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A Comprehensive Study of Open-loop Spatial Multiplexing and Transmit Diversity for Downlink LTE

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***Abstract*— Long Term Evolution (LTE) , which standardized by the 3GPP group, is designed to have wider channels up to 20MHz, with low latency and packet optimized radio access technology. The peak data rate envisaged for LTE is 100 Mbps in downlink and 50 Mbps in the uplink. The 3GPP has chosen the Orthogonal Frequency Division Multiple Access as the radio access technology due to his simple implementation in receiver and high performance and high spectral efficiency. In addition OFDMA technology, Different MIMO transmission methods are deployed to achieve data rate compliance with the LTE standards. To achieve high throughput required by the downlink LTE system, Adaptive Modulation and Coding (AMC) has to ensure a BLER value smaller than 10%. The SNR-to-CQI mapping is required to achieve this goal. In this paper, we made a comprehensive study to evaluate the performances of open loop spatial multiplexing (OLSM) and transmit diversity (TxD) in downlink LTE system for different transmission mode. A comparison is performed between these transmission modes to achieve optimal utilization of the resources. We observe that, at lower values of SNR, TxD give higher throughput and reduced Block Error Rate (BLER) but, when the SNR value are increased, OLSM performs better than the TxD in terms of throughput.**

***Index Terms*— Layer Mapping, MIMO, OLSM, Precoding and Spatial Multiplexing**

I. INTRODUCTION

IN modern world, requirement of high data rate communication has become inevitable. The applications like Streaming, video and images transmission and browse the World Wide Web require high speed data transmission with mobility. In order to fulfill theses data requirements, the 3rd Generation Partnership Project (3GPP) introduced Long Term Evolution (LTE), in order to provide high speed data rate for mobile communication.

The physical layer and multiple access schemes for downlink LTE, which is chosen by 3GPP, is the Orthogonal Frequency Division Multiple Access (OFDMA), in both Time Division Duplexing (TDD) and Frequency Division Duplexing (FDD), because of the high degree of flexibility in the allocation of radio resources to the Users Equipments (UEs) and his robustness to the selectivity of multipath channels [2], [3]. LTE is capable of supporting different transmission band of spectrum allocation (multiple channel bandwidth), ranging from 1.4 MHz to 20 MHz, for both paired and unpaired bands. The high peak transmission rate reaches the LTE system is 100 Mbps in downlink (DL) and 50 Mbps in uplink (UL). To achieve the performance objectives, LTE employs the several enabling technologies which include Hybrid Automatic Repeat Request (HARQ) technical and different multiple input multiple output (MIMO) transmission methods are deployed.

In this paper we evaluate and compare the performances of different transmission mode of TxD and OLSM techniques in a multipath channel which use the profile ITU-pedestrian B (Ped-B). These simulation results are compiled on based standard parameters of LTE Release8 specified by the 3GPP working group [1]. The section II of this paper give an over view of LTE physical layer. In section III, the channel quality indicators (CQI) are describe and the LTE MIMO channel are modeled in section IV. The section V is dedicated to define and describe the TxD and OLSM technique. Finally, the section VI explains and discusses the simulation result.

II. AN OVERVIEW OF LTE PHYSICAL LAYER

The Physical layer of LTE covers the downlink and uplink transmission between the UE and the eNB base transceiver station. In FDD mode, both the uplink and downlink scheme use the same frame structure which consisted of 10 sub-frames, for 2 slots. One radio frame is10ms long. LTE downlink physical resource can be represented as a time-frequency resource grid. A Resource Block (RB) has duration of 0.5 ms (one slot) and a bandwidth of 180 kHz (12 subcarriers). It is a straight forward to see that each RB has 12x7 = 84 resource elements in the case of normal cyclic prefix and 12x6 = 72 resource elements in the case of extended cyclic prefix.

The scheduler assigns resources to users with the granularity of resource blocks (RBs) every TTI, based on the channel condition feedback received from UEs in the form of Channel Quality Indicator (CQI).

III. CHANNEL QUALITY INDICATOR

To help the e-NodeB (eNB) to select appropriate modulation and code rate scheme for downlink transmission, the 3GPP has standardized a coefficient quality indicator as parameters; send by the UE, to indicate the data rate supported by the downlink channel. The UE send to the eNodeB a value of CQI who is corresponds to the highest Modulation and Coding Scheme (MCS) allowing the UE to decode the transport block with error rate probability not exceeding 10% [4]. The UE who send the best CQI can received downlink data with the higher modulation and code rate scheme (MCS). Table I shows modulation scheme, code rate along with efficiency for various CQI index [5].

