WIDEBAND CDMA PACKET DATA WITH HYBRID ARQ

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ABSTRACT

The performance of wideband CDMA packet data with soft combining of packets is analysed in this paper. First, the main parameters of WCDMA (wideband CDMA) are presented. WCDMA refers here to the air interface that was decided by ETSI to be standardised for UMTS air interface for paired bands [1]. Secondly, the WCDMA packet transmission scheme with soft combining of packets is introduced. Soft combining indicates here the combining of the soft values of the unsuccessful transmission with the retransmission before feeding them to the channel decoder. The performance of soft combining is compared to the performance of non-combining packet solution. The results show that soft combining can increase capacity and extend cell range up to 2 dB against Gaussian noise if no fast power control is used. With fast power control the gain is 0.3-2.0 dB. Soft combining can also be used to decrease the maximum packet delays. In this paper it is also shown that using slow power control instead of fast power control can increase packet data capacity in downlink.

1. INTRODUCTION

The performance of WCDMA packet data with type-I hybrid ARQ is studied in this paper. The capacity gains of applying soft combining of packets is evaluated both with and without fast power control. The performance evaluation is based on the link level simulations. In the simulations WCDMA transmitter and receiver are modelled together with fading multipath radio channel. The air interface is modelled according to the ETSI WCDMA specification.

The paper is organised as follows. In Section 2 the main parameters of WCDMA physical layer are shown. The principles of soft combining of packets is introduced in Section 3. The simulation parameters are shown in Section 4 and the simulation results are presented in Section 5. In Section 6 implementation aspects of soft combining in WCDMA are discussed. Finally, conclusions are drawn in Section 7.

2. OVERALL DESCRIPTION OF WCDMA PHYSICAL LAYER

The main features of WCDMA physical layer are summarised in Table 1 [1].

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

Multiple access method	DS-CDMA
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 • Continuous transmission in the uplink • Rate changes dynamically frame-by-frame
Rate detection	• Rate information in each frame protected with a block code and/or • Blind rate detection
Interleaving	Intra-frame / inter-frame interleaving
Spreading factors	1 to 256
Spreading codes	UL: Orthogonal variable spreading codes, long scrambling codes, optional short scrambling codes DL: Orthogonal spreading codes, long scrambling codes
Modulation	UL: Dual channel QPSK with complex scrambling DL: QPSK
Pulse shaping	Root raised cosine, roll-off = 0.22
Intra-frequency handover	Mobile controlled soft handover, hard handover possible for packets
Inter-frequency handovers	Hard handover
Inter-frequency measurements	Dual receiver / slotted mode
Detection	UL/DL: Coherent detection (reference symbol based)
Power control	UL: Open loop and fast closed loop DL: Fast closed loop

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.

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Dedicated physical data channel (DPDCH) is used to transmit data generated at layer 2 and above. Figure 1 shows the principle of the frame structure for the uplink DPDCH. Each DPDCH frame on a single code carries $160*2^k$ bits ($16*2^k$ kbps), where k=0,1...8, 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 signalling bits and rate information for rate detection.

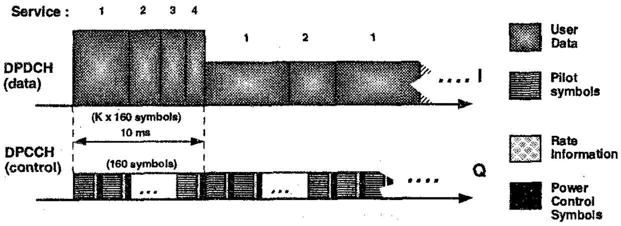

Figure 1. Physical data channel (DPDCH) and control channel (DPCCH)

3. SOFT COMBINING OF PACKETS IN WCDMA

Error control schemes can be classified into Forward Error Correction (FEC) and Automatic Repeat reQuest (ARQ) schemes. The combination of these two is called as a hybrid ARQ. There are two basic properties that differentiate the various hybrid ARQ schemes [2]

- Are the original packet and the retransmitted packets combined?
- Is any incremental redundancy transmitted in the re-transmissions?

