Performance Analysis of Downlink Transmit Diversity System Applied to the UTRA FDD Mode

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Abstract – **This paper analyses the performance of the downlink transmit diversity techniques specified in the standard of the UTRA FDD mode.**

The Downlink DPCH can use either closed loop or open loop transmit diversity (space time block coding based transmit diversity) or closed loop transmit diversity to improve performance.

In order to evaluate how these techniques work, a simulator of the physical layer of UMTS has been implemented in the C language.

Simulation results show that the closed loop methods are the best way of getting diversity gain in radio environments with a low Doppler frequency, especially mode 2. Nevertheless, when it does not exist a correct channel knowledge (high Doppler frequency), the open loop transmit diversity mode is the best option.

I. INTRODUCTION

The UMTS system, like other mobile communication systems, requires mechanisms to overcome the problems of the radio environment, like the propagation channel, which is both random and time varying (Rayleigh fading channel). The downlink capacity could be improved by using receive antenna diversity in the mobile, based on having two signals in reception, affected by two different propagation channels. Combining them or choosing one, we can get a received signal with a better quality, that is, a diversity gain. However, for small and cheap mobiles it is not feasible to use two antennas and receiver chains. So, the terminal emulates its effect by using the transmit diversity techniques: two antennas in the base station transmitting two different signals. The result in the receiver, which is able to recover the original signal, allows to get a diversity gain.

Several studies have been done in this topic [1] – [3]. In this paper we present the results of simulations of the transmit diversity schemes proposed in the 3GPP standard [4] – [7], using a simulator of the physical layer of the UMTS system. We discuss the effect of the mobile environment (Doppler frequency as a result of mobility and multipath propagation [8]) and the real correlation between transmit antennas.

II. TRANSMIT DIVERSITY SCHEMES

The UTRA FDD standard [4] specifies several transmit diversity techniques. This paper studies two types, classified as open loop and closed loop methods.

A. Open loop transmit diversity

The open loop diversity mode is also denoted in the 3GPP specification [4] as space-time block coding based transmit diversity (STTD). Operating in an "open loop" mode means to do it without channel knowledge at the transmitter.

This method is based on transmitting two signals: the desired signal and a different one generated by coding the first one. The way of encoding is as follows [4]:

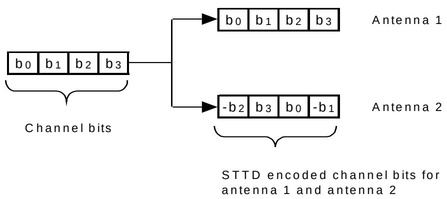

Fig. 1. STTD encoding

A block diagram of a generic STTD encoder for channel bits b_0, b_1, b_2, b_3 is shown in the Fig. 1 above. Channel coding, rate matching and interleaving are done as in the non-diversity mode, as it is shown in the Fig. 2. The bit b_i is real valued { 0 } for DTX bits and { -1, 1 } for all other channel bits.

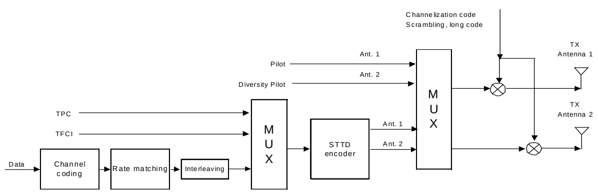

Fig. 2. STTD encoding in the transmission chain.

The way the subscriber decodes the signal, assuming the use of a conventional Rake receiver, is as follows [1]:

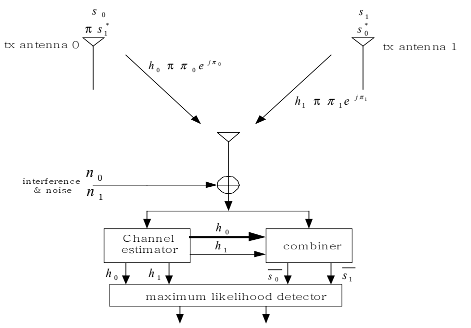

Fig. 3. Reception scheme.