TABLE I
OVERVIEW OF DIFFERENT CQI

CQI Index	Modulation	Code rate X1024	Efficiency
0	No transmission		
1	QPSK	78	0.1523
2	QPSK	120	0.2344
3	QPSK	193	0.3770
4	QPSK	308	0.6016
5	QPSK	449	0.8770
6	QPSK	602	1.1758
7	16QAM	378	1.4766
8	16QAM	490	1.9141
9	16QAM	616	2.4063
10	64QAM	466	2.7305
11	64QAM	567	3.3223
12	64QAM	666	3.9023
13	64QAM	772	4.5234
14	64QAM	873	5.1152
15	64QAM	948	5.5547

The eNB is informed about the channel quality through CQI information. During good channel conditions, AMC would employ a code rate along with efficiency for various CQI index, and higher modulation, such as 64-Quadrature Amplitude Modulation (64-QAM) which uses less redundancy in the transmission. However, if the channel suffers from poor conditions, AMC would choose a lower order of modulation, such a modulation would be Quadrature Phase-Shift Keying (QPSK) [6].

IV. MIMO CHANNEL MODEL FOR LTE

A. Channel model

MIMO technology has attracted attention in modern wireless communication standards, such as LTE, because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. The 3GPP has proposed a specified MIMO schemes for LTE specifications.

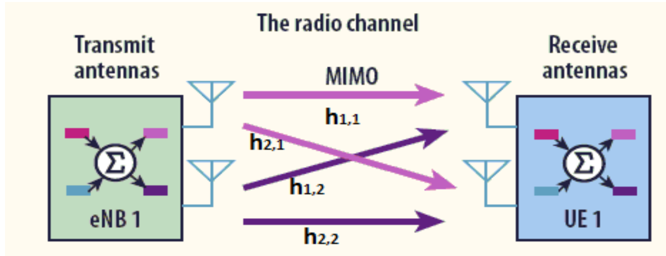

Fig. 1: Block diagram of typical 2X2 MIMO antennas system

The received signal for MIMO system model consisting of N_T transmits antennas and M_r receives antennas can be represented by the following Equation:

$$y = Hx + b \tag{1}$$

Where $y= [y_1, y_2 \ldots y_{Mr}]$ is the received vector, H is the channel coefficient matrix of the dimensions M_r x N_T express the channel gain and $b= [b1, b2 \ldots\ldots b_{Mr}]^T$ is the noise vector. The matrix H is written as follow:

$$H_{MR,NT} = \begin{pmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,NT} \\ h_{2,1} & h_{2,1} & \cdots & h_{2,1} \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot \\ h_{MR,1} & h_{MR,2} & & h_{MR,NT} \end{pmatrix} \tag{2}$$

Where $h_{i,j}$ is the channel coefficients from j^{th} transmitter to i^{th} receiver. The received data is processed with sphere decoders which give the Maximum Likelihood (ML) solution with soft outputs. The Sphere Decoding (SD) signal detection scheme is intended to find the transmitted signal vector with minimum ML metric. Let y_{jR} and y_{jI} denote the real and imaginary parts of the received signal at the j^{th} receive antenna, that it y_{jR} = Re{y_j} and y_{jI} = Im{y_j}. Similarly, the input signal x_i from the i^{th} antenna can be represented by x_{iR} =Re {x_i} and x_{iI} = Im {x_i}. The received signal can de expressed as follow:

$$\underbrace{\begin{bmatrix} y_{1R} \\ y_{2R} \\ y_{1I} \\ y_{2I} \end{bmatrix}}_{\bar{y}} = \underbrace{\begin{bmatrix} h_{11R} & h_{12R} & -h_{11I} & h_{12I} \\ h_{21R} & h_{22R} & -h_{21I} & h_{22I} \\ h_{11I} & h_{12I} & h_{11R} & h_{12R} \\ h_{21R} & h_{22R} & h_{21R} & h_{22R} \end{bmatrix}}_{\bar{H}} \underbrace{\begin{bmatrix} x_{1R} \\ x_{2R} \\ x_{1I} \\ x_{2I} \end{bmatrix}}_{\bar{x}} + \underbrace{\begin{bmatrix} b_{1R} \\ b_{2R} \\ b_{1I} \\ b_{2I} \end{bmatrix}}_{\bar{b}} \tag{3}$$

