SIMULATED AND MEASURED PERFORMANCE OF 4-BRANCH UPLINK RECEPTION IN WCDMA

Harri Holma and Antti Tölli

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

In the initial deployment phase of the WCDMA networks the coverage is important to be able to provide 3G services to as many customers as possible, and to reduce the required number of base station sites and the related costs. It is shown in [1] that the WCDMA macro cell coverage is uplink limited. In this paper a base station four-branch receiver antenna solution is studied using simulations and field measurements as an approach to increase the coverage area of the WCDMA cell. The effect of the four-branch reception to the uplink capacity is also studied.

The simulations show that the four-branch reception gives an average coverage gain of 3 dB compared to the traditional two-branch receiver diversity in ITU Vehicular A channel. When the amount of multipath diversity is lower, like in ITU Pedestrian A channel, the gain is higher – up to 4 dB. The four-branch reception can be implemented with two polarisation diversity antennas. When the correlation of those antennas is 1.0, i.e. the antennas are very close to each other, the gain reduces by 0.5 dB to 2.5 dB in ITU Vehicular A channel.

The field measurements indicate an average reduction of 3 dB in the mobile transmission power, which is well in line with the simulation results. When the antennas are close to each other, the gain is reduced 0.3–0.4 dB which is also close to the corresponding simulation result.

1. INTRODUCTION

The coverage of the WCDMA networks determines the number of required cell sites in the initial phase of UMTS deployment. Only when the amount of traffic increases, the capacity of the WCDMA network becomes more important, and cell sites need to be added to provide enough capacity. To minimise the initial investments the WCDMA coverage should be improved. The coverage will be more challenging in WCDMA than in the 2nd generation networks because of the higher bit rates. The higher is the bit rate, the smaller is the uplink coverage. Also, the path loss in 2 GHz UMTS frequency band is higher than in GSM900 band. These factors emphasise the importance of the good coverage in WCDMA.

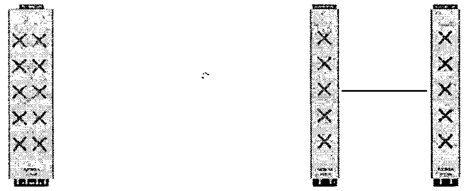
It is shown in [1] that the macro cell coverage of WCDMA is uplink limited. In this paper an uplink antenna solution is presented that targets for uplink coverage improvement. This antenna solution is based on four-branch uplink diversity reception. The performance of this antenna solution is studied in this paper by using computer simulations and by field measurements.

This paper is organised follows. Section 2 introduces the four-branch reception concept. Simulation assumptions and results are presented in Sections 3 and 4. Field measurement setup and results are covered in Sections 5 and 6. Conclusions are drawn in Section 7.

2. FOUR-BRANCH RECEIVER DIVERSITY

The four-branch receiver diversity uses four complete RF receiver chains. The four antenna signals are combined in the baseband Rake receiver. This section presents the typical antenna structure and the baseband combining algorithm.

The four-branch receiver diversity can be obtained by a combined polarisation and space diversity. Figure 1 b) shows an antenna configuration with two polarisation diversity antennas, with a separation of a few meters. It will be shown later in the paper that the space diversity is not crucial for the performance of this scheme, and therefore, those two polarisation antennas can be combined under one radome, as shown in Figure 1 a). The advantage of the combined antenna is the compact size and easier installation. The width of such an antenna is 25–30 cm with a 3-sector antenna with 65° horizontal beamwidth.



a) Single antenna b) Separate antennas

Figure 1. Antenna configurations

The signals from the four receiver paths are combined in the baseband Rake receiver. From the Rake receiver point of view the combining of the antenna signals is similar to the combining of the multipath components. The

Rake receiver 'rakes up' the signal energy from all the received signal multipaths from all antennas. The phase angle distortions caused by fading at each Rake finger can be compensated for by multiplying the received signal from i^{th} antenna and j^{th} Rake finger $r_{i,j}$ with the complex conjugate of the estimated channel impulse response $\hat{h}^*_{i,j}$. The channel estimate can be obtained from the pilot symbols on the dedicated physical control channel. The result is

$$r=\sum_{i=1}^{4}\sum_{j=1}^{M}\hat{h}^*_{i,j}r_{i,j} \qquad (1)$$

where r is the envelope of the combined and co-phased signals of M fingers from four antennas. The total number of Rake fingers is $4 \cdot M$.