$$\begin{aligned} r(T) &= r_0 = h_0 S_0 + h_1 S_1 + n_0 \\ r(2T) &= r_1 = -h_0 S_1^* + h_1 S_0^* + n_1 \end{aligned} \qquad (1)$$

$$\begin{aligned} \tilde{S}_0 &= h_0^* r_0 + h_1 r_1^* \\ &= h_0^*(h_0 S_0 + h_1 S_1 + n_0) + h_1(-h_0^* S_1 + h_1^* S_0 + n_1^*) \\ &= [(\alpha_0)^2 + (\alpha_1)^2] S_0 + h_0^* n_0 + h_1 n_1^* \end{aligned} \qquad (2)$$

$$\begin{aligned} \tilde{S}_1 &= h_1^* r_0 - h_0 r_1^* \\ &= h_1^*(h_0 S_0 + h_1 S_1 + n_0) - h_0(-h_0^* S_1 + h_1^* S_0 + n_1^*) \\ &= [(\alpha_0)^2 + (\alpha_1)^2] S_1 - h_0 n_1^* + h_1^* n_0 \end{aligned} \qquad (3)$$

B. Closed loop transmit diversity

The closed loop transmit diversity is based on a feedback procedure. The UE (User Equipment) estimates the two propagation channels (based on the CPICH – Common Pilot Channel – information and the pilot fields of the downlink DPCCH) and, thanks to this knowledge, it is able to decide how the BS must transmit to maximise the reception power. Therefore, the UE has to send the appropriate feedback information so that the BS could change the transmission parameters. This information is sent in a specific field in the uplink DPCCH (dedicated physical control channel), in particular, the D-bits of the FBI field. Fig. 4 shows the general transmitter structure to support this diversity mode for DPCH (dedicated physical channel).

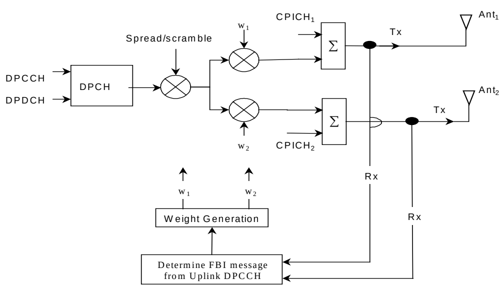

Fig. 4. The generic downlink transmitter structure to support closed loop mode transmit diversity for DPCH transmission

The closed loop transmit diversity itself has two modes of operation. In mode 1, the feedback commands from the user terminal control the phase adjustments that are expected to maximise the power received by the terminal. The base station adjusts the phase of antenna 2 (the phase of antenna 1 is constant) based on the sliding averaging over two consecutive feedback commands. Four different phase settings can be applied to antenna 2. In mode 2, the amplitude is also adjusted. The same signalling rate is used, but now the command is spread over four bits in four uplink DPCCH slots, with a single bit for amplitude and three bits for phase adjustment. This gives a total of 16 combinations for signal transmission from the base station (eight different phase values between –135º and 180º and two different amplitude values, 0.2 and 0.8). In this mode the last three slots of the frame contain only phase information, while amplitude information is taken from the previous four slots. This allows the command period to go even with 15 slots as with mode 1, where the average at the frame boundary is slightly modified by averaging the commands from slot 13 and slot 0 to avoid discontinuities in the adjustment process. The whole process of initialisation, weights application and adjustment are completely explained in the 3GPP standard [7].

The characteristics of each mode are summarised in the Table I. The use of the modes is controlled via higher layer signalling.

TABLE I.
CLOSED LOOP MODES (CHARACTERISTICS)

Closed loop mode	N_{FBD}	N_W	Update rate	Feedback bitrate	N_{po}	N_{ph}	Constel. Rotation
1	1	1	1500 Hz	1500 bps	0	1	Π/2
2	1	4	1500 Hz	1500 bps	1	3	N/A

- N_{FBD} : number of feedback information bits per slot.
- N_W : feedback command length in slots.
- N_{ph} : number of phase bits per signalling word.
- N_{po} : number of amplitude bits per signalling word.

C. Effect of correlation factor

One of the more relevant effects that reduce the theoretical improvement of the diversity methods is the real dependency between the two propagation paths. The diversity gain is obtained assuming independent Rayleigh-fading paths. In this case, one path is expected to compensate the fading effects of the other. Unless this assumption, a real dependency implies the existence of simultaneous fading effects and the desired compensation is not obtained.

