Simulated and Measured WCDMA Uplink Performance

Harri Holma, David Soldani and Kari Sipilä
Nokia Networks, IP Mobility Networks,
P.O. Box 301, FIN-00045 Nokia Group, FINLAND
fax: +358-9-51130040, tel: +358-40-5232609
email: harri.holma@nokia.com

Abstract - **This paper studies the WCDMA mobile transmission power and its variations due to fast power control with theoretical calculations, simulations, laboratory measurements and field measurements. The effect of mobile speed, multipath profile and base station reception antenna diversity is studied. The results show that the mobile speed of 120 km/h requires less transmission power than low mobile speeds because of time diversity provided by interleaving. With little multipath diversity and without antenna diversity the difference in terms of transmitted power is up to 2 dB. The measurements and simulations show that the multipath diversity gain of ITU Vehicular A channel compared to ITU Pedestrian A channel is 3 dB without antenna diversity and 1 dB with antenna diversity at 3km/h. At higher mobile speeds the multipath diversity gains are smaller. The base station antenna diversity gain is shown to be 3–4 dB in ITU Vehicular A channel and 4–6 dB in ITU Pedestrian A channel. The results show good agreement between simulations and measurements. The results also showed inaccuracies in the implementation of the SIR estimation in the experimental WCDMA base station receiver.**

I. INTRODUCTION

This paper studies the link level performance of WCDMA uplink with theoretical calculations, with simulations and with measurements in the laboratory and in the field. The WCDMA mobile transmission power and its variations due to fast power control are studied. The effect of mobile speed, multipath profile and base station reception antenna diversity is evaluated.

The understanding of the WCDMA uplink performance is needed to model accurately the link budget and to evaluate the coverage of the WCDMA system both in the dimensioning and in the network planning phases. The WCDMA macro cell coverage is shown to be uplink limited [1].

The comparison of simulations and measurements can be used to analyse the performance of implemented algorithms and to verify that the simulation assumptions are correct.

This paper is organised as follows. Section 2 presents theoretical calculations of the power distribution. The simulation assumptions are presented in Section 3 and the laboratory measurement setup is shown in Section 4. The simulations and the laboratory measurements are compared in Section 5 and the results of the field measurements are presented in Section 6. The conclusions are drawn in Section 7.

II. THEORETICAL CALCULATIONS

The ideal power control would be able to control the transmit power of the mobile so that the received power and thus the received E_b/N_0 would be constant. If the instantaneous multipath channel gain was X (with average value of 1) then the transmit power would be directly proportional to 1/X omitting the large scale of propagation loss. Fig. 1 shows the distribution of 1/X for the ITU Pedestrian A and Vehicular A multipath channel profiles. The average channel gain has been normalised to 1. The distribution has been calculated assuming 2-branch antenna diversity with uncorrelated antennas. The variance of the transmit power, calculated directly from the distribution in dB scale is 9.7 dB for the ITU Pedestrian A channel and 3.5 dB for the ITU Vehicular A channel.

III. SIMULATION ASSUMPTIONS

A link level simulation chain was built to evaluate the uplink transmitted powers in WCDMA. The main output of the simulations is the average required transmission power and the distribution of the power. Both uplink and downlink chains are modelled in the simulation environment. The downlink direction is used to generate real power control signalling errors to the uplink power control. The main simulation parameters are shown in Table I. Further simulation results with the same simulation model are presented in [2] and in [3].

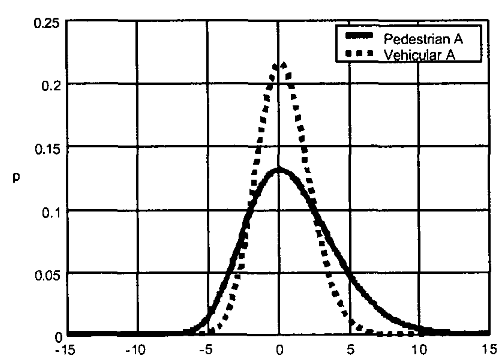

Fig. 1. Transmit power distribution relative to average channel gain in the case of ideal power control

