Performance Evaluation of LTE-Advanced Channel Estimation Techniques in Vehicular Environments

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***Abstract*-In this paper; two linear channel estimation techniques, Least Square (LS) and Minimum Mean Square Error (MMSE), are studied for the downlink of 3GPP LTE-A system which is based on MIMO-OFDM technology. The performance of the system is evaluated using different transmission schemes (Transmit Diversity (TxD) and Open Loop Spatial Multiplexing (OLSM)) and different detectors (Zero Forcing (ZF) and Soft Sphere Decoder (SSD)), also the evaluation is conducted using 4x2 transmit-receive antennas (Multiple input Multiple Output MIMO). LTE-A link level simulator (LTE-A v1.0_r100) from "Vienna University of Technology" using Matlab is used to evaluate the performance of the system in term of Bit Error Rate (BER) for different wireless channel models that consist of Vehicular A (VehA) and Vehicular B (VehB) channels.**

Keywords-LTE-A, LS, MMSE, TxD, OLSM, ZF, SSD, VehA, VehB

I. INTRODUCTION

The 3GPP Long Term Evolution (LTE) Standard Release 10 [1], referred to as Long Term Evolution Advanced (LTE-A), supports different of new features compared to Release 8 [2] for reaching the targets for 4G communications [3]. LTE-A specification includes increasing the peak data rate and the enhancement of spectrum efficiency, latency and mobility. LTE-A system is designed to be backwards compatible with LTE system, that means an LTE mobile can communicate with a base station that is operating LTE-A and vice-versa [4].

The LTE-A Physical Layer (LTE-A PHY) is responsible for carrying both data and control information between a base station (eNodeB) and mobile user equipment (UE). The LTE-A PHY uses some advanced technologies like Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) data transmission that are new to cellular applications [5]. Orthogonal Frequency Division Multiplexing (OFDM) is a necessary part of LTE-A and is used to convert the frequency selective fading behavior of the channel to frequency flat fading channel behavior [6]. This improves the bandwidth efficiency by eliminate Inter Symbol Interference (ISI).

Multiple transmit and receive antennas improves the communication quality and capacity of mobile wireless systems. Knowing channel behavior is required for coherent detection, and decoding at the receiver. So, accurate channel estimation is very important for LTE-A system.

Channel estimation techniques for LTE-A system can be categorized as follows: (1) Least-squares (LS). (2) Minimum Mean Square Error (MMSE) [7].

Different MIMO transmission schemes are used to achieve data rate consistence with the LTE-A standards requirements. MIMO transmission schemes include Transmit Diversity (TxD) and Open Loop Spatial Multiplexing (OLSM). Decoding process for LTE-A simulations is done with the use of Zero Forcing (ZF) and Soft Sphere Decoder (SSD) [6].

II. SYSTEM MODEL

Fig 1 illustrates the model of 3GPP LTE-A downlink system. In LTE-A, data streams are encoded using Turbo coding scheme, where the channel coding is a method to reduce the BER and increase reliability of the system.

The baseband signal transmission of LTE downlink physical channels is performed by the following steps:

A. Scrambling

LTE-A scrambling suggests that multiplying the block of bits by (M bits) scrambling sequence using exclusive-or operation as illustrated in fig. 2.

For each codeword q, the block of bits $b^{(q)}(0),\ldots,b^{(q)}(M_{bit}^{(q)}-1)$, where $M_{\text{bit}}^{(q)}$ is a number of bits in codeword q transmitted on the physical channel in one subframe, shall be scrambled for modulation process. The result is a block of scrambling bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)}-1)$ according to

$$\tilde{b}^{(q)}(i) = (b^{(q)}(i) + c^{(q)}(i)) \text{ mode } 2 \qquad (1)$$

Where the scrambling sequence $c^{(q)}(i)$ is a Pseudo-random sequences are defined by a length-31 Gold sequence as in [8,9].

B. Modulation

Data modulation converts a block of scrambled bits to a corresponding block of complex modulation symbols. For each codeword q the block of scrambled bits $\tilde{b}^{(q)}(0),\ldots,\tilde{b}^{(q)}(M_{\text{bit}}^{(q)}-1)$ shall be modulating by one of the modulation schemes like QPSK, 16-QAM and 64-QAM, resulting in a block of complex-valued modulation symbols $d^{(q)}(0),\ldots,d^{(q)}(M_{\text{symb}}^{(q)}-1)$ as in [8].