The way of modelling this effect mathematically is the use of a correlation factor between the two branches. One channel depending on the other is represented by a lineal combination of the first one and the second one. Mathematically, the typical equation is as follows:

$$h_1(t) = \alpha_1 + j\beta_1$$
$$h_2(t)' = \rho \times h_1(t) + \sqrt{(1-\rho^2)} \times h_2(t) =$$
$$= \left[\rho \times \alpha_1 + \sqrt{(1-\rho^2)} \times \alpha_2\right] + j\left[\rho \times \beta_1 + \sqrt{(1-\rho^2)} \times \beta_2\right] \quad (4)$$

$$h_1 = \alpha_1 + j\beta_1$$
$$h_2 = \alpha_2 + j\beta_2$$
$$\rho = correlation\ factor \quad (5)$$

Since the transmission power of each antenna is half the transmission power without diversity, the real SNR obtained is worse. The gain is obtained only assuming that without diversity, the signal is faded, and with diversity, the signal is recovered, as it is shown in the following equations [1]:

Transmitted symbols in antenna 1:

$$\frac{1}{\sqrt{2}}\left(S_0, -S_1^*\right) \quad (6)$$

Transmitted symbols in antenna 2:

$$\frac{1}{\sqrt{2}}\left(S_1, S_0^*\right) \quad (7)$$

Propagation channel 1:

$$h_0 = \alpha_0 e^{j\theta_0} \quad (8)$$

Propagation channel 2:

$$h_1 = \alpha_1 e^{j\theta_1} \quad (9)$$

Received symbol without diversity:

$$\tilde{S}_0 = (\alpha_0)^2 S_0 + h_0^* n_0 \quad (10)$$

Received symbols with diversity:

$$\tilde{S}_0 = \left[(\alpha_0)^2 + (\alpha_1)^2\right]\frac{S_0}{\sqrt{2}} + h_0^* n_0 + h_1^* n_1$$

$$\tilde{S}_1 = \left[(\alpha_0)^2 + (\alpha_1)^2\right]\frac{S_1}{\sqrt{2}} - h_0 n_1^* + h_1^* n_0 \quad (11)$$

If the two propagation channels are similar (α_0 similar to α_1) there is no SNR gain, but if α_0 is very low and α_1 compensate this effect, S_0 is recovered, thus, there is diversity gain.

III. SIMULATION

A. Conditions.

The conditions of simulations according to the UTRA FDD standard are shown in Table II.

In order to simplify the theoretical analysis of the diversity techniques, the UMTS simulator includes a special model of a Rayleigh fading one ray channel. So, multipath effect is not considered. This model allows to change the speed of the terminal (then, the Doppler frequency) so that the temporal variability of the channel could be analysed. The power control has not been included, so that we could analyse the effect of the Rayleigh channel directly over the signal, without changing the transmission power.

TABLE II.
SIMULATION CONDITIONS

Access Method	DS-CDMA
Transmission Bit Rate	120 kbps
Chip Rate	3.84 Mcps
Frame size	10 ms
Modulation	QPSK
Transmitting Filter	0.22 SRC
Receiving Filter	0.22 SRC
Channel coding and interleaving	Not included
Burst Structure …………Control …………Data	 300 bits 900 bits
Channel Models (ideal estimation)	
Theoretical analysis	Real models
Two independent Rayleigh fading one ray model (3 – 50 – 120 km/h) – 0 dBm –	Two independent Rayleigh fading two ray model (case 1 [8])
Rake finger assignment	5 fingers 1 chip delayed

B. Results

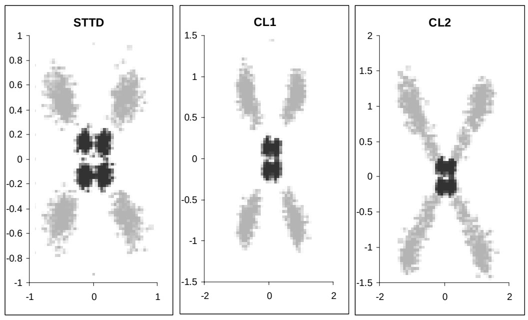

Fig. 5. Signal at the end of the reception chain (Rake receiver) for STTD, CL1 and CL2 diversity modes (grey). –3 km/h–

Fig. 5 shows the constellation of symbols in the Rake receiver for the non-diversity mode versus each diversity mode. The simulation with a high E_b/N_o of 19 dB intends to evaluate the effect of the diversity modes directly over the received symbols, which would be impossible to detect visually with a lot of noise. The channel model used during simulations is a theoretical one, with a single Rayleigh time-varying path with a Doppler frequency due to a movement of 3 km/h in the mobile. The reception power of the symbols is greater if the diversity mode of transmission is used, so, the symbols are farther from the detection threshold (in the figure, the coordinated axis). Comparing the three possibilities of diversity, it can be demonstrated that the closed loop techniques are better, since the symbols are more expanded than in the other cases.