TABLE I
SIMULATION PARAMETERS

Bit rates	8 kbps speech
FER target in the outer loop power control	1%
Channel estimation	From pilot symbols, average of three slots in uplink and two slots in downlink
Number of Rake fingers per antenna M	2 for Pedestrian A 5 for Vehicular A
Interleaving depth	10 ms, 1 radio frame
Power control signalling errors in downlink	Real downlink connection modelled
Power control delay	Inner loop: 1 time slot = 0.625 ms Outer loop: 1 radio frame = 10 ms
Power control step	Inner loop: 1 dB Outer loop: 0.5 dB
Mobile speeds	3 km/h and 50 km/h
Antenna diversity	Uncorrelated antennas

ITU Vehicular A and ITU Pedestrian A channel profiles are used in the simulations and also in the laboratory measurements using a channel emulator. The channel profiles are presented in Table II.

ITU Pedestrian A channel model is used in these simulations to study the effect of low multipath diversity case. ITU Pedestrian A channel is close to 1-path channel and does not give much multipath diversity while ITU Vehicular A channel gives quite significant multipath diversity.

IV. LABORATORY MEASUREMENTS SETUP

WCDMA experimental system was used to evaluate the uplink performance both in the laboratory conditions with channel emulator and in the field measurements. The experimental system is shown in Fig. 8. Other field measurements with this system are presented in [4] [5]. The laboratory measurement setup is illustrated in Fig. 2 and the main measurement parameters are shown in Table III.

TABLE II
ITU VEHICULAR A AND ITU PEDESTRIAN A CHANNEL MODELS, TAPS IN CHIP RESOLUTION

	Pedestrian A	Vehicular A
Tap 1	0.0 dB	0.0 dB
Tap 2	−12.5 dB	−2.4 dB
Tap 3	-	−6.5 dB
Tap 4	-	−9.4 dB
Tap 5	-	−12.7 dB

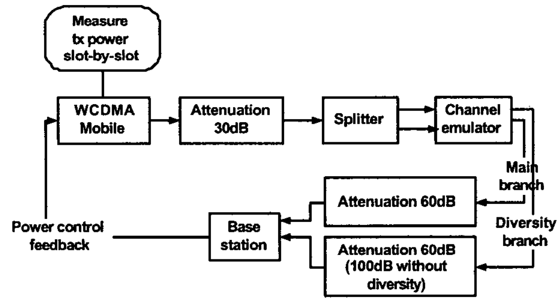

Fig. 2. Laboratory measurement setup

TABLE III
LABORATORY MEASUREMENT PARAMETERS

Bit rate	8 kbps
FER target in the outer loop power control	1%
Channel estimation and Rake allocation	From pilot symbols
Number of Rake fingers per connection	8
Interleaving depth	10 ms, 1 radio frame
Multipath profiles	ITU Pedestrian A ITU Vehicular A
Antenna diversity	Uncorrelated antennas
Main output	Mobile transmission power, recorded slot-by-slot

V. COMPARISON OF RESULTS

The results of the simulations and the laboratory measurements are shown in this section. The effect of mobile speed, multipath profile and base station reception antenna diversity is studied.

A. Effect of Mobile Speed

The measurement results are scaled so that the average transmission power over all channel profiles at 3 km/h is the same as the corresponding simulation results. With that approach we can compare the differences between the terminal transmitted powers at different mobile speeds in the simulations and in the measurements.

The differences between the required transmission powers depending on the mobile speed are shown in Table IV. In here, we compare the required average transmission power at 20 km/h and at 120 km/h to the required average transmission power at 3 km/h. We can notice that the measured transmission power is higher than the simulated transmission power at 20 km/h, especially without antenna diversity. The mobile speed of 20 km/h is such a speed where the fast power control cannot any more fully compensate the fast fading, and also the interleaving of 10 ms cannot provide proper time diversity. The accurate performance of fast power control is important for the performance at 20 km/h. These results reveal that there are some inaccuracies in the implementation of the SIR estimation in the measurement set-up.

The measured performance at 120 km/h relative to 3 km/h is better than in the simulations. With the mobile speed of 120 km/h the fast power control does not affect the results because fading is so fast. The mobile speed of 120 km/h corresponds to the Doppler frequency of about 220 Hz while the power control frequency is 1600 Hz. There are only a few power control commands per fade and it is not enough to compensate the fading. Therefore, the results at 120 km/h only show the performance of the receiver channel estimation and detection, which is better than in the simulations.

