Performance Evaluation of MIMO Schemes in 5 MHz Bandwidth LTE System

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***Abstract*—In this paper, we study the performance of the MIMO Schemes in the 3GPP Long Term Evolution (LTE) system with 5 MHz bandwidth. As performances metrics, the Block Error Rate (BLER) and the Data Throughput are evaluated in terms of Signal to Noise Ratio (SNR) for three different Multi-Input Multi-Output (MIMO) schemes as defined in LTE standard. Two transmit diversity schemes known as Space Frequency Block Codes (SFBC) and Frequency Switched Transmit Diversity (FSTD) as well as one Open Loop Spatial Multiplexing (OLSM) scheme are considered in the evaluation. The performance of the three MIMO schemes are compared to the performance of Single Input Single Output (SISO) scheme to evaluate the improvement in BLER and data throughput of the system. The ITU pedestrian B channel with high order modulation and coding scheme is considered for the evaluation.**

Keywords- Multi-antenna MIMO system, LTE, BLER, Data Throughput

I. Introduction

The 3GPP Long Term Evolution is the latest evolution of the wireless communication systems. LTE is part of the UMTS standards but includes many changes and improvements identified by the 3GPP consortium. The goal of LTE is to increase the data throughput and the speed of wireless data using a combination of new methods and technologies like OFDM and MIMO technics. The LTE downlink transmission is based on Orthogonal Frequency Division Multiple Access (OFDMA). OFDM is a technique of encoding digital data on multiple carrier frequencies and it is known to be efficient to improve the spectral efficiency of wireless system. Another important advantage of OFDM technique is to be more resistant to frequency selective fading than single carrier system by converting the wide-band frequency selective channel into a set of many flat fading subchannels. In addition, OFDMA allows for adding frequency domain scheduling to time domain scheduling. In order to optimize the system data throughput and the coverage area for a given transmission power, LTE make use of the Adaptive Modulation and Coding (AMC). In AMC, the transmitter should assign the data rate for each user depending on the channel quality from the serving cell, the interference level from other cells, and the noise level at the receiver. To achieve the target in terms of data throughput and reliability, the LTE standard makes MIMO as its essential core. MIMO was recognized to be a very powerful technique to improve the performance of wireless communication systems. Multiple antenna techniques can be used in two different modes namely the diversity and multiplexing mode. In diversity mode, the same signal is transmitted over multiple antenna and hence the reliability of the system is improved by the diversity gain. In diversity mode, the mapping function of each symbol to which transmit antenna is called Space Time Block Code (STBC). In multiplexing mode, two different spatial streams are sent from two different antennas and hence the data rate is improved. To study the performance of LTE systems a MATLAB based downlink physical layer simulator [1] [2] for Link Level Simulation (LLS) has been developed. A System Level Simulation [3] of the Simulator is also available. The goal of the development of the simulator was to facilitate comparison with work of different research group and it is publicly available for free under academic non-commercial use license [2]. The main features of the simulator are adaptive coding and modulation, MIMO transmission and scheduling. As the simulator includes many physical layer features, it can be used in different application in research [3]. In [4], the simulator was used to study the channel estimation of OFDM systems and the performance evaluation of a fast fading channel estimator was presented. In [5] and [6], a method for calculating the Precoding Matrix Indicator (PMI), the Rank Indicator (RI) and the Channel Quality Indicator (CQI) were studied and analyzed with the simulator.

In this paper, the BLER and the Data Throughput of SISO and MIMO schemes in 5 MHz LTE system for high Modulation and Coding Scheme (MCS) are investigated in terms of SNR using the Link Level LTE simulator [1] [2]. The MCS corresponds to Channel and Quality Indicator (CQI) value of 15 [1].

The remainder of this paper is organized as follows. In Section II, we present the system and channel model used in the simulation. In Section III, we present the MIMO schemes as defined in LTE. A brief review of the diversity schemes used in LTE systems is given in this section. A brief description of the Open Loop Spatial Multiplexing (OLSM) scheme is also reviewed in this section. The simulation results and discussion

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of results will be presented in Section IV. Finally, we conclude our paper in Section V.