In type-I hybrid ARQ schemes incremental redundancy is not transmitted in the retransmissions but the original packet and the retransmissions corresponding to it are identical. In the basic version of type-I hybrid ARQ scheme, if an error is detected in the packet, that packet is simply discarded. Type-I hybrid ARQ without combining is known to be best suited for channels that have a fairly constant signal to interference ratio (SIR) [2]. The reason is that FEC can be designed for that particular SIR. At low mobile speeds the received SIR is fairly constant in WCDMA because of the fast power control.

The performance of the basic type-I hybrid ARQ can be improved if the unsuccessful transmissions are not discarded but the received samples are used together with the retransmission to detect the packet. By using soft combining all transmitted data is used for detection thus reducing unnecessary interference.

Soft combining of the packets affects also the transmission delays. Let's assume that non-combining packet transmission operates at FER=10 % after the first transmission and also assume that the frame errors are uncorrelated. In Table 2 the delay distribution of the packets without combining are calculated. It is assumed that each retransmission requires 3 frames (30 ms) additional delay and there are no errors in the feedback channel.

Table 2. Delay distribution without combining

Number of transmissions	Probability	Delay
1	90 %	10 ms
2	10 %	40 ms
3	1 %	70 ms
4	0.1 %	100 ms
5	10^{-4}	130 ms
6	10^{-5}	170 ms
7	10^{-6}	200 ms

With soft combining the number of 3rd, 4th etc. transmissions could be reduced and so the maximum delay will be shorter. Therefore, ARQ with soft combining could be used to support long delay real time services.

Fast power control in WCDMA keeps the received SIR fairly constant. That enables efficient transmission of low delay real time services, like speech. However, for non-real time services another approach is to rely on retransmissions during channel fades instead of increasing transmission power through fast power control. The performance of packet transmission with and without fast power control is compared in this paper. The case without fast power control occurs if the power amplifier is working close to its maximum power at the cell border and cannot utilise full dynamics. Also, it is possible to apply slow power control in WCDMA downlink since the downlink fast power control is not needed to prevent near-far effects as in uplink.

4. SIMULATION PARAMETERS

The performance comparisons are done with link level simulations where WCDMA transmitter and receiver are modelled together with fading multipath radio channel. The air interface is modelled according to ETSI WCDMA specification. The performance is evaluated against Gaussian noise both with fast power control and without fast power control. In downlink no explicit intra-cell interference is modelled. Constant level Gaussian noise corresponds to the downlink case when the mobile is close to the cell edge. Simulations are run in ITU Outdoor-to-Indoor A fading channel [4] at model mobile speeds of 3 km/h and 120 km/h. The simulations are done with 32 kbps user bit rate where one 10 ms physical frame contains one packet. The results of these simulations can also be used to evaluate the performance of higher bit rates where one physical frame contains several packets. The simulation parameters are shown in Table 3.

Table 3. Simulation parameters

Transmission direction	Downlink
Service	
Bit rate	32 kbps
Throughput	(1-FER)·bit rate
Retransmission block size (packet size)	320 bits
CRC bits	16 bits
Tail bits	8 bits
Physical layer	
Spreading factor	64
Modulation	QPSK
Symbol rate	128 kbps (64 ksymbol/s)
DPCCH	
Reference symbols per slot	4
PC symbols per slot	1
RI symbols per slot	1
DPDCH	
Data symbols per slot	34
Forward error correction (FEC)	1/3-rate convolutional code (K=9)
Rate matching	1032 -> 1088 (repetition)
Total FEC rate	0.29
Interleaving	10 ms
Fast power control	1.6 kHz, 1 dB step size, 1 % error ratio in feedback channel
Environment	
Multipath profile	ITU Outdoor-to-indoor A 2 taps: 0 dB and –12.5 dB
Mobile speed	3 km/h and 120 km/h
Interference modelling	Gaussian noise
Mobile receiver	
Receiver antenna diversity	No
Other assumptions	
Feedback channel for retransmissions	Error-free

5. SIMULATION RESULTS

The effect of soft combining on the capacity is analysed both in terms of the required received energy per user bit and the required transmitted energy per user bit. In case of transmitted energy only fast fading is considered, no path loss or shadowing is taken into account. When fast power control is used, the transmitted energy is higher than the receiver energy. Without fast power control those two measures are the same if the average power of the channel is equal to 1. The required received energy in uplink determines how much intra-cell interference is generated. The required transmitted energy determines how much interference is generated in downlink and how much inter-cell interference in uplink. In downlink we can compared the transmitted energies to estimate the differences in the radio network capacity. The transmitted energies also determine the maximum cell range.

