Transmit Diversity in LTE Network

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***Abstract* — This paper investigate the effect of transmit diversity in LTE downlink transmission. Transmit diversity scheme known as Space Frequency Block Codes (SFBC) is considered. As performances metrics, the average BER is evaluated in terms of signal to interference-plus-noise ratio (SINR). We evaluate the channel estimation scheme for LTE downlink based on 3GPP LTE downlink specifications in presence of high Doppler deviations. Finally the accuracy and effectiveness of the theoretical analysis is verified by the simulation with idealized multipath channel models as well as the ITU pedestrian and vehicular channel with high order modulation and coding scheme.**

***Keywords* — LTE, SFBC, MIMO, OFDM.**

I. Introduction

THE conflict of limited bandwidth resources and rapidly growing number of users becomes exceptional, so the spectrum efficiency of system should be improved by adopting some advanced technologies. It has been demonstrated in both theory and practice that some novel technologies such as Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input, and Multiple-Output (MIMO) systems can enhance the performance of the current wireless communication systems [1]. High data rates and high capacity can be attained by using the advantages of the two technologies. For this reason, Long Term Evolution (LTE) will be the basis on which future mobile telecommunications systems will be built. LTE is the first cellular communication system optimized from the outset to support packet-switched data services, within which packetized voice communications are just one part. The LTE solution provides spectrum flexibility with scalable transmission bandwidth between 1.4 MHz and 20 MHz depending on the available spectrum for flexible radio planning. The 20 MHz bandwidth can provide up to 150 Mbps downlink user data rate and 75 Mbps uplink peak data rate with 2×2 MIMO, and 300 Mbps with 4×4 MIMO. A summary of release 8 can be found in [1].

The effect of radio propagation conditions on the transmitted information must be estimated in order to recover the transmitted information accurately. Therefore channel estimation is a vital part in the receiver designs of LTE.

There are two modes in which MIMO can improve LTE system performance. One mode is spatial multiplexing and the other mode is transmit diversity, in which the Space-Frequency Block Codes (SFBC) [2] are used to obtain diversity gain.

SFBC is a frequency domain adaptation of renowned Space-Time Block Coding (STBC) where encoding is done in antenna-frequency domains rather than in antenna-time domains. STBC is also recognized as Alamouti coding [3].

In LTE, transmit diversity is defined only for 2 and 4 transmit antennas and these antennas usually need to be uncorrelated to take full advantage of diversity gain.

The advantage of SFBC over STBC is that in SFBC coding is done across the subcarriers within the interval of OFDM symbol while STBC applies coding across a number of OFDM symbols equivalent to number of transmit antennas [3]. The implementation of STBC is not clear in LTE as it operates on the pairs of adjacent symbols in time domain while in LTE number of available OFDM symbols in a sub-frame is often odd. The operation of SFBC is carried out on pair of complex valued modulation symbols [3]. Hence, each pair of modulation symbols are mapped directly to OFDM subcarriers of first antenna while mapping of each pair of symbols to corresponding subcarriers of second antenna are reversely ordered, complex conjugated and signed reversed[4].

The resulting SFBC can realize full space diversity but is not guaranteed to achieve full diversity (space and frequency) [5]. As the Alamouti STBC which suffers performance degradation in presence of high Doppler [6], the LTE SFBC can't achieve optimal performance unless the channel remaining constant over at least two consecutive subcarriers.

The investigation is conducted by means of a LTE system-level simulator [7]. Most parts of the LTE simulator are written in plain Matlab code. Only computationally intensive functions like soft-sphere or channel decoding are implemented in C++ as MEX functions.

This paper is structured as follows: in Section II a description of SFBC in LTE network is presented. Section III describes theoretical analyze of the average signal to interference-plus-noise ratio (SINR) with imperfect channel estimation, delay spread, and correlated channels. Results are presented in Section IV. Section V presented the conclusions.

II. SFBC in LTE Network

The use of transmit diversity is common in the downlink of cellular systems because it is cheaper and easy to install multiple antennas at base station eNodeB than to put multiple antennas at every handheld device

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(UE-User Equipment). In transmit diversity to combat instantaneous fading and to achieve considerable gain in instantaneous SINR, the receiver is being provided with multiple copies of the transmitted signal. Hence transmit diversity is applied to have extended converge and better link quality when the users experience terrible channel conditions.