C. Layer Mapping

Layer mapping works on mapping of the modulation symbols of each codeword into one or multiple transmission layers. The complex-valued modulation symbols to be transmitted from each of the codewords must be mapped onto one or several layers. So complex-valued modulation symbols $d^{(q)}(0),....,d^{(q)}(M_{\text{symb}}^{(q)}-1)$ for codeword q shall be mapped onto the layers as follows [8]:

$$\boldsymbol{x}\,(\boldsymbol{i}) = [\,x^{(0)}(i) \quad .... \quad x^{(v\text{-}1)}(i)]^T,\quad i = 0,1,....,M_{\text{symb}}^{\text{layer}}-1 \tag{2}$$

Where v is the number of layers and $M_{\text{symb}}^{\text{layer}}$ is the number of modulation symbols per layer.

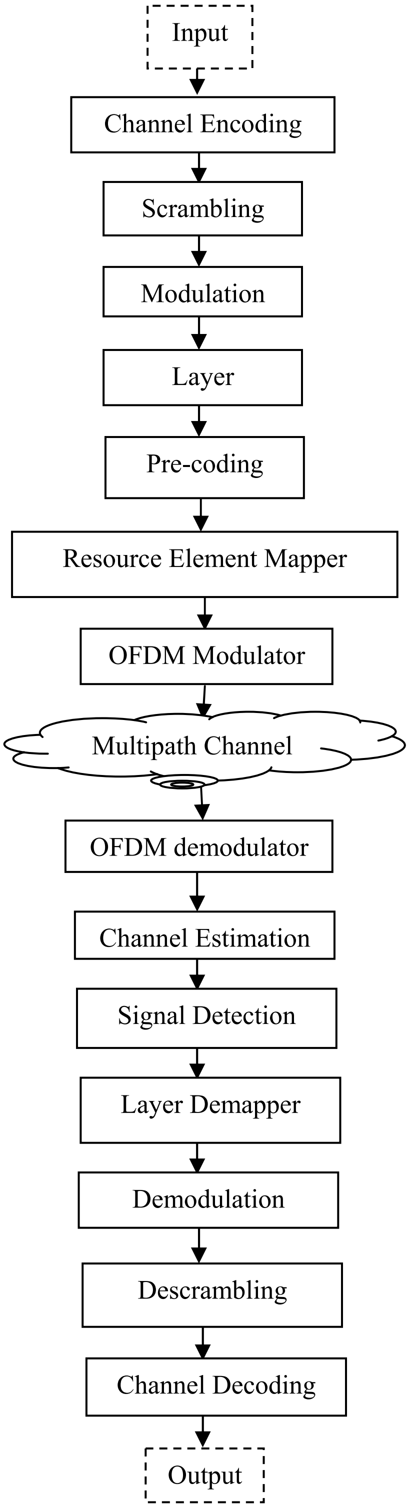


Fig. 1 LTE-A Downlink System Model

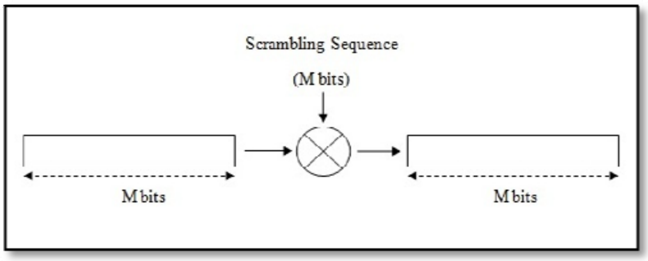


Fig. 2 Downlink Scrambling

D. *Pre-coding*

Pre-coding works on extract exactly one modulation symbol from each layer and maps the extracted symbols in the frequency and time domain.

