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Agenda item:	**10(?) [Release 4]**
Source:	**SBC Technology Resources and Golden Bridge Technology**
Title:	**Impact of the packet mode (CPCH) capacity gain on 3G deployment of non real time services.**
Document for:	**Information and Discussion**

This contribution is a full scale comparison of various packet transmission methods in UMTS. Specifically, we have compared the performance of CPCH, RACH and DCH in the uplink direction from the spectrum efficiency perspective. The spectrum efficiency factor impacts the number of required cell sites to support the non real time traffic. For example, if the overall system capacity gain in the uplink and downlink direction was a factor 7 (data-centric deployment), then the number of required cell sites could be reduced by a factor of seven in the initial system roll-out and capacity can be traded with coverage. In the final stages of deployment when system is capacity driven, the number of cell sites will be similar, but the system capacity will be different by a factor of 7. In this contribution, we have shown a capacity gain of 21 (UL is 20% of total traffic @ 32 kbps) in uplink and 3.3 (DL is 80% of total traffic @ 128 kbps) in downlink. This translates into an overall (uplink plus downlink) gain of 7. The comparison in downlink is also included in the contribution. In downlink, we compare the packet mode DSCH or FACH with circuit mode DSCH.

Abstract: *In this paper we address issues concerning technology selection for non-real time, near real time and interactive data services for 3G W-CDMA systems. Specifically, we compare the packet mode of operation with the circuit mode of operation in UMTS W-CDMA. We show that the use of packet channels such as the Common Packet Channel (CPCH) and Forward Access Channel (FACH) lead to an order of magnitude higher spectrum efficiency as compared to use of the dedicated channels. We also show in an example and under a set of service mixture assumptions that their use lead to a factor of 3.3 higher spectrum efficiency in downlink and 21 in uplink, and to more than two order of magnitude resource utilization efficiency gain in the range of 2-134. Finally, CPCH offers eight fold increase in throughput and capacity efficiency as compared to Random Access Channel (RACH). We find that the level of resource utilization gain is sensitive to the level of bursty-ness of traffic as is the case with the spectrum efficiency gain.*

1 Introduction

Currently, there are two modes of operation for packet data transport in the 3GPP W-CDMA: packet mode and circuit mode [1]. In the packet mode, the downlink transport channels include use of FACH. The uplink transport channels for packet mode are RACH and CPCH. The Dedicated Channel (DCH) is used to transfer packet data in a circuit mode of operation in both directions. Downlink Shared Channel (DSCH) can be used in either modes. In this paper, we analyze the performance of DSCH in the circuit mode of operation.

The User Equipment (UE) in the connected mode can be in one of four states. Two of these states correspond to the paging operation[1]. The UE transmits or receives data packets in the other two states: Cell-FACH and Cell-DCH, which are used for packet mode and circuit modes, respectively. Cell-FACH state is primarily intended for non-real time and bursty data while the Cell-DCH state is suited for real-time applications. Cell-FACH consists of two sub-states: RACH/FACH and CPCH/FACH. On the other hand, Cell-DCH state consists of DCH/DCH and DCH/DCH+DSCH sub-states.

Transport channels such as CPCH, FACH, DCH, DSCH and RACH will primarily support the packet mode and circuit mode of operations in the UMTS W-CDMA system. The Dedicated Channels are primarily suited for the real time data while the Common Channels such as CPCH and FACH are primarily planned for non-real time data applications In what follows, we give a brief description of each of these transport channels' functionality. However, the reader is referred to the up-to-date definitions provided by 3GPP standard [1].

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[1] The paging operation is not considered in this paper.

[*] Please contact the author for all inquiries about this paper.

Dedicated Channel (DCH) is a downlink or uplink transport channel that is to be used for transfer of voice and data in a circuit switched mode. CPCH is an uplink transport channel for non-real time packet data. CPCH radio access protocol can best be described as a Digital Sense Multiple Access with Collision Resolution Access (DSMA-CR). FACH could also be used as a downlink packet channel. Downlink Shared Channel (DSCH) is another transport channel, which is primarily used in the downlink direction. The term “Shared” refers to downlink channelization code sharing. The use of downlink-shared channel is only possible in conjunction with the Dedicated Channel (DCH), Random Access Channel (RACH) is an uplink channel that is primarily intended for signaling. RACH could also be used for short packet transmissions.

