Modeling and Performances Evaluation of HARQ Technique for MIMO Transmission in Downlink LTE Cellular Networks

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***Abstract*— Long Term Evolution (LTE) is designed for deployment in a variety of spectrum allocation ranging from 1.4 MHz to 20 MHz. The peak data rate envisaged for LTE is 100 Mbps in downlink and 50 Mbps in the uplink. Unfortunately, different constraints have a strong influence on system performance such as the velocity of user equipment and effect of multipath channel. To achieve data rate compliance with LTE standard, Different transmissions techniques are deployed such as MIMO transmission, Adaptive Modulation and Coding (AMC) and Hybrid Automatic Repeat request (HARQ) Technique. In this paper we simulate and discuss the performances of HARQ process for downlink LTE system using MIMO transmit diversity and spatial multiplexing. In first time, we study the effect of HARQ technique over AWGN channel then we perform different MIMO transmission schemes for downlink LTE system in multipath channel. Extended Vehicular-A tapped delay channel model are used to model high speed user equipment.**

Keywords—Hybrid Automatic Repeat reQuest; transmit diversity; Open loop spatial multiplexing; Mutiple input mutiple output

I. INTRODUCTION

The 3GPP has standardized Long Term Evolution (LTE) as the successor of UMTS in order to ensure a high speed data transmission with mobility for mobile communication. The design of the LTE physical layer (PHY) is heavily influenced by the requirements for high peak transmission rate. The radio access technology chosen for LTE system 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 [1][2]. 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 MIMO transmission methods are deployed. The MIMO transmission modes, which standardized by the 3GPP in [3], are describe in section IV.

In wireless transmission, when there is error packets received on user equipment (UE) or eNodeB, there would be some sort of mechanism applied on the devices to rectify the errors. Therefore, in LTE, the HARQ mechanism is implemented to detect and correct the errors packets in the PHY layer. To compare and discuss the effect of HARQ technique, we use to simulate the physical layer of downlink LTE system for SISO and MIMO transmission mode, such as MIMO Transmit Diversity, Open Loop Spatial Multiplexing (OLSM) and Close Loop Spatial Multiplexing (CLSM), without and with HARQ technique. The results of simulation are plotted and discuss in section V.

This paper is organized as follow, the second section describe the downlink LTE physical layer. In section III, the HARQ technique is described. The section IV describes the MIMO transmission modes and finally the section V resumes and discusses the obtained simulation result.

II. AN OVER VIEW OF DOWNLINK LTE PHYSICAL LAYER

The LTE physical layer implements a number of technologies to deliver on requirements for high data rates and spectral efficiency. The design of the physical layer and system parameters are well matched with the characteristics of mobile propagation channel to allow optional downlink and uplink frequency selective scheduling thereby enhancing throughput performance. Adaptive modulation and coding maximizes throughput to individual subscribers and increases overall cell capacity.

In time domain, different time intervals within LTE are expressed as multiples of a basic time unit $Ts = 1/30720000\ s$. The radio frame has a length of 10 ms ($T_{frame} = 307200*\ Ts$). Each frame is divided into ten equally sized sub frames of 1 ms in length ($T_{subframe}=30720*Ts$). Scheduling is done on a subframe basis for both the downlink and uplink. Each subframe consists of two equally sized slots of 0.5 ms in length ($T_{slot} = 15360*Ts$). Each slot in time consists of a number of OFDM symbols which can be either seven (Normal Cyclic

Prefix) or six (extended cyclic prefix). The useful symbol time is $T_u = 2048*Ts \approx 66.7\ \mu s$. For the normal mode, the first symbol has a cyclic prefix of length $T_{CP} = 160*Ts \approx 5.2\ \mu s$. The remaining six symbols have a cyclic prefix of length $T_{CP} = 144*Ts \approx 4.7\ \mu s$. The reason for different cyclic prefix (CP) length of the first symbol is to make the overall slot length in terms of time units divisible by 15360. For the extended mode, the cyclic prefix is $T_{CP} = 512*Ts \approx 16.7\ \mu s$. The CP is longer than the typical delay spread of a few microseconds typically encountered in practice [4].