The input to the pre-coder assumed to be a block of vectors as follow:

$$\boldsymbol{x}\,(\boldsymbol{i}) = [\,x^{(0)}(i) \quad ...... \quad \mathrm{x}^{(v\text{-}1)}(i)]^T,\ i = 0,1,....,M_{\text{symb}}^{\text{layer}}-1 \tag{3}$$

Which the block of vectors in eq. (3) taking from the layer mapping and generates a block of vectors $u\,(i)$ as in eq. (4) to be mapped onto resources on each of the antenna ports:

$$\boldsymbol{u}\,(\boldsymbol{i}) = [\ .... \quad u^{(p)}(i) \quad ....]^T,\ i = 0, 1,..., M_{\text{symb}}^{\text{ap}}-1 \tag{4}$$

Where $u^{(p)}(i)$ represents the signal for antenna port p as in [8].

E. *Mapping to Resource Elements*

In LTE-A system, the downlink Physical Resource Block (PRB) is a number of subcarriers during 0.5 ms slot. Each PRB contains 12 subcarriers with 7 OFDM symbols that make PRB contains in total 84 resource elements. As shown in fig. 3, the PRB maps the transmitted symbols from each antenna to the resource elements of the set of PRBs specified for the transmission [8].

For each of the antenna ports used for transmission, the block of complex-valued symbols $u^{(p)}(0),...,u^{(p)}(M_{\text{symb}}^{\text{ap}}-1)$ shall be mapped in sequence starting with $u^{(p)}(0)$ to resource elements (k, l).

The mapping to resource elements for transmission in one antenna port p not reserved for other purposes in any other antennas and shall increasing the order of the first index (k) over the assigned PRB then increasing the index (l) starting with a first slot in a subframe.

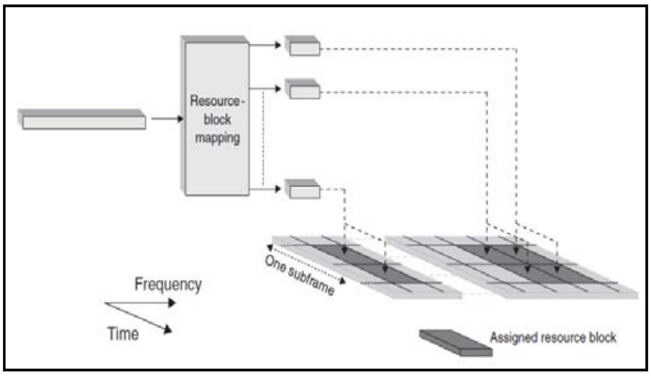


Fig. 3 Downlink Resource Block Mapping [9]

F. OFDM Baseband Signal Generation

The final stage of the system transmitter is the generation of OFDM signal where the signal $\boldsymbol{S_l^{(p)}(t)}$ in OFDM symbol l for a slot transmitted on antenna

$$\boldsymbol{S_l^{(p)}(t)} = \sum_{k=-[N_{RB}^{DL}N_{Sc}^{RB}]}^{-1} a_{k^{(-)},l}^{(p)} \cdot e^{j2\pi k\Delta f(t-N_{CP,l} \cdot T_S)} + \sum_{k=1}^{\left[\frac{N_{RB}^{DL}N_{Sc}^{RB}}{2}\right]} a_{k^{(+)},l}^{(p)} \cdot e^{j2\pi k\Delta f(t-N_{CP,l} \cdot T_S)} \quad (5)$$

For $0 \leq t < (N_{CP,l} + N_A) \text{ x } T_s$

Where

$k^{(-)} = k + \lfloor N_{RB}^{DL} N_{sc}^{RB} / 2 \rfloor$, and $k^{(+)} = k + \lfloor N_{RB}^{DL} N_{sc}^{RB} / 2 \rfloor - 1$. The variable N_A equals 2048 for $\Delta f = 15$ KHz subcarrier spacing and 4096 for $\Delta f = 7.5$ KHz subcarrier spacing. The OFDM symbols in a slot shall be transmitted by increasing the order of l, starting with $l = 0$, where OFDM symbol $l > 0$ starts at time $(\sum_{l'}^{l-1}(N_{CP,l'} + N_A) \times T_s)$ within the slot where Table 1 lists the value of $N_{CP,l}$ that shall be used [8].