The variance of the mobile transmission power is shown in Fig. 3 in the case of ITU Pedestrian A channel. The variance is higher with low mobile speed, because the fast power control is able to follow fast fading, and thus increasing variance of the transmission power. The differences between the measurements and the simulations are small and they can be explained by the SIR estimation inaccuracies. At 3 km/h the inaccurate SIR estimation causes that the fast power control is not able to follow fast fading as well as in the simulations. On the other hand, at 120 km/h the inaccurate SIR estimation causes just an unnecessary increase in the variance of the mobile transmission power.

TABLE IV
EFFECT OF THE MOBILE SPEED

Multipath profile	Rx div	Mobile speed km/h	Simulated Tx power	Measured Tx power
ITU Ped A	No	3	-	-
	No	20	0.0 dB	1.4 dB
	No	120	-2.0 dB	-2.5 dB
ITU Ped A	Yes	3	-	-
	Yes	20	0.5 dB	0.8 dB
	Yes	120	-0.5 dB	-1.6 dB
ITU Veh A	No	3	-	-
	No	20	-0.2 dB	1.7 dB
	No	120	-0.7 dB	0.1 dB
ITU Veh A	Yes	3	-	-
	Yes	20	0.0 dB	0.5 dB
	Yes	120	0.0 dB	0.0 dB
Average		**3 km/h**	**-**	**-**
over all		**20 km/h**	**0.1 dB**	**1.1 dB**
4 cases		**120 km/h**	**-0.8 dB**	**-1.0 dB**

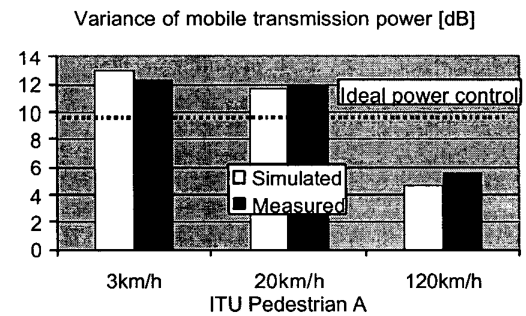

Fig. 3. Variance of mobile transmission power

The variance of the transmission power is higher in the simulations and in the measurements compared to the ideal power control of Section 2, which gives a variance of 9.7 dB. The reason is the non-ideal power control in practise that is caused by SIR estimation errors, power control feedback errors and delays, and fixed power control step size and dynamics.

B. Effect of Antenna Diversity

The reduction in the average mobile transmission powers with base station antenna diversity compared to 1-antenna reception are shown in Table V and are referred here as antenna diversity gains. The measured antenna diversity gains are close to the simulated values. The higher gain at 20 km/h can be explained by the worse performance without diversity at 20 km/h, which was discussed in Section A.

In Vehicular A multipath the base station antenna diversity gain is 3.0–3.7 dB including both the simulations and the measurements. In ITU Pedestrian A the antenna diversity gain is higher because Pedestrian A channel has less multipath diversity: 4.0–5.9 dB including both the simulations and the measurements.

TABLE V
ANTENNA DIVERSITY GAINS

Multipath profile	Mobile speed	Div gain in simu-lations	Div gain in lab measurements	Difference
Static	-	-	2.8 dB	
ITU Ped A	3 km/h	5.5 dB	5.3 dB	-0.2 dB
ITU Ped A	20 km/h	5.0 dB	5.9 dB	0.9 dB
ITU Ped A	120 km/h	4.0 dB	4.4 dB	0.4 dB
Average in ITU Ped A		**4.8 dB**	**5.2 dB**	**0.4 dB**
ITU Veh A	3 km/h	3.7 dB	3.3 dB	-0.4 dB
ITU Veh A	20 km/h	3.5 dB	3.5 dB	0.0 dB
ITU Veh A	120 km/h	3.0 dB	3.4 dB	-0.4 dB
Average in ITU Veh A		**3.4 dB**	**3.4 dB**	**0.0 dB**