The system capacity (C) of an Additive White Gaussian Noise (AWGN) channel is calculated with Shannon–Hartley theorem:

$$C=B\ \mathrm{Log2}\ (1+SNR) \tag{1}$$

Where *C* is channel capacity in bits per second (b/s), B is bandwidth of channel in hertz (Hz) and SNR refers to Signal to Noise Ratio (dB).

The transmission of an OFDM signal requires the transmission of a Cyclic Prefix (CP) to avoid inter-symbol interference and the reference symbols for channel estimation [5]. Therefore, some arrangements are made on the Shannon in equation (1) by the factor F in equation (2). This factor F accounts the inherent system losses and is calculated as in equation (3).

$$C=F*B\ \mathrm{Log2}\ (1+SNR) \tag{2}$$

$$F = \frac{T_{frame} - T_{cp}}{T_{frame}} * \frac{N_{sc} * \frac{N_s}{\square}_2 - 4}{N_{sc} * \frac{N_s}{\square}_2} \tag{3}$$

Where T_{frame} is the frame duration, T_{cp} is the cyclic prefix duration. N_{sc} is the number of subcarrier and N_s is the FFT size.

III. HARQ Technique for LTE

In wireless communication, the channel quality can vary faster than in a wired context because the presence of fading due to mobility and interferences. The transmission over multi-path channel is protected by forward error coding (FEC), thanks to additional coded bit in the packet. However, FEC could lead to very inefficient transmission. As a solution, the combining of FEC and ARQ technique, which result a Hybrid scheme called Hybrid ARQ (HARQ), has been defined [6].

The HARQ technique is used to increase throughput in packet transmission. It is based on the rate matching functionality. It adapts the bits number of the input packet at the bits number. This bits adaptation is done by the rate matching pattern algorithm normalized by 3GPP. It is based on the redundancy versions (RV) parameter which is transmitted by eNodeB [7]. For FDD, there are exactly eight uplink HARQ processes, while the downlink can have up to eight. Downlink HARQ processes can be transmitted in any order without fixed timing (asynchronous HARQ).

The receiver HARQ transmissions are associated with previous transmissions in time by more than one antenna and the resulting signal at j^{th} HARQ transmission can be express into vector as:

$$\mathbf{Y}^{(j)} = \mathbf{H}^{(j)}\ \mathbf{X} + \mathbf{b}^{(j)} \tag{4}$$

where $H^{(j)}$ is the channel matrix of the j^{th} HARQ transmission between the transmit and receive antennas and $b^{(j)}$ is a vector of complex white Gaussian noise samples of the j^{th} HARQ transmission.

The received data code blocks at the j^{th} HARQ transmission are combined with the stored erroneous received data code blocks of the previous HARQ transmission at the input of the channel decoder. In this paper, the receiver uses maximum ratio combining (MRC) to combine the received code locks.

IV. MIMO Transmission for LTE

The 3GPP has proposed a specified MIMO schemes for LTE specifications because it offers significant increases in data throughput and link range without additional bandwidth or increased transmit power. Figure 2 shows the simplified block diagram of a 4x4 MIMO antenna 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:

$$\mathbf{y} = \mathbf{H}\mathbf{x} + \mathbf{b} \tag{5}$$

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 $b= [b_1, b_2 \ldots\ldots b_{MR}]^T$ is the noise vector.

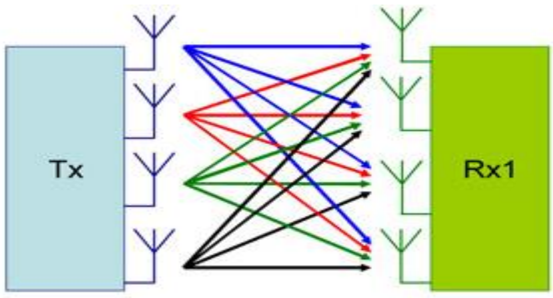

Fig. 1. Block diagram of typical 4x4 MIMO Antenna system

The matrix H is written as follow [8]:

$$\mathbf{H}_{M_R,N_T} = \begin{pmatrix} \mathbf{h}_{1},\mathbf{1} & \mathbf{h}_{1},\mathbf{2} & \ldots & \mathbf{h}_{1,NT} \\ \mathbf{h}_{2},\mathbf{1} & \mathbf{h}_{2},\mathbf{1} & \ldots & \mathbf{h}_{2},\mathbf{1} \\ \vdots & \vdots & \vdots & \vdots \\ \mathbf{h}_{MR,1} & \mathbf{h}_{MR,2} & & \mathbf{h}_{MR,NT} \end{pmatrix}$$

Where $h_{i,j}$ is the channel coefficients from j^{th} transmitter to i^{th} receiver.