TABLE 1 OFDM PARAMETERS

Configuration	**Cyclic prefix length $N_{cp,l}$**
Normal cyclic prefix $\Delta f = 15$ KHz	160 for $l = 0$ 144 for $l = 1, 2,...,6$
Extended cyclic prefix $\Delta f = 15$ KHz	512 for $l = 0, 1,...., 5$
$\Delta f = 7.5$ KHz	1024 for $l = 0, 1, 2$

The first step at the receiver side is the removing of (CP) samples followed by the transformation of the remaining sequence into the frequency domain using (FFT); as a result the received signal can be described as:

$$\boldsymbol{Y = HS + W} \quad (6)$$

Where Y is the received signal vector, H is the vector of channel coefficient in the frequency domain, W is the Additive White Gaussian Noise (AWGN) with variance σ_w^2 at the receive antenna and S is the matrix that contain the elements of the transmitted signals on its diagonal where the matrix S include data symbols S_d and pilot symbols S_p on the main diagonal.

As a result, the vectors Y, H and W in Eq. (6) can be divided into two parts, First part corresponding to the pilot positions Y_p, H_p and W_p, and the Second part corresponding to the remaining data symbol positions Y_d, H_d and W_d.

From channel estimation, the symbols on pilot positions are the most important. So frequency domain received signal can be expressed as in [10]:

$$\boldsymbol{Y_p = H_p\, S_p + W_p} \quad (7)$$

Because of the inability of LTE-A link level simulator (LTE-A v1.0_r100) to support the channel estimation of (8x1) Transmit Diversity, the author designed a simplified LTE-A model that shown in fig. 4. The channel estimation has been implemented to investigate and evaluate the performance of the system for (8x1) transmit-receive antennas that achieve TxD.

At the transmitter side, the generation of the data was configured then coding is applied using convolutional coding scheme where coding is a technique that add redundant bits to the original bit sequence to increase the reliability of the communication.

QPSK modulation scheme was used to modulate the symbols, after that constructing the LTE-A frame which is of 10 subframe and each subframe consist of two slots each one has 7 OFDM symbols with 12 subcarriers. In total there are 20 slots in LTE-A frame and each slot contains 84 OFDM symbols.

For the purpose of channel estimation process, pilots are inserted in the frequency domain where 4 pilot symbols are added to each slot in a pattern includes added one pilot symbol after 20 OFDM symbols. After that, padding occurs to make the LTE-A symbols met the size of the IFFT and a (CP) that has been assumed to be 1/8 of the total size of a slot was inserted to eliminate the (ISI) that occurs.

LTE-A symbols were transmitted via 8 transmit antennas and they pass through AWGN channel which is employed for analyzing modulation symbols.

At the receiver side, the inverse of the previous operations was made in which CP is removed and the time-domain LTE-A symbols are converted to frequency-domain by using FFT. Moreover, extracting pilot symbols for the channel estimation is done followed by decoding the modulation symbols using viterbi decoder and then demodulating the received signal to produce the received data symbols

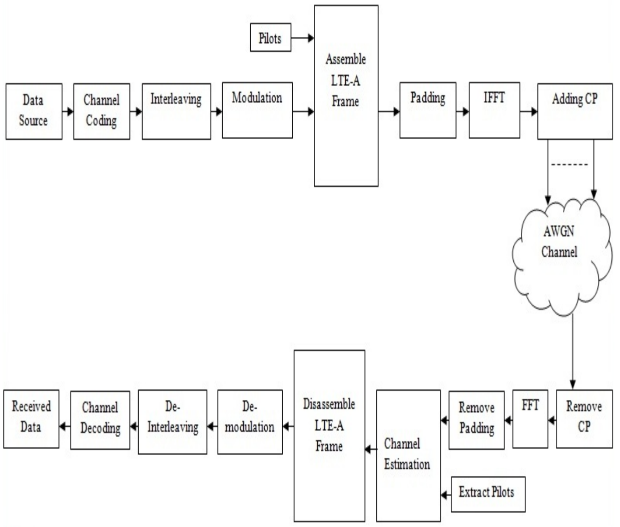


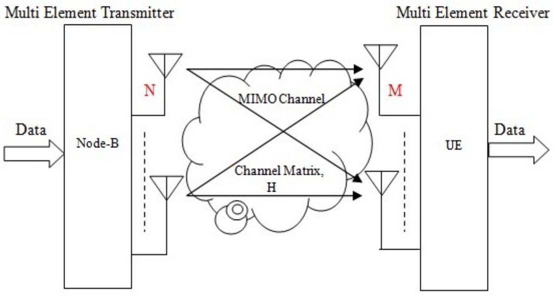
Fig. 4 LTE-A Simplified Model

III. TRANSMISSION SCHEMES

LTE-A system performance depends on a number of factors such as the MIMO transmission schemes that will be more effective on the system. MIMO transmission schemes can be categorized as follows:

A. Transmit Diversity

TxD, as shown in fig. 5, assumed to transmit the same signal from multiple antennas with different code based on Space-Frequency Block Codes (SFBC). By applying this scheme the peak rate is not improved but the quality becomes more robust and lower SNR is required to decode the signal [10].

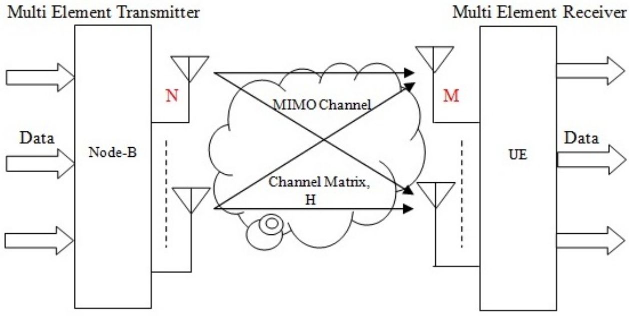


N Tx and M Rx are multiple parallel channels

Fig. 5 Block diagram of a MIMO Transmission using Transmit Diversity [6]

B. *Open Loop Spatial Multiplexing*

Spatial Multiplexing (SM) provides extra gain as compared to TxD. Independent data streams are transmitted from the N_T transmit antennas in spatial multiplexing. OLSM transmits the independent data streams without deploying any feedback algorithm. High data rate is achieved as compared to TxD as multiple independent streams are transmitted that lead to high BER [6]. OLSM illustrated in fig. 6.



N Tx and M Rx are multiple parallel channels

Fig. 6 Block diagram of a MIMO Transmission using OLSM [6]

IV. MIMO DETECTORS

A. *Zero Forcing (ZF)*

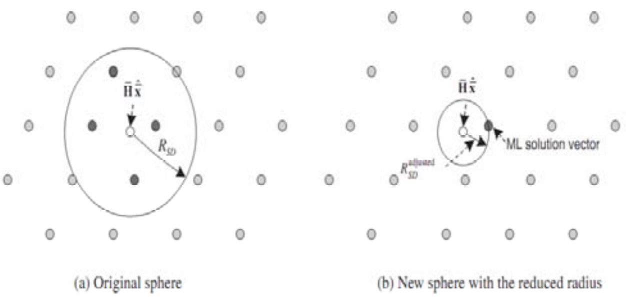
Zero Forcing detection considered as the simplest signal detection schemes and it is less complexity comparing with other schemes. The receiver with the ZF detection scheme uses the estimated channel matrix to detect the transmitted signal as described by the following equation [12]:

$$\hat{S} = (H^H H)^{-1} H^H Y = H^+ Y \qquad (8)$$

Where H^H is the Hermitian conjugate and H^+ is the pseudo inverse respectively. The drawback of this scheme that it neglects the correlation between eNodeB and UE and that in turn lead to not fully remove the ISI by ZF detector.

B. *Soft Sphere Decoder (SSD)*

SSD gives the ML solution with soft outputs. These ML symbols are chosen from a reduced set of vectors within the radius of a given sphere rather than a complete vector length. The radius of the sphere is adjusted, so that there exist only one ML symbol within the given radius. SSD provides sub optimal ML solution with reduced complexity [13].



(a) Original sphere

(b) New sphere with the reduced radius

Fig. 7 Illustration of the sphere in sphere decoding [13]

V. CHANNEL ESTIMATION FOR LTE-A SYSTEM

In communication systems, the mobile radio channels generally face multipath fading, which causes a distortion in the received signal. These distortions are named "channel fading", which result an errors at the receiver side. In order to suppress the multipath fading, improve BER and recover the transmitted information correctly, some forms of channel estimation techniques are required [14].

