Performance Simulation of 3G Closed Loop Transmit Diversity Systems

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Abstract- It is well known that the third generation partnership project (3GPP) for WCDMA FDD has chosen Space Time Transmit Diversity (STTD) (known also as open loop transmit diversity) and Feedback Mode Transmit Diversity (FBTD) (known also as closed loop transmit diversity) as transmit diversity techniques for two transmit antennas. In this paper, we look into the performance of closed loop transmit diversity schemes in the downlink of a WCDMA systems release 4. More specifically, we compare by simulations in a very realistic environment the mode 1 and mode 2 performance of the FBTD scheme. The resulting simulation curves show (i) the effect of varying mobile speeds on the performance of the two modes of FBTD with and without fast closed loop power control, (ii) the impact of channel estimation errors on the average bit error rate (BER), and (iii) the consequences of errors in the feedback path between receiver and transmitter.

Key-Word: - WCDMA, Transmit Diversity, 3G

1 Introduction

The usage of high data rate and multimedia services has considerably increased. To cope with this demand, emerging and proposed systems are reducing the effect of fading by using multiple transmit antennas and capitalizing on the resulting diversity gain to obtain an important capacity improvement. Since transmit diversity in a Direct Sequence Code Division Multiple Access (DS-CDMA) system is generally implemented in the downlink link (DL), multiple transmit antennas giving rise to diversity have been shown to increase DL capacity in cellular systems. An attempt has been made in this paper to capture the essential elements of FBTD transmit diversity in 3G Wide band Code Davison Multiple Access (WCDMA) systems. After an overview of the FBDT modes is provided, the performance comparison of the various modes of operation is given and issues related to these modes are discussed.

Transmit diversity schemes are normally divided into two categories, the ones requiring User Equipment (UE) feedback to the base station, and referred to as the closed loop transmit diversity schemes and the ones not requiring the UE feedback to base station, and referred to as the open loop transmit diversity schemes. Universal Mobile Telecommunications System (UMTS) in 3G standardization has employed transmit diversity (TD) as a means of enhancing the down link (DL) capacity. Several studies have been done on this topics [1-5**]**.

Depending on the feedback rate, the open loop transmit diversity schemes ultimately do better than the closed loop diversity schemes at high Doppler [6]. An open loop transmit diversity scheme was first proposed in [6] and it includes the delay diversity scheme of as a special case. The delay diversity for CDMA systems was also proposed in the distributed antenna concept of [7, 8]. The delay diversity for CDMA has the drawback of increased multipath interference. Orthogonal spreading sequences for diversity antennas of CDMA systems was proposed in [8, 9]. Further the implementation of the maximum likelihood receiver for the fading resistant modulation is more complex compared to the maximum likelihood receiver for space time block codes, which turns out to be a linear receiver [1].

2 Closed Loop Transmit Diversity

Both open-loop and closed-loop Tx diversity schemes maintain orthogonality between users in a single-path channel. To achieve supplementary diversity in DL transmission, all schemes assume that Tx antenna separation is roughly 10-20 wavelengths. Then, the signals transmitted from both BTS antennas arrive virtually synchronously at the UE. In addition, the channels are only slightly correlated, which brings the required diversity [10-13].

UMTS Terrestrial Radio Access (UTRA) Tx diversity concepts are targeted for environments where sufficient diversity is not available by conventional diversity techniques. Hence, these techniques are aimed at increasing DL capacity in channels/environments with small delay spread or channels with small Doppler spread.

In a closed loop system, the mobile unit periodically determines the optimal transmit antenna weights to maximize the SNR at the mobile unit. Quantized versions of the optimal weights obtained are transmitted to the base station through the feedback channel.

The weight factors (actually the corresponding phase adjustments in closed loop mode 1 and phase/amplitude adjustments in closed loop mode 2) are determined by the UE, and signaled to the Universal Terrestrial Radio Access Network (UTRAN) access point using the D sub-field of the Feed Back Information (FBI) field of uplink Dedicated Physical Control Channel (DPCCH).

For the closed loop mode 1 different orthogonal dedicated pilot symbols in the DPCCH are sent on the 2 different antennas. For closed loop mode 2 the same dedicated pilot symbols in the DPCCH are sent on both antennas.

