PERFORMANCE ANALYSIS OF DIVERSITY TRANSMISSION MODES IN UTRA FDD UNDER TIME-VARYING MULTIPATH CHANNELS

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Abstract -
This paper analyses the effect of the propagation environment on the theoretical performance of the downlink transmit diversity techniques specified in the standard of the UTRA FDD mode. These techniques are classified as open loop and closed loop modes. Simulation results, obtained via a C simulator of the physical layer of UMTS, show the negative effect of mobility. The diversity gain got with the closed loop techniques, which are the best ones, drops drastically when the Doppler frequency rises. In that case, the open loop mode of diversity performs well. Nevertheless, it is highly dependent on the correlation of the antennas, which reduces the theoretical improvement.

Keywords –
UMTS, UTRA FDD, CDMA, Spread Spectrum, Diversity transmission.

I. INTRODUCTION

Any mobile communication system requires mechanisms to overcome the problems of the radio environment. The propagation channel, which is both random and time varying (Rayleigh fading channel) makes the signal fade, reducing the average BER. The downlink capacity could be improved by using receive antenna diversity in the mobile, which is 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. Nowadays, the I+D efforts point to emulate the same effect but using two transmitting antennas in the base station. The receiver recovers the original signal, getting a diversity gain.

Several studies have been carried out about this topic [1] – [3]. In this paper we present the simulation results of the transmit diversity schemes proposed in the 3GPP standard [4] – [7] and we discuss the effect of the mobile environment (Doppler frequency, multipath, correlation between antennas) on the theoretical performance.

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 the original desired signal and a codified version of it. The way of encoding is shown in the Fig. 1 below. Channel coding, rate matching and interleaving are done as in the non-diversity mode

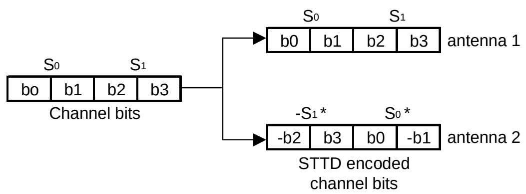

Fig. 1. STTD encoding [4]

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

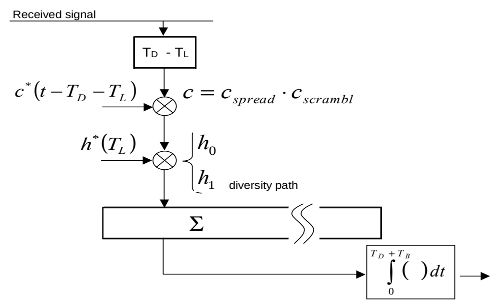

Fig. 2. Reception scheme

Signal after the rake receiver:

$$rk_1(T) = \left(S_0 \cdot C \cdot h_0 - S_1^* \cdot C \cdot h_1 + n_0\right) \times C^* \cdot h_0^* = S_0 \cdot |C|^2 \cdot |h_0|^2 - S_1^* \cdot |C|^2 \cdot h_1 \cdot h_0^* + n_0' \quad (1)$$

$$rk_2(T) = \left(S_0 \cdot C \cdot h_0 - S_1^* \cdot C \cdot h_1 + n_0\right) \times C^* \cdot h_1^* = S_0 \cdot |C|^2 \cdot h_0 \cdot h_1^* - S_1^* \cdot |C|^2 \cdot |h_1|^2 + n_0' \quad (2)$$

$$rk_1(2T) = \left(S_1 \cdot C \cdot h_0 + S_0^* \cdot C \cdot h_1 + n_1\right) \times C^* \cdot h_0^* = S_1 \cdot |C|^2 \cdot |h_0|^2 + S_0^* \cdot |C|^2 \cdot h_1 \cdot h_0^* + n_1' \quad (3)$$

$$rk_2(2T) = \left(S_1 \cdot C \cdot h_0 + S_0^* \cdot C \cdot h_1 + n_1\right) \times C^* \cdot h_1^* =$$
$$= S_1 \cdot |C|^2 \cdot h_0 \cdot h_1^* + S_0^* \cdot |C|^2 \cdot |h_1|^2 + n_1' \quad (4)$$

Combination:

$$\tilde{S}_0 = rk_1(T) + rk_2(2T)^* = S_0 \cdot |C|^2 \cdot \left(|h_0|^2 + |h_1|^2\right) + n'' \quad (5)$$

$$\tilde{S}_1 = rk_1(2T) - rk_2(T)^* = S_1 \cdot |C|^2 \cdot \left(|h_0|^2 + |h1|^2\right) + n'' \quad (6)$$

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 can change the transmission parameters. This information is sent in a specific field in the uplink DPCCH (dedicated physical control channel).