II. System and Channel Model

In this section, the structure of the OFDM LTE signal is described. The OFDM signal has a time and a frequency domains. In the time domain, the LTE signal is composed of succesive frames. Each frame has a duration of 10 ms (T_{frame}). Each frame is divided into ten equally 1 ms long subframes. Each subrames consists of two equally long slots with 0.5 ms time duration (T_{slot}). For normal cyclic prefix length each slot consists of N_s = 7 OFDM symbols. In the frequency domain, the OFDM technique converts the LTE wide band signal into a number of narrowband signals. Each narrowband signal is transmitted on one subcarrier frequency. In LTE the spacing between subcarriers is fixed to 15 KHz. Tweleve adjacent subcarriers, occupying a total of 180 KHz, of one slot forms the so-called Resource Block (RB). The number of Resource Blocks in an LTE slot depends on the allowed system bandwidth. The minimum number of RB is equal to 6 corresponding to 1.4 MHz system bandwidth. For 20 MHz system bandwidth (Maximum Allowed bandwith in LTE) the number of RB is equal to 100. In MIMO system with M_R receive antenna and M_T transmit antenna, the relation between the received and the transmitted signals on subcarrier frequency k ($k \in 1, ...K$), at sampling instant time n ($n \in 1, ...N$) is given by

$$\mathbf{y}_{k,n} = \mathbf{H}_{k,n}\mathbf{x}_{k,n} + \mathbf{n}_{k,n} \tag{1}$$

$\mathbf{y}_{k,n} \in C^{M_R \text{X } 1}$ is the received vector, $\mathbf{H}_{k,n} \in C^{M_R \text{X } M_T}$ represents the channel matrix on subcarrier k at instant time n, $\mathbf{x}_{k,n} \in C^{M_T \text{X } 1}$ is the transmit symbol vector and $\mathbf{n}_{k,n} \sim \mathcal{CN}(0, \sigma_n^2.\mathbf{I})$ is white, complex valued Gaussian noise vector with variance σ_n^2. Assuming perfect channel estimation, the channel matrix and noise variance are considered to be known at the receiver. A linear equalizer filter given by a matrix $\mathbf{F}_{k,n} \in C^{M_T \text{X } M_R}$is applied on the received symbol vector $\mathbf{y}_{k,n}$ to determine the post-equalization symbol vector $\mathbf{r}_{k,n}$ [6]

$$\mathbf{r}_{k,n} = \mathbf{F}_{k,n}\mathbf{y}_{k,n} = \mathbf{F}_{k,n}\mathbf{H}_{k,n}\mathbf{x}_{k,n} + \mathbf{F}_{k,n}\mathbf{n}_{k,n} \tag{2}$$

The Zero Forcing (ZF) or Minimum Mean Square Error (MMSE) design criterion [7] are typically used for the linear receiver and the input signal vector is normalized to unit power. In MIMO-OFDM systems, the key factor of link error prediction and performances is the signal to noise ratio (SNR) which represents the measurement for the channel quality information. In practice, there are different measures and calculation procedures for the SNR in SISO and MIMO systems. In this study, the SNR is defined as follows [1]:

$$\gamma_{k,n} = \frac{\|\mathbf{H}_{k,n}\mathbf{x}_{k,n}\|_{\text{F}}^2}{N_R\sigma_n^2} = \frac{N_R}{N_R\sigma_n^2} = \frac{1}{\sigma_n^2} \tag{3}$$

III. MIMO Schemes in LTE

From theory it is well known that in MIMO systems the multiple antennas at the transmitter and the receiver can be used in two different modes, namely the diversity and multiplexing modes. Diversity mode can be used in the receiver (Receive Diversity) or at the transmitter (Transmit Diversity). Where receive diversity is simply a combining operation of different replica of the same transmitted signal, transmit diversity requires a space time coding operation of the transmitted signal. In LTE the two different modes are defined. In this section the different MIMO schemes defined in LTE are described.

