Benefits of Handset Antenna Diversity for UMTS

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Abstract: The benefits of receiver antenna diversity in a Universal Mobile Telecommunications System (UMTS) handset were studied. Two different channel models were used, one an extension to the 3GPP multipath fading channels and the other based on 3-D scattering and angular weighting via a practically realisable antenna configuration. Simulated performance benefits arising from the use of a second receive antenna with coded UMTS data are compared with the benefits for uncoded data. Plots of coded block-error-rate (BLER) against uncoded physical bit-error-rate (BER) for cases with and without receive antenna diversity show improvements in block error rate up to 1 dB better than predicted by the change in physical bit-error-rate.

1 Introduction.

There is considerable interest in the use of multiple antennas to increase the performance of a radio link. A second receive antenna provides link diversity, hence immunity to multipath propagation effects such as fading. Much of the published work demonstrates improvements in physical bit-error-rates when multiple receive antennas are used. This paper extends such work to a system where other techniques have simultaneously been used to counter fading. Such techniques include the use of a wide bandwidth (spread-spectrum i.e. CDMA); path diversity (through the Rake equaliser), interleaving, forward-error-correction data coding and optional (open or closed)-loop transmit antenna diversity.

Simulated link performance results are presented here for coded data, and the block-error-rates are compared with physical bit-error-rates obtained from the same simulations.

The system studied uses coding described in the downlink reference measurement channel for UMTS[1], at 12.2, 64 and 144 kbps. Only the downlink was simulated because transmit antenna diversity from the handset to the basestation is not supported by the standard. The simulated basestation was set to produce several dedicated physical channels over a range of powers as well as a common pilot channel and the synchronisation channel. Interference from other cells was simulated by adding white Gaussian noise. For closed-loop transmit diversity, a bit-error-rate of 4% was assumed for the uplink, independent of the downlink channel.

2. The UMTS FDD Standard

The access method in the frequency division duplex (FDD) mode is direct-sequence CDMA, with the wanted signal spread over a 5 MHz bandwidth by way of a 3.84 Mcps chipping sequence. Data bits are protected by convolutional or turbo coding and then interleaved with a block period between 10 ms and 40 ms before being spread by between 512 × and 4 × depending on the service. A common pilot channel is simultaneously broadcast by the basestation to aid demodulation.

3. Channel Models

Two basic channel models were studied as described in the following subsections.

3.1 Extensions to the UMTS multipath channel models[1] – Case 1 and Case 3

The intention with this channel model was to simulate antenna diversity but otherwise be as close as possible to established UMTS channel models. The same (decorrelated) statistics were used for the paths from the basestation to each of the antennas on the user equipment. An antenna correlation of 0.1 was assumed on the handset. The multipath scenarios used were pedestrian case 1 and automotive case 3.

3.2 Dynamic Directional Channel Model (DDCM)

This channel model tries to have a closer physical basis, at the expense of increased simulation time and being further away from the standard UMTS test channels. It is an extension of the CoDiT model[2] with scattering sites located in three dimensions. Transmit and receive antenna diversity were handled in different ways: It was assumed that the basestation antennas were carefully positioned to avoid scattering objects but relatively close together, so scattering objects exist only around the handset. Therefore the same propagation paths exist for both basestation antennas, but the phase difference between these paths is randomly assigned to each path.

Scattering objects are allocated in three dimensions using spherical polar coordinates centred on the handset. Plane waves are propagated from these objects to the handset, so each path has direction-of-arrival information as well as the faded and delayed basestation signal. These paths are combined into a received antenna signal using a look-up table of the directional response of a realistic handset-antenna combination simulated in Ansoft HFSS.

This model includes path-loss from the basestation to the handset, so the ratio of power from the local basestation to interference from other cells $\hat{I}_{or}/I_{oc}$ was distributed with the same statistics as the path-loss.

Many propagation scenarios are possible in the DDCM. The one selected was a pedestrian micro-cell environment (street, non-line-of-sight, mobile in side street). This is a difficult channel for a UMTS rake to resolve because the delay spread is less than 600 ns, and only two rake fingers are normally useful. The average path loss for this scenario was 110.6 dB, so the added white Gaussian noise was set at 120 dB below the wanted basestation power giving $\hat{I}_{or}/I_{oc}$ as approximately 9 dB (the same as UMTS Case 1 Multipath).

Since many of the parameters in this channel model control statistics rather than directly defining the propagation, it is necessary to simulate many instances of a channel to be sure of a representative result. For the simulations described here, the DDCM was allowed to progress for 150 UMTS slots (100 ms) before being reinitialised with a new set of random numbers. As each simulation represented 40 seconds, 400 channels were explored to give a good average and therefore allow comparison between different systems using the same channel model.