Figure 2 shows the throughput as a function of the required received E_b/N_0 with and without fast power control and with and without combining at 3 km/h. With soft combining the throughput is higher for low E_b/N_0 than without combining. Figure 3 presents the corresponding transmitted powers. With fast power control the transmitted powers are about 5 dB higher than received powers. At transmitted E_b/N_0 values below 12 dB the throughput is higher without fast power control than with fast power control. Soft combining gives higher throughput than non-combining solution especially without fast power control. The results at 120 km/h are shown in Figures 4 and 5. At 120 km/h the effect of fast power control is smaller than at 3 km/h because fast fading cannot be compensated.

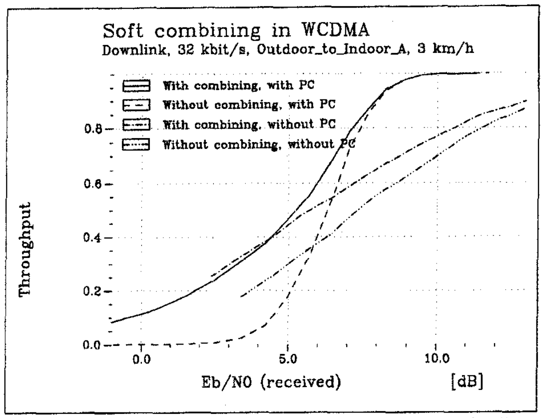

Figure 2. Throughput vs. E_b/N_0 (received) at 3 km/h

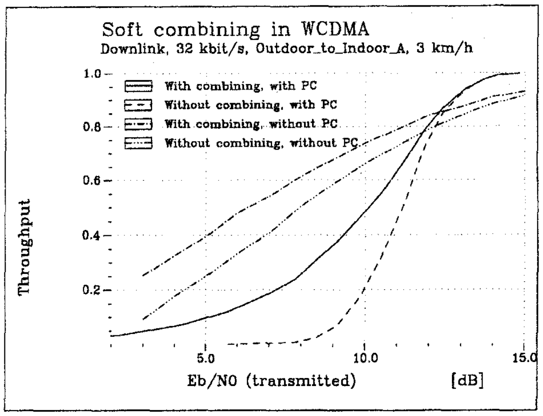

Figure 3. Throughput vs. E_b/N_0 (transmitted) at 3 km/h

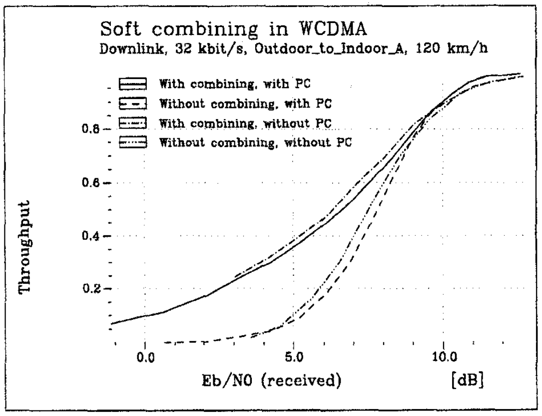

Figure 4. Throughput vs. E_b/N_0 (received) at 120 km/h

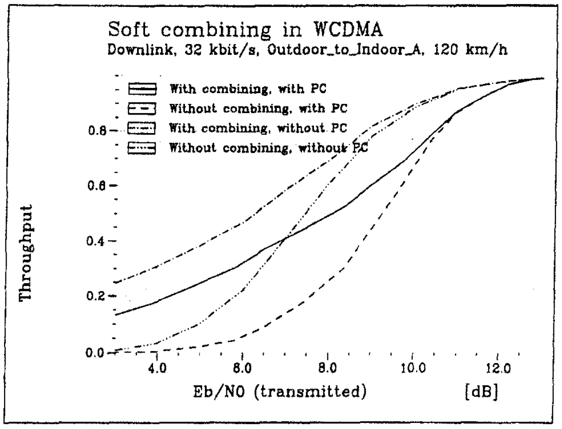

Figure 5. Throughput vs. E_b/N_0 (transmitted) at 120 km/h

In Figures 6-9 in x-axis E_b = energy per user bit in channel during one transmission and in y-axis E_b = energy per correctly received user bit.