The detected desired signal from the transmitting antenna can be obtained using the following relation [9]:

$$\bar{x} = \left(\bar{H}^{H}\bar{H}\right)^{-1}\bar{H}^{H}\bar{y} \tag{7}$$

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 [9].

A. Precoding for SpatialMultiplexing

Within spatial multiplexing, there are two schemes; precoding with large delay cyclic delay diversity (CDD), also known as open loop spatial multiplexing (OLSM) and precoding without CDD, also known as closed loop spatial multiplexing (CLSM). The process can be described by three parameters: transmit vector X, precoding matrix W and output vector Y. thus,

$$\mathbf{y} = \mathbf{W} * \mathbf{X} \tag{8}$$

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

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:

$$\begin{bmatrix} \mathbf{y}^{(0)}(\mathbf{i}) \\ \vdots \\ \mathbf{y}^{(\mathbf{p}-1)}(\mathbf{i}) \end{bmatrix} = \mathbf{W}(\mathbf{i}) \begin{bmatrix} \mathbf{x}^{(0)}(\mathbf{i}) \\ \vdots \\ \mathbf{x}^{(\upsilon-1)}(\mathbf{i}) \end{bmatrix} \tag{9}$$

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

In case of Two Layers, the precoding matrix *W* is fixed to either [10],

$$\mathbf{W} = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}, \tag{10}$$

B. Precoding for Transmit Diversity

S. M. Alamouti proposed a simple two branch diversity scheme [12]. 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].

An Alamouti scheme is used for precoding, which defines the relationship between input and output, for two antenna port, as shown in the following equation:

$$\begin{bmatrix} \mathbf{y}^{(0)}(2\mathbf{i}) \\ \mathbf{y}^{(1)}(2\mathbf{i}) \\ \mathbf{y}^{(0)}(2\mathbf{i}+1) \\ \mathbf{y}^{(1)}(2\mathbf{i}+1) \end{bmatrix} = \frac{1}{2} * \begin{bmatrix} 1 & 0 & j & 0 \\ 0 & -1 & 0 & j \\ 0 & 1 & 0 & j \\ 1 & 0 & -j & 0 \end{bmatrix} * \begin{bmatrix} \mathrm{Re}\{\mathbf{x}^{0}(\mathbf{i})\} \\ \mathrm{Re}\{\mathbf{x}^{1}(\mathbf{i})\} \\ \mathrm{Im}\{\mathbf{x}^{0}(\mathbf{i})\} \\ \mathrm{Im}\{\mathbf{x}^{1}(\mathbf{i})\} \end{bmatrix} \tag{11}$$

The figure 2 Shown summarize of channel processing for downlink LTE system.

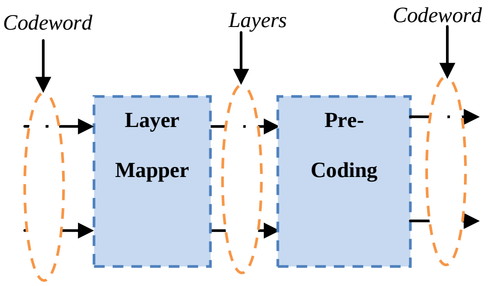

Fig. 2. Overview of physical channel processing

C. Downlink PDSCH transmission mode

In downlink LTE, Physical Downlink Shared Channel (PDSCH) is used to downlink transmission data for users. LTE has configured particular transmission modes to the configuration of PDSCH. These transmissions modes are chosen from the UE request for PDSCH. The different transmissions modes specified by the 3GPP are as follow [11]:

- Transmission mode 1: using a single antenna port at eNodeB; Port 0.
- Transmission mode 2: Transmit diversity (TxD)
- Transmission mode 3: SU-MIMO Open loop Spatial Multiplexing
- Transmission mode 4: SU-MIMO Close loop Spatial Multiplexing
- Transmission mode 5: MU-MIMO Spatial Multiplexing
- Transmission mode 6: Closed-loop Rank=1 precoding.
- Transmission mode 7: Single antenna port; port 5.

