CDMA System for UMTS High Bit Rate Services

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ABSTRACT

CDMA based radio system capable of supporting UMTS services up to 2 Mbit/s user bit rates is considered. The performance of the system is evaluated by link level simulations, cell range calculations and network level capacity simulations in urban macro cell, urban street micro cell and indoor cell environment using three bandwidths. According to the results 2 Mbit/s transmission was achieved with reasonable signal-to-noise ratio in all the simulated environments. Moreover, sufficient cell ranges can be realized using reasonable power levels in the indoor and micro cell environments. In the macro cell environment the achievable range should be larger. In the considered case the downlink capacity of cellular network offering 2 Mbit/s services is only moderate and much lower than the uplink capacity.

1. INTRODUCTION

Universal Mobile Telecommunication System (UMTS) services like high quality audio, video telephony, electronic newspaper and unconstrained digital data transfer require user bit rates up to 2 Mbit/s with bit error rates of 10^{-6} and maximum one-way transmission delays of 40 - 200 ms [1].

Air interface solutions suitable for high bit rate services have been developed in many research projects like CDMA (Code Division Multiple Access) based approach in CODIT [2] and TDMA (Time Division Multiple Access) based approach in ATDMA [3]. Experimental results of 2 Mbit/s transmission are published in [4].

In this paper CDMA system capable of supporting high bit rate services with UMTS requirements up to 2 Mbit/s user bit rates is presented. In addition, link performance simulation results for three different propagation environments are presented. The achievable cell ranges are considered based on empirical path loss models and finally the capacity of cellular network offering 2 Mbit/s service is studied by simulations. The performance of the system is evaluated for three bandwidths.

2. CDMA AIR INTERFACE

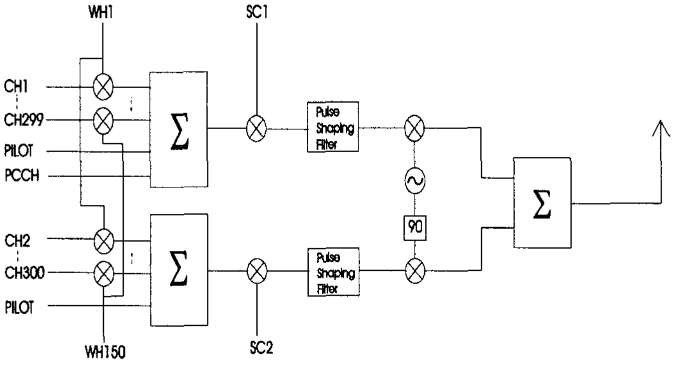
CDMA air interface is based on the system presented in [5]. Downlink solution is near-orthogonal multicode multirate synchronous transmission. Pilot code channel is exploited for channel estimation in RAKE-reception. Spreading codes are allocated from Walsh-Hadamard code set shortened by one chip. Gold codes of the same length are used as scrambling codes to separate different base stations. Dual channel QPSK spreading modulation is exploited. The same spreading code is used for both I and Q branches but the scrambling codes are different. For example using codes of length 255 chips and 5.10 Mchip/s one code channel corresponds to 20 kbit/s raw data rate. Consequently, it is possible to allocate 510 separate code channels simultaneously. For the bandwidths of 10.22 Mchip/s and 20.48 Mchip/s the code lengths of 511 and 1023 chips are used.

Fast power control based on signal-to-interference ratio with command rate of 1 kbit/s in the downlink is employed to mitigate the multipath fading. Frame control header transmitted at Physical Control Channel (PCCH) is used to inform the receiver about the transmission rate of the next frame. Pulse shaping is carried out with square root raised cosine filters.

Flexible forward error correction techniques are exploited in order to facilitate services with different bit error rate and delay requirements. Services can be uncoded or protected against channel errors by using convolutional coding. In order to realize high quality services concatenated Reed-Solomon outer codes can be employed. Unequal repetition coding is exploited to match user bit rates to available multirates.