This paper quantifies the performance of packet data transfer over the circuit data transfer for use of non-real time, bursty packet data transfer in the W-CDMA system. The gain in capacity[2] and throughput is achieved from fast set-up and release of resources in the packet mode. The circuit mode of operation is not suited for non real-time data due to long connection set-up/release time and excessive end-to-end TCP acknowledgement delays. The packet mode approach in the uplink and downlink directions eliminates these inefficiencies leading to the capacity and throughput gains discussed in this paper.

The set of formulas derived and presented in this paper can be utilized for planning data services in the UMTS W-CDMA system. Given the expected traffic model and the planned number of subscribers, we can determine the number of required modem cards for the sub-state (e.g. DCH/DCH, etc.) and the total number of required Base Nodes in the system. We also present that the spectrum efficiency of the W-CDMA system is optimized for non-real time data by utilizing the packet mode of operation. The degree of bursty-ness impacts the extent of spectrum efficiency and resource utilization gains directly. In particular, we show that the use of CPCH/FACH sub-state is the optimum solution for non-real time multimedia services and improves spectral efficiency and resource utilization significantly. We show that the packet mode achieves an order of magnitude more capacity and throughput in the downlink and uplink directions.

Our objective in this paper is to address various issues concerning the technology selection strategy and method. The first issue in planning data services in the CDMA system is the problem of downlink, uplink capacity and the capacity imbalance in both directions. Section 2 addresses the CDMA downlink and uplink capacity issues. Section 3 addresses the spectrum utilization ratio for both modes of operation. . Section 4 provides tele-traffic engineering background associated with circuit mode of operation. In Section 5, we introduce a method to quantify the number of required circuit switched (DCH/DCH+DSCH or DCH/DCH) or packet switched (CPCH/FACH) resources in the system. Finally, Section 6 provides the conclusion.

2 CDMA Uplink and Downlink Capacity Formulation

The first issue in system engineering of data services in UMTS is the determination of W-CDMA uplink and downlink capacity. This is important because the packet data services are primarily asymmetric. Also the bi-directional asymmetric services such as Web-browsing require significantly more downlink capacity than uplink. In this section, we show the dependency of uplink and downlink capacity on parameters such as adjacent cell interference factor, and orthogonality. We show that the downlink capacity could be an order of magnitude higher than uplink capacity depending on the orthogonality factor.

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[2] We refer to capacity and throughput as spectrum efficiency and resource utilization efficiency, respectively.

2.1 *Impact of Orthogonality and Bursty-ness on Uplink and Downlink Capacity*

The CDMA packet data system capacity (for downlink and uplink directions) when Base Node allocates equal power to each mobile can be written as follows:

$$N_{DL} = \frac{A \times PG}{G_{DL}(g) \times (f_{spill} + r_{orth}) \times SNR_{req-DL}} \qquad (1)$$

$$N_{UL} = \frac{A \times PG}{G_{UL}(g) \times (f_{spill} + 1) \times SNR_{req-UL}} \qquad (2)$$

Where *PG* is the processing gain, *A* is the number of sectors, *SNR* is the required signal-to-noise ratio, f_{spill} is the interference spillover from adjacent cells or sectors, $G(?)$ is the required capacity increase due to bursty-ness nature of the non-real time packet data traffic (eqs. 14 and 15) and r_{orth} is:

$$r_{orth} ? \frac{\text{Power of largest path}}{\text{Total power of the multipaths}}$$

$G(?)$ in (1) and (2) is equal to 1 for packet mode of operation because The orthogonality factor is different for various environments. Using the ITU channel model A [2] and the above equation we find the following orthogonality factors:

$$r_{orth\,(\text{indoor})} = 0.11,\ r_{orth\,(\text{vehicular})} = 0.67,\ r_{orth\,(\text{pedestrian})} = 0.067$$

Furthermore, using (1), (2) with 50% spillover for both directions and 1-2 dB imbalance between the uplink and downlink SNR_{req}, we can use the following formula ratios for the 3 types of environments, i.e., indoor, pedestrian, and vehicular:

$$?_i ? \frac{N_{DL}}{N_{UL}} ? \frac{(f_{spill} ? 1) ? SNR_{req-UL}}{(f_{spill} ? r_{orth}) ? SNR_{req-DL}} \qquad i ? 1, 2 \text{ and } 3 \qquad (3)$$

The values of ?$_i$ are shown in Table 1. Note that downlink capacity is 1.56-2.0 higher than uplink capacity in the indoor and pedestrian environments. This is primarily due to the fact that orthogonality is better preserved in the downlink direction.