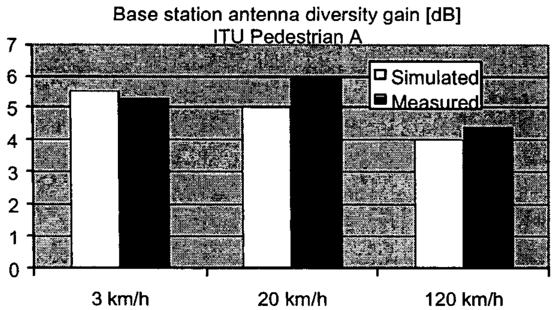

Fig. 4. Base station antenna diversity gain in ITU Pedestrian A

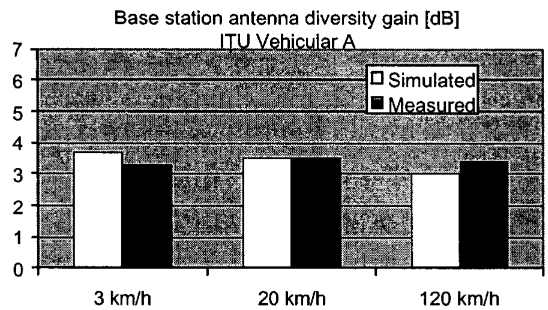

Fig. 5. Base station antenna diversity gain in ITU Vehicular A

C. *Effect of Multipath Diversity*

The reduction in the average mobile transmission powers with multipath diversity is shown in Table VI. ITU Vehicular A represents here channel with quite much multipath diversity while ITU Pedestrian A represents here channel with little multipath propagation. The multipath diversity gain in here is the difference between the required transmission power in ITU Pedestrian A and in ITU Vehicular A.

The multipath diversity gain at low mobile speed of ITU Vehicular A channel compared to ITU Pedestrian A channel is 2.8 dB in the simulations and 3.3 dB in the measurements without antenna diversity. With antenna diversity the corresponding gains are 1.0 dB and 1.3 dB. At higher mobile speeds the multipath diversity gains are smaller both in the simulations and in the measurements.

The measured multipath diversity gains are close to the simulated values. The higher gain at 20 km/h in the measurements can be explained by the worse performance without diversity at 20 km/h, which was discussed in Section A.

TABLE VI
MULTIPATH DIVERSITY GAINS (=ITU VEHICULAR A VS. ITU PEDESTRIAN A)

Mobile speed	**Rx diversity**	**Div gain in simulations**	**Div gain in lab measurements**	**Difference**
3 km/h	No	2.8 dB	3.3 dB	0.5 dB
20 km/h	No	3.0 dB	4.0 dB	1.0 dB
120 km/h	No	1.5 dB	0.7 dB	-0.8 dB
Average without rx diversity		**2.4 dB**	**2.7 dB**	**0.3 dB**
3 km/h	Yes	1.0 dB	1.3 dB	0.3 dB
20 km/h	Yes	1.5 dB	1.6 dB	0.1 dB
120 km/h	Yes	0.5 dB	-0.3 dB	-0.8 dB
Average with rx diversity		**1.0 dB**	**0.9 dB**	**-0.1 dB**

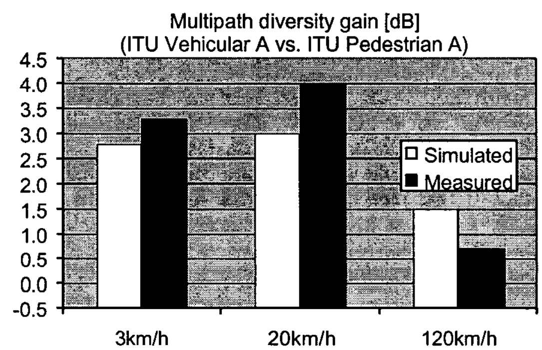

Fig. 6. Multipath diversity gain without antenna diversity

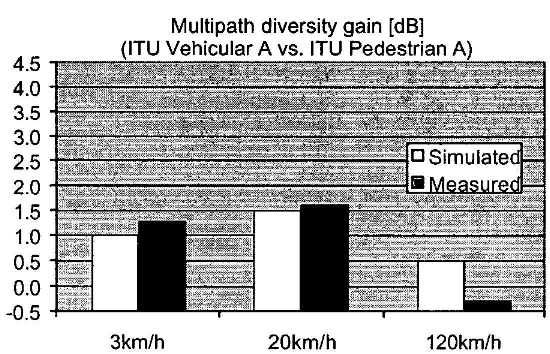

Fig. 7. Multipath diversity gain with antenna diversity

VI. Field Measurements

The measurement set-up in the field measurements is shown in Fig. 8. The same equipment was used as in the laboratory measurements. Mobile Control Centre - Simulator (MCC-SIM) corresponds to Radio Network Controller (RNC) and is responsible for outer loop power control and for handovers.

