE in the UE could be less complex as well. Although, the cost of having similar number of RAKE receivers in the UE and Base Node is minimal. The latter factor could lead to a 1-2 dB imbalance between the uplink and downlink in the SNR sense.

Let’s assume that the SNR required in the uplink and downlink is imbalanced by 1-2 dB in favor of the uplink direction. In that case we will have the following tabulated results:

Environment/ SNR imbalance	1 dB	2 dB
Indoor	1.95	1.56
Pedestrian	2.1	1.68
Vehicular	1.01	.80

The table entries are the capacity ratio of downlink over uplink. As can be seen in most cases there is a significant imbalance in favor of the downlink direction. The exact figure depends on the SNR imbalance and the operating environment.

Two conclusions can be drawn from the above formulation: 1) There is a direct dependency on SNR$_{req}$ for both uplink and downlink capacity.2) the orthogonality in the downlink leads to significantly more capacity in the downlink. In case of downlink capacity, the lower Eb/N0 necessitates lower transmit power, which translates into more capacity.

3. Downlink CDMA Capacity formulation

In order to see the dynamics of the CDMA capacity in the downlink direction and answer questions such as: Does CLPC and lower Eb/N0 provide any system capacity gain in downlink? We need to derive at an appropriate forward link CDMA capacity for packet data.

Reference [1] provides the overall system picture and interference-limited downlink capacity analysis.
Reference [2] provides a detailed analytical method for downlink capacity estimation and show that less closed loop power control error leads to more capacity.

$P_{ti} = [\ EbN0 \times R_v / W\ ]\ \rho_i \times [r_{orth} + f_{spill}]$

$f_{spill} = I_{oc} / I_{sc}$
$I_{sc} = P0 \times L0$ = Total power from the traffic channels x path loss
$I_{oc} = \text{sum}\ [P_k \times L_k]$
ρ_i = data transmission time of the ith mobile/ {Channel Holding Time}
P_{ti} = fraction of the Base Node power allocated to mobile i at the Base Node

In order to complete the picture, the effective data rate can be defined as follows:

T = Effective data rate after HARQ = $R (1\text{-}FER) / N_{re\text{-}tx}$

This is further discussed in section 5.

	Example 1	**Example 2**
W	3.84 Mcps	3.84 Mcps
R	**256 kbps**	**64 kbps**
Received Required EbN0	4 dB	4 dB
ρ_i	.1875	.1875
r_{orth}	.2	.2
f_{spill}	**.1**	**1.1**
P0 = Total Base Power	100 W	100 W
$P_{1\text{-clpc-fach}}$	.0093 $\Rightarrow P_{Tavg}$ = 930 mW	.0093 $\Rightarrow P_{Tavg}$ = 930 mW
$P_{1\text{-olpc-fach}}$	.0145 $\Rightarrow P_{Tavg}$ = 1450 mW	.0145 $\Rightarrow P_{Tavg}$ = 1450 mW
$P_{1\text{-dch}}$	.0186 $\Rightarrow P_{Tavg}$ = 1860 mW	.0186 $\Rightarrow P_{Tavg}$ = 1860 mW

These two examples show the sensitivity to the spillover factor. We can see that a cell-edge located mobile require much more power than a nearby mobile for the same data rate. The power requirement for the DCH operation is arrived at by taking the duty cycle into account. We have assumed a 3 dB difference in the operation of CLPC FACH and DCH. The proof for this is given in the next section.

4. Impact of Bursty-ness on Downlink Capacity.

The following formula and the definition show the relationship between bursty-ness and downlink capacity. Note that in finding this parameter, which is, the effective channel holding time is the variant in comparing the usage of common and dedicated channels.

$P_{ti} = [\, EbN0 \times R_v / W \,]\, \rho_i \times [r_{orth} + f_{spill}]$
ρ_i = data transmission time of the ith mobile/ {Channel Holding Time}

When the level of bursty-ness is very high, the gain in using Common Channels is significantly high [an order of magnitude in terms of spectrum efficiency]. In this section we have taken a web-browsing example, which is less bursty than an e-mail application. However, we can show that even in this case where the channel transmission time is close to 20% of the overall channel holding time, there is a significant spectrum efficiency gain.

Let's take a look at the performance of DCH/DCH+DSCH or DCH/DCH with the following assumptions:

Reference: R1#13(00)0686
Number of packers in a packet call = 25
64 kbps packet data
480 bytes packet
Average reading time between packet calls = 20 s
In new Tahoe TCP model, the packet call would look like the following:
Packet Transmission Time = 60 ms x 25 =1500 ms
Connection Release Timer = 2.25 s
Control Channel Rate = 16 kbps

1 packet + 2 packets + 4 packets + 8 packets + 10 packets
RTT = 500 ms
Inter-packet arrival time at the Base Node = 30 ms

Then the packet call would take:

1.5 s (pkt transmission time) + .75 (inter-pkt idle time) + .5 (Link set-up+ release Time) + 5 x .5 (RTT) + 2.25 = 7.5 s