Environment	**SNR Imbalance**	
	1 dB	**2 dB**
Indoor	1.95	1.56
Pedestrian	2.10	1.68
Vehicular	1.01	0.80

Table 1: ?$_i$ Capacity ratio of downlink to uplink as a function of SNR imbalance.

2.2 *Impact of Non-equal Power and Bursty-ness on Downlink Capacity*

Downlink CDMA system capacity for packet data is a special case of the formulation in this section and requires a more comprehensive analysis. The work in [3] addresses this issue in more detail. The following formula shows the relationship between bursty-ness (g_i) and downlink capacity [3]:

$$P_{ti} ? S_{1?DL}(?_i) ?SNR ??r_{orth} ? f_{spill} ? \quad (4) \qquad ?_i ? \frac{\text{Channel Holding Time}}{\text{Data Tansmission Time of the i}^{\text{th}}\text{ Mobile}} \quad (5)$$

Equation (4) also expresses the downlink capacity in terms of the transmit power, P_{ti} (where P_{ti} is the transmit power for the ith mobile). Ideally, when there is nothing to transmit, the resources are released and no excessive interference is generated. This will keep the transmit power to its lowest level as it is the case with common channels. In contrast, with the dedicated channel approach, a control channel per connection is maintained until the expiry of a connection release timer resulting in excessive interference. In Section 3, we will show when the level of bursty-ness is high then the packet data system capacity will be an order of magnitude higher using common channels as compared to dedicated channels.

3 Capacity Improvement Ratio

In the previous Section, we addressed the issue of impact of bursty-ness on CDMA system capacity. In this Section, we perform the following capacity comparisons: 1) the circuit mode of operation in downlink (DCH/DCH+DSCH) with the packet mode of operation (CPCH/FACH), 2) the circuit mode of operation in uplink (DCH/DCH) versus CPCH/FACH, and finally 3) two uplink packet mode of operations: RACH/FACH versus CPCH/FACH. The packet call model proposed in [4] is used in the system analysis that follows.

3.1 *DCH/DCH+DSCH versus CPCH/FACH Capacity Gain in Downlink*

To determine the capacity gain introduced by packet mode in W-CDMA system as compared to the circuit mode, we define the following variables:

T:	Transmission time per packet in ms
T_{set-up} :	Link set-up time in ms.
$T_{release}$:	Link release time in ms.
T_{int}:	Inter-packet arrival time in a packet call, 10 ms
$T_{inactivtiy}$:	Connection Release Timer (1 s)
Packet Sizes:	80 bytes, 240 bytes, and 480 bytes
RTT:	TCP-TCP Round Trip Delay, 80, 250, 500 ms
n:	Number of packet calls in an active session, (1,2,3,…,7)
m:	Total Number of packets in an active session, (1,3,…, 127)
$F_{1DPCCH-DL}$:	Downlink Control Channel Rate, 10 kbps
$F_{1DPCCH-UL}$:	Uplink Control Channel Rate for downlink asymmetric transfer, 16kbps
F_{DSCH}:	Downlink Shared Channel Data Transfer Rate, 32, 64 kbps
N_{DSCH}:	Number of allocated DSCH codes

To characterize the level of bursty-ness, we further expand (5) to derive the following relationship:

$$?_{DL} ? \frac{T_{set?up} ? T_{release} ? n ?RTT ? m ?(T ? T_{int}) ? T_{inactivity}}{m ?T} \qquad (6)$$

Note that this equation applies to the DCH/DCH+DSCH method. Also note that when using CPCH/FACH method, g is equal to 1. Since g is the ratio of the channel holding time to the channel transmission time, it can also be used to derive the downlink spectrum efficiency. The control channel rate is lower than the data channel rate. Equation (7) defines the downlink capacity gain of packet mode over circuit mode:

$$G_{1?DL} ? 1? (?_{DL} ? 1) ?\frac{F_{1DPCCH?DL}}{F_{DSCH}} \qquad (7)$$

The extra required control channels in (7) contribute to the increase in the required downlink capacity. The uplink capacity requirement (in kbps) for asymmetric downlink transfer is defined as