For the aim of channel estimation, LTE-A system provides a reference signals which are take place on a specific resource elements within the downlink time–frequency grid. In LTE-A, there are different types of downlink reference signals but the most basic one is the Cell-Specific Reference Signal (CRS) where it can be one, two or four CRS in a cell corresponding to one, two, four antenna ports as in [1].

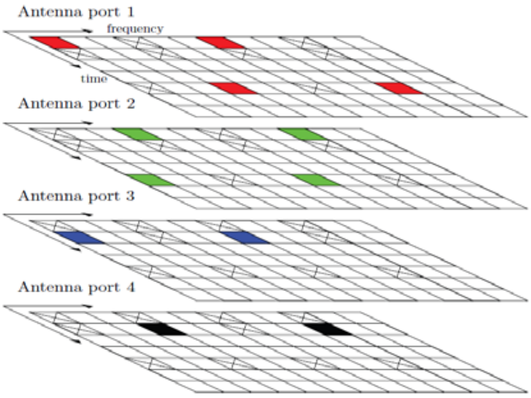


Fig. 8 Reference Signal Mapping in LTE-A

The channel estimation block diagram illustrated in fig. 9, show that the first step on the received signal after FFT is to extract pilot signals from the received signals, and then the transfer function of the channel is estimated from the received pilot signals and the known one. After that, interpolating is done for the channel response of the subcarriers that carry data by using neighboring pilot channel responses [7].

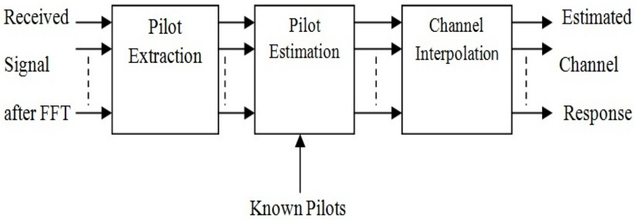


Fig. 9 Block diagram of Channel Estimation [7]

A. *Least Square (LS) Channel Estimation*

LS channel estimation technique represents as the simplest technique to estimate the channel and easy to implement due to it's less complexity but have less performance in minimizing the Mean Squared Error (MSE). The LS estimator for subcarriers on which pilot symbols are located is given by [10]:

$$\hat{H}_{LS} = (S_p)^{-1} Y_p \quad (9)$$

B. Minimum Mean Square Error (MMSE) Channel Estimation

The MMSE channel estimator provides channel coefficients that minimize the mean squared error (MSE). MMSE can be acquired by filtering the LS estimate by matrix A_{MMSE} which obtained as follow:

$$A_{MMSE} = R_{h,h_{LS}} (R_{h_{LS}} + \sigma_w^2 I)^{-1} \quad (10)$$

Where $R_{h,h_{LS}}$ is a cross-correlation matrix between the channel at the data symbol position and the channel at the pilot symbol position, $R_{h_{LS}}$ is the auto-correlation matrix of the channel at the pilot symbol position

So the MMSE channel estimator can be expressed as:

$$\hat{H}_{MMSE} = A_{MMSE} \hat{H}_{LS} \quad (11)$$

As a result the MMSE channel estimate can be as:

$$\hat{H}_{MMSE} = R_{h,h_{LS}} (R_{h_{LS}} + \sigma_w^2 I)^{-1} \hat{H}_{LS} \quad (12)$$

σ_w^2 is the variance of the Additive White Gaussian Noise (AWGN) and $\hat{H}_{LS}$ obtained from Eq. (9) as in [15].

VI. SIMULATION RESULTS AND DISCUSSION

In this section, simulation results are given to explain the performance of LS and MMSE estimation techniques for 4x2 LTE-A downlink system based on the 5MHz. The performance of LS and MMSE are tested and evaluated using TxD and OLSM transmission schemes with ZF and SSD detectors. Vehicular A (VehA) and Vehicular B (VehB) channels are employed in the simulation and QPSK has been considered as a modulation scheme. Results are presented in terms of BER as a function of the average Signal-to-Noise Ratio (SNR). The parameters for LTE-A downlink system used in simulation are illustrated in Table 2.