This means that 5 packet calls can co-exist on this code. The data requires 64 kbps modem and the control channel takes up (5-1) x 16 kbps = 64 kbps. There is a 100% excessive interference overhead in the downlink in this scenario. The required uplink capacity will be 5 x 16 kbps = 80 kbps [more than 100%] in this case. Note that the uplink will only have 1/6 of the downlink data in case of web browsing. Which means 80 kbps channels are used to transfer 2 kbytes x 5 = 10 kbytes of data in 8 seconds. This means an effective data rate of 10 kbps and waste of 70 kbps in the uplink direction:

If we assume 4 64 kbps channels are operating in the (DCH/DCH+DSCH) mode to support 20 simultaneous sessions, then we will arrive at the results shown in the table in the next page:

Note that the difference in the performance of DCH/DCH+DSCH and CLPC FACH is the advantage of not having multiple control channels running to support the circuit operation. The advantage is highly dependent on the level of bursty-ness. We have chosen the web browsing application for the comparison purposes. If we picked e-mail application which is more bursty in nature, the spectrum efficiency advantage would be much more dramatic.

Table of comparison:

Method	Allocated Downlink Capacity	Allocated Uplink Cap	Required Base Node Resource	Application
DCH/DCH+DSCH	512 kbps	320 kbps	20 DCH/DCH 1 DSCH code	Web 12 kbytes down 2 kbytes up
CPCH/OLPC FACH	404 kbps	16 kbps	1 CPCH 1 FACH @ 256 or 4 FACH operating @ 64 kbps	Web 12 kbytes down 2 kbytes up
CPCH/CLPC FACH	264 kbps	32 kbps	2 CPCH @ 16 kbps 1 FACH@256	Web 12 kbytes down 2 kbytes up

Although, each state should be optimized independently of others, it is instructional to see if the overall gain justifies the extra effort to optimize any of these methods. In this section, we showed that introduction of CLPC on FACH can introduce and overall system gain as compared to the circuit mode of operation. We have assumed an overall 2 dB capacity gain for OLCP FACH over CLPC FACH.

5. Impact of HARQ on the Forward Link Capacity

What is the BER operating point for NRT data applications? This mechanism provides more gains at lower BER. Note that data applications require BER in the order of 10^{-6}. However, RLC layer will provide some error recovery. For example, with N=3, FER of .1 can be improved to FER=.03. Note that RLC failure will cause a packet loss that will cause a re-start in the TCP sessions, which will be costly to end-to-end throughput performance. So, the dynamics of RLC, TPC, physical layer performance and the TPC should all be considered in assessing the gain.

The relationship between FER and BER is as follows:

$BER = \{FER1 / N_{frames} \times F_{bits}\}^{½}$
For N=4, $FER1 = 4 \times (1- FER) \times (FER)^3$
N_{frames} = Number of radio Frames in the interleaved block
F_{bits} = Number of bits in a 10 ms frame

Fb	N bits in 10 ms	N bits in 20 ms	Required BER after ARQ	FER1 N=4	FER	BER before ARQ
30 kbps	300		10 -4	.000003	.009	.007
60 kbps	600		10 –4	.000006	.018	.0055
60 kbps		1200	10 -4	.000012	.023	.0044
120 kbps	1200		10 -4	.000012	.023	.0044
120 kbps		2400	10 -4	.000024	.029	.0035
240 kbps		4800	10 -4	.000048	.0364	.0028

The main point here is that BER before ARQ could still be a low BER. The treatment here is not exact and is only for illustrative purposes. We can then assume a BER of .005 for our further discussions on results of the simulations. Note that assuming higher values for N will increase the end-to-end delay.

Last point in this section is to formulate the impact of HARQ on capacity for the sake of completeness:

$T = R (1-FER) / N_{re-tx}$
R =the bit rate
FER = Frame error rate after HARQ
N_{re-tx} = average number of re-transmissions = 1+ P1 + P12 + P123
T = average throughput
P1 = FER during the first transmission
P12 = Probability of first and second frames being in error
P123 = Probability that the first, second and third frames are in error

Any kind of HARQ will change the BER and FER operating point at the expense of increasing the re-transmissions. So the capacity impact of such is a trade off between number of re-transmissions and the lowering of the required received Eb/N0. However, we cannot have excessive number of re-transmissions due to negative impact on higher layer timers. In this paper we assume the initial BER to be in the range of .01-.001 which can be lowered to 10^{-6} after several re-transmissions and employment of HARQ technique.

6. Impact of power control and interleaving in various fading environments

In this section we present some more simulation results that have been produced during the last month in continuation of the study on this topic. We have simulated the performance of OLPC and CLPC in medium and high-speed environments with limited dynamic range and 40 ms interleaving. The results are shown below and they indicate that ideal OLPC outperforms CLPC.