$$S_{1?UL} ? ?_{DL} ? N_{DSCH} ? F_{1DPCCH?UL} \qquad (8)$$

$$G_{1-UL} = \frac{S_{1-UL}}{F_{DCH}} \qquad (9)$$

Where G_{1-UL} is the uplink capacity gain, which is equal to S_{1-UL} normalized to the total uplink capacity. The result in Table 2 entails the downlink capacity gain of packet mode as compared to circuit mode. The results are obtained for various file sizes. The first column lists various (n, m) values. Where n is the number of packet calls in a session and m

n, m	F_{DSCH} = 64 kbps		
	480 Bytes	**240 Bytes**	**80 Bytes**
1, 1	5.53	7.56	21.78
2, 3	2.98	4.09	8.50
3, 7	2.04	2.55	4.43
4, 15	1.59	1.83	2.80
5, 31	1.34	1.47	1.98
6, 63	1.20	1.28	1.58
7, 127	1.125	1.19	1.52

Table2 : Downlink packet mode spectrum efficiency gain of CPCH/FACH over DCH/DCH with DSCH.

indicates the number of packets in the overall file. As can be seen for small file sizes and more bursty traffic, the gain is high. The gain ranges between 1.125-5.53 for 480 byte packets and DSCH rate of 64 kbps. The capacity gain versus file size is also plotted in Figure 1. Table 3 shows the uplink capacity requirement for the asymmetric downlink transfer if two DSCH (source rate = 64 kbps) codes were allocated for the downlink transfer. The table entries indicate the uplink bandwidth requirements to support the transfer of 128 kbps when the DCH/DCH+DSCH method is used. For example, for transfer of a 7.2 kbyte file in downlink (n=4, m=15, packet size = 480 bytes and the DCH/DCH+DSCH method is used) a 153.6 kbps uplink capacity is required. This uplink capacity is consumed solely for the control purposes and not for any data transfer. The ratio of the uplink capacity requirement to the 64 kbps data rate is plotted against the file size in kbyte in Figure 1 (dashed line). This capacity ratio ranges from 1-15.

n, m	**F_{DSCH} = 64 kbps**		
	480 Bytes	**240 Bytes**	**80 Bytes**
1, 1	960 kbps	1376 kbps	4288 kbps
2, 3	422 kbps	664 kbps	1568 kbps
3, 7	246 kbps	348 kbps	736 kbps
4, 15	153.6 kbps	201.6 kbps	400 kbps
5, 31	102 kbps	128 kbps	234 kbps
6, 63	73.2 kbps	89 kbps	150 kbps
7, 127	58 kbps	70.4 kbps	109 kbps

Table 3: Uplink spectrum requirement to support the downlink asymmetric transfer in circuit mode.

Therefore, we see that the use of DCH/DCH+DSCH is associated with high level of control overhead as compared to CPCH/FACH. At high level of bursty-ness characterized by smaller file sizes, the capacity gain associated with packet mode could be as high as 5.5 for 480 bytes packets. Another significant detriment to the usage of DCH/DCH+DSCH for unidirectional downlink traffic is the significant amount of uplink capacity wastage as shown in this sub-section.

3.2 *DCH/DCH versus CPCH/FACH Capacity Gain in Uplink*

In this sub-section, we analyze the reverse condition, i.e., the uplink unidirectional asymmetric data transfer. We derive similar formulas for the uplink transfer and determine the spectrum efficiency gain associated with the usage of CPCH/FACH over DCH/DCH method. The following list entails the additional parametric assumptions for uplink:

$F_{2DPCCH\text{-}DL}$:	Downlink Control Channel Rate for uplink- asymmetric-transfer, 10 kbps
$F_{2DPCCH\text{-}UL}$:	Uplink Control Channel Rate, 16kbps
F_{DCH}:	Uplink Dedicated Channel Data Transfer Rate, 16 kbps

The following formulas are similar to the downlink case in section 3.1. We define the uplink inverse duty cycle as:

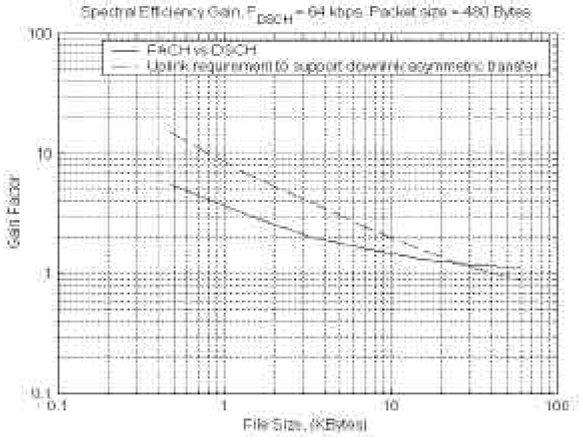


Figure 1: Capacity gain of CPCH/FACH over DCH/DCH+ DSCH or unidirectional downlink transfer.

$$?_{UL} ? \frac{T_{set?up} ? T_{release} ? n ?RTT ? m ?(T ? T_{int}) ? T_{inactivity}}{m ?T} \qquad (10)$$

The uplink capacity gain ratio is defined as:

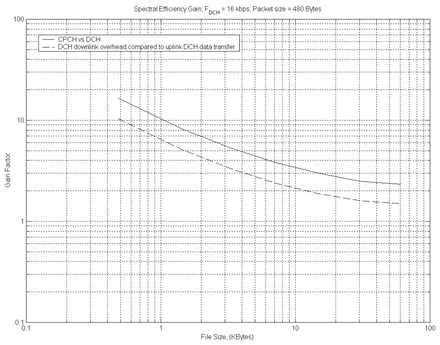
$$G_{2?UL} ? ?_{UL} \frac{F_{2DPCCH?UL} ? F_{DCH}}{F_{DCH}} \qquad (11)$$

The downlink spectrum requirement for uplink-asymmetric transfer is defined as:

$$S_{2?DL} \; ? \; ?_{UL} \; ?N_{DCH} \; ?F_{2DPCCH?DL} \quad (12) \qquad\qquad G_{2-DL} = \frac{S_{2-DL}}{N_{DSCH} \times F_{DSCH}} \quad (13)$$

Where G_{2-DL} is the downlink capacity gain, which is equal to S_{2-DL} normalized to the total downlink capacity. The slight difference in the formulations in (11)-(13) from those in (7)-(9) arises from the lack of shared channel in the uplink. Figure 2 provides the capacity gain of packet mode as compared to circuit mode in the uplink direction. The results are obtained for various file sizes. This figure is for the packet size of 480 bytes (the file size varies from 0.48 kbytes to 60 kbytes). The gain varies between 2.3-16.6. The ratio of the downlink capacity requirement to the DCH data rate (16 kbps) is plotted against the file size in kbyte in Figure 2. This ratio ranges from 1.5-10.

Figure 2: Spectrum efficiency gain of CPCH/FACH over DCH/ DCH for unidirectional uplink transfer.



In this sub-section, we showed that the use of DCH/DCH for uplink transfer is associated with high level of control overhead as compared to the use of CPCH/FACH. At higher levels of bursty-ness characterized by smaller file sizes, the spectrum efficiency gain associated with packet mode could be as high as 20. Another significant detriment to the usage of DCH/DCH for unidirectional uplink traffic is the significant amount of downlink capacity wastage as shown in this sub-section.

3.3 *CPCH/FACH versus DCH/DCH+DSCH and DCH/DCH: Capacity Gain in both directions*

In this sub-section, we examine a traffic model that includes the following applications in uplink and downlink directions: E-mail, Web-browsing and FTP. The downlink capacity requirement (128 kbps) is assumed to be four times the uplink capacity (32 kbps) requirement. Table 4 illustrates the traffic model assumptions employed in this example and analysis.

Applications	Uplink Usage	Uplink Packet size per user (Bytes)	Downlink Usage	Downlink Packet size per user (Bytes)	n, m	File sizes (kbytes)
E-mail	80%	240	40%	240	2,3	7.2
Web-browsing	10%	80	50%	480	4,15	7.2(down) 1.35(up)
FTP	10%	480	10%	480	7,127	61

Table 4: Traffic model.