3. SIMULATION EVALUATION

The performance of the 4-branch receiver diversity is first evaluated with the link level simulations. The main output of the simulations is the required E_b/N_0 per antenna and the required transmission power to achieve the given frame error rate (FER) target. Both uplink and downlink chains are modelled in the simulation environment, and these 2-way simulation models are used both in the single link and in the soft handover simulation cases. 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 1.

Table 1. Simulation parameters

Bit rates	144 kbps (Vehicular A) 384 kbps (Pedestrian A)
FER target in the outer loop power control	10%
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 = 0.667 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
Correlation of the polarisation branches	0.0
Correlation of the two antennas	0.0 and 1.0
Soft handover	0–3 dB difference in the path loss to active set base stations. Uncorrelated fast fading.

The uplink performance is challenging for high bit rate data, and therefore, the performance of 144–384 kbps data was studied in here. The target of the simulations is to evaluate the coverage and the capacity of the four-branch diversity as compared to the traditional two-branch diversity. The maximal coverage is obtained when the mobile is transmitting with full constant power. In the simulations the coverage is therefore evaluated by setting the fast power control off. The capacity gain is evaluated by measuring the required E_b/N_0 and the required transmission power with fast power control.

Table 2. Evaluation of coverage and capacity gains

	Coverage gain	*Capacity gain*
Fast power control	Off	On
What to measure	Required transmission power	Required E_b/N_0 and required transmission power

The polarisation branches are assumed to be uncorrelated, and the correlation of the two polarisation diversity antennas is set to 0.0 and to 1.0. The correlation between the antennas depends on the distance between the antennas and on the radio environment, mostly on the angular spread. The spatial properties of the radio channel can be characterised by exploiting one dimensional channel models and introducing correlation and power distribution between them. ITU Vehicular A and ITU Pedestrian A channel profiles are used in the simulations, and they are presented in Table 3.

Table 3. ITU Vehicular A and ITU Pedestrian A channel models, taps in chip resolution

	Pedestrian A	*Vehicular A*
Tap 1	0.2 dB	0.0 dB
Tap 2	−12.3 dB	−2.4 dB
Tap 3	-	−6.5 dB
Tap 4	-	−9.4 dB
Tap 5	-	−12.7 dB

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.

4. SIMULATION RESULTS

The simulation results are shown in the following four tables. The results are presented as the performance improvement of four-branch diversity (4-rx) over two-branch diversity (2-rx). The results can be found in detail in [2].

According to Table 4 the gain from 4-rx is 2.5–2.9 dB in the mobile transmission powers in ITU Vehicular A channel. The effect of the mobile speed is very small on the performance gain. The antenna correlation degrades the performance up to 0.5 dB, especially in the transmission powers. At slow mobile speed the correlation does not effect the required E_b/N_0 because the fast power control can compensate the fast fading.

Table 4. ITU Vehicular A, with power control

	4-rx gain over 2-rx	
Correlation between antennas	No correlation	Correlation = 1.0
3 km/h, E_b/N_0	2.5 dB	2.5 dB
50 km/h, E_b/N_0	2.7 dB	2.4 dB
3 km/h, tx power	2.9 dB	2.4 dB
50 km/h, tx power	2.9 dB	2.5 dB

The results in ITU Vehicular A with constant full power are shown in Table 5. In that case the gain from 4-rx is higher than with power control, especially at low mobile speeds: 3.3 dB with constant power compared to 2.9 dB with power control. At low mobile speeds the additional diversity gain of 4-rx is important to reduce the fading of the received signal when the power control is not able to compensate the fading.

The soft handover reduces the 4-rx gain by 0.2–0.3 dB because there is less need for extra antenna diversity when there is macro diversity.

Table 5. ITU Vehicular A, constant full power

	4-rx gain over 2-rx, no correlation between antennas
3 km/h, single link	3.3 dB
50 km/h, single link	3.1 dB
3 km/h, soft handover	3.0 dB
50 km/h, soft handover	2.9 dB

The simulation results in ITU Pedestrian A channel are shown in Table 6 and in Table 7. ITU Pedestrian A has less multipath propagation than ITU Vehicular A, and consequently the gain from the additional diversity with 4-rx is higher than in ITU Vehicular A.

The performance gain of 4-rx reception can be explained as follows: the 4-rx receiver can collect two times, 3 dB, more energy than 2-rx receiver. That assumes perfect coherent combining in the Rake receiver. Because the combining is not ideal the gain from 4-rx is 2.4–2.7 dB when the antenna correlation is 1.0. The loss in the combining is therefore 0.3–0.6 dB. When the antenna correlation is smaller, there is also an additional diversity gain from 4-rx, and the total gain is 3–4 dB.

