PERFORMANCE OF HIGH BIT RATES WITH WCDMA OVER MULTIPATH CHANNELS

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ABSTRACT

IMT-2000 systems are required to provide bit rates up to 2 Mbps with high spectrum efficiency. In this paper the performance of 512 kbps – 2 Mbps with UTRA wideband CDMA [1] in multipath channels is evaluated. The evaluation is based on the link level simulations with a Rake receiver in different multipath profiles. The performance of high bit rates in the air interface is affected by the multipath propagation. The multipath propagation gives diversity gain but causes also inter-path interference. The effect of inter-path interference is analyzed and the possible gains from advanced receiver structures in canceling inter-path interference are evaluated. Also, the multipath diversity gain is studied for high bit rates. The results of this paper show that inter-path interference can cause a degradation of about 2 dB for 2 Mbps transmission in 2-path Rayleigh fading channel if an ordinary Rake receiver is used. The more multipath components are present, the higher the degradation. It is also shown that the required transmission power is lower in multipath channels than in a 1-path channel because the multipath diversity gain is typically larger than the loss due to the inter-path interference.

I. INTRODUCTION

One of the main targets of UMTS is to provide mobile multimedia services with high bit rates. UMTS Terrestrial Air Interface (UTRA) is required to provide 2 Mbps services in limited environments, like in indoors and in small micro cells. The high bit rates in WCDMA are obtained with low processing gain, i.e. symbols are shorter or/and there are more parallel codes. Therefore, in multipath channels inter-symbol interference (i.e. inter-path interference IPI) is caused at high bit rates. In this paper the effect of inter-path interference on the performance of 512 kbps - 2 Mbps WCDMA transmission is studied. The simulated performance of high bit rates is compared to the simulation results where inter-path interference is not modeled. This comparison is used to evaluate how much gain could be achieved if the inter-path interference could be cancelled. The multipath propagation provides also multipath diversity in addition to causing inter-path interference. The gain from the multipath diversity with high bit rates is evaluated in the paper to understand the total effect of the multipath propagation. This study has been carried out with link level simulations (COSSAP) with different multipath profiles. The performance and feasibility of 2 Mbps in microcellular environment has been analyzed also in [2] where multipath profiles are obtained by ray-tracing calculations.

This paper is organized as follows. Chapter II introduces the main parameters of UTRA WCDMA physical layer. The methods for performance evaluation are presented in Chapter III. The simulation parameters and environments are shown in Chapter IV. The degradation due to inter-path interference is analyzed in Chapter V and the results of the multipath diversity gain study are shown in Chapter VI. Conclusions are drawn in Chapter VII.

II. MAIN PARAMETERS OF WCDMA PHYSICAL LAYER

The main parameters of WCDMA physical layer are summarized in Table 1.

Table 1. Main parameters of WCDMA (DL = downlink, UL = uplink)

Duplexing method	Frequency division duplex (FDD)
Base station synchronization	Asynchronous operation
Chip rate	4.096 Mcps
Frame length	10 ms
Service multiplexing	Multiple services with different quality of service requirements multiplexed on one connection
Multirate concept	• Variable spreading factor and multicode • Rate matching at layer L1 with repetition or puncturing • Rate changes dynamically frame-by-frame
Spreading codes	UL: Orthogonal variable spreading codes, long scrambling codes DL: Orthogonal spreading codes, long scrambling codes

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Multiple bit rates in WCDMA are achieved through variable spreading factors, multicode or a combination of them in both uplink and downlink. Bit rates from a few kbps up to 2 Mbps can be provided with the basic chip rate of 4.096 Mcps.

Separate physical data and control channels are used in layer 1 in WCDMA. Dedicated physical data channel (DPDCH) is used to transmit data generated at layer 2 and above. Each DPDCH frame on a single code carries $160*2^k$ bits ($16*2^k$ kbps), where k=0,1...6, corresponding to a spreading factor of $256/2^k$ with the 4.096 Mcps chip rate. Multiple parallel variable rate services (=dedicated logical traffic and control channels) can be multiplexed in each DPDCH frame. The overall DPDCH bit rate is variable on a frame-by-frame basis. In most cases, only one DPDCH is allocated per connection, and services are jointly interleaved sharing the same DPDCH.

Dedicated physical control channel (DPCCH) is needed to transmit pilot symbols for coherent reception, power control signaling bits and transport format indication for the rate detection.

In uplink DPDCH and DPCCH are I-Q/code multiplexed and in downlink time multiplexed. Figure 1 shows the uplink physical dedicated channels and Figure 2 the downlink ones.