We attempt to answer the following question: Given 128 kbps downlink capacity, 32 kbps uplink capacity, a certain mix of non-real time traffic (e.g., E-mail, Web-browsing, FTP), what is the capacity requirement in the uplink and downlink directions to support this traffic in the packet mode and circuit mode of operation? The packet mode of operation is CPCH/FACH and the circuit mode of operation is DCH/DCH or DCH/DCH+DSCH. Note that the total uplink and downlink capacity gains can be expressed as follows (using equations 7-13):

$$G_{DL} = G_{1-DL} + G_{2-DL} \quad (14) \qquad\qquad G_{UL} = G_{1-UL} + G_{2-UL} \quad (15)$$

Where G_{DL} and G_{UL} are the total downlink and uplink capacity gain, respectively. Using the packet sizes shown in Table 4 for each application, and the number of packets in the session, the uplink and downlink capacity requirements for each application are shown in Table 5 using equations 7-8 and 11-12. From Table 5 we note that the total downlink capacity requirement is 420 kbps while the total uplink capacity requirement is 669 kbps. The spectrum efficiency gain of CPCH/FACH as compared to DCH/DCH or DCH/DCH+DSCH is 420 kbps/128 kbps = 3.3 and 669 kbps/32 kbps = 21 in the downlink and uplink, respectively. In conclusion, if the DCH/DCH+DSCH and DCH/DCH pairs are selected to support the non-real time traffic in the uplink and downlink direction as shown in Table 4, the capacity requirement to provide 128 kbps in the downlink and 32 kbps in the uplink would be: DL: 420 kbps, UL: 669 kbps. Whereas the use of CPCH/FACH will only require DL: 128 kbps and UL: 32 kbps.

Applications	**Uplink Application Data (kbps)**	**Downlink Control for uplink transfer**	**Uplink Control for downlink Transfer**	**Downlink Application Data (kbps)**
E-mail	0.8 x 11.8 x (16+16) = 302	0.8 x 118 = 94.4	0.4 x 664 = 265	0.4 x 4 x 128 = 205
Web Browsing	0.1 x 3.8 x (16+16) = 12.2	0.1 x 38 = 3.8	0.5 x 153 = 76.5	0.5 x 128 x 1.59 = 101
FTP	0.1 x 2.32 x (16+16) = 7.4	0.1 x 23.24 = 2.32	0.1 x 58 = 5.8	0.1 x 128 x 1.125 = 14.4
Total	**321.6**	**100.5**	**347.3**	**320**

Table 5: Downlink and uplink Capacity requirements.

3.4 RACH/FACH versus CPCH/FACH: Capacity Comparison

In this sub section, we compare the capacity of the RACH and CPCH. Both transport channels are in the uplink direction and both methods can be categorized as packet mode methods. The use of Closed Loop Power Control, variable packet length, collision resolution, Base Node Status Broadcast and channel assignment capability for CPCH leads to a two-fold gain in spectrum efficiency over RACH.

	F_d = 30 Hz			**F_d = 5 Hz**	**F_d = 120 Hz**
Interleaver (ms)	40	20	10	40	40
CPCH	3 dB	4 dB	5dB	-	-
RACH	6 dB	6 dB	6dB	-	-
CPCH/RACH Gain	3 dB	2 dB	1 dB	2 dB	2.5 dB

Table 6: E_b/N_o requirement comparison of CPCH and RACH

The authors in [5] showed the performance of the closed loop power control over open loop power control for the W-CDMA system. CPCH operates in closed loop power control as compared to the RACH, which operates in open loop power control during the message transmission phase. The results in [5] are not directly applicable since the ramp-up process in RACH provides an initial accurate mobile transmit power requirement estimate. This leads to a two-fold capacity improvement of CPCH over RACH from the spectrum efficiency point of view when the Doppler frequency, F_d is 30 Hz [6]. Extensive link level simulations of CPCH and RACH using the Cadence Design System's SPW simulation tool have shown the results tabulated in Table 6. The ITU channel model (A) is used for these link level simulations [2]. These results are for RACH interleaving of 10 ms and for the convolutional code of rate R=1/2 for both CPCH and RACH. These results show a 3 dB gain at BER of 10^{-3} when 40 ms interleaving is employed for CPCH. Note that the preamble ramp up in both RACH and CPCH is modeled as closed loop power control operating at 400 bps. The preamble ramp-up is followed by

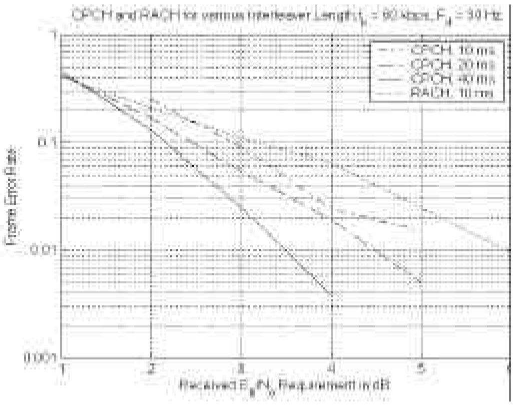


Figure 3: Frame error rate of CPCH and RACH with various interleaver lengths.