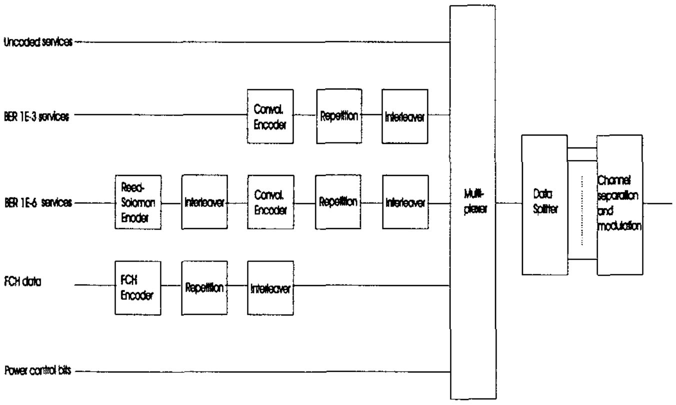
2 Mbit/s service was realized by using 1/3 convolutional code with constraint length of nine. Consequently, 300 parallel code channels each 20 kbit/s were allocated for the 2 Mbit/s for BER of 10^{-3}. The required lower BER of 10^{-6} can be achieved by using e.g 4/5 Reed-Solomon code as an outer code. Convolutional interleaving introducing 100 ms one-way delay was employed. The downlink transmission scheme is

presented in Figure 1. The coding scheme is presented in Figure 2.



CH = Channel
PCCH = Physical Control Channel
SC = Scrambling Code

Figure 1. Downlink transmission scheme for 2 Mbit/s



FCH = Frame Control Header

Figure 2. Coding scheme

Uplink is based on reference symbol aided coherent transmission with variable processing gain multirate scheme. The advantage of this kind of solution is that the requirements for the power amplifier linearity are not so stringent than in the downlink multicode multi-rate case. On the other hand the spreading factor may become too small for high bit rates. Dual channel OQPSK spreading modulation with VL-Kasami codes augmented with one bit is applied. The reference symbols (1 ksym/s) are multiplexed with the data.

For instance using 10.24 Mchip/s bandwidth a spreading code of length 1024 chips can be divided into 256 subcodes of length 4 chips. Consequently, 5.12 Mbit/s raw data rate is achieved. For the chip rates of 5.12 Mchip/s and 20.48 Mchip/s the code lengths of 512 and 2048 chips are used.

Fast power control based on signal-to-interference ratio with command rate 2 kbit/s is employed to mitigate the multipath fading. Power control dynamics is 80 dB. Pulse shaping is carried out with similar square root raised cosine filters as in the downlink. The uplink transmission scheme is described in Figure 3.

An ordinary RAKE-receiver followed by multiuser detection unit is utilized in the base station in order to reduce interference [6]. In this paper multiuser detector is assumed to cancel only intersymbol interference not multiple access interference from other users. The effect of multiuser detector can be seen in link level results. In network capacity simulations no gain from multiuser detector is assumed. In addition, antenna diversity is used in the base station. Forward error correction is arranged in the same way as in the downlink except convolutional code of rate 1/2 is applied.

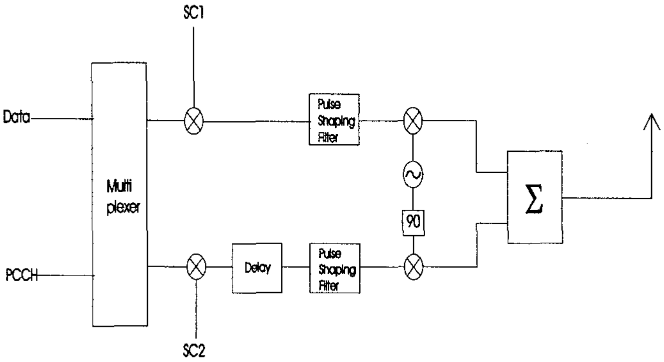


Figure 3. Uplink transmission scheme

3. LINK PERFORMANCE SIMULATIONS

Link level performance simulations for 2 Mbit/s user bit rate and bit error rate of 10^{-3} were carried out using similar wideband channel models as in CODIT project for urban macro and urban street micro at the speed of 3 and 36 km/h and indoor environments [7] at the speed of 3 km/h using three different chip rates of 5.12 (5.10) , 10.24 (10.22) and 20.48 (20.46) Mchip/s.