TABLE 2 SIMULATION PARAMETERS

Parameters	**Values**
Bandwidth	5 MHz
IFFT Size	512
Cyclic Prefix (CP)	Normal
Channel Estimation Techniques	PERFECT, LS, MMSE
Channel Type	Vehicular A (VehA) 30 km/h Vehicular B (VehB) 120 km/h
Receiver Detection Type	Zero Forcing (ZF) Soft Sphere Decoder (SSD)
Transmission Schemes	Transmit Diversity (TxD) Open Loop Spatial Multiplexing (OLSM)
Modulation Type	QPSK

Fig. 10 and 11 display the BER results of channel estimation techniques (MMSE and LS) in VehA channel. The vehicle is assumed to be moved with speed 30 km/h.

From figures, it is obvious that MMSE reduce the BER efficiently as compared to LS with fast moving vehicle, so MMSE is considered to be the best estimation technique in reducing the errors.

The speed of 30 km/h in vehicular environment represented as a normal speed which make the Inter Carrier Interference (ICI) power is normal and that leads the subcarriers to preserve their orthogonality and improves the ratio of errors resulting from the movement of vehicles.

From both figures the system performance using TxD scheme has better results in term of BER than that when using OLSM scheme. As shown in fig. 10 there clearly exist a wide margin between the system in TxD and in OLSM when using ZF detector, while that margin decreased when using SSD detector as shown in fig. 11, that mean the system performance in OLSM become better with using SSD detector, however the system in TxD scheme have just about the same results with using both detectors.

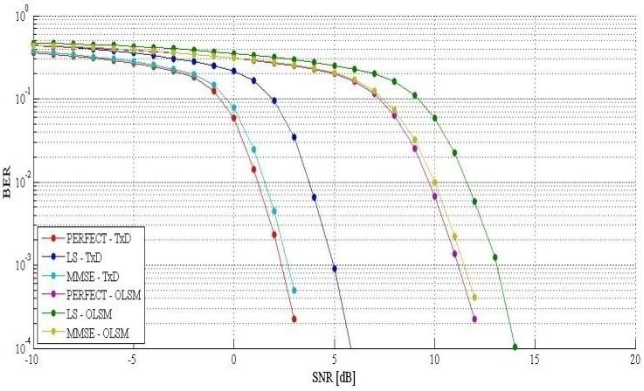


Fig. 10 BER versus SNR for VehA channel with different estimation techniques and transmission schemes for a mobile user with speed of 30 km/h using ZF detector

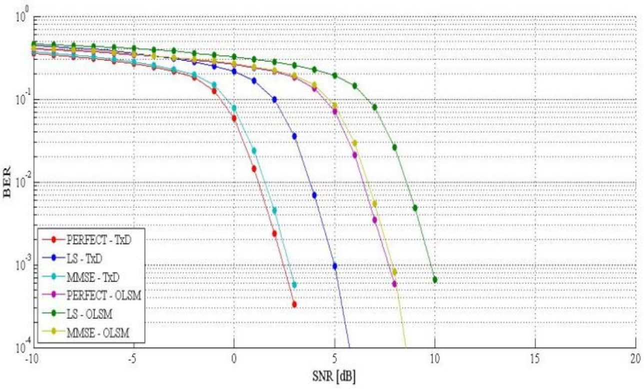


Fig. 11 BER versus SNR for VehA channel with different estimation techniques and transmission schemes for a mobile user with speed of 30 km/h using SSD detector

Fig. 12 and 13 shows the BER performances of channel estimation techniques in a VehB channel where a vehicle is assumed to be moved with a speed of 120 km/h.

As it is clear from figures, the performance of the overall system is decreased in conjunction with the increase of user mobility and MMSE have better performance than LS in minimizing the BER. When the speed of the vehicle is increased, the subcarriers not preserve their orthogonality which leads to imperfect channel estimation. As a result the interference has a great impact on the system performance. LS and MMSE performances are better in TxD scheme as compared in OLSM scheme. As shown from fig. 12 and 13, the SSD detector also in this environment in spite of high speed of vehicle be the best detector when using OLSM and is preferred, while ZF and SSD have the same impact on LS and MMSE when using TxD scheme.