V. SIMULATION RESULTS

A. Simulation parameters

For simulating the radio link performance of, different parameters have been chosen and defined in Table I. As shown, for all transmission modes, we have performed the BLER and throughput vs. SNR without and with HARQ technique. For transmission over AWGN and Extended-Vehicular A channel, our simulation has been performed on 2000 sub-frames.

TABLE I. SIMULATION PARAMETERS

Parameters	Value
Transmission bandwidth	1.4 MHz
Carrier frequency	2.1 GHz
Data modulation	16QAM(CQI 9)
Channel	E-VehA
Retransmission Algorithm	HARQ
Number of retransmission	0,2, 3 retransmission
Routing Algorithm	Round Robbin
Decoder	SSD
Channel Estimation	Perfect Channel Estimation

B. Simulation results and discuss

In order to observe the effect of HARQ technique, we simulate and plot the performances of SISO transmission over AWGN channel without HARQ transmission then with 1, 2 and 3 HARQ transmission. The simulations were carried out for the CQI=9 of LTE downlink physical layer. The Block Error Rate (BLER) and throughput vs. SNR results are investigated in figure 3 and 4 respectively.

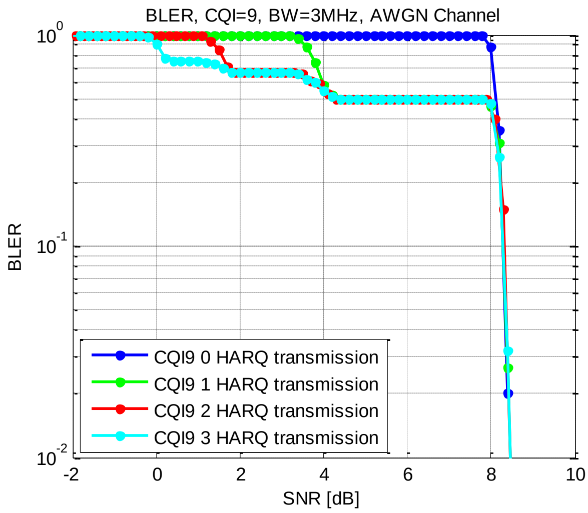

Fig. 3. Resulting of BLER at CQI=9 for differents number of HARQ transmission over AWGN Channel.

From the figure 3, we can see that in case of low SNR, the impact of increasing HARQ retransmissions is demonstrated. A considerable gain is achieved after the first and second retransmission. This figure shows that the HARQ technique improves the performance of downlink LTE system by almost than 4 dB and 7.5 dB after the first and third retransmission respectively. However, in case of high SNR, the performances of downlink LTE system are equal in term of BLER vs. SNR for all three number of retransmission as compare with 0HARQ retransmission.

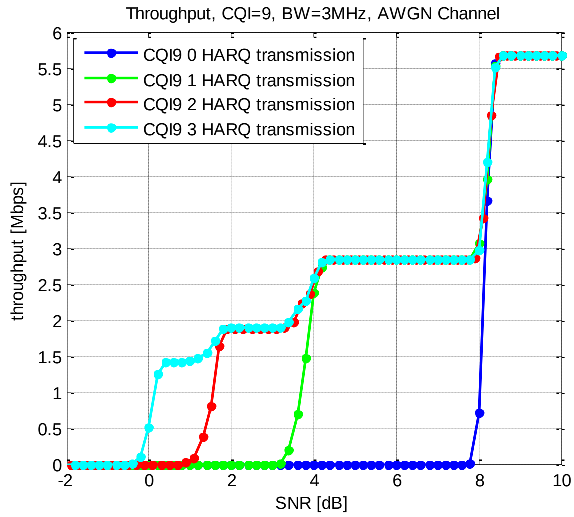

Fig. 4. Resulting of Throughput at CQI=9 for differents number of HARQ transmission over AWGN Channel.

The throughput performances are investigated in figure 4. It is observed that the using of HARQ retransmission over AWGN channel, increase the system throughput in case of low SNR by almost than 2.7 Mbps for SNR=4 dB and 1.4 Mbps for SNR=0 dB after the first and third retransmission respectively.