The bit error rate of 10^{-6} was not simulated due to very high computational efforts required. In the downlink simulations enough RAKE-fingers were allocated to gather all the signal energy. In the uplink simulations the number of RAKE-fingers was restricted in the case of macro channel in order to limit the complexity of the base station receiver with multiuser detector.

The most important parameter used in the comparison of different configurations in noise limited case is E_b/N_0 which represents the energy per bit versus noise power density. In the own cell interference case energy per bit versus interference power E_b/I_0 was compared.

The E_b/I_0 values have been calculated using the following equation:

$$\frac{Eb}{Io} \equiv \frac{WP_{user}}{R(NP + P_{pilot})}$$

where,
W = chip rate of the downlink (5.10 Mchip/s, 10.22 Mchip/s and 20.46 Mchip/s),
R = user data rate (2000 kbit/s),
P_{user} = power of the wanted signal (300 code channels),
N = number of interfering channels,
P = power of one interfering channel and
P_{pilot} = power of the pilot signal (equal to the power of four code channels)

The corresponding link performance results are presented in Tables 1 and 2.

Table 1. Downlink performance without power control (BER 10^{-3})

Bandwidth	5.12 Mchip/s		10.24 Mchip/s		20,48 Mchip/s	
Channel	E_b/N_o	E_b/I_o	E_b/N_o	E_b/I_o	E_b/N_o	E_b/I_o
Macro 3km/h	10.25	9.8	6.75	5.70	5.25	4.20
Macro 36km/h	9.50	8.80	6.25	5.50	4.75	4.20
Micro 3 km/h	14.25	3.50	12.25	2.20	9.00	2.50
Micro 36 km/h	9.75	2.20	8.75	1.90	6.75	2.50
Indoor 3 km/h	9.75	0.40	9.25	-0.20	6.75	1.70

Table 2. Downlink performance with fast power control (BER 10^{-3})

Bandwidth	5.12 Mchip/s		10.24 Mchip/s		20.48 Mchip/s	
Channel	E_b/N_o	E_b/I_o	E_b/N_o	E_b/I_o	E_b/N_o	E_b/I_o
Macro 3km/h	10.25	9.8	6.00	5.70	5.25	4.20
Macro 36km/h	9.50	8.80	6.25	5.50	4.75	4.20
Micro 3 km/h	8.25	3.50	6.40	2.20	4.00	2.50
Micro 36 km/h	5.95	2.20	4.50	1.90	3.95	2.50
Indoor 3 km/h	4.70	0.40	4.20	-0.20	3.55	1.70

According to the downlink simulation results the requirements are achieved using reasonable E_b/N_o values (4 dB - 10 dB) even with the narrowest 5 Mchip/s bandwidth. Only the performance in the macro channel seems to be somewhat poorer when only 5 Mchip/s are used. This is due to too low processing gain. The higher the chip rate, the more multipath diversity is available and the lower is the E_b/N_0 requirement. The E_b/I_0 figure does not get lower with higher chip rates in micro cell because multipath propagation causes a loss in orthogonality of the spreading codes.

The performance of uplink is excellent (4 dB - 6 dB without antenna diversity) with all simulated bandwidths. Reception antenna diversity was not used in the link level simulations but diversity gain of 3.0 dB is taken into account in the range and capacity simulations. Fast power control offered considerable gains in the micro and indoor environments. In the macro channel, instead, only little gain was achieved due to good multipath diversity of the channel. In uplink the higher chip rates do not result into lower E_b/N_o because fast power control is able to combat fast fading. In addition, the number of RAKE fingers was limited in the base station receiver with multiuser detector and only part of the energy was captured with wide bandwidths. Uplink simulation results for bit error rate 10^{-3} with fast power control and without antenna diversity are shown in Table 3. The corresponding results without power control are presented in Table 4.