A. Diversity Schemes

The transmit diversity techniques are defined only for 2 and 4 transmit antennas and one data stream. When two eNodeB antennas are available for transmit diversity operation, the Space Frequency Block Code (SFBC) [8] is used. SFBC is based on the well known Space Time Block Codes (STBC), also known as Alamouti codes [9]. STBC is defined in the UMTS and it operates on pairs of adjacent symbols in the time domain. As the signal in LTE is two dimensional (time and frequency domains) and the number of available OFDM symbols in a subframe is not always even, the direct application of STBC is not straightforward. In LTE for SFBC transmission, the symbols are transmitted from two eNodeB antenna ports on each pair of adjacent subcarriers as follows [8]:

$$\begin{bmatrix} y^{(0)}(1) & y^{(0)}(2) \\ y^{(1)}(1) & y^{(1)}(2) \end{bmatrix} = \begin{bmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{bmatrix} \tag{4}$$

where $y^{(p)}(k)$ denotes the symbols transmitted on the k^{th} subcarrier from antenna port p. One important characteristic of such codes is that the transmitted signal streams are orthogonal and a simple linear receiver is required for optimal performances. Unfortunately, there is no known orthogonal codes for antenna configurations beyond 2 x 2 and the SFBC has been modified in order to be applied to the case of 4 transmit antennas. The new modified scheme of SFBC is known as Frequency Switched Transmit Diversity (FSTD). The frequency space code for 4 antennas is as follows:

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$$\begin{bmatrix} y^{(0)}(1) & y^{(0)}(2) & y^{(0)}(3) & y^{(0)}(4) \\ y^{(1)}(1) & y^{(1)}(2) & y^{(1)}(3) & y^{(1)}(4) \\ y^{(2)}(1) & y^{(2)}(2) & y^{(2)}(3) & y^{(2)}(4) \\ y^{(3)}(1) & y^{(3)}(2) & y^{(3)}(3) & y^{(3)}(4) \end{bmatrix} = \begin{bmatrix} x_1 & x_2 & 0 & 0 \\ 0 & 0 & x_3 & x_4 \\ -x_2^* & x_1^* & 0 & 0 \\ 0 & 0 & -x_4^* & x_3^* \end{bmatrix} \quad (5)$$

The benefits of diversity can be exploited in different manners. It can increase the reliability of the radio link and it is quantified by the so called *diversity gain*. As a consequence of the diversity gain the error rate decreases. The data rate can also be improved logarithmically with respect to the number of antennas as antenna diversity increases the SNR linearly [10].

$$C = B\log_2(1+\gamma) \quad (6)$$

In addition, the coverage area can be improved or, for the same coverage area, the required power can be reduced. The *diversity gain* in MIMO systems is usually characterized by the number of independent fading diversity branches, also called *Diversity Order*. The diversity order is defined as the slope of the BLER versus SNR curve on a log-log scale. For a MIMO system with N_t transmit antennas and N_r receive antenna, it is said that the diversity order is N_d = $N_t.N_r$. The diversity order has a dramatic effect on the system reliability since the probability of one of the diversity branches having high SNR is higher compared to only one branche. In LTE, the SFBC (2x1) and FSTD (4x2) have a diversity order of 2 and 8 respectively.

B. Multiplexing Schemes

In Contrast to the diversity mode described in the previous section, the spatial multiplexing mode, which refers to splitting the incoming high data rate stream into N_t independent data streams, is considered, from a data throughput standpoint, as the most exciting type of MIMO systems. In MIMO system with N_t transmit antennas, the nominal spectral efficiency can be increased by a factor of N_t if the streams can be successfully and independently decoded. The factor N_t is known as *Multiplexing Gain*. In spatial multiplexing (N_t x N_r) MIMO system, the maximum data rate grows as [11]:

$$\min(N_t, N_r)\log(1+\gamma) \quad (7)$$

when γ is large.