4. Rake Signal Processing and Antenna Combining

Rake fingers were allocated at the start of each simulation, but afterwards allowed to track the received signal. Up to four rake fingers were simulated, and the tracking was arranged to prevent fingers from getting closer than one symbol apart. For the DDCM, the fingers were reassigned whenever the channel was reset.

Finger-level diversity combining was used since it was assumed that the same set of delays would apply to paths for both receive antennas. Each rake finger delays signals from both antennas, with time tracking based on the total common pilot power detected. The delayed signals were processed based on the information in the common pilot channel. Three diversity combining options were simulated: to maximise pilot power (for a normalised combination of the input signals), equal-gain from both antennas (after aligning pilot phase), or the amplitude and phase combination that maximises the signal-to-noise ratio of the pilot symbols.

Figure 1 shows the relative performances of the different combining schemes as a function of the fraction of basestation power allocated to the dedicated channel, measured by physical (uncoded) bit-error-rate. The conditions in this case are: 60 kbps (corresponding to 12.2 kbps coded data), Case 1 multipath propagation, one basestation antenna. The antenna diversity combining option for maximising pilot signal-to-noise ratio gave the best results (max_snr), although options for maximising pilot power (max_signal) and equal-gain combining were not much worse. Over the range simulated, the diversity gain (reduction in relative signal power for a given bit-error-rate) is around 3 to 4 dB measured at 0.1 BER. As performance is limited by interference rather than thermal noise, this gain is due to antenna diversity rather than the second antenna merely collecting more power.

5. Diversity Benefits for Coded Data

The previous section showed no measurable difference between the performance of maximising pilot power or measured pilot SNR. Once data coding is taken into account, the BLER obtained is as plotted in figure 2. This time, maximising pilot power proved 1 dB better than maximising measured pilot signal-to-noise ratio at 0.01 BLER level. This is thought to be because of the small number of pilot symbols – ten for the common pilot and four or eight for the dedicated pilot, leaving little redundancy to allow cancelling of coherent interference between the two antenna signals once the pilot has been fitted. Assuming equal noise power is received by each antenna, maximising the pilot signal equates to maximal ratio combining. The diversity gain for a BLER of 0.1 is 4.0 dB and for a BLER of 0.01 it is 4.5 dB. Therefore RX antenna diversity is still beneficial when data coding is applied.

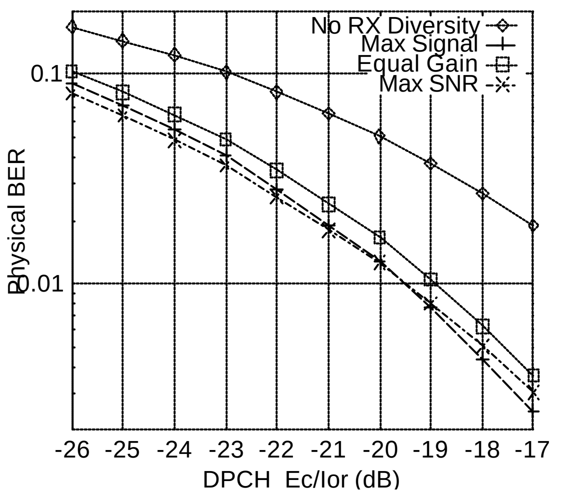

Figure 1 BER of Uncoded Data under Case 1 Multipath conditions

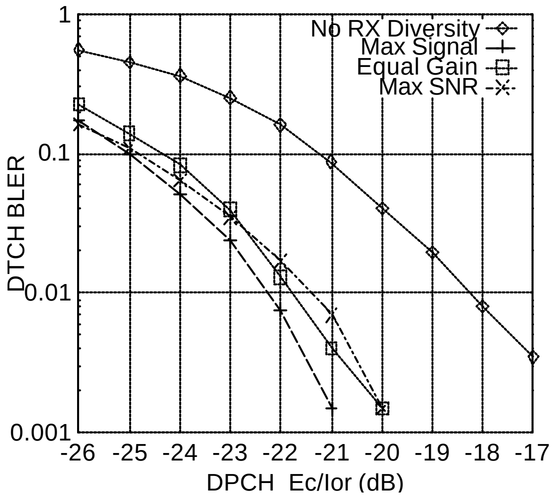

Figure 2 Block-Error-Rate of 12.2 kbps Coded Data under Case 1 Multipath conditions