Fig. 1 depicts the generic downlink transmitter structure used to support closed loop mode transmit diversity for Dedicated Physical Channel (DPCH) transmission [10]. Common Pilot Channel (CPICH) CPICH1 and CPICH2 are orthogonal, which allows the UE to estimate the channels seen from each antenna separately.

In this paper, we focus on closed loop: Mode 1 and 2 performances for varying UE speeds over single- and multi-Rayleigh Fading channel with CPICH channel estimation. Before presenting some performance results obtained after extensive simulations in realistic wireless environments, we first briefly review the theory behind closed-loop transmit diversity and the way mode 1 and 2 (as specified by the 3GPP standard) operate.

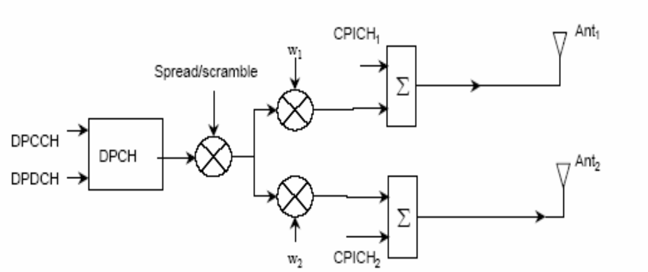

Fig. 1 Block Diagram Of Feedback Transmit Diversity

The received signal at the UE RAKE is

$$y = \left(\sum_{i=1}^{fn} x(h^i{}_1 w_1 + h^i{}_2 w_2) + n(t)\right), \quad (1)$$

where y is the DPCCH received at the UE receiver, $x =$ is the DPCCH after spreading and scrambling, $h^i{}_1$, $h^i{}_2 =$ are the complex fades corresponding to the transmit antenna 1 and 2 of finger i, w_1, w_2 are the feedback weight determined from the phone for antenna 1 and 2, $n(t)$ is the total noise at the UE receiver and $fn =$ is the number of fingers. The complex weights, w_1, w_2 are computed at the UE to maximize the received signal power. After the weight is computed, the feedback signal is transmitted to the base station in the FBI field, at the rate of one bit per slot [13].

The receiver power P is given by

$$P = \underline{w}^H H^H H \underline{w} \quad (2)$$

where $H = [\underline{h}_1 \quad \underline{h}_2]$ is the channel coefficient matrix. The first weight is fixed at zero degrees, and as such we can maximize the received signal power by the following settings [12, 13]

$$\angle w_2 = \angle(\underline{h}_2{}^H \underline{h}_1) \quad (3)$$

$$|w_2|^2 = \frac{\underline{h}_2{}^H \underline{h}_2}{\underline{h}_1{}^H \underline{h}_1 + \underline{h}_2{}^H \underline{h}_2} \quad (4)$$

$$|w_1|^2 = \frac{\underline{h}_1{}^H \underline{h}_1}{\underline{h}_1{}^H \underline{h}_1 + \underline{h}_2{}^H \underline{h}_2} \quad (5)$$

To calculate the demodulated symbols, let the channel estimate for antenna be denoted by $\hat{h}_1$ and let the channel estimate for antenna 2 be denoted by $\hat{h}_2$ then for the no transmit diversity (ND) case the channel estimate $= \underline{\hat{h}_1}$ and the demodulated symbols $= (\underline{\hat{h}_1})^H \cdot \underline{y}$. On the other hand for the CLDT case the channel estimate $= \underline{\hat{h}_1} + \underline{\hat{h}_2} w_2$ and the demodulated symbols $= (\underline{\hat{h}_1} + \underline{\hat{h}_2} w_2)^H \underline{y}$.