In LTE, the spatial multiplexing mode is designated as Mode 3 and it is know as OLSM (Open Loop Spatial Multiplexing)

In SISO OFDM systems, the maximal data throughput depends on the available bandwidth and the parameter of the OFDM signal, like the number of subcarriers and the modulation order (QPSK, 16QAM, 64QAM). For a given frequency band (B) the maximal data throughput in bits per second can be approximated by the following simple equation [1]:

$$\textbf{Throughput}(bps) = \frac{N_{FB}.N_{SC}.N_{OFDM}.N_b.ECR}{T_{sub}} \quad (8)$$

where N_{FB} is the number of Frequency Block in the given frequency band (B); N_{SC} is the number of subcarrier in one Frequency Block; N_{OFDM} is the number of OFDM symbols in one subframe; N_b is the number of bits in one subcarrier; ECR is the Effective Code Rate, and T_{sub} is the duration of one subframe equal to 1 ms. In LTE, N_{SC} and N_{OFDM} are fixed and equals to 12 and 14 respectively [12]. For 5 MHz ($N_{FB} = 25$) bandwidth LTE system with 64 QAM Modulation ($N_b = 6$) and ECR = 0.9, the maximal data throughput that can be supported by the system is 22.68 Mbps.

B (MHz)	N_{FB}
1.4	6
5	25
10	50
15	75
20	100

IV. Simulation Results

In this section, we illustrate the results of the performances evaluation of three different MIMO schemes in 5 MHz LTE system using the MATLAB LTE link level simulator [1]. For comparison purpose, the performance of SISO scheme in the same system is also evaluated and presented. The three MIMO schemes are 2x1 (2 transmit antennas and only one receive antenna) SFBC diversity mode, 4x2 (4 transmit antennas and 2 receive antennas) FSTD diversity mode and 4x2 Open Loop Spatial Multiplexing (OLSM). The common simulation settings for the results are summarized in the next Table.

Parameter	Setting
Transmission Schemes	2x1 SFBC; 4x2 FSTD; 4x2 OLSM
Bandwidth	5 MHz
Simulation length	5000 subframes
Channel Type	Pedestrian B
Channel knowledge	perfect
CQI	15

The CQI value used in the simulation determines both the modulation order (64QAM) and the Effective Code Rate (0.92).

A. BLER Results

The Block Error Rate (BLER) results of SISO and MIMO schemes are shown in Figure 1. From the figure it is clear that the worst performances corresponds to the SISO curve (blue curve). The rate of change of the BLER in terms of SNR give us the estimation of the slope of the curve. As discussed in the previous sections, the slope of the BLER curve reflects the diversity order of the system. From the curve it can be observed that the slope is almost equal to one which means that the diversity order is equal to one as expected for the SISO configuration. As the modulation order is 64QAM a relatively high SNR is observed for the good BLER performance. An SNR of 41 dB is required to achieve a 10^{-3} value of BLER. The green curve represents the BLER results of the 2x1 diversity scheme. Asymptotically, the slope of this curve can be observed to be equal to two which corresponds to the diversity order of 2x1 system and hence a diversity gain of 2 as expected for 2x1 diversity scheme. An SNR gain can also be observed with respect to SISO scheme. In fact, it can be observed that to achieve a 10^{-2} value of BLER, the 2x1 diversity scheme needs about 8 dB less in SNR. In fact the BLER of 10^{-2} is achieved with 38 dB of SNR in SISO configuration however the same value of BLER is achieved with only 30 dB in the 2x1 diversity scheme. So an SNR gain of 8 dB is clearly observed for the 2x1 diversity scheme. The BLER results of the 4x2 Diversity scheme are represented by the red curve in Fig.1. In high SNR region the slope of the curve tends to be equal to 8. This value corresponds to the diversity order of a 4x2 system and hence a Diversity Gain of 8 can be observed from the curve. The SNR gain with respect to SISO configuration is more important than the case of 2x1 diversity scheme. In this case, an SNR gain of almost 18 dB at 10^{-2} value of BLER is obtained. Finally, the BLER results of the OLSM scheme are represented by the light blue curve and we can easily observe that the curve is almost parallel to the curve of 4x2 diversity scheme. This results is explained by the fact that the OLSM scheme uses the same antenna configuration as in the 4x2 diversity scheme and should have the same diversity order, which is equal to 8 (4x2) in this case. However the SNR gain is not the same as in 4x2 diversity mode but it is almost equal to SNR gain of 2x1 diversity system at 10^{-2} value of BLER (8 dB). This result is explained by the fact that in 4x2 OLSM scheme two different stream are sent from different antennas.