Where h_{ijR} = Re {h_{ij}}, h_{ijI} = Im{h_{ij}}, b_{iR} = Re{b_i}, and b_{iI} = Im{ b_i }.
The detected desired signal from the transmitting antenna can be obtained using the following relation [10]:

$$\bar{x} = (\bar{H}^H\bar{H})^{-1}\bar{H}^H\bar{y} \tag{4}$$

B. MIMO channel correlation matrix

In MIMO systems, there is correlation between transmit and receive antennas. This depends on a number of factors such as the separation between antenna and the carrier frequency. For maximum capacity, it is desirable to minimize the correlation between transmit and receive antennas. There are different ways to model antenna correlation. One technique makes use of correlation matrices to describe the correlation between multiple antennas both at the transmitter and the receiver. These matrices are computed independently at both the transmitter-receiver and then combined by means of a Kronecker product in order to generate a channel spatial correlation matrix [12].

The independent correlation matrixes at eNodeB and UE, RBS and RMS, respectively, are shown for different set of antennas (1, 2 and 4). The Spatial Correlation matrix can be represented by Kronecker product technique as given by the expression of correlation matrix for 4X2 configuration for downlink MIMO LTE as follow:

$$R_{spat} = R_{eNB} \otimes R_{UE}$$

$$= \begin{pmatrix} 1 & \alpha^{1/9} & \alpha^{4/9} & \alpha \\ \alpha^{1/9^*} & 1 & \alpha^{1/9} & \alpha^{4/9} \\ \alpha^{4/9^*} & \alpha^{1/9^*} & 1 & \alpha^{1/9} \\ \alpha^{*} & \alpha^{4/9^*} & \alpha^{1/9^*} & 1 \end{pmatrix} \otimes \begin{pmatrix} 1 & \beta \\ \beta^{*} & 1 \end{pmatrix} \qquad (5)$$

The parameters α and β are defined for each level of correlation as shown in the following table of correlation values [7].

- Low Correlation : $\begin{cases} \alpha = 0 \\ \beta = 0 \end{cases}$
- Medium Correlation : $\begin{cases} \alpha = 0.3 \\ \beta = 0.9 \end{cases}$
- Low Correlation : $\begin{cases} \alpha = 0.9 \\ \beta = 0.9 \end{cases}$

V. MIMO TRANSMISSION FOR LTE

In LTE MIMO transmission, the supported multi-antenna transmit mode employ transmit diversity (TxD) or spatial multiplexing (SM) transmission in order to increase diversity, data rate, or both [8].

A. Transmit diversity

The concept of transmit diversity is to send the same information via various antenna, whereby each antenna uses different coding and different frequency resources. Since the transmit diversity can be still provided by using Space Time Block Coding (STBC). The best STBC scheme varies with SNR. S. M. Alamouti proposed a simple two branch diversity scheme. The diversity created by the transmitter utilizes space diversity and either time or frequency diversity. The Alamouti space-time coding scheme can achieve full spatial diversity gain. The issue for the TxD that it is single ranks i.e. it does not support multi stream transmission [9].

B. Open Loop Spatial Multiplexing (OLSM)

In MIMO spatial multiplexing (SM), independent data stream are transmitted from a transmitter at the same time and frequency. The same numbers of antenna are needed to decode the symbols at a receiver. Combined with OFDM, MIMO SM is widely to increase the data rate with the number of transmitting antennas [11]. Two classes of spatial multiplexing open and closed loop spatial multiplexing (CLSM). In OLSM, no precoding matrix feedback is employed, while in CLSM, the optimum precoding matrix information is feedback by the UE to the eNB. In our paper, we investigate only the OLSM technique on downlink LTE.

In an SM scheme, the process can be described by three parameters: transmit vector X, precoding matrix W and output vector Y. thus,

$$y = W\,x \qquad (6)$$

Complex-valued modulation symbols, for codeword q, $d^{(q)}(0), \ldots, d^{(q)}(M_{symb}^{(q)} - 1)$ are mapped onto the layers $x(i) = \left[x^{(0)}(i), \ldots, x^{(v-1)}(i)\right]^T$ where v is the number of layers and M_{symb}^{layer} is the number of modulation symbols per layer.

Take the example of transmission on a four antenna port, the layer mapping shall be done as follow:

$$\left.\begin{aligned} x^{(0)}(i) &= d^{(0)}(2i) \\ x^{(1)}(i) &= d^{(0)}(2i+1) \\ x^{(2)}(i) &= d^{(1)}(2i) \\ x^{(3)}(i) &= d^{(1)}(2i+1) \end{aligned}\right\} M_{symb}^{layer} = M_{symb}^{(0)}/2 = M_{symb}^{(1)}/2 \qquad (7)$$

Spatial multiplexing supports two or four antenna ports and the set of antenna ports used is, $p \in \{0,1\}$ or $p \in \{0,1,2,3\}$ respectively.