PC 30 Hz, 40 ms, [-10, +10 dB]

```
Rate dpdch(dB) FD(Hz)   No_frames  BER             FER

60      2       5.07    30.00       700     0.17790945     0.97000000
60      2       5.57    30.00      700     0.03095779     0.66857143
60      2       6.07    30.00     700     0.00201299      0.16714286
60      2       6.57    30.00     700     0.00004089      0.01428571
```

No PC 30 Hz, 40 ms,

```
60      2       4.07    30.00       700     0.02538901      0.39285714
60      2       6.07    30.00       700     0.00236291      0.06285714
60      2       8.07    30.00       700     0.00006914      0.00857143
```

PC 120 Hz, 40 ms, [-10, +10 dB]

```
60      2       5.57    120.37     1200    0.04139064      0.76750000
60      2       6.07    120.37     1200    0.00299874      0.26916667
```

No PC, 120 Hz, 40 ms

```
60      2       2.07    120.37     700     0.11615079      0.96000000
60      2       3.07    120.37     700     0.03618086      0.76142857
60      2       4.07    120.37     700     0.00714707      0.37000000
60      2       5.07    120.37     850     0.00083581      0.10823529
```

These results indicate that ideal OLPC outperforms the CLPC under some conditions such as 40 ms interleaving and fast fading combined with limited dynamic range.

Two points are important to note regarding these results:

1. These results are obtained by neglecting any implementation error on OLPC estimate.

2. High data rate applications will mostly occur at slow fading environment. Given the fact that these services are capacity demanding and could take up a significant percentage of the cell capacity, the gain in slow fading environment is significant

7. Dynamics of transmit power, required received Eb/N0 and CDMA downlink Capacity

This section addresses the controversy of the positioning of received Eb/N0, Base Node transmit power and overall downlink system capacity. To do so, some further link level simulations were performed.

Simulation method: Simulations have been performed at the link level for both Open Loop Power Control and Closed Loop Power Control methods. The simulations were carried out for each point by running sufficient amount of frames. In each case, the initial transmit power level (Open Loop Power estimate) is computed by the base station. In case of OLPC, that power level is maintained throughput the simulation. For the case of CLPC, the transmission begins at this level during each burst. During the burst the power level is adjusted by fast inner loop power control. In the case of CLPC, the transmit power level is averaged during the transmission to provide a stronger basis for comparison of the two cases.

	CLPC	CLPC	**CLPC**	OLPC	**OLPC**
Dynamic Range	[-10, +10]	[-10,+30]	**[-10, +5]**	NA	**NA**
Average transmit power	.938	.944	**.912**	1	**1**
Channel Rate	60	60	**60**	60	**60**
Source Bits	2376	2376	**2376**	2376	**2376**
Encoded Bits	4800	4800	**4800**	4800	**4800**
Received Eb/N0	6.07	6.07	**6.07**	6.07	**8.07**
Fd (Hz)	5.56	5.56	**5.56**	5.56	**5.56**
Interleaving	40 ms	40 ms	**40 ms**	40 ms	**40 ms**
No-Frames	750	750	**750**	750	**750**
BER	.00185	.00159	**.00554**	.033	**.0055**
FER	.171	.168	**.20**	-	**-**

As can be seen, even when the dynamic range is taken to be [-10,+30], the average transmit power is below 1. A realistic dynamic range at the base station is more like [1-0, +5] dB. As can be seen, there is a 2 dB advantage in received Eb/N0 for CLPC, which translates into 2 dB less initial Open loop estimate.

What is the impact on downlink capacity? In order to translate this into capacity, we should determine the bottom-line difference in transmit power given the same BER. In comparing the two bolded columns and considering the simulation method, we can observe that the transmit powers in the two cases with equal BER would be:

$TX_{olpc} = 1$
$TX_{clpc} = .91 /[2 \text{ dB}] = .91 / 1.6 = .57$

Since the downlink capacity is power-limited, any gain in the transmit power level translates into more users and capacity directly. For example, if the required transmit power in the case of OLPC was 50 mW, the same UE would require 28.5 mW with CLPC. That simply indicates another user with the same characteristics can b added to the system.

8. **Conclusion and recommendation**

Given the BER range of .01-.001, we have shown in this contribution that CLPC can provide capacity gain in the downlink direction in slow fading environment as compared to an ideal OLPC. Implementation errors in OLPC are neglected in the simulations. However, the results show that in slows fading environment, there is a 1.5-3 dB gain in received Eb/N0 which results in 1.5-3 dB less required transmit power at the base node. This in turn translates into more downlink capacity. The simulations show that this is not necessarily true for the medium and high-speed environments, longer interleaving depth and limited dynamic range. Under certain conditions, ideal OLPC outperforms CLPC.

Based on the simulation results given in R1-00-625 and the treatment in this document, we recommend WG1 to conclude that use of CLPC on FACH provides downlink capacity gain for packet data services.

Reference

[1] GBT contribution R1WG#13-000688
[2] W Choi, et al, “Forward Link Erlang Capacity of 3G CDMA system”, International Conference on 3G Mobile Communications Technologies, March 2000, UK.

[3], A Computer & Communications Network Performance Analysis primer, B.W. Stuck, E. Arthurs, Prentice Hall [page 273]