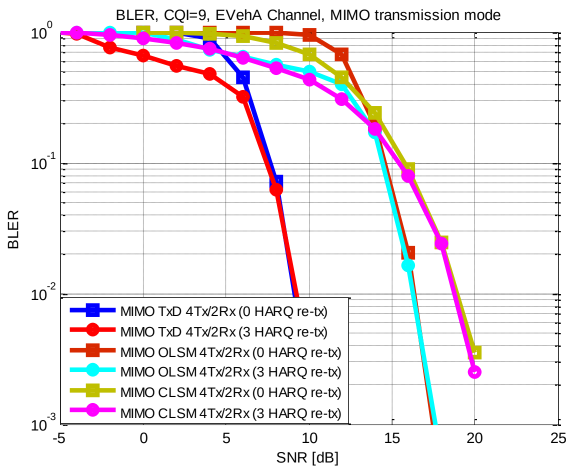

Fig. 5. BLER plot at CQI=9 for differents transmission mode(TxD, OLSM and CLSM) with both 0 and 3 HARQ retransmission over Extended Vehicular A Channel.

Figure 5 shows the BLER vs. SNR (dB) for different MIMO transmission mode in downlink LTE transmission over multi-path channel which uses the profile of Extended-Vehicular A. Simulation result shown that Transmit diversity mode outperforms the OLSM and CLSM technique. This enhancement is due to equalizer who exploits the diversity offered by the multiple antennas. We can also see the impact of HARQ technique in case of low SNR. A considerable gain is achieved for all transmission modes with 3HARQ retransmission as compare with that of '0' retransmission.

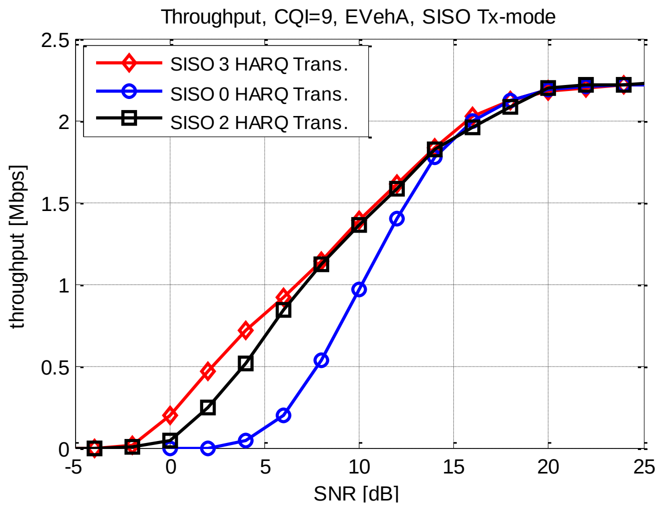

Fig. 6. Throughput plot at CQI=9 for SISO transmission setting with 0, 2 and 3 HARQ retransmission over Extended Vehicular A Channel.

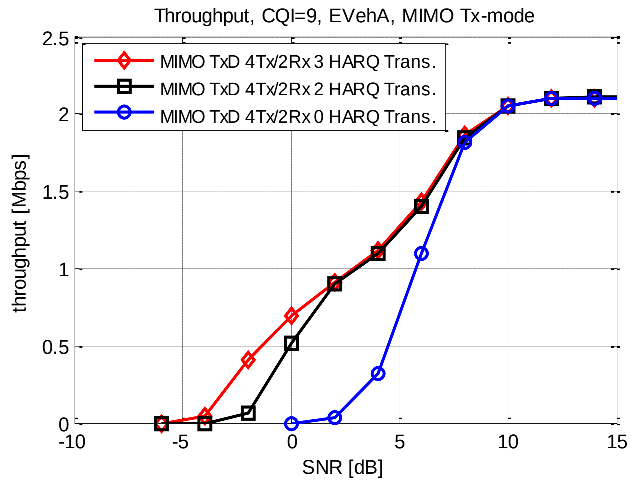

Fig. 7. Throughput plot at CQI=9 for MIMO transmission setting 242 with 0, 2 and 3 HARQ retransmission over Extended Vehicular A Channel.