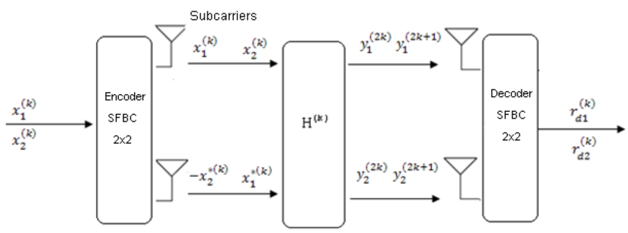

Fig. 1. Transmit diversity with 2x2 MIMO-SFBC

In MIMO system with N_{UE} receive antenna and M_{eNodeB} transmit antenna, the relation between the received „y" and the transmitted „x" signals is given by:

$$y = \frac{1}{\sqrt{2}} Hx + n \tag{1}$$

Fig. 1 shows transmit diversity for „k" subcarriers with 2x2 MIMO-SFBC. $k = 0, 1, 2, \ldots, (N_c - 1)$, where N_c is the total number of subcarriers.

OFDM symbols transmitted from two and four antennas can be written in matrices form as follows:

$$X_{M_{eNodeB=2}} = \overset{\text{Space}\;\longrightarrow}{\begin{bmatrix} x_0 & -x_1^* \\ x_1 & x_0^* \end{bmatrix}} \Big\downarrow \text{Frequency} \tag{2}$$

$$X_{M_{eNodeB=4}} = \overset{\text{Space}\;\longrightarrow}{\begin{bmatrix} x_0 & 0 & -x_1^* & 0 \\ x_1 & 0 & x_0^* & 0 \\ 0 & x_2 & 0 & -x_3^* \\ 0 & x_3 & 0 & x_2^* \end{bmatrix}} \Big\downarrow \text{Frequency} \tag{3}$$

The symbols received from 2×2 MIMO-SFBC [4] are:

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \frac{1}{\sqrt{2}} \begin{bmatrix} h_{00} & -h_{01} \\ h_{11}^* & h_{10}^* \end{bmatrix} \begin{bmatrix} x_0 \\ x_1^* \end{bmatrix} + \begin{bmatrix} n_0 \\ n_1^* \end{bmatrix} \tag{4}$$

Where $h_{i,j}$, $i, j \in \{0,1\}$ represents the channel response at the i[th] symbol from transmit antenna j and n_0, n_1 are complex additive white Gaussian noises. It should be noticed that h_{0i} and h_{0j}, $(i, j \in \{0,1\})$, may not be identical because of the delay spread. Moreover, h_{i0} and h_{i1}, may not be independent because of the correlation between antennas.

Assuming that the receiver estimate channel by pilot symbols, the estimated channel responses can be modeled by [8]. Let $\widehat{H}$ be the estimate of channel impulse responses at the pilot symbols:

$$\widehat{H} = H + \widetilde{H} \tag{5}$$

where $\widetilde{H}$ is zero mean complex circular white noise vector.

The desired signal after maximum likelihood decoding [9] is:

$$R = \widehat{H}^H y = \frac{1}{\sqrt{2}}\left(H^H + \widetilde{H}^H\right)\frac{1}{\sqrt{2}}(Hx + n) \tag{6}$$

$$\begin{aligned} R &= \frac{1}{2}\begin{bmatrix} |h_{00}|^2 + |h_{11}|^2 & h_{10}^* h_{11} - h_{00}^* h_{01} \\ h_{10} h_{11}^* - h_{00} h_{01}^* & |h_{10}|^2 + |h_{01}|^2 \end{bmatrix} x + \\ &+ \frac{1}{2}\widetilde{H}^H Hx + \frac{1}{\sqrt{2}}\left(H^H + \widetilde{H}^H\right)n = \\ &= \frac{1}{2}\begin{bmatrix} (|h_{00}|^2 + |h_{11}|^2)x_0 \\ (|h_{10}|^2 + |h_{01}|^2)x_1^* \end{bmatrix} + \frac{1}{2}\begin{bmatrix} (h_{10}^* h_{11} - h_{00}^* h_{01})x_1^* \\ (h_{10} h_{11}^* - h_{00} h_{01}^*)x_0 \end{bmatrix} + \\ &+ \frac{1}{2}\widetilde{H}^H Hx + \frac{1}{\sqrt{2}}\left(H^H + \widetilde{H}^H\right)n \end{aligned} \tag{7}$$

The first two terms in equation (7) gives the desired data symbols after decoding, the third term represents self-interference and the fourth term denotes additive noises.

Mathematical derivations of channel estimation algorithms for MIMO case can be found in [10]-[11].

III. AVERAGE BER

The imperfect channel estimation, delay spread, and correlated channels influence the average Bit Error Rate (BER) in two modes. One mode is that these non-ideal factors introduce self-interferences, which result in a smaller average $\overline{SINR}$. The other mode is that the correlated channels may cause a lower diversity order „n" [12]. If the sum of self-interference and noise can be approximated by a Gaussian distribution, the average BER is given by $P_{Rayleigh}(\overline{SINR}, n)$. $P_{Rayleigh}(\overline{SINR}, n)$ is the function that return the average BER in Rayleigh channel with a average $\overline{SINR}$ and a diversity order „n". For common modulation schemes, $P_{Rayleigh}(\overline{SINR}, n)$ can be found from [12]-[14].