The length of the column vectors $\underline{\mathbf{h}}_1$ and $\underline{\mathbf{h}}_2$ is dependent upon the number of finger assignment. The components of $\underline{\mathbf{h}}_1$ and $\underline{\mathbf{h}}_2$ are obtained by CPICH channel estimator. $\underline{\mathbf{w}} = [w1,w2]^T$ is the weight vector whose optimal values calculated according to the following procedure:

Step 1: Rotate the channel coefficients from antenna 2 through multiplication by $e^{j\phi_r(i)}$. The UE uses the CPICH transmitted both from antenna 1 and antenna 2 to calculate the phase adjustment to be applied at the UTRAN access point in order to maximize the UE received power. In each slot, the UE calculates the optimum phase adjustment, ϕ, for antenna 2, which is then quantized into ϕ_Q which takes two possible values:

$$\phi_Q = \begin{cases} \pi, & \text{if } \pi/2 < \phi - \phi_r(i) \le 3\pi/2 \\ 0, & \text{otherwise} \end{cases} \quad (6)$$

Where

$$\phi_r(i) = \begin{cases} 0, & i = 0,2,4,6,8,10,12,14 \\ \dfrac{\pi}{2}, & i = 1,3,5,7,9,11,13 \end{cases} \quad (7)$$

and i represents the uplink slot number.

Step 2: Calculate the optimum phase adjustment (in order to maximize the UE received power) by solving the weight vector $\underline{w}$ that maximizes

$$P = \underline{W}^H H^H H \underline{w}$$

where

$$H = [\underline{h_1} \quad \underline{h_2} ....] \quad and \quad \underline{w} = [w_1; w_2] \quad (8)$$

The weight w_2 is then calculated by averaging (through sliding window) the received phases over 2 consecutive slots. Algorithmically, w_2 is calculated as in [13]:

$$W_2 = \frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}},\ -\frac{1}{\sqrt{2}} + j\frac{1}{\sqrt{2}},\ \frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}},\ or\ -\frac{1}{\sqrt{2}} - j\frac{1}{\sqrt{2}} \quad (9)$$

And $w_1 = 1/\sqrt{2}$ (10)

In this case, there is no need to send the weight of antenna 1 since it is fixed, thus we only have to send the weight used for antenna 2.

Step 3: The phase of w_2 gives the maximum receive power. It is quantized into ϕ_Q according to (2)

$$\frac{-\pi}{2} < phase \;\; of \;\; w_2 \le \frac{\pi}{2} \quad Yields\ to\ \phi_Q = 0 \quad (11)$$

$$\frac{\pi}{2} < phase \;\; of \;\; w_2 \le \frac{3\pi}{2} \quad give \quad \phi_Q = \pi \quad (12)$$

If ϕ_Q = 0, a command '0' is send to UTRAN using the FSM_{ph} field. Correspondingly, if ϕ_Q = π, command '1' is send to UTRAN using the FSM_{ph} field.

Step 4: Mapping between phase adjustment, ϕ_i, and received feedback command for each uplink slot. Due to the rotation of the constellation at the UE, the UTRAN interprets the received commands according to table 1 which repesents the phase adjustments, ϕ_i, corresponding to feedback commands for the slots *i* of the UL radio frame.

Table 1 UTRAN Interpretive

Slot #		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14
FSM	0	0	π/2	0	π/2	0	π/2	0	π/2	0	π/2	0	π/2	0	π/2	0
	1	π	-π/2	π	-π/2	π	-π/2	π	-π/2	π	-π/2	π	-π/2	π	-π/2	π

Step 5: w_1 and w_2 are multiplied by the incoming signal and the resulting signals are transmitted from the two antennas of the UTRAN.

In FBDT mode 2, every slot time the UTRAN constructs the FSM from the most recently received bits. In FBDT mode 2 there are 16 possible combinations of phase and power adjustment from which the UE selects and transmits the FSM [13]. As opposed to FBDT mode 1, no constellation rotation is done at the UE and no filtering of the received weights is performed at the UTRAN. In this case the weight vector, $\underline{w}$, is calculated as:

$$\underline{w} = \begin{bmatrix} \sqrt{power\_ant1} \\ \sqrt{power\_ant2}\,\exp(j\ phase\_diff) \end{bmatrix} \quad (13)$$

3 Two Antenna Channel Estimation

This section explains channel estimation for the demodulated data-stream heading towards the channel decoder. It is performed by averaging over a 2-symbol period and using the CPICH IMALI method as in [14]. Estimates are combined in the proportion of power on the respective channels to give a combined channel estimate. All simulations have been executed with channel estimates from the CPICH1 and CPICH2 channels. Fig. 2 illustrate of the common pilot pattern.