Table 3. Uplink performance with fast power control but without antenna diversity (BER 10^{-3})

Bandwidth	5.12 Mchip/s	10.24 Mchip/s	20.48 Mchip/s
Channel	E_b/N_o	E_b/N_o	E_b/N_o
Macro 3 km/h	4.60	5.50	6.20
Micro 3 km/h	3.90	3.60	4.10
Indoor 3 km/h	-	3.60	3.30

Table 4. Uplink performance without power control and without antenna diversity (BER 10^{-3})

Bandwidth	5.12 Mchip/s	10.24 Mchip/s	20.48 Mchip/s
Channel	E_b/N_o	E_b/N_o	E_b/N_o
Macro 3 km/h	7.00	7.00	6.50
Micro 3 km/h	10.40*	9.90	7.50
Indoor 3 km/h	-	6.00	5.30

* With dual antenna diversity

4. CELL RANGES

Cell ranges are calculated based on the uplink simulation results presented in Table 4. Empirical path loss models [7] were used for the range calculations in noise limited case. Hata model with path loss factor of 3.6 was used in the macro cell case, modified Sakagami-Kuboi model with flat ground and base station height of 25 m in the micro cell case and Motley model in the indoor cell case with three floors and 10 light walls. The achievable ranges seem to be independent of used bandwidth except in the micro cell environment in which for the bandwidth of 5.12 Mchip/s ranges are 30 % shorter. The resulting cell ranges are sufficient in micro and indoor cell cases. The range of macro cell, however, is only moderate. The calculated cell ranges may be optimistic since the effect of interference was not taken into account but unloaded system is assumed. The resulting cell ranges for all three bandwidths with three different mobile transmission powers are presented in Table 5.

Table 5. Cell radius for uplink with antenna diversity.

Environment	Macro	Micro	Indoor
Cell radius (m) 10 mW	800	600 (400)*	50
Cell radius (m) 100 mW	1500	1100 (800)*	200
Cell radius (m) 1000 mW	2900	2000 (1400)*	500

* Ranges for 5.12 Mchip/s in parenthesis

5. NETWORK CAPACITY

Finally, cellular network capacity for 2 Mbit/s service was estimated by simulations in macro and micro cell cases. The interference limited capacity was computed for C/I threshold values corresponding to bit error rate 10^{-3} and outage requirement of 5 %. The interfering users were also assumed to be 2 Mbit/s users. The shadow fading was taken into account log-normally. Since adjacent channel interference was neglected the results are somewhat optimistic.

In the case of the macro cell environment the path loss was calculated according to the following Okumura-Hata model:

$$L = 131 + 36\log_{10}(d) \ [dB],$$

where d is the distance in kilometers between the transmitter and the receiver. In the case of macro cell environment the standard deviation of shadow fading was 6 dB.

The micro cell environment was modelled using a Manhattan grid with block size of 100 m and junctions of 30 m x 30 m. The base stations were located in every second corners. The standard deviation for shadowing was 4 dB. The path loss for line-of-sight connection was given by the following equations:

$$L_{LOS} = 82 + 20\log_{10}(\frac{d}{300}) \ [dB] \ \ if\, d \le 300m,$$
$$L_{LOS} = 82 + 40\log_{10}(\frac{d}{300}) \ [dB] \ \ if\, d > 300m,$$

where d is distance in meters. In the case of non-line-of-sight connection, the corner effect is taken into account by the following equation:

$$L = L_{LOS}(d_{corner}) + 17 + 0.05 d_{corner} + (25 + 0.2 d_{corner})\log_{10}\left(\frac{d}{d_{corner}}\right),$$

where d_{corner} is the distance between the transmitter and the corner and d is the distance between the transmitter and the receiver. Figure 4 shows the micro cell simulation configuration.

Table 6 presents the results of the downlink capacity simulations with and without admission control (AC) and power control (PC). The capacity results have been scaled with the required channel spacing which is assumed to be 6.0 MHz for 5.12 Mchip/s, 12.0 MHz for 10.24 Mchip/s and 24.0 MHz for 20.48 Mchip/s. The power control offered considerable capacity gain. The capacity of cellular network offering 2 Mbit/s services, however, seems to be quite low being 40 - 220 kbit/s/MHz/cell for the downlink. Consequently, supporting one active 2 Mbit/s user in every cell simultaneously requires 10 - 20 MHz bandwidth.