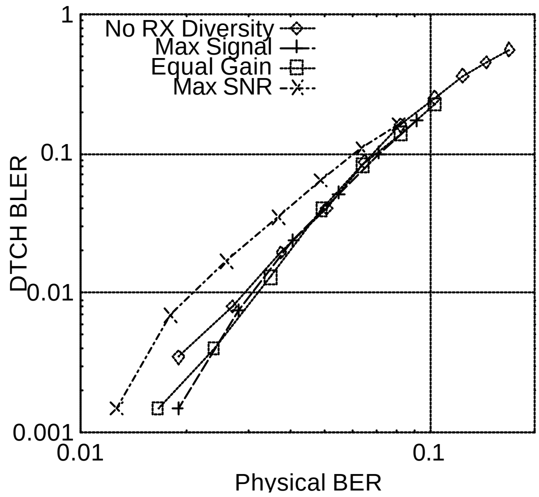

Figure 3 Block-Error-Rate vs Bit-Error-Rate of 12.2 kbps Coded Data with Case 1 Multipath

To quantify the worsening of the max_snr mode, BLER was plotted against BER, shown in figure 3. All the modes are similar with the exception of max_snr, which is typically 1 dB worse (markers are at 1 dB intervals).

Extending the test to include turbo coding at 64 kbps (rather than the convolutional coding used at 12.2 kbps) but still case 1 multipath propagation, the BLER vs BER curve is as shown in figure 4. The interesting result in this case is that a lower block-error-rate is obtained for a given bit-error-rate when receive antenna diversity is used compared with when it is not used, particularly at lower error rates.

Figures 3 and 4 were for a pedestrian channel – Case 1 multipath with the user equipment moving at 3 km/h. The fading period will be around $t = l/2v = 80\,\mathrm{ms}$ where l is the wavelength and v the speed of movement. This is larger than the interval over which time-interleaving works (10 – 40 ms). One might therefore expect time-diversity to be compromised.

Time-interleaving is likely to be more effective when the user travels at 120 km/h under case 3 multipath propagation conditions. The BLER vs BER curves for this case are shown in figure 5. The max_snr option is still bad. Again the benefits of antenna diversity are greater with coded data than would be predicted by simulations on physical data. This is despite the fact that time-diversity is likely to be more effective with faster fading.

The results for the DDCM at 64 kbps are shown in figure 6. When receive diversity was not used, the block error rate could not be brought down below 0.05 even using 10% of the total basestation power. This is unsurprising given the difficulty of this propagation channel, with a small number of resolvable paths.

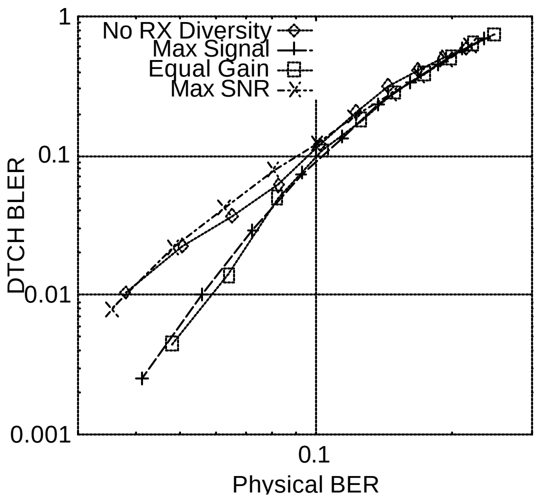

Figure 4 Block-Error-Rate vs Bit-Error-Rate of 64 kbps Coded Data with Case 1 Multipath

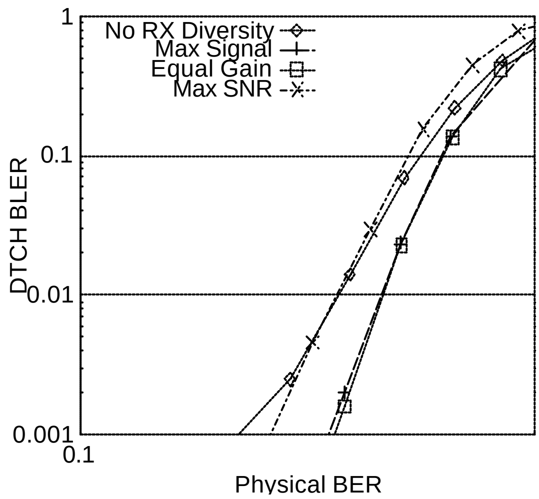

Figure 5 Block-Error-Rate vs Bit-Error-Rate of 144 kbps Coded Data with Case 3 Multipath