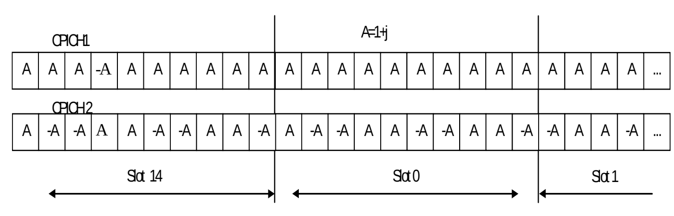

Fig. 2 CPICH1 and CPICH 2 Pattern

Assume that the receiver vector is

Rx*(n) = {[h₁, h₁']. x [A, A] + [h₂, h₂']. x [A, -A]}* (14)

Accordingly, if h_1~h_1' and h_2~h_2', then the channel coefficients can be estimated by

$$h_1 \sim h_1' = \mathbf{Rx}(n)\ [A, A]^H/2 \text{ and} \quad (15)$$

$$h_2 \sim h_2' = \mathbf{Rx}(n)\ [A, -A]^H/2 \quad (16)$$

The constellation diagram shown in Fig. 3 which depicts the FBTD mode 2, with 4 finger rake receivers, 4 paths fading channel model (the multipath delay set to 0)

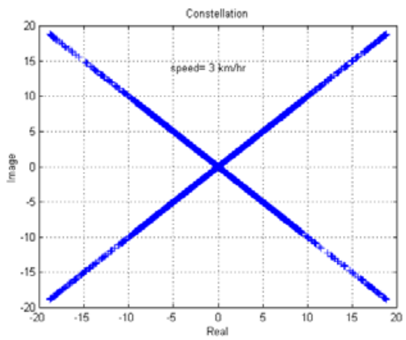

Fig. 3 FBMD mode 2 Constellation, no close loop power control, UE speed =3 km/hr.

4 Performance Results

The transmit diversity environments and the simulation parameters used for the performance gains evaluation is shown in Table 2. The performance results are illustrated in Figs. 4-11.

Table 2 Simulation environments and parameters

Description	Parameters
Modified ITU channel models	2 paths with UE speed 3 km/hr
	Case 2: 3 paths with UE speed 30 km/hr.
	Case 3: 4 paths with UE speed 120 km/hr
Relative power levels of CPICH and DTCH are	parameterized
FEC	Convolutional / Viterbi decoder, 1st and 2nd interleaver and CRC)
Sampling rate (no RRC filters):	1 sample/chip
UE velocities	3 km/h (6 Hz), 30 km/hr (56 Hz) and 120 km/h (222 Hz)
Slot format	9
Channel bit rate	60 Kbps in physical channel
Bits per slot	40 bits/slot
Channel estimation	2-symbol CPICH
CPICH power	3 dB higher than DTCH
Errors introduced in TPC bits	0
Errors introduced in FBI bits	4 % and 0%
TPC power level factor	0.625
AFC/AGC and timing jitter:	0