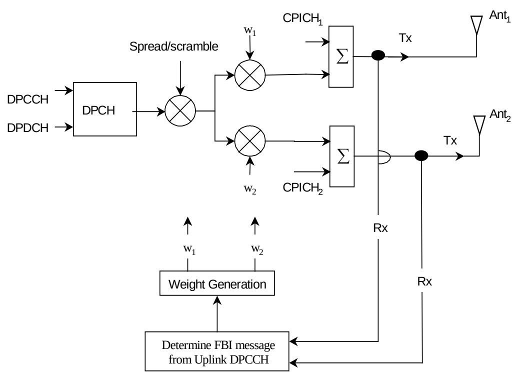

Fig. 3. The generic downlink transmitter structure to support closed loop mode transmit diversity for DPCH transmission

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 using four different phase settings (the phase of antenna 1 is constant). 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 –). 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 1. The use of the modes is controlled via higher layer signalling.

Table 1.
Summary characteristics of the two closed loop modes

Closed loop mode	NFBD	NW	Update rate	Feedback bit rate	Npo	Nph	Constellation rotation
1	1	1	1500 Hz	1500 bps	0	1	π/2
2	1	4	1500 Hz	1500 bps	1	3	N/A

– NFBD: number of feedback information bits per slot.

– NW: feedback command length in slots.

– Nph: number of phase bits per signaling word.

– Npo: number of amplitude bits per signaling word.

C. Multipath

The negative effect of multipath is theoretically resolved with a conventional Rake receiver, which takes advantage of the properties of the scrambling sequences to separate each delayed path and performs a best received signal adding coherently the energy contribution of each branch (based on a correct channel estimation).

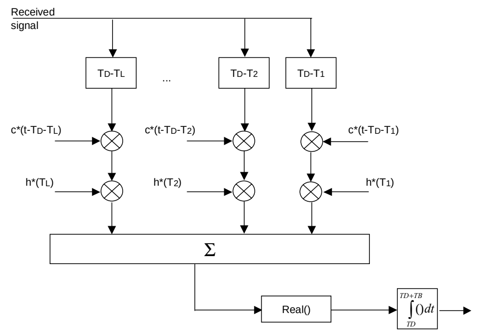

Fig. 4. Rake receiver

The diversity techniques intend to resolve the problem of the fast fading due to a Rayleigh time-varying channel.

Both problems (multipath and fading) are not totally separable. So, the simultaneous work of the Rake receiver and the diversity modes of transmission cannot get an increasing gain. In Section 3, we can observe the real influence of them.

D. Correlation

The basic idea of diversity is to compensate the negative effects of the propagation channel thanks to another independent path, which makes it possible to recover the original signal. This assumption, actually, is not real in practice, because there is an effective correlation between the transmitting antennas, which produces a real dependency between the propagation paths. A real dependency implies the existence of simultaneous fading effects due to both paths and there is not a desired compensation, so the diversity gain is reduced or not obtained.

The way of modeling this effect mathematically is the use of a correlation factor between the two branches.

The typical equation is as follows:

$$h_1(t) = \alpha_1 + j\beta_1$$
$$h_2(t)^{'} = \rho \times h_1(t) + \sqrt{(1-\rho^2)} \times h_2(t) = \\ = \left[\rho \times \alpha_1 + \sqrt{(1-\rho^2)} \times \alpha_2\right] + j\left[\rho \times \beta_1 + \sqrt{(1-\rho^2)} \times \beta_2\right] \quad (7)$$

$$h_1 = \alpha_1 + j\beta_1$$
$$h_2 = \alpha_2 + j\beta_2$$
$$\rho = correlation\ factor \quad (8)$$

For instance, if we analyse the equations in the STTD mode, since the transmission power of each antenna is half the transmission power without diversity, the actual SNR obtained is worse. The gain is obtained only assuming that without diversity the signal is faded, and with diversity the signal is recovered.