Without cyclic delay diversity (CDD), precoding for spatial multiplexing is defined by:

$$\begin{bmatrix} y^{(0)}(i) \\ \vdots \\ y^{(p-1)}(i) \end{bmatrix} = W(i) \begin{bmatrix} x^{(0)}(i) \\ \vdots \\ x^{(v-1)}(i) \end{bmatrix} \qquad (8)$$

Where the precoding matrix *W(i)* is of size $P \; x\, v$, $i = 0,1, \ldots, M_{symb}^{layer}$.

The precoding matrix W is fixed to either [6],

$$W = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 \\ 1 \end{bmatrix}, \qquad where\ , v = 1 \qquad (9)$$

$$W = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} , \qquad where\ , v = 21 \qquad (10)$$

In the OLSM mode, only Rank Indicator (RI) feedback information is available; that is, how many layers should be employed. As a solution, OLSM incorporates Cyclic Delay Diversity (CDD) [8].

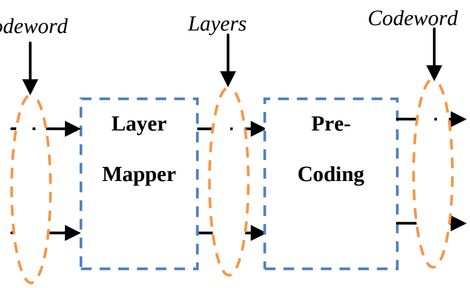

Fig. 2: Overview of physical channel processing

VI. SIMULATIONS RESULTS

For simulating the radio link performance of OLSM and TxD techniques for downlink LTE, in this paper, different parameters have been chosen as shown in Table III. As shown, 3HARQ retransmissions were used for simulation. For transmission over ITU-Pedestrian B channel, simulation has been performed on 5000 sub-frames. To performs and compare the MIMO OLSM and TxD system, we have choose these different transmissions modes settings: SUSISO (111), SUMIMO transmit diversity (222 and 242) and SUMIMO open loop spatial multiplexing (322 and 342). Each transmission mode is normalized and describe as shown on [5].

The performances of LTE downlink system for different transmissions modes are simulated for CQI 8 and CQI 11. The predefined CQIs parameters (modulation and coding rate) used in this work are shown in TABLE I.

TABLE II
SIMULATIONS PARAMETERS

Parameters	Value
Transmission bandwidth	1.4 MHz
Carrier frequency	2.1 GHz
Data modulation	16QAM(CQI 8), 64QAM(CQI 11)
Channel	Ped B
Retransmission Algorithm	HARQ
Number of retransmission	3
Routing Algorithm	Round Robbin
Decoder	SSD
Channel Estimation	Perfect Channel Estimation

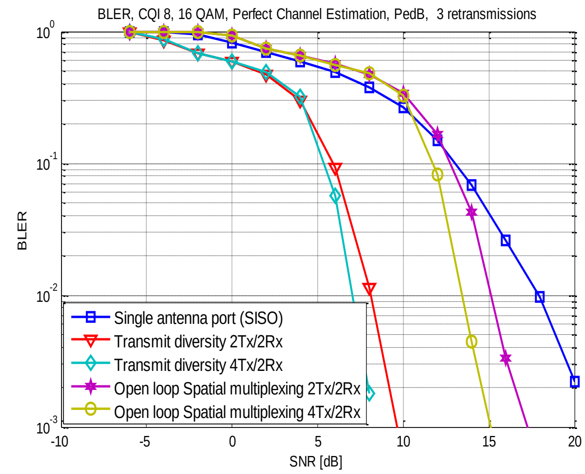

Fig. 3: BLER of transmit diversity and spatial multiplexing compared with a single transmit antennas for PedB MIMO Configurations, CQI=8