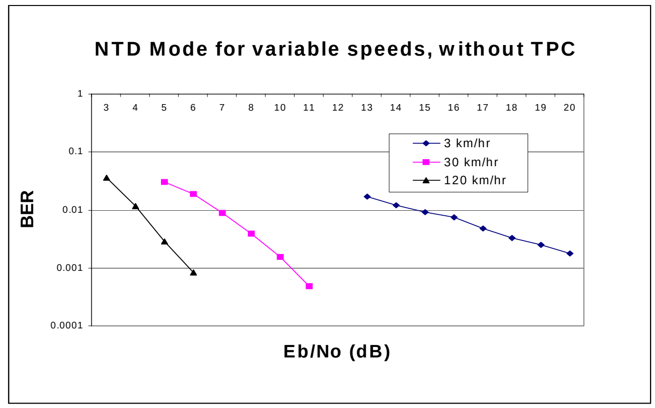

Fig. 4 NTD Mode for UE; Variable Speeds; No TPC

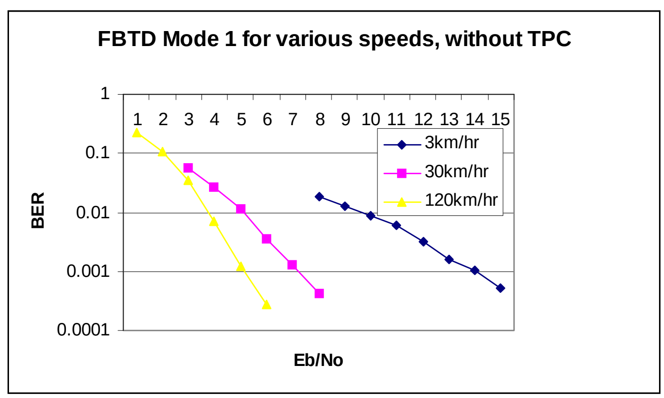

Fig. 5 FBTD Mode 1; Variable UE Speeds; No TPC

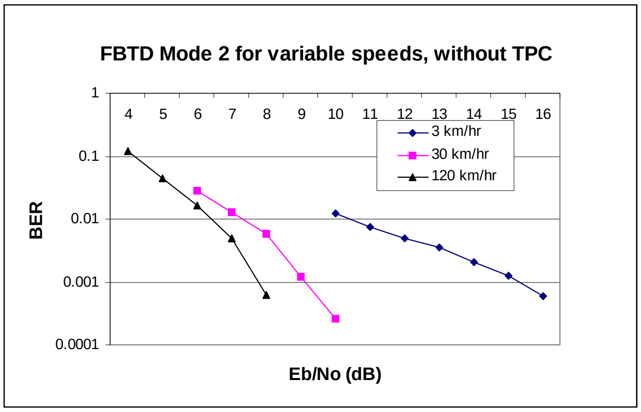

Fig. 6 FBTD Mode 2; Variable UE Speeds; No TPC

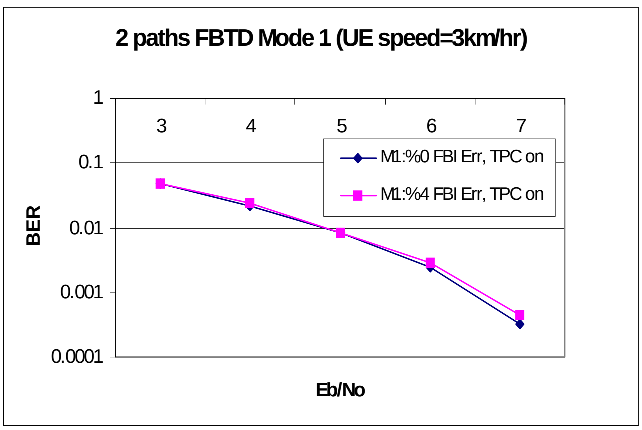

Fig. 7 Two Paths FBTD Mode 1; UE Speed = 3 km/hr

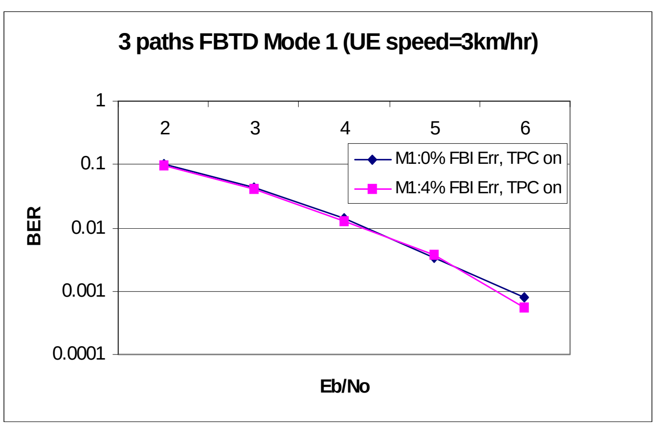

Fig. 8 Three Paths FBTD Mode 1; UE Speed = 30 km/hr

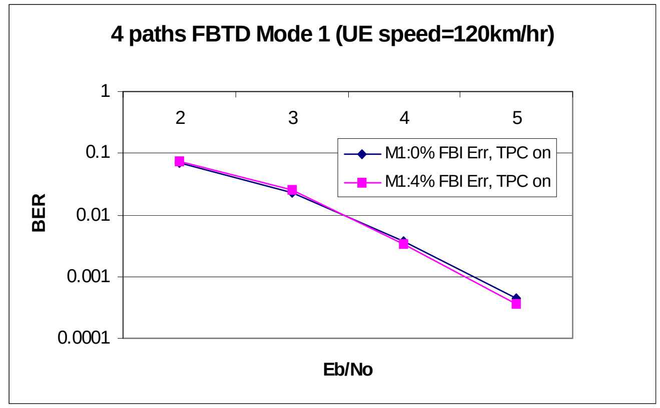

Fig. 9 Four Paths FBTD Mode 1; UE Speed = 120 km/hr

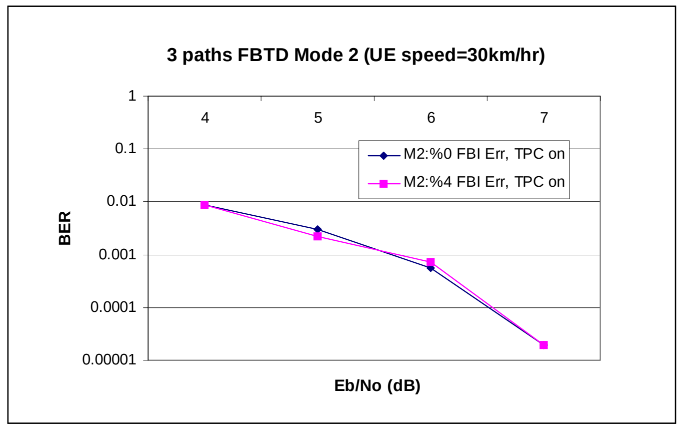

Fig. 10 Three Paths FBTD Mode 2 , UE speed = 30 km/hr

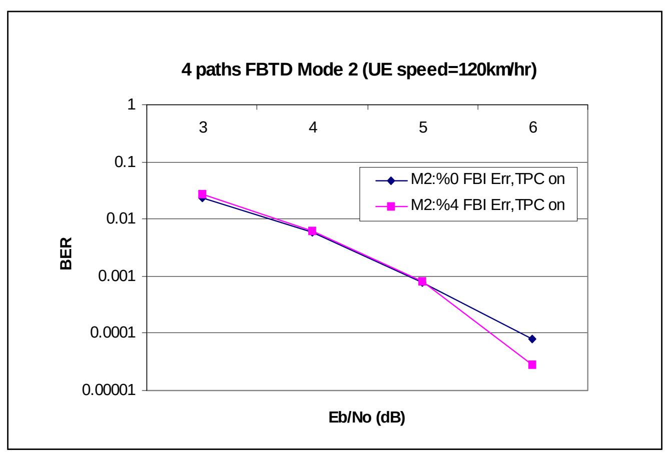

Fig. 11 Four Paths FBTD Mode 2 ,UE speed = 120 km/hr

5 *Results Discussion*

For the single channel model without power control, at low UE speeds (3km/hr), FBTD has much better performance than NTD. However, the performance improvement degrades as the speed increases. FBTD Mode 1 and Mode 2 have similar performance at all speeds. On the other hand, for the multi-path channel model with power control conditions, Mode 1 and Mode 2 achieve similar performances for the three cases under consideration (2, 3, or 4 paths conditions). In order to perform power control and the FBTD mode, it is necessary to stabilizes system performance by tuning the power level. Also we can conclude from Figs. 7 to 11, that an FBI error of 4%, does not affect the system performance. We can also conclude from these Fig.s that the performance of closed loop FBTD with TPC enabled is worse compared to the no diversity case when the UE is in high speed conditions. From this, we can conclude that FBTD should be used in slow fading channels. It can also be concluded that with SIR based closed loop power control and CPICH channel estimation, diversity gains are not significant in the downlink of 3G WCDMA system at high mobile speeds.

Acknowledgments

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