If the correlation coefficient $\eta = E(h_{00}h_{01}^*) = E(h_{10}h_{11}^*)$ is greater than 0.5 is very complicated to compute the diversity order „n" for the channels with the correlation coefficient.

The covariance matrix of noises is:

$$\frac{1}{2}E\left(\left(H^H + \widetilde{H}^H\right)nn^H\left(H + \widetilde{H}\right)\right) = NI_2 \tag{8}$$

where $N = \sigma_n^2(1 + \sigma_{\tilde{h}}^2)$ is average power of noise.

The average power of the self-interference due to power delay can be evaluated as:

$$\begin{aligned} \mathrm{I}_1 &= \frac{1}{4}E(|h_{10}^* h_{11} - h_{00}^* h_{01}|^2 |x_0|^2) \\ &= \frac{1}{4}E(|h_{10} h_{11}^* - h_{00} h_{01}^*|^2 |x_1|^2) \\ &= \frac{1}{4}E(|h_{10}|^2|h_{11}|^2 + |h_{00}|^2|h_{01}|^2 \\ &\quad - h_{10}^* h_{11} h_{00} h_{01}^* - h_{10} h_{11}^* h_{00}^* h_{01}) \\ &\approx \frac{1}{4}(E(|h_{10}|^2|h_{11}|^2) + E(|h_{00}|^2|h_{01}|^2) \\ &\quad - E(h_{00}h_{10}^*)E(h_{00}^* h_{11}) \\ &\quad - E(h_{00}^* h_{10})E(h_{01}h_{11}^*)) \\ &= \frac{1 - \Re(\rho_0 \rho_2)}{2} \end{aligned} \tag{9}$$

where $\Re(\cdot)$ is a function that returns the real part of complex numbers.

The channel correlation for two consecutive subcarriers can be written as (10) and (11):

$$\rho_0 = E(h_{00}h_{10}^*) \tag{10}$$
$$\rho_0 = E(h_{00}h_{10}^*) \tag{11}$$

If $|\eta| \ll min\{|\rho_0|, |\rho_1|\}$ which means that $h_{00}h_{10}^*$ and $h_{01}h_{11}^*$ are approximately independent, and $\rho_0 = \rho_1$, $\sigma_T\Delta f \ll 1$ we have [9]:

$$I_1 \approx 2(\pi\sigma_T\Delta f)^2 \tag{12}$$

Δf=15kHz is the frequency difference between two consecutive subcarriers, and σ_T is rms delay spread.

Hence, its average power is:

$$I_2 = \sigma_{\tilde{h}}^2 \tag{13}$$

Finally, the average $\overline{SINR}$ is:

$$\overline{SINR} = \frac{1}{I_1+I_2+N} = \frac{1}{\sigma_{\tilde{n}}^2+(1+\sigma_{\tilde{n}}^2)\sigma_{\tilde{h}}^2-\frac{1-\Re(\rho_0\rho_1^*)}{2}} \tag{14}$$

IV. RESULTS

We considered the following parameters in our simulations for LTE downlink.

- the number of subcarriers is 2048 and the subcarriers spacing Δf= 15 kHz.
- Frequency used: 1.8GHz.
- Bandwidth used: 100Mhz.
- the number of transmit antennas M_{eNodeB} is 2 or 4.
- the number of receiver antennasN_{UE} is 2.
- the basic time unit $T_s = \frac{1}{2048\cdot\Delta f} = \frac{1}{2048\cdot 15} \approx 32{,}552ns$.
- modulation schemes: QPSK, 16QAM, and 64QAM.
- $T_{slot} = 0.05ms = 15630T_s$
- each frame occupies 10 ms and consists of 20 slots.
- each slot occupies $T_{slot} = 0.05ms = 15630T_s$ and consists 7 OFDM symbols. The first OFDM symbol in each frame has a cyclic prefix of length 160Ts, and the other 6 OFDM symbols each has a cyclic prefix of length 144Ts (2048 × 7 + 160 + 144 × 6 = 15360).
- Channel models: Equal amplitude two-ray Rayleigh fading channel models are used to verify the theoretical analysis, and ITU pedestrian and vehicular channel models [15] are used for the performance in real environment.

TABLE 1: ITU-R CHANNEL MODELS [15].

Profile	Profile description	μ_T (ns)	σ_T (ns)
ITU-R3GB	Outdoor to indoor and pedestrian	409	633
ITU-R3GA	Vehicular (A)	254	370
ITU-R3GBB	Vehicular (B)	1498	4001

μ_T **is** average delay spread and σ_T **is** rms delay spread.

In Fig.2, the theoretical prediction is quite accurate in most scenario except the 64QAM at high $\overline{SINR}$, when the 5Hz Doppler spread still causes a difference that can't be ignored.