The received symbol with diversity, as seen in equation (5) but transmitting half the initial power, is as follows:

$$\tilde{S}_0 = rk_1(T) + rk_2(2T)^* = \frac{S_0}{\sqrt{2}} \cdot |C|^2 \cdot \left(|h_0|^2 + |h_1|^2\right) + n'' \quad (9)$$

The received symbol without diversity is:

$$\tilde{S}_0 = rk(T) = S_0 \cdot |C|^2 \cdot |h_0|^2 + n \quad (10)$$

If $|h_0|$ fades the signal (S_0 is lost) and $|h_1|$ can recover it, the final result is a diversity gain, although there is not a real SNR gain.

III. SIMULATION

A. Conditions.

The conditions of simulations according to the UTRA FDD standard are shown in Table 2.

Table 2.
Simulation conditions

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
RAKE FINGER ASSIGNMENT	5 fingers 1 chip delayed
CHANNEL MODELS (IDEAL ESTIMATION)	
THEORETICAL ANALYSIS	REAL MODELS
Two independent Rayleigh fading one ray model, 0 dBm (3 – 50 – 120 km/h)	Two independent Rayleigh fading two ray model (case 1, case 4 [9])
NOTATION NDV STTD CL1 CL2	 Non-diversity Open loop mode Closed loop mode 1 Closed loop mode 2

In order to simplify the theoretical analysis of the diversity techniques, the 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, and then, the Doppler frequency, so that the temporal variability of the channel can be analysed. Moreover, the power control has not been included, to facilitate the analysis of the Rayleigh channel effect directly on the signal, without changing the transmission power.

B. Results

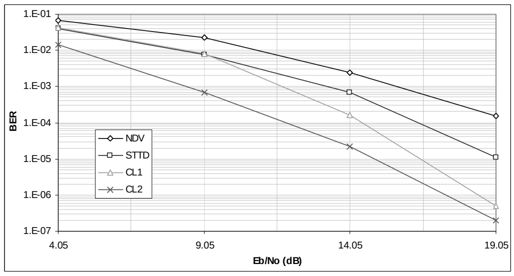

Fig. 5. Probability curve for STTD, CL1 and CL2 versus a non-diversity mode –3 km/h–

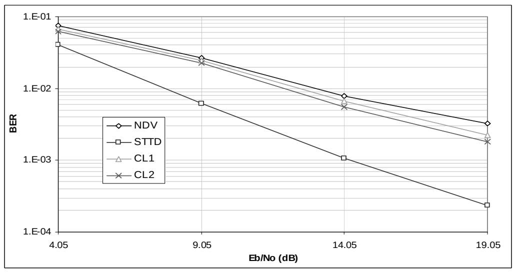

Fig. 6. Probability curve for STTD, CL1 and CL2 versus a non-diversity mode –50 km/h–

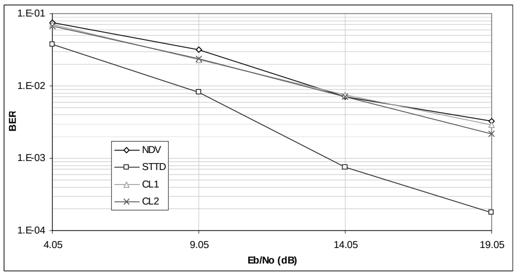

Fig. 7. Probability curve for STTD, CL1 and CL2 versus a non-diversity mode –120 km/h–

Fig. 5, Fig. 6 and Fig. 7 show the error probability simulation results for a range of E_b/N_o in reception between 4 and 19 dB. (The noise power implies both the white gaussian noise and the interference caused by other users). The channel model is a single Rayleigh path with a 3, 50 and 120 km/h Doppler frequency respectively. These figures show that the closed loop modes of diversity are better in case of low Doppler frequencies (low speed) but with high Doppler frequencies the open loop mode is better.