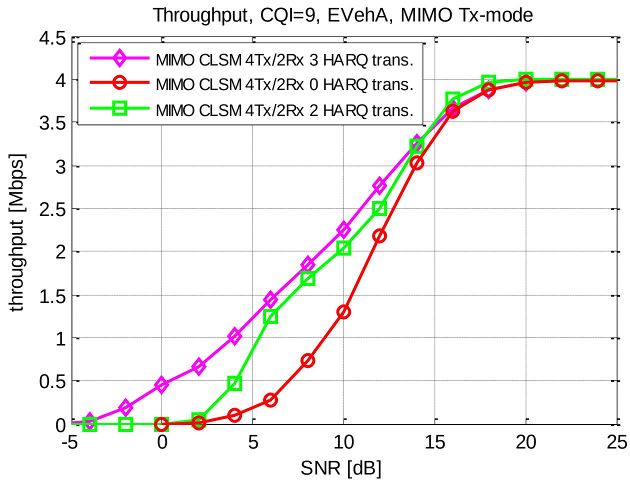

Fig. 8. Throughput plot at CQI=9 for MIMO transmission setting 342 with 0, 2 and 3 HARQ retransmission over Extended Vehicular A Channel

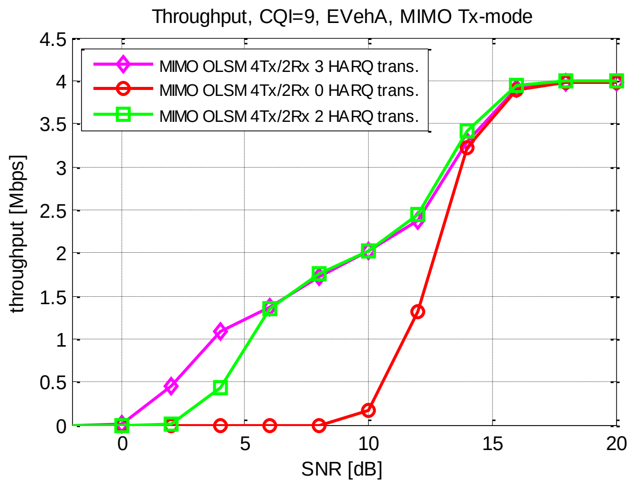

Fig. 9. Throughput plot at CQI=9 for MIMO transmission setting 442 with 0, 2 and 3 HARQ retransmission over Extended Vehicular A Channel

Figure 6, 7, 8 and 9 shows the throughput comparison for different transmission mode with 0, 2 and 3HARQ retransmission at CQI=9 over Extended Vehicular A channel. It is observed that in case of low SNR, the total throughput increase with increasing the number of HARQ retransmission. But, in case of high SNR, for all transmission modes, the HARQ technique not has an effect and we obtained a constant throughput for both methods; with and without HARQ technique. It is also observed that the OLSM and CLSM technique outperforms the transmit diversity technique in term of throughput vs. SNR. This is because the data rate is saturated in TxD technique whereas independent data streams are transmitted in the OLSM technique. This provides us with another option to achieve optimal BLER and throughput while we use to maximize the HARQ process in case of low SNR and minimum number retransmission in case of high SNR transmission.

VI. CONCLUSION

In this paper, we study and perform the HARQ technique for different MIMO schemes in downlink LTE cellular network using the multi-path channels which use the profile of ITU-Extended Vehicular A. The obtained results show that Transmit Diversity (TxD) outperforms the OLSM and CLSM technique in term of BLER vs. SNR, but, for the system capacity (Throughput vs. SNR), the using of the OLSM and OLSM technique achieved the gain almost than 1.5 Mbit/s for SNR=10 dB as compare with transmit diversity technique. This is because the data rate is saturated in TxD technique whereas independent data streams are transmitted in the OLSM and CLSM technique.

We can also show that the HARQ technique have an important impact in case of low SNR. A considerable gain, almost than 3 dB, is achieved using the HARQ technique as compare with the transmission without using this technique. This achieved gain is obtained for both result; BLER vs. SNR and system capacity. This provides us with another option to achieve optimal BLER and throughput while we use to maximize the HARQ process in case of low SNR and minimum number retransmission in case of high SNR transmission.

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