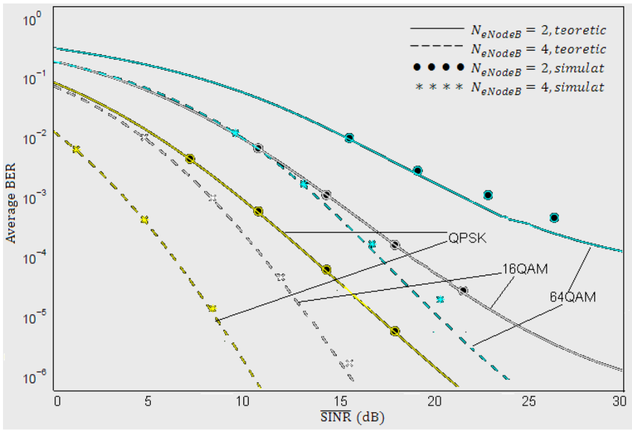

Fig. 2. Average BER for ITU-R3GB model ($f_{Doppler}$=5Hz, η=0,8, NUE=2).

It can also be seen that 4 transmit antennas provide much larger array gain and diversity gain than 2 transmit antennas. The use of multiple antenna arrays provides additional diversity gain.

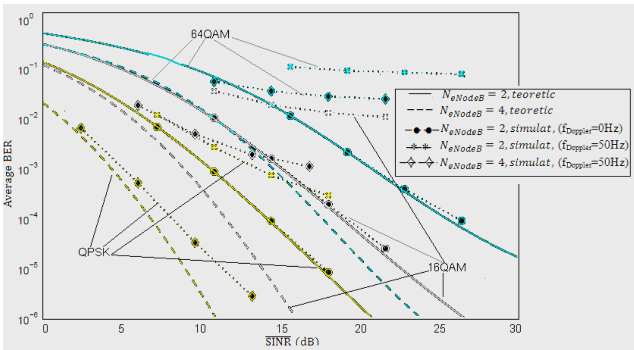

Fig. 3. Average BER for ITU-R3GA model (η=0,8, N_{UE}=2)

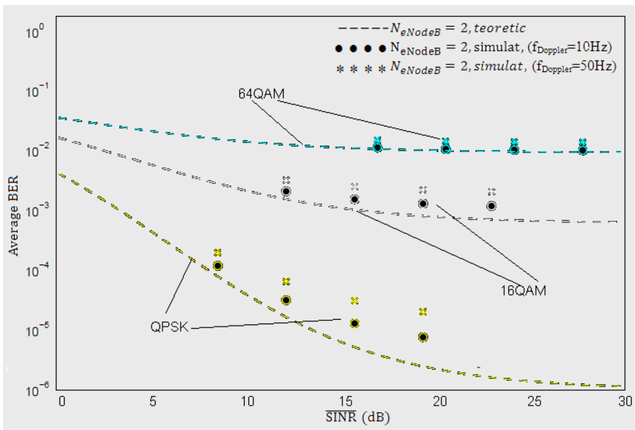

Fig. 4. Average BER for ITU-R3GBB model (η=0,8, N_{UE}=2)

Fig. 3 shows how the Doppler spread and the numbers of receiver antennas influence the average BER. The ITU-R3GA model has a small delay spread, the influence of ISI (Inter Symbol Interference) is eliminated and a good performance in terms of BER is attained. Because our channel estimation is not perfect, the Doppler results in great performance degeneration.

Again we can see that the 64QAM is more sensitive to the non-ideal factors, and more transmit antennas can improve the system performance greatly.

In Fig. 4, we tested the most unfavorable conditions. In this case the significant ISI due to large delay spread causes important performance deterioration even if the QPSK modulation is used and the Doppler spread is as low as 10 Hz. Superficially, not only is the average BER of 64QAM predicted better than QPSK and 16QAM, but the 64QAM also is hardly affected by the high Doppler. However, a significant ISI occurs for these channel models. In addition, the presence of large Doppler spreads causes imperfect channel estimates and the system performance further degrades.

V. CONCLUSIONS

The purpose of this work is to evaluate the channel estimation schemes for LTE downlink based on 3GPP LTE downlink specifications [1] in presence of high Doppler. We have focused on the task of channel estimation and equalization for OFDM based SFBC LTE downlink transmission. The results for 2 or 4 antennas at eNodeB have been presented. The performance is measured in terms of average BER and average $\overline{SINR}$ and the obtained results are compared with theoretical values. The results showed that:

- a four antenna transmitter is indispensable to reduce the transmit power for the high date rate application.
- is absolute necessary to create a sophisticated channel estimation algorithm in the presence of high Doppler spread.
- the use of multiple antenna arrays provides additional diversity gain.

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