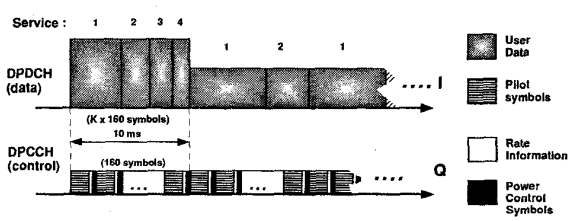

Figure 1. Physical data channel (DPDCH) and control channel (DPCCH) in uplink

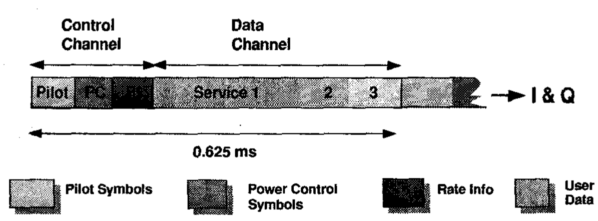

Figure 2. Physical data channel (DPDCH) and control channel (DPCCH) in downlink

III. HIGH BIT RATES IN WCDMA

In the WCDMA air interface higher bit rates are realized with lower processing gain – either with variable spreading factor or with multicodes. The interference properties and the performance of those two solutions have been shown to be equal [3][4]. Since the autocorrelation and cross-correlation properties of the spreading codes are not ideal, multipath components interference with each other. If the processing gain is large, this inter-path interference is negligible but with a low processing gain the inter-path interference clearly affects the performance. In TDMA systems this problem is solved with the equalizer.

In the link level simulations the E_b/N_0 performance in different multipath profiles depends on the following factors

1. inter-path interference
2. diversity gain
3. accuracy of the channel estimation with different number of Rake fingers

If we want to observe only the effect of the inter-path interference, we need to know the effect of the diversity gain and the channel estimation. Therefore, in the simulation results we show performance with such a simulation model where the inter-path interference is not modeled but the multipath components are kept orthogonal. In Figure 3 it is shown that the effect of diversity gain is negligible in the received E_b/N_0 values at slow mobile speeds if fast power control is used. It is also shown that the accuracy of the channel estimation does not affect the performance at high bit rates since there is enough energy in the pilot symbols for the channel estimation in multiple Rake fingers.

Since the multipath propagation causes inter-path interference but also provides multipath diversity, the total effect of multipath diversity depends on the bit rate. For very high bit rates the inter-path interference may cause more degradation than what is gained from the multipath diversity.

IV. SIMULATION PARAMETERS

The system parameters for the uplink simulations are shown in Table 2 and for the downlink simulations in Table 3. In the uplink 512 kbps is obtained with a single code transmission supporting an efficient power amplifier operation in the mobile station. In the downlink 2 Mbps is achieved with four parallel code channels. In uplink 1/2 rate convolutional coding is used while in downlink 1/3 coding is used. The frame error rate of packet data transmission is used as a performance measure in this paper. The used packet size is 320 user bits.

Table 2. Uplink 512 kbps simulation parameters

Throughput	(1-FER)*512 kbps
Antenna diversity	2 receiver antennas
Modulation	Dual channel BPSK
DPDCH	
Spreading factor	4
Channel bit rate	1.024 Mbps
Packet size	320 user bits
CRC bits	16
Tail bits	8
Forward error correction (FEC)	1/2-rate convolutional, *K*=9
Rate matching	Puncturing 11008 -> 10240
Total code rate	0.54
Interleaving depth	10 ms
DPCCH (I-Q/code multiplexed)	
Spreading factor	256 (16 kbps)
Pilot bits in slot	6
Power control bits in slot	2
Rate information bits in slot	2
Power difference DPCCH – DPDCH	-10 dB

Table 3. Downlink 2.3 Mbps simulation parameters

Throughput	(1-FER)*2.3 Mbps
Antenna diversity	No antenna diversity
Spreading factor	4
Number of parallel codes	4
Modulation	QPSK
Channel bit rate	8.192 Mbps (4.096 Msymbol/s)
DPDCH	
Number of DPDCH	4
Data bits per slot	5040
Packet size	320 user bits
CRC bits	16
Tail bits	8
Forward error correction (FEC)	1/3-rate convolutional, *K*=9
Rate matching	Repetition 74304 -> 80640
Total code rate	0.31
Interleaving depth	10 ms
DPCCH (Time multiplexed)	
Reference symbols in slot	8 symbol = 16 bits
Power control symbols in slot	1 symbol = 2 bits
Rate information symbols in slot	1 symbol = 2 bits

The simulation environment is described in Table 4.