closed loop power control operating at 1500 bps for CPCH as compared with open loop power control for RACH. The use of closed loop power control results in less required E_b/N_o and subsequently more capacity. In Section 2, we showed the direct relationship between the uplink capacity and the required E_b/N_o. Figure 3 is a plot of Frame Error Rate versus E_b/N_o requirement for RACH (10 ms interleaving) and CPCH (10 ms, 20 ms, and 40 ms interleaving) cases in the 30 Hz fading environment.

4 Quality of Service (QoS): Blocking Probability and Delay

This section addresses the delay issue for the circuit mode of operation. The throughput delay curves and simulations guide the performance management of the packet mode of operation and therefore are not discussed in this section.

Erlang-B loss formula and the Erlang-C Delay formulas may be used for tele-traffic engineering of the infrastructures when circuit-switched modems are used for data transfer over the air interface. We can determine the blocking probability by using the Erlang-B formula and then determine the waiting time by using the Erlang-C formula [7]. In other words, given P circuits, impinging Erlang-A traffic will cause an x% blocking probability. As an example, given 4 circuits operating at 384 kbps, we will have the following:

P=4 Circuits @ 20% Blocking Probability ? A= 3 ? Waiting time = $C(P, A)$ = 400 ms.

For packet switched modems, the throughput delay formulation may be used to derive the delay and throughput efficiency of the radio access protocol. For example, the RACH Protocols has a throughput efficiency of 0.18 at the 10D delay point for average packet length of 80 bytes. (See Figure 4). The CPCH Radio Access Protocol results indicate that acceptable radio access delays [10D], occurs at the normalized throughput of 62-78% for average packet length of 240 bytes (Figure 4). The service provider will have the choice of setting the mode of operation and other parameters that impact the throughput delay performance thus setting the Grade of Service (GoS) in the delay sense.

5 Throughput Improvement Ratio

5.1 *CPCH/FACH versus DCH/DCH+DSCH and DCH/DCH*

The resource utilization ratio using circuit switching and packet switching methods has been addressed [8]. In [6], the author reports the resource utilization gain that varies between 5-40. In this section, we show this gain to be 16 for the mixture of services described in section 3.3. The ratio depends on the bursty-ness of the traffic. In Sections 3.1 and 3.2, we derived the expressions for the level of bursty-ness for the uplink (10) and downlink (6) directions. Using the parameters and assumptions of the examples in sub-sections 3.1 and 3.2, we can find the resource utilization gain in the uplink and downlink directions as a function of file size and packet size. Figure 4 shows the resource utilization gain in the uplink and downlink to be in the following ranges: UL: 1.2-34 and DL: 2-134. The resource utilization gain of CPCH/FACH over DCH/DCH and DCH/DCH+DSCH given the traffic model in sub-section 3.3 is the following: uplink gain factor of 5, downlink gain factor of 11, and overall gain factor of 16. In summary, 16 DCH/DCH or DCH/DCH+DSCH pairs are

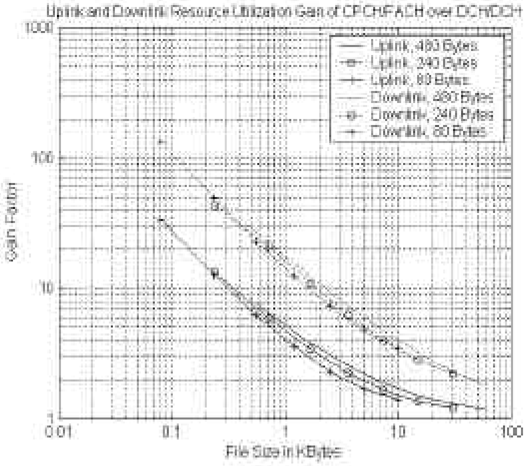


Figure 4: Resource utilization gain of CPCH/ FACH over DCH/DCH+DSCH.

needed to support 128 kbps in the downlink and 32 kbps in the uplink as postulated in section 3.3. In contrast, utilizing the packet mode of operation, i.e., CPCH/FACH will only require one transceiver modem in the Base Node.