$$\frac{E_b}{N_0}_{y\text{-}axis} = \frac{\dfrac{E_b}{N_0}_{x\text{-}axis}}{throughput} \qquad (1)$$

The lower the E_b/N_0 in y-axis, the less interference is needed to transmit the data and the higher is the capacity. The minimum of that curve gives the highest capacity. In downlink the capacity directly depends on the required transmitted powers.

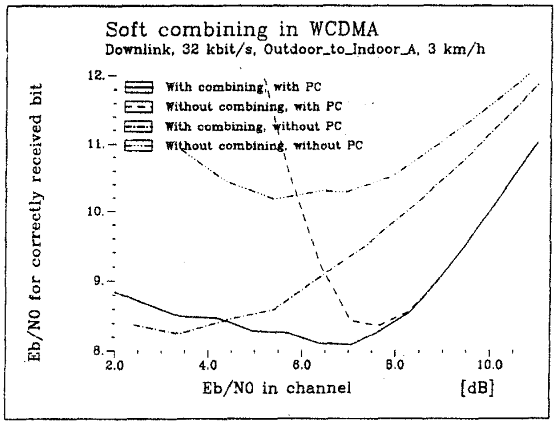

Figure 6. E_b/N_0 (received) for correctly received bit vs. E_b/N_0 in channel at 3 km/h

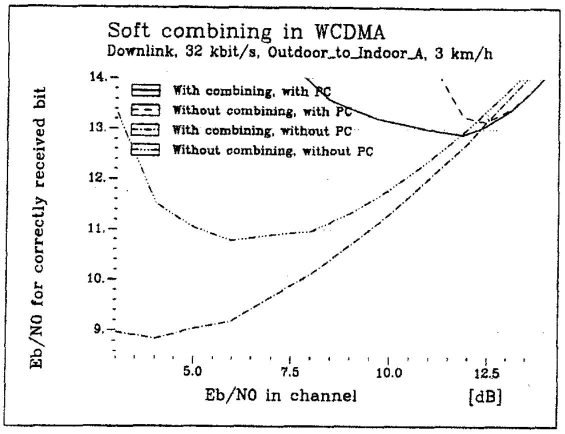

Figure 7. E_b/N_0 (transmitted) for correctly received bit vs. E_b/N_0 in channel at 3 km/h

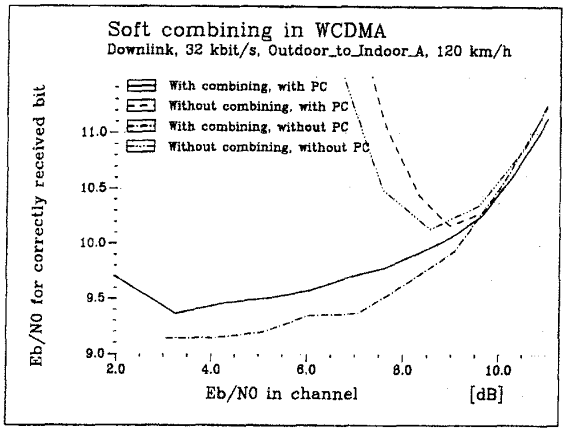

Figure 8. E_b/N_0 (received) for correctly received bit vs. E_b/N_0 in channel at 120 km/h