Table 4. Simulation environment

Multipath profiles	1-, 2- and 3-path Rayleigh fading
Mobile speed	3 km/h
Multiple access interference modeling	Gaussian noise

V. INTER-PATH INTERFERENCE

A. Uplink 512 kbps

The uplink performance of 512 kbps has been simulated both with a chip level simulator and with a symbol level simulator. In the chip level simulator spreading and despreading are modeled with a time resolution of 0.24 µs while in the symbol level simulator only symbol level time resolution is used. In the symbol level simulator multipath components as well as I- and Q-branches are kept separate and orthogonal, therefore, inter-path interference is not modeled.

The received E_b/N_0 requirements with chip and with symbol level models are shown in Figure 3, in Table 5 and in Table 6. The difference in performance between 1-, 2- and 3-path channels with symbol level model is less than 0.2 dB. This indicates that the multipath diversity does not cause differences because of fast power control and slow mobile speed. Also, the difference in the channel estimation between different number of Rake fingers is negligible. Therefore, we can assume that the reason for the difference between chip and symbol level results is the inter-path interference. In these simulations all multipath components have equal average powers.

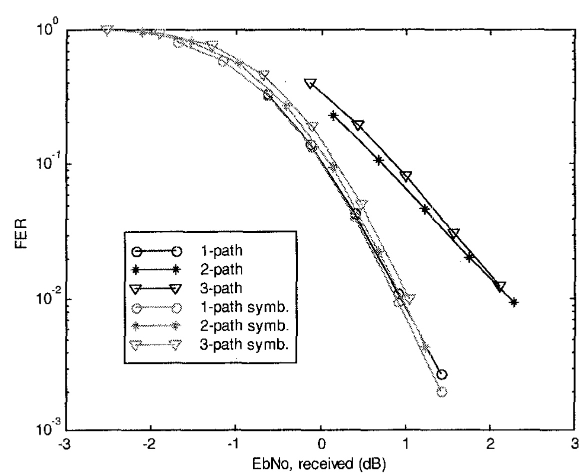

Figure 3. Uplink received E_b/N_0 with chip and with symbol level simulation models at 3 km/h.

Table 5. Uplink 512 kbps performance at FER=10%

	Received E_b/N_0 per antenna		
	Chip level with ISI	Symbol level, no IPI	Degradation due to IPI
1-path	0.0 dB	0.0 dB	No IPI
2-path	0.7 dB	0.1 dB	0.6 dB
3-path	0.8 dB	0.2 dB	0.6 dB

Table 6. Uplink 512 kbps performance at FER=1%

	Received E_b/N_0 per antenna		
	Chip level with ISI	Symbol level, no IPI	Degradation due to IPI
1-path	0.9 dB	0.9 dB	No IPI
2-path	2.2 dB	0.9 dB	1.3 dB
3-path	2.2 dB	1.0 dB	1.2 dB

The simulation results show that the degradation caused by inter-path interference is about 0.6 dB at FER=10%. At lower FER operation points the degradation is larger, at FER=1% about 1.2 dB.

B. Downlink 2.3 Mbps

The downlink simulation results are shown in Figure 4 and for FER=10% in Table 7. With 2.3 Mbps in downlink the degradation due to inter-path interference can be up to 4 dB at FER=10%.

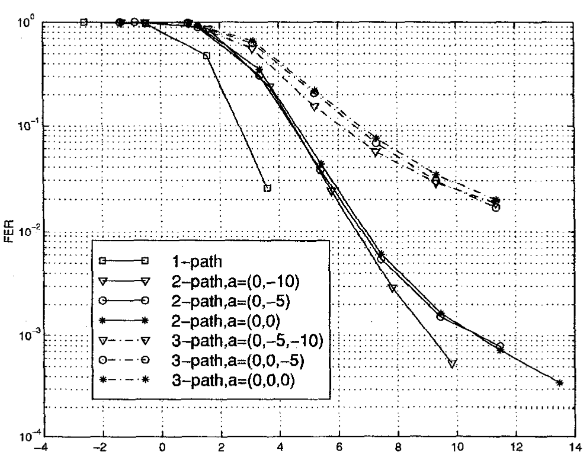

Figure 4. Downlink received E_b/N_0 with inter-path interference at 3 km/h

Table 7. Downlink 2.3 Mbps performance at FER=10%

	Received E_b/N_0	
	Chip level with ISI	Degradation due to IPI
1-path	2.7 dB	No IPI
2-path	4.6 dB	1.9 dB
3-path	6.1 dB – 6.8 dB	3.4 dB – 4.1 dB

C. Inter-path interference cancellation

The degradation due to inter-path interference could be mitigated by using an advanced receiver structure where interference would be cancelled. The implementation of such a receiver would not be excessively complex because only self-interference would be cancelled and the cancellation does not need information about the other users. The maximum gains from such a receiver structure could be up 4 dB with 2 Mbps.