Polarisation diversity and space diversity antennas were used. The mobile antenna was located within the measurement van in the vertical position.

The distribution of the mobile transmission power with low mobile speed is shown in Fig. 9. The average variance is 7 dB. The variance has been calculated by taking first the average over 2 meters, and then calculating the variance around that mean value. In the laboratory measurements of Fig. 3 the variance with 3 km/h in ITU Pedestrian A channel was 12 dB. The variance of 7dB in the field measurements shows that there was clearly more multipath diversity in the measurements environment than in ITU Pedestrian A channel model. The measurement environment was sub-urban type.

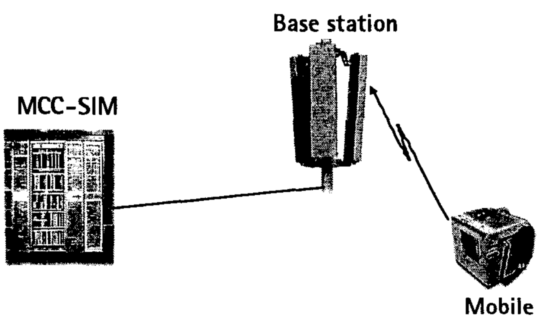

Fig. 8. WCDMA experimental system

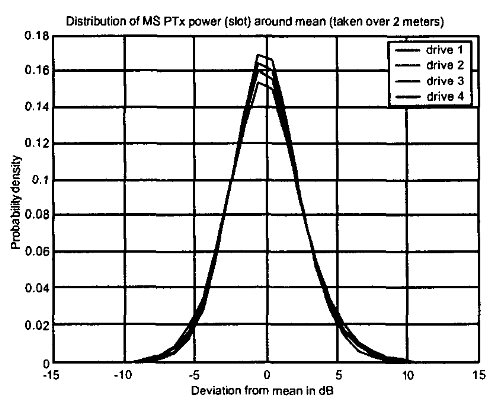

Fig. 9. Variance of the mobile power in the field measurements

VII. Conclusions

The WCDMA mobile transmission power and its variation due to fast power control in fading channels was studied in this paper by a theoretical calculation, link level simulations, laboratory measurements and field measurements.

The results showed that the mobile speed of 120 km/h requires less transmission power than low mobile speeds because of time diversity provided by interleaving. With little multipath diversity and without antenna diversity the difference was up to 2 dB.

The multipath diversity gain of ITU Vehicular A channel compared to ITU Pedestrian A channel was 3 dB without antenna diversity and 1 dB with antenna diversity at 3 km/h. At higher mobile speeds the multipath diversity gains were smaller.

The antenna diversity gain both in simulations and in measurements was 3-4 dB in ITU Vehicular A channel and 4–6 dB in ITU Pedestrian A channel.

The results showed good agreement between simulations and measurements. The results also revealed inaccuracies in the implementation of the SIR estimation in the experimental receiver.

The field measurements showed that clearly more multipath diversity could be obtained in the measurement environment than in ITU Pedestrian A channel model.

VIII. Acknowledgements

The authors would like to acknowledge the suggestions and the contributions from several colleagues within Nokia Networks.

IX. References

[1] Holma H. & Toskala A. (Editors.) "WCDMA for UMTS", John Wiley & Sons, April 2000, 344 p.

[2] Tölli A. "Comparison of Different Uplink Antenna Array Configurations for WCDMA Base Station", M.Sc. E.E. Thesis, University of Oulu, Finland, 2000, 96 p.

[3] Tölli A. & Holma H. "Comparison of WCDMA Uplink Antenna Solutions with 4 Receiver Branches", CDMA International Conference (CIC), South Korea, October, 2000.

[4] Grandell J. & Salonaho O. "Macro cell measurements with the Nokia WCDMA Experimental System", IEE Antennas and Propagation Conference, Manchester, April 2001

[5] Holma, H. and Tölli A. "Simulated and Measured Performance of 4-branch Uplink Reception in WCDMA", VTC'2001 Spring in Rhodes Islands, Greece.