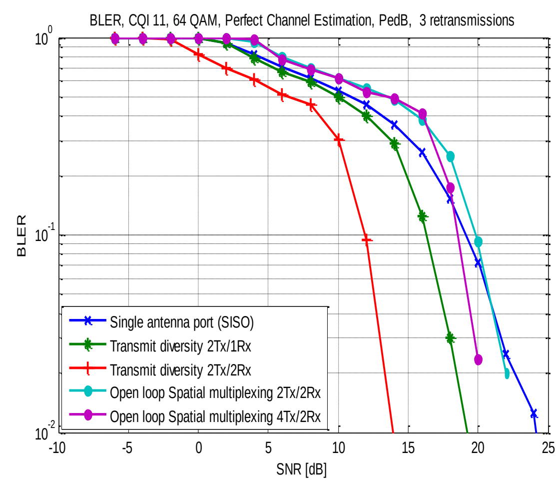

Fig. 4: BLER of transmit diversity and spatial multiplexing compared with a single transmit antennas for PedB MIMO Configurations, CQI=11

The Block Error Rate (BLER) vs. SNR (dB) result, for different transmission modes, is shown in Fig. 3 and Fig. 4, for both CQI value 8 and 11 respectively. We use a multi-path channels which use the profile of ITU-Pedestrian B for configuration CQI 8 and CQI 11 respectively. For CQI 8, In MIMO 2X2 and compared with Single antenna, we see that performances enhancement almost than 3 dB and 10 dB at a BLER=10^{-2} when we use OLSM and TxD respectively. But compared with OLSM, we can see that considerable gain is achieved, when we use Transmit diversity (Almost than 6 dB). This is because the equalizer who exploit the diversity offered by the multiple antenna. In figure 4(CQI 11), we see that as to CQI 8, the TxD performances are larger than that of OLSM but the gain value decreases because we use the 64QAM modulation that is very sensible to the multipath effect.

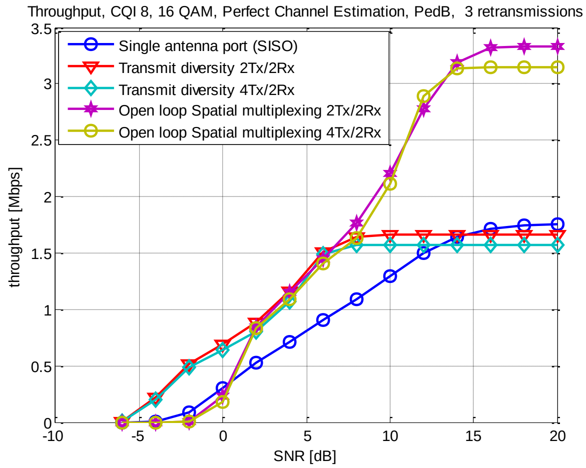

Fig. 5: Throughput of transmit diversity and spatial multiplexing compared with a single transmit antennas for PedB MIMO Configurations, CQI=8

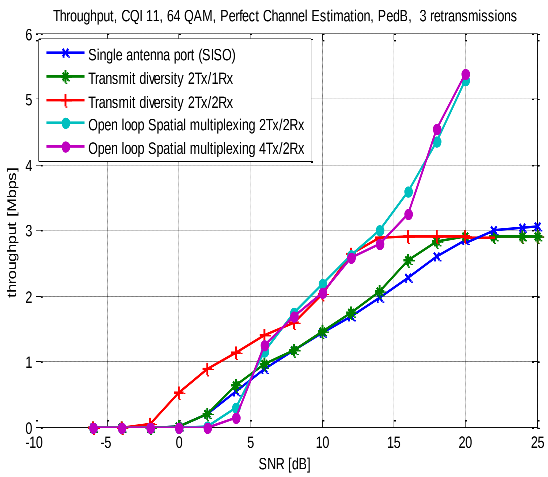

Fig. 6: Throughput of transmit diversity and spatial multiplexing compared with a single transmit antennas for PedB MIMO Configurations, CQI=11

The throughput results of LTE downlink transmission for different transmission modes is shown in Fig. 5 and Fig. 6. We can see that at low SNR, the TxD technique give the best performance in terms of throughput as compared with that of the OLSM and single antenna. In case of high SNR, it is also observed that the OLSM technique outperforms the transmit diversity technique in term of throughput vs. SNR. While the TxD technique gives a constant throughput at high SNR. This is because the data rate is saturated in TxD technique whereas independent data streams are transmitted in the OLSM technique.

VII. CONCLUSION

In this paper we evaluate the performances of downlink LTE system in multi-path channels which use the profile of ITU-Pedestrian B and we compare the transmit diversity to open loop spatial multiplexing technique. We showed that the TxD technique achieved a considerable gain compare to the OLSM technique in term of BLER. But the OLSM technique outperforms the TxD technique in term of throughput in case of high SNR. This provides us with another option to achieve optimal BLER and throughput while we use the minimum number of antennas in case of high SNR transmission.

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