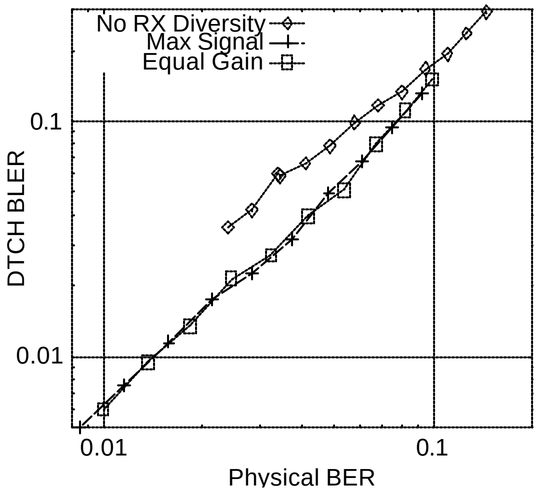

Figure 6 Block-Error-Rate vs Bit-Error-Rate of 64 kbps Coded Data with DDCM

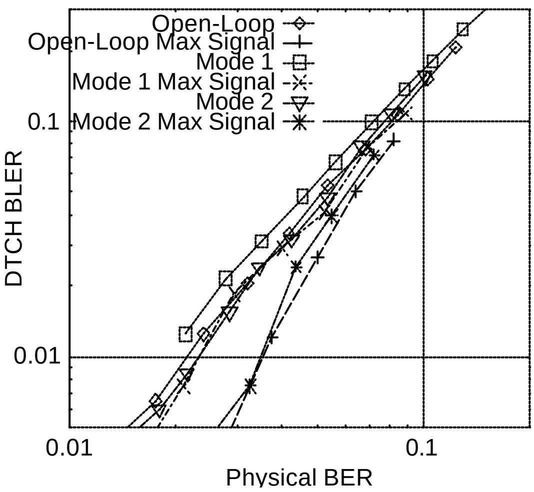

Figure 7 BLER vs BER 64 kbps Coded Data with DDCM and basestation transmit diversity

6. Receive Antenna Diversity in the presence of Basestation Transmit Antenna Diversity

Figure 7 compares the relationship between BLER and BER when transmit antenna diversity is used at the basestation for the DDCM at 64 kbps. For clarity, the equal gain diversity option is not plotted. At the time of study, three transmit diversity options were proposed: open-loop (space-time transmit diversity), and two closed loop modes which required the handset to report back the optimal phasing of the two transmit antennas. Both open-loop and mode 2 show clear differences between the BLER vs BER curves depending on the presence of RX diversity. There is no significant difference for mode 1. Mode 2 had more information fed back from the handset allowing greater optimisation of the transmitted signal, at the expense of slower adaptation. Mode 2 has since been withdrawn from release 99 of the UMTS specifications.

7. Discussion

Since the relationship between coded block-error-rate and physical bit-error-rate depends on whether the receiver has antenna diversity, it was inferred that the statistics of the received signal and interference are different. As similar results were obtained with pedestrian and automotive channels, time-interleaving is not the major factor controlling fading statistics.

Other possible factors relate to the distribution of the noise: with hard decisions for physical bits, the instantaneous noise power must be greater than the signal to cause a bit error. With soft decisions for coded bits, an error occurs when a noise spike is much larger than the signal, or when several consecutive samples (after time-interleaving) have a poor signal-to-noise ratio. The probability in either case is low, but it only takes one uncorrected error to spoil a block of data that contains hundreds of bits. Errors occur when the signal-to-noise ratio is small, and this can arise because the signal is weak through fading.

8. Conclusions

The benefits of receive antenna diversity are not diluted by the use of data coding – they are enhanced by it for UMTS. Block error rates for coded data are improved by up to 1 dB more than would be predicted from simulations with physical data. The improvement still applies when open-loop transmit antenna diversity is present. For closed-loop transmit antenna diversity, the benefit of receive antenna diversity is similar for coded and physical data.

These benefits are seen on several simulated propagation environments, both pedestrian and automotive. Similar results are seen with channel models extended from the UMTS standard and with a three-dimensional channel model derived from first principles and simulations of practical antenna structures.

References.

[1] 3GPP TS 25.101: "UE Radio Transmission and Reception (FDD)" Annex A.3

[2] V. Perez and J. Jimenez, editors, "Final Propagation Model, CoDiT Deliverable number R2020/TDE/PS/DS/P/040/bl", June 1994