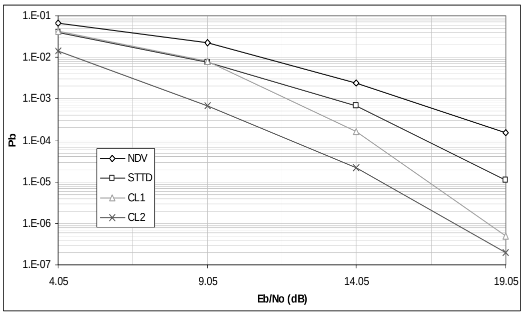

Fig. 6. Probability curve for STTD, CL1 and CL2 versus a non diversity mode –3 km/h–

Fig. 6 shows the error probability curves for a range of E_b/N_o in reception between 4 and 19 dB, in the same conditions as Fig. 5. In this figure, it is shown that the closed loop modes of diversity are better in any case, although their effect are more relevant in very noisy environments. The best alternative is the use of the closed loop mode 2, which refine the transmission parameters choosing among more possibilities than mode 1.

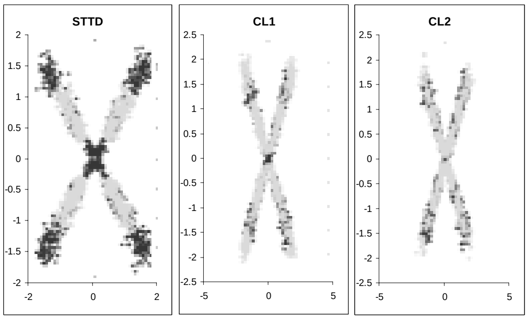

Fig. 7. Signal at the end of the reception chain (Rake receiver) for STTD, CL1 and CL2 diversity modes (grey). –50 km/h–

Fig. 7 shows the constellation of symbols in the Rake receiver for the non-diversity mode versus each diversity mode, with an E_b/N_o of 19 dB. The channel model is a single Rayleigh path with a 50 km/h Doppler frequency. In this case, it is difficult to find a real improvement in the constellation of received symbols. Only in the case of the open loop mode of diversity, the worse symbols in the non-diversity mode (which has suffered from fast fading) are improved (they are far from the detection threshold).

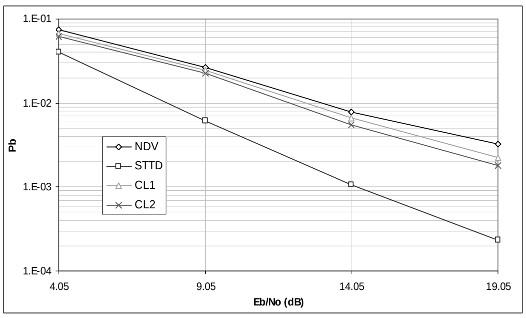

Fig. 8. Probability curve for STTD, CL1 and CL2 versus a non diversity mode –50 km/h–

Fig. 8 shows the error probability results of simulation for a range of E_b/N_o in reception between 4 and 19 dB, in the same conditions as Fig. 7. In this case, the reduction of the error probability is only relevant using the open loop diversity mode (STTD). The closed loop diversity modes are worse because the channel estimation cannot follow the real variations of the channel, so the calculated transmission parameters are wrong and the advantage of the feedback information cannot be actually used.

Additional simulation results cannot show any appreciable variation in the probability curves as the mobile speed increases (so the Doppler frequency).

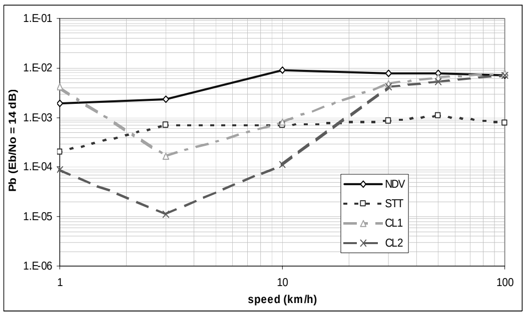

Fig. 9. Probability curve for the non-diversity mode, STTD, CL1 and CL2 versus the mobile speed

Fig. 9 shows the error probability results of simulation for an E_b/N_o in reception of 14 dB versus the mobile speed. If there is no fading to compensate (1 km/h), the diversity modes can even make the performance get worse (CL1), instead of getting diversity gain. But when the mobile speed increases (time-varying channel), these techniques are useful. Closed loop modes are better only with low speeds but at high speeds the STTD mode is the best one. In fact, the open loop mode is hardly affected by speed (Doppler frequency). In addition, this mode of transmission is not affected by the uplink errors.