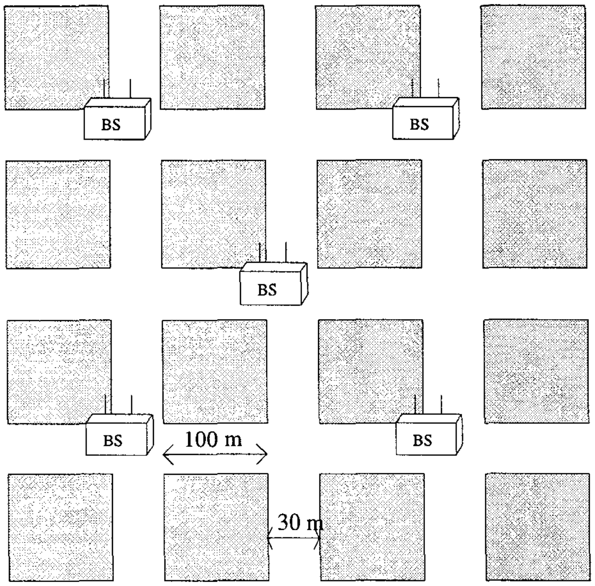


Figure 4. Microcell network layout.

The uplink capacity was much better being 200 - 500 kbit/s/MHz/cell. Therefore, even 5 - 10 MHz bandwidth could be sufficient for the uplink in order to facilitate one 2 Mbit/s user in every cell. The main reason for higher capacity in uplink is the antenna diversity gain in the base station receiver. In the uplink capacity simulations the effect of the multiuser detector was not taken into account in cancelling multiple access interference. The effect of multiuser detector in cancelling intersymbol interference can be seen in the link level E_b/N_0 values. The results of uplink capacity simulations are presented in Table 7.

With admission control the number of users connected to each base station is forced to be equal resulting into gain in capacity. This leads, however, into increased blocking rate compared to the case without admission control.

Table 6. Downlink capacity kbit/s/MHz/cell.

AC	OFF	OFF	ON	ON
PC	OFF	ON	OFF	ON
Micro 6.0 MHz	40	60	40	150
Micro 12.0 MHz	40	160	60	220
Macro 6.0 MHz	-	30	-	30
Macro 12.0 MHz	-	70	-	80

AC = Admission Control
PC = Power Control

Table 7. Uplink capacity kbit/s/MHz/cell.

AC	OFF	ON
Micro 6.0 MHz	250	500
Micro 12.0 MHz	400	460
Macro 6.0 MHz	180	200
Macro 12.0 MHz	220	220

It should be noted here that CDMA uplink capacities can also be calculated with analytical formulas, e.g. with Eq. (5) in [8]. This formula, however, gives capacity figures that are nearly two times higher than the simulated figures. The reason is that the formula assumes interference to be Gaussian. This assumption is not valid in the case of 2 Mbit/s users because the number of users and thus the number of interference sources is too low for Gaussian approximation. Therefore, we have resorted to simulation approach to find out realistic capacities.

6. CONCLUSIONS

CDMA system capable of supporting UMTS services up to 2 Mbit/s user bit rates was presented. At the link level the system was capable of supporting 2 Mbit/s user bit rate transmission with reasonable signal-to-noise-ratio in urban macro, urban street micro and large room indoor cell channels using three different bandwidths of 5 Mchip/s, 10 Mchip/s and 20 Mchip/s.

The resulting cell ranges for 1 Watt transmitter power were sufficient in the micro cell (1.4 - 2.0 km) and indoor cell (500 m) environment. The achievable range in the macro cell (2.9 km) environment could be better in order to avoid large number of base stations.

The cellular capacity of network offering 2 Mbit/s services seemed to be quite low due to the poor downlink capacity. Unfortunately, high downlink capacity would have been more important for the considered services. According to the results 10 - 20 MHz bandwidth is required to support one active 2 Mbit/s user in every cell. However, since all the users transmit seldom simultaneously, packet reservation multiple access techniques can be exploited to alleviate the capacity problem. The UMTS cellular network offers a 2 Mbit/s peak data rate which can be shared by packet access among the users.

A TDMA system supporting 2 Mbit/s transmission under the same constraints presented in this paper has been studied in [9]. The comprehensive results from the comparison between the considered CDMA and TDMA solutions are presented in [10]. The main conclusion from the comparison, however, is that with the same operator bandwidth, the same channel models, the same delay and bit error rate, the same path loss models for capacity and range and the same transmit power the differences between the CDMA and the TDMA solutions are minor.

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