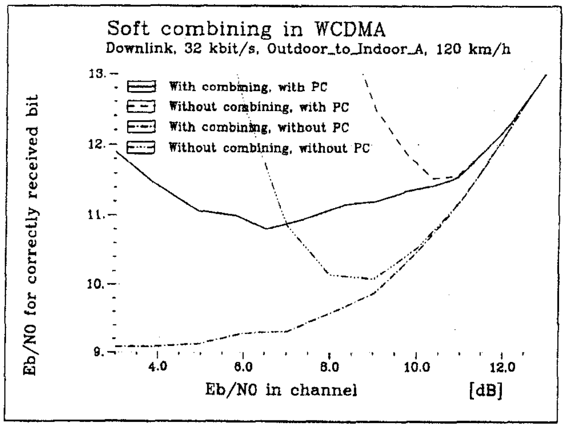

Figure 9. E_b/N_0 (transmitted) for correctly received bit vs. E_b/N_0 in channel at 120 km/h

The simulation results are summarised in Table 4.

Table 4. Capacity gain with soft combining

	Minimum required E_b/N_0 for correctly transmitted bit		
Packet combining	**No**	**Soft**	**Gain by combining**
3 km/h, with fast PC, received energy	8.4 dB	8.1 dB	0.3 dB
3 km/h, with fast PC, transmitted energy	13.2 dB	12.9 dB	0.3 dB
3 km/h, no fast PC, received energy	10.2 dB	8.2 dB	2.0 dB
3 km/h, no fast PC, transmitted energy	10.8 dB	8.8 dB	2.0 dB
120 km/h, with fast PC, received energy	10.2 dB	9.4 dB	0.8 dB
120 km/h, with fast PC, transmitted energy	11.5 dB	10.8 dB	0.7 dB

At mobile speed of 3 km/h the required transmitted energy is 2.4 dB (13.2 dB vs. 10.8 dB) lower without fast power control than with fast power control. The disadvantage of not using fast power control will be that the transmission delays will be longer when channel is faded, i.e. low delays cannot be guaranteed. Introducing soft combining without fast power control further reduces the transmitted interference 2 dB from 10.8 dB to 8.8 dB. At high mobile speeds (120 km/h) the gain from soft combining is 0.7 dB..0.8 dB.

It should be noticed that with soft combining the curves in Figures 6-9 are quite flat, i.e. the changes in the E_b/N_0 operation point do not affect dramatically the capacity. With fast power control and without combining, the efficient E_b/N_0 operation area is narrow. This flexibility in the E_b/N_0 operation point with soft combining gives freedom for the WCDMA radio network load control and enables quick reactions to overload situations.

6. IMPLEMENTATION CONSIDERATIONS

Before applying layer 1 soft combining to WCDMA concept, the following implementation aspects need to be considered.

Soft combining requires that ARQ is controlled by layer 1 because layer 1 must know exactly which packets are being received in order to combine the packets correctly.

In the receiver memory is needed to store the soft values of the unsuccessful transmissions to be combined with the following retransmissions.

The highest capacity with soft combining is given at fairly low E_b/N_0 values where 1-3 transmissions are typically needed. The average total code rate including FEC and ARQ can be quite low. With low code rate more resources are needed at the physical layer. In WCDMA downlink the number of orthogonal codes is limited and it may limit the choice of the optimal operation point. More downlink codes are available but those are not orthogonal.

If the retransmissions have the same FER as the data packets and FER operation point is high, additional delays will be introduced due to erroneous retransmission requests. In that case more powerful coding is needed for the retransmission requests than for data packets. Also, when more retransmissions are required, more signalling is needed in the other transmission direction. causing more interference

In uplink macro diversity combining with soft values is not feasible because it would require transmission of soft values over the I_{bis} interface between base station and macro diversity combining point. Uplink soft combining can be done within one base station.

In Section 5 average transmission powers are compared. With fast power control the variation of the transmitted power is higher than without power control. These variations set higher requirements for the power amplifier design because some headroom is needed for the power control dynamics.

7. CONCLUSIONS

It has been shown that adding soft combining to type-I hybrid ARQ packet data in WCDMA can give a gain of 0.3-2.0 dB in capacity and in cell range compared to the non-combining solution. The gain depends on the amount of diversity and on the mobile speed. The effect of fast power control has also been studied. For non-real time services in downlink slow power control has been shown to give up to 2.5 dB higher capacity than fast power control.

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