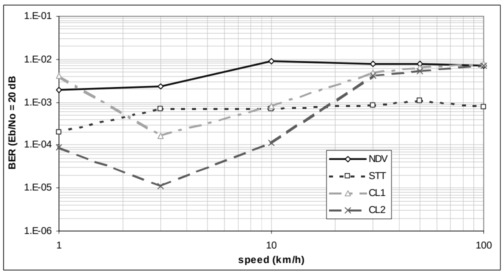

Fig. 8. Probability curve for the non-diversity mode, STTD, CL1 and CL2 versus the mobile speed

Fig. 8 shows the error probability simulation results for an E_b/N_o in reception of 14 dB versus the mobile speed. In this figure we can compare the different speed values all together. In a stationary case, since there is no fading to compensate, the diversity modes can even make the performance get worse (CL1), instead of getting diversity gain. When the mobile speed increases (time-varying channel), these techniques are useful. So, closed loop modes are better with low speeds but they do not improve the non-diversity probability at high speeds. Mode 1 of the closed loop techniques is worse than expected, because the two possibilities of transmission are not enough to improve the quality (mode 2 uses 16 possibilities). At high speeds, the STTD mode is the one that gets diversity gain. This mode is hardly affected by speed since it does not consider any knowledge of the channel whose variations, difficult to follow, are the real problem of the closed loop methods.

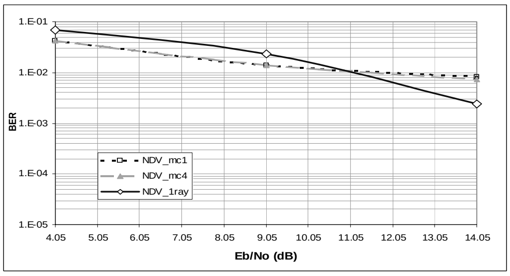

Fig. 9. Probability curve for the non-diversity mode. Propagation channel models 1 – 4 [8] and 1 path – 3 km/h –

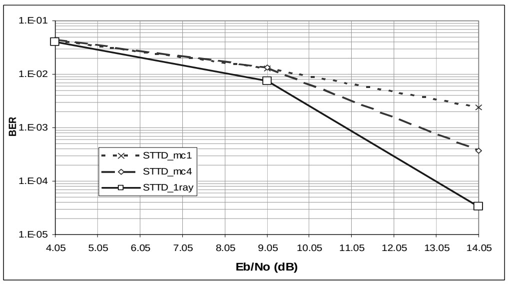

Fig. 10. Probability curve for the STTD-diversity mode. Propagation channel models 1 – 4 [8] and 1 path – 3 km/h –

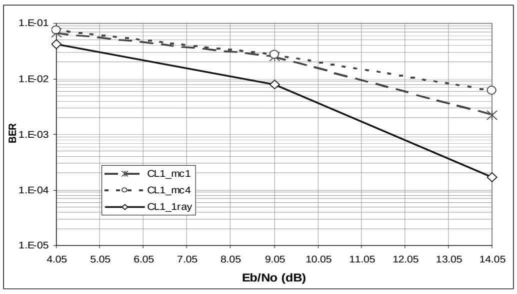

Fig. 11. Probability curve for the CL1-diversity mode. Propagation channel models 1 – 4 [8] and 1 path – 3 km/h –

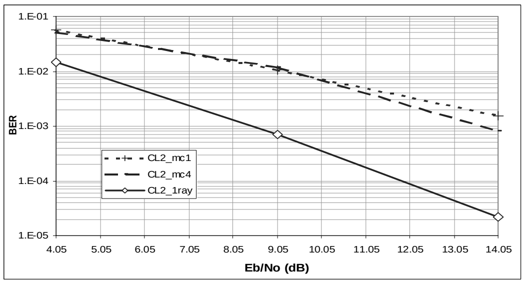

Fig. 12. Probability curve for the CL1-diversity mode. Propagation channel models 1 – 4 [8] and 1 path – 3 km/h –

Fig. 9, Fig. 10, Fig. 11 and Fig. 12 show the result of multipath propagation over the diversity and non-diversity modes. In these figures we can observe how in the case of more than one delayed path, the error probability is greater than in the case of a single Rayleigh path, both with a 3 km/h Doppler frequency. Open loop techniques suffer less than the closed loop modes, since the special encoding of the STTD mode makes it easier to separate the fading and multipath effects (Fig. 10). The results with the closed loop modes get worse if multipath exists, as seen in Fig. 11 and Fig. 12.