5.2 *CPCH/FACH versus RACH/FACH*

Incorporation of Collision Resolution and Status Broadcast scheme into CPCH provides a more intelligent Access Protocol and a four-fold throughput advantage over RACH, which is based on Slotted Aloha. Note that the throughput performance of the RACH is less than the theoretical value of 36%. In the system level simulations, which yielded in the throughput delay performance results, the payload size per RACH attempt was only 80 bytes (10 ms) whereas the overall average packet size was 240 bytes (30 ms). The results of the system level simulations of the Random Access Channel and Common Packet Channel (two modes: Channel Assignment and Channel Selection Modes) are shown in Figure 5. In these simulations, there are 5 CPCH or RACH channels operating at 1 x 128 ksps, 2 x 48 ksps, and 2 x 16 ksps. The maximum acceptable packet length for the CPCH radio protocol is 80 ms.. The average packet length is 240 bytes, which is equal to 30 ms when the CPCH Channel Selection or Channel Assignment modes are utilized. Figure 5 shows a four-fold throughput advantage for CPCH as compared to RACH. Note that at 10D, the CPCH throughput is 62-78% while the RACH throughput is 18%. D is the average packet transmission time. In these simulations, the number of slots between successive preambles is set to be 3. The initial preamble power level is subjected to a random error (uniform density: standard deviation =3 dB). The throughput delay curve (Figure 5) shows two delay traces per each protocol. One trace is the end-to-end delay, which includes the following four components:

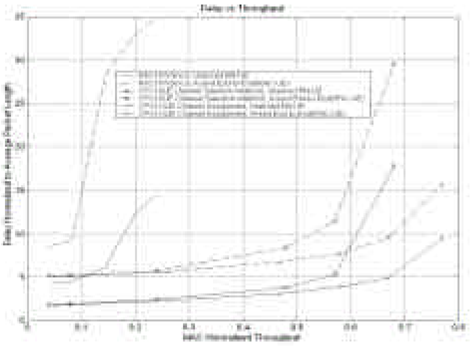


Figure 5 : Throughput delay performance of CPCH and RACH.

UE RLC buffer waiting time:	Random
Radio protocol access delay:	Random
Packet transmission time:	Random: mean value of 30 ms
I_{ur}-I_{ub} delay:	Fixed: 100 ms round trip delay
ARQ delay (UE TX - RNC Ack):	Random

We term the first trace, which is the sum of the five components above as the UE-RNC end-to-end delay. The second trace is the sum of the first three elements. We call that the UE-Base Node Delay in Figure 5. The ARQ delay is the time lapse from the end of the packet transmission over the air to

Average Packet Transmission Time, ms	MAC throughput	D (end-to-end) ms	Waiting time In UE Queue ms	Radio Access Time ms	ARQ Delay ms	2-way Fixed I_{ur}-I_{ub} Delay, ms
30	0.052	151	3	18	3.2	100
30	0.077	153	3.2	20	3.2	100
30	0.26	167	6.6	31	4.6	100
30	0.47	203	12	50	16	100
30	0.58	230	20	67	22	100
30	0.67	288	34	84	42	100
30	0.77	470	132	124	123	100

Table 7: Delay elements for the CPCH (Mode 2) protocol throughput delay performance

the receipt of the Acknowledgement by the UE. Tables 7 include the detailed breakdown of the delay elements as plotted in Figure 5 in mode 2.

Our results show that a capacity ratio advantage of 2 and throughput advantage of 4 is achievable by CPCH over RACH. We can therefore conclude that CPCH offers eight-fold increase in efficiency as compared to RACH.

6 Conclusion

The treatment in this paper lays the groundwork for developing a wireless Internet system-planning tool to be used for a UMTS W-CDMA system operating in FDD mode. The gains associated with deployment of CPCH/FACH are traffic model dependent. However, the results in this paper show that the improvement due to use of common packet channels over dedicated channels can be as great as a factor of 34 in uplink and 134 in downlink in the throughput efficiency. More importantly, the work in this paper show a capacity gain factor of up to 21 in uplink and up to 3.3 in downlink using CPCH/FACH instead of DCH/DCH+DSCH. We also showed using CPCH/FACH one can gain a factor of up to 2 in capacity and a factor of up to 4 in throughput versus RACH.

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