Table 6. ITU Pedestrian A, with power control

	4-rx gain over 2-rx	
Correlation between antennas	No correlation	Correlation = 1.0
3 km/h, E_b/N_0	2.8 dB	2.7 dB
50 km/h, E_b/N_0	3.4 dB	2.7 dB
3 km/h, tx power	4.0 dB	2.5 dB
50 km/h, tx power	3.7 dB	2.6 dB

Table 7. ITU Pedestrian A, constant full power

	4-rx gain over 2-rx, no correlation between antennas
3 km/h, single link	4.4 dB
3 km/h, soft handover	3.9 dB

Coverage gains

The low mobile speed is the limiting factor for coverage because of the higher required power control head room (=fast fading margin) [1]. Therefore, we evaluate the coverage performance by using the simulation results without fast power control at 3 km/h as shown in Table 8.

Table 8. Coverage gain (the range shows 0–3 dB relative attenuations to active set base stations)

Multipath profile	*Coverage gain of 4-rx over 2-rx*
ITU Vehicular A	3.0 – 3.3 dB
ITU Pedestrian A	3.9 – 4.4 dB

With a coverage gain of 3.0 dB, the same coverage probability can be obtained with 33% less sites assuming a path loss exponent of 3.5 [1]. A gain of 4.0 dB allows a site reduction of 41%.

Antenna correlation

The performance loss due to the correlated antennas is shown in Table 9. The performance difference is shown between fully correlated antennas and fully uncorrelated antennas. It is assumed that the polarisation branches are uncorrelated.

The effect of the antenna correlation is quite small in ITU Vehicular A. The reason is the amount of multipath diversity which reduces the need for antenna space diversity.

Table 9. Effect of antenna correlation at 3 km/h

Multipath profile	*Degradation due to correlation of 1.0 instead of no correlation*
ITU Vehicular A	0.5 dB
ITU Pedestrian A	1.5 dB

Capacity gains

The uplink capacity gains are estimated from the simulations results with uncorrelated antennas using the formulas from [3]. In order to evaluate the capacity gain we need to record also the power rise from the link level simulations. The power rise is the difference between average transmission and reception powers when the average attenuation of the channel equals one [1]. The higher the power rise, the more interference is caused to the adjacent cells. The simulated power rise values are shown in Table 10. The increased diversity reduces the power rise.

Table 10. Power rise

	4-rx	2-rx
3 km/h, ITU Vehicular A	0.3 dB	0.7 dB
50 km/h, ITU Vehicular A	0.2 dB	0.3 dB
3 km/h, ITU Pedestrian A	1.0 dB	2.2 dB
50 km/h, ITU Pedestrian A	0.5 dB	0.9 dB

In the capacity calculations we assume that the other-cell to own-cell interference ratio is 0.65, without power rise which is a typical value for 3-sector macro cells. The capacity gains are calculated in Table 11 and it is 85–130% depending on the multipath profile.

Table 11. Capacity gain

Multipath profile	*Capacity gain of 4-rx over 2-rx*
ITU Vehicular A, 3 km/h	85% = 2.7 dB
ITU Vehicular A, 50 km/h	88% = 2.7 dB
ITU Pedestrian A, 3 km/h	120% = 3.3 dB
ITU Pedestrian A, 50 km/h	130% = 3.6 dB

If the two antennas are correlated, the capacity gain would be smaller.

5. MEASUREMENT SETUP

The field performance of four-branch reception was tested in the WCDMA network in Espoo, Finland. The network consists of mobile stations, base stations and MCC-SIM, which corresponds to RNC including uplink outer loop power control and handover functionalities. Other measurements using the same system are presented in [4].

The measurement environment is urban and sub-urban type. Three different measurement routes were used.

The main measurement parameters are shown in Table 12.

Table 12. Main 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 (on average 2 fingers per antenna when 4 antennas are used)
Interleaving depth	10 ms, 1 radio frame
Base station antennas (two antennas)	±45° diversity antenna with 15.5 dBi gain
Mobile station antenna	Within measurement van, vertical position
Route A	up to 40 km/h in Leppävaara / Lintuvaara
Route B	up to 70 km/h on Ring I
Route C	below 10 km/h in Mäkkylä

The two base station antennas in the WCDMA system are shown in Figure 2. In this figure the antennas are separated by 1 m. In the other tested antenna configuration the two antennas are put side-by-side without any separation.