Different multiuser detection techniques can be applied to reduce the inter-path interference. Those techniques are presented for example in [5]. If more than 1 receiver antenna is available, interference rejection techniques can be applied. Interference rejection combining for WCDMA is presented in [6].

VI. Multipath Diversity Gain

The multipath propagation causes inter-path interference but provides also multipath diversity. At low mobile speeds this diversity gain can be seen in the transmitted powers which are lower with diversity. In Figure 5 the average required transmitted powers in uplink with 512 kbps are shown. The highest average transmission power is needed in 1-path channel even if there is no inter-symbol interference. In Table 8 the effect of multipath propagation for 512 kbps is shown in transmitted powers. The transmission power is 1.2 dB lower in 2-path channel than in 1-path channel. In 3-path channel the transmission power is even lower. In the following figures the transmitted E_b/N_0 refers to the transmitted powers and those values are normalized in the same was as the received E_b/N_0 values. The average attenuation of the channel is 0 dB.

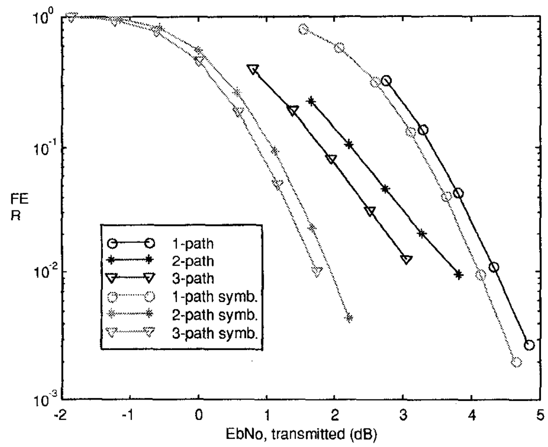

Figure 5. Uplink transmitted E_b/N_0 with chip and with symbol level simulation models with 512 kbps at 3 km/h

Table 8. Effect of multipath propagation in uplink transmission powers at FER=10%. Bit rate 512 kbps. Receiver antenna diversity used.

	Transmitted E_b/N_0, with inter-path interference	Total multipath gain including inter-path interference
1-path	3.4 dB	-
2-path	2.2 dB	1.2 dB
3-path	1.8 dB	1.6 dB

In Figure 6 the downlink transmission powers are shown with 2 Mbps and the effect of multipath propagation is summarized in Table 9. At FER=10 % 2-path and 3-path results are equal and the required transmission power is 2-3 dB less than in 1-path channel. At FER=1% the effect of inter-path interference is larger than at FER=10%.

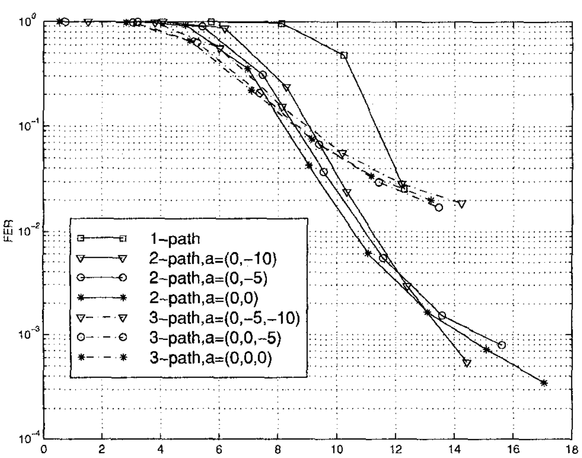

Figure 6. Downlink transmitted E_b/N_0 with chip and with symbol level simulation models with 2 Mbps at 3 km/h

Table 9. Effect of multipath propagation in downlink transmission powers at FER=10%. Bit rate 2 Mbps. No receiver antenna diversity used.

	Transmitted E_b/N_0, with inter-path interference	Total multipath gain including inter-path interference
1-path	11.3 dB	-
2-path	8.2 – 9.1 dB	2.2 – 3.1 dB
3-path	8.6 – 9.1 dB	2.2 – 2.7 dB

The total multipath gain is larger in downlink than in uplink because receiver antenna diversity is assumed for the base station in uplink but not for the mobile station.

VII. Conclusions

The performance of high bit rates with UTRA WCDMA in multipath channels has been simulated. The effect of inter-path interference and multipath diversity has been evaluated with link level simulations. It is shown that 2 Mbps is feasible with 5 MHz WCDMA in multipath channels. The inter-path interference can cause a degradation of about 2 dB for 2 Mbps transmission in 2-path Rayleigh fading channel if an ordinary Rake receiver is used. The more multipath components are present, the higher the degradation. This degradation could be reduced with advanced receiver structures and algorithms. It is also shown that the required transmission power is in most cases in multipath channels lower than in 1-path channel due to multipath diversity gain.

VIII. References

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