B.1 Correlation

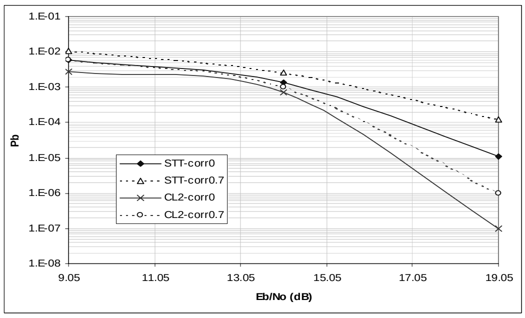

Fig. 10. Probability curve for diversity modes STTD and CL2 with a correlation factor of 0.0 and 0.7.

Fig. 10 shows the effect of the correlation between the two branches of transmission, the normal path and the diversity path. The dashed lines correspond to the modes STTD (open loop mode) and CL2 (closed loop mode 2) both with a correlation factor of 0.7 (experimental data has shown that the correlation coefficient as seen at the mobile from the two antennas may be as large as 0.7). These results are worse than the ones of two independent paths, represented by the continuous line. The effect is more relevant in better environment conditions (19 dB), because in other case, the probability is too high to be considered.

B.2 Multipath

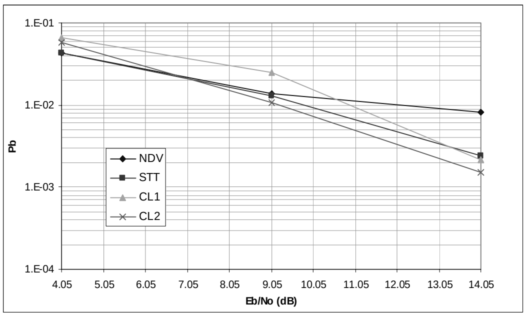

Fig. 11. Probability curve for STTD, CL1 and CL2 versus a non diversity mode –Channel model 1–

Fig. 11 shows the negative effect of multipath over the theoretical improvement of the diversity techniques. The channel model used in the simulation consists of two Rayleigh paths with powers of 0 and –10 dBm. The Rake receiver is supposed to resolve the multipath effect, and the diversity techniques are supposed to resolve the fading effect. However, it is more difficult to solve both problems simultaneously, because they are not totally separable. The figure shows that in a better environment (14 dB E_b/N_o) the results are as expected for 3 km/h: the closed loop mode 2 is the best option, followed by the closed loop mode 1 and the open loop mode (STTD).

IV. CONCLUSIONS

The use of the transmit diversity techniques specified in the UMTS standard allows to improve the quality of the received signal, but the diversity gain obtained depends on many factors, which reduce the theoretical improvement.

In general, with low mobile speeds (low Doppler frequencies) both open loop and closed loop methods are suitable to obtain diversity gain, although the closed loop modes allow to improve more the received signal (better in case of closed loop mode 2), due to the channel knowledge in the terminal, which makes the BS to adjust the transmission parameters to maximise the reception power. However, the improvement drops when the mobile speed increases, because it makes the channel estimation and tracking too difficult. In that case, the open loop techniques are particularly appealing, since it is no necessary to know the channel for transmitting.

The diversity gain obtained via the open loop transmit mode (STTD) depends highly on the correlation of the two propagation channels. In this diversity mode, the BS transmits without any channel knowledge, but it is assumed that one of the propagation paths will compensate the fading effects of the other, and this is real only in case of no dependency (0 correlation).

In the presence of multipath, the use of a conventional Rake receiver reduces the ISI (Intersymbolic Interference) effect, but it also complicates the analysis of the diversity methods. The final result is a reduction of the diversity gain (even it is not obtained) unless the environment conditions were suitable (a better E_b/N_o).

ACKNOWLEDGEMENTS

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