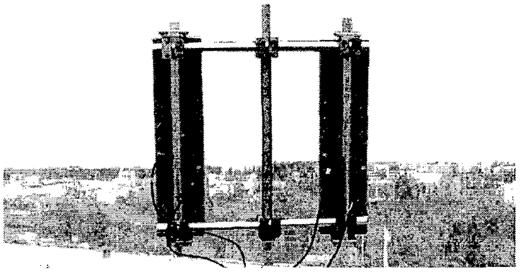


Figure 2. Base station antennas (about 1 m separation)

In the field measurements the mobile transmission power was recorded slot-by-slot with three different base station antenna configurations:

1. Two-branch reception with one polarisation diversity antenna
2. Four-branch reception with two polarisation diversity antennas separated by 1 m
3. Four-branch reception with two polarisation diversity antennas side-by-side

Several iterations are driven with each configuration. Example mobile speeds on route B are shown in Figure 3. The different measurement drives are made comparable using differential GPS. The average transmission power over the measurement route is calculated from dBm values.

The receiver algorithms in the simulations and in the measurements had some differences. The simulations used unlimited number of Rake fingers without Rake allocations while the base station used 8 Rake fingers per connection.

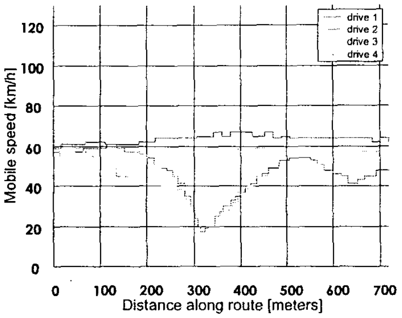


Figure 3. Example mobile speeds on route B

6. MEASUREMENT RESULTS

An example measurement result is shown in Figure 4. In this example the 4-rx reception reduces the transmission power on average 3.3 dB. The averaged measurement results are shown in the following three tables.

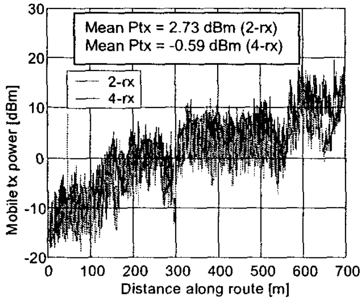


Figure 4. Example measurements

Table 13. Measurements on route A

Antenna separation	*2-rx*	*4-rx*	*4-rx gain*
1 m separation	6.95 dBm	4.44 dBm	2.5 dB
no separation	6.95 dBm	4.83 dBm	2.1 dB

Table 14. Measurements on route B

Antenna separation	*2-rx*	*4-rx*	*4-rx gain*
1 m separation	7.90 dBm	4.59 dBm	3.3 dB
no separation	7.90 dBm	4.86 dBm	3.1 dB

Table 15. Measurements on route C

Antenna separation	*2-rx*	*4-rx*	*4-rx gain*
1 m separation	5.63 dBm	2.54 dBm	3.1 dB

The multipath propagation in the measured environment is closer to ITU Vehicular A than to ITU Pedestrian A. The simulated gain with fast power control in the transmission power with antenna correlation of 0.0 is 2.9 dB in ITU Vehicular A. The measurement results with 1 m separation between the antennas show a gain of 2.5–3.3 dB. On average, the measurement results are close to the simulated values.

The simulated difference between the antenna correlation of 1.0 and 0.0 is 0.5 dB. The measured difference is only 0.2–0.4 dB. In the measurements the antenna correlation is above 0.0 with 1 m separation, and below 1.0 without separation, which explains the smaller difference in the measurements than in the simulations.

7. CONCLUSIONS

The performance of the uplink four-branch diversity reception was studied in this paper by link level simulations and by field measurements. The simulations show that the four-branch reception gives an average coverage gain of 3 dB compared to the traditional two-branch receiver diversity in ITU Vehicular A channel. When the amount of multipath diversity is lower, like in ITU Pedestrian A channel, the gain is higher up to 4 dB. The four-branch reception can be implemented with two polarisation diversity antennas. When the correlation of those antennas is 1.0, i.e. the antennas are very close to each other, the gain reduces 0.5 dB in simulations in ITU Vehicular A.

The field measurements indicate an average reduction of 2.9 dB in the mobile transmission power, which is well in line with the simulation results. When the antennas are close to each other, the gain is reduced 0.2–0.4 dB which is close to the corresponding simulation result.

8. ACKNOWLEDGEMENTS

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