B. Data Throughput Results

The data throughput results of the three MIMO schemes are presented in the Fig.2 where they are compared to data throughput of SISO configuration. The data throughput of SISO configuration is shown by the blue curve. It can be observed that as the SNR increase the data throughput increase and it reaches its maximum at almost 40 dB. As in BLER results, the high order modulation is behind the high SNR required to achieve the maximum capacity. Beyond this value, the data throughput is constant and it corresponds to the maximum value as calculated in Section III-B. The green curve in Fig.2 represents the data throughput of the 2x1 diversity scheme. As expected there is no improvement in the data throughput as in 2x1 diversity scheme the same data is transmitted from the two antennas and no multiplexing gain can be achieved. However, the improvement comes from the fact that to achieve 15 Mbps, the 2x1 diversity scheme requires 5 dB less in SNR with respect to SISO configuration. In other words, the 15 Mbps is achieved by 30 dB SNR in SISO configuration and by only 25 dB in 2x1 diversity scheme. For the 4x2 diversity scheme, red curve in Fig.2, the improvement is even more and the gain in SNR is almost about 11 dB. It means that the 15 Mbps data throughput is reached by only 19 dB instead of 30 dB in SISO configuration. In this scheme also no multiplexing gain is observed as expected because as in the case of 2x1 diversity scheme only one signal stream is transmitted over the 4 transmit antennas. The multiplexing gain can easily be observed in the case of OLSM scheme, light blue curve. As in this scheme two different signal stream are transmitted simultaneously multiplexing gain of 2 is observed and the data throughput is almost doubled in high SNR.

V. CONCLUSION

In this paper, the performance evaluation of three different MIMO scheme in 5 MHz bandwidth LTE simulation using the MATLAB LTE simulator is presented. The improvement of these scheme with respect to SISO configuration is discussed. The difference between diversity mode and multiplexing mode and their respective gain in LTE MIMO schemes are also presented. The results clearly show an important improvement in terms of BLER and data throughput can be achieved in the three schemes.

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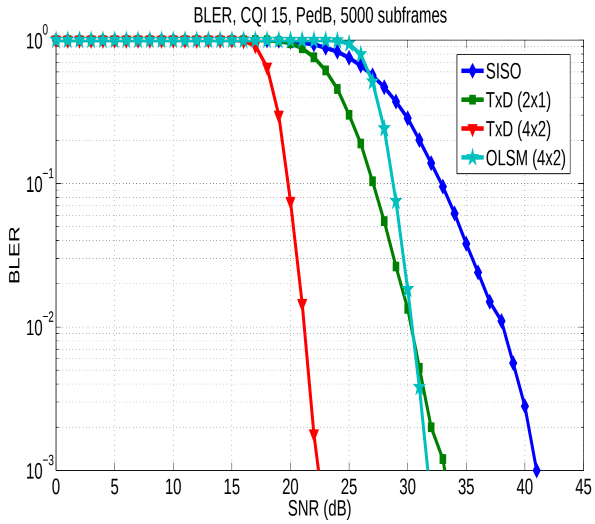

Fig. 1. BLER Performances of SISO and MIMO LTE Schemes

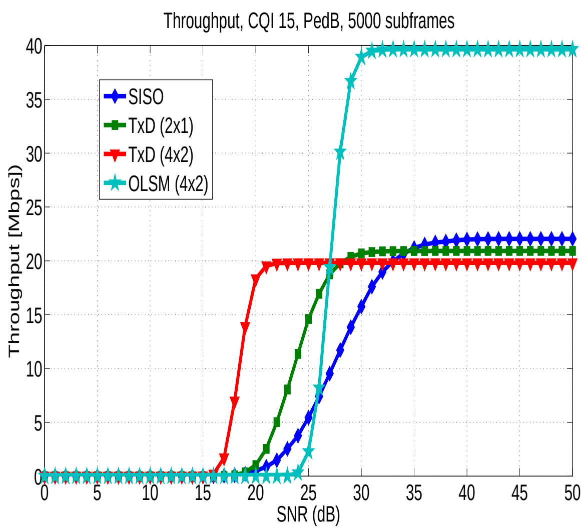

Fig. 2. Data Throughput of SISO and MIMO LTE schemes with 5 MHz bandwidth

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