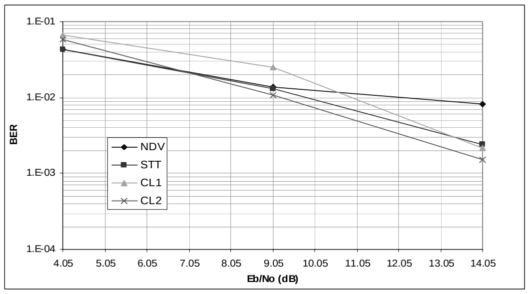

Fig. 13. Probability curve for the transmit diversity modes vs. the non-diversity mode. Channel model 1

Fig. 13 shows the simulation results for the real channel model 1 (two Rayleigh paths with powers of 0 and –10 dBm), comparing the diversity techniques versus the non-diversity transmission. The figure shows that in a better environment (14 dB E_b/N_o) the results are as expected in that case of Doppler frequency (3 km/h): the closed loop mode 2 is the best option.

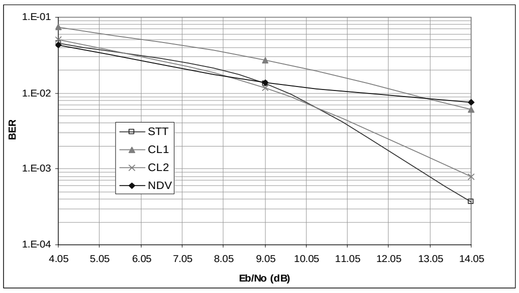

Fig. 14. Probability curve for the transmit diversity modes vs. the non-diversity mode. Channel model 4

Fig. 14 shows the same results as Fig. 13, but using a channel with the same Doppler frequency (3 km/h) and two delayed rays (almost 4 chips) but both with a power of 0 dBm. The curves show how the closed loop techniques get worse with a stronger multipath effect, whereas the open loop mode works well.

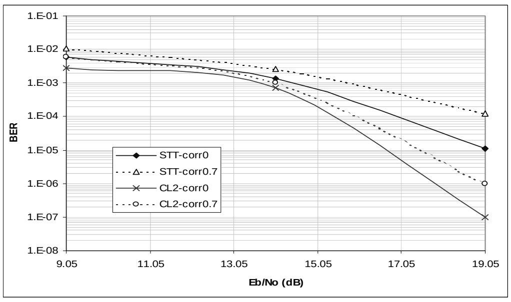

Fig. 15. Probability curve for diversity modes STTD and CL2 with a correlation factor of 0.0 and 0.7.

Fig. 15 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. These results are worse than the ones of two independent paths, represented by the continuous line.

IV. CONCLUSIONS

The negative effect of the radio environment on the quality of downlink reception may be overcome thanks to the transmit diversity techniques supported by the terminal, although the obtained diversity gain depends on many factors, which reduce the theoretical improvement.

In general, with low mobile speeds, which imply low Doppler frequencies, the environment is stable enough to get a good estimation of the propagation channel. Both open and closed loop methods are suitable to obtain diversity gain, although it is higher with the closed loop modes due to the channel knowledge in the terminal. This knowledge makes the BS adjust the transmission parameters to maximise the reception power. Mode 2 of closed loop transmit diversity, gets a best performance since the BS can choose among more possibilities of transmission than the mode 1. However, the improvement drops when the mobile speed increases, because the fast time variations make the channel estimation and tracking too difficult. Therefore, the open loop techniques are particularly appealing, since no knowledge of the channel is used.

The actual obtained diversity gain highly depends on the correlation between the two propagation channels. The theoretical improvement is reduced since the assumption of independency (one of the propagation paths will compensate the fading effects of the other), is not real in practise.

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 unless the environment conditions are suitable (a better SNR).

ACKNOWLEDGEMENTS

This work has been supported by grants TIC2001-2481 and 2FD97-1070 from the Spanish Government (CICYT) and FEDER

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