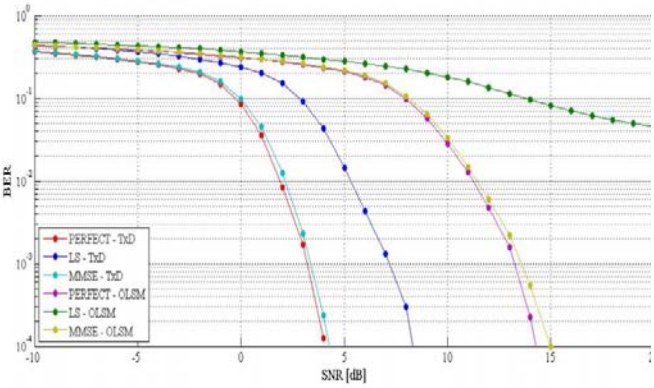


Fig. 12 BER versus SNR for VehB channel with different estimation techniques and transmission schemes for a mobile user with speed of 120 km/h using ZF detector

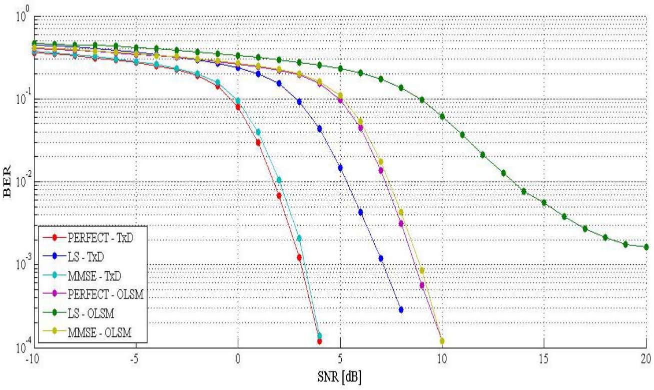


Fig. 13 BER versus SNR for VehB channel with different estimation techniques and transmission schemes for a mobile user with speed of 120 km/h using SSD detector

The parameters used in simulating LTE-A (8x1) system can be organized as shown in Table 3.

TABLE 3 PARAMETERS VALUE OF LTE-A FOR 8X1 TRANSMIT DIVERSITY

Parameter	Value
OFDM subcarriers per slot	12
OFDM symbols per slot	7
Total number of OFDM symbols for each slot	84
CP	1/8 of slot size
IFFT/FFT	128
No. of Pilots	4
Modulation	QPSK
TX antenna	8
RX antenna	1

The system has been designed as in fig. 4 and the result has been shown in fig. 14 in the form of BER vs. SNR in AWGN channel. QPSK has been used as a modulation scheme.

Fig. 14 clarify that in LTE-A system when increasing the number of transmit antennas to (8), the data are transmitted 8 times and then combined as one signal at the receiver by using 1 receive antenna. This achieve the transmit diversity between the eNodeB and UE which make BER keeps on decreasing and the system to provide better performance in term of BER.

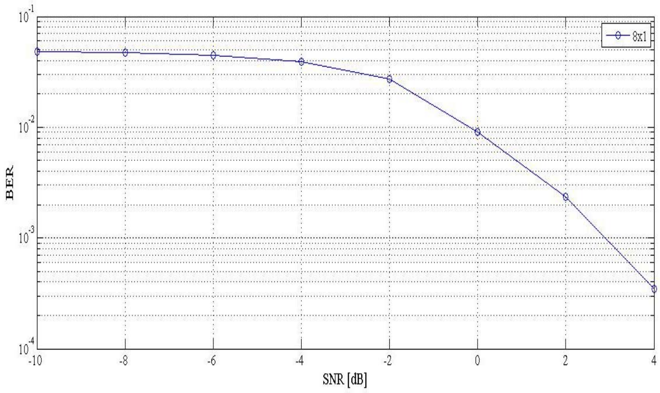


Fig. 14 BER versus SNR for 8x1 Transmit Diversity in AWGN channel

VII. CONCLUSION

In this paper, simulations show that MMSE estimator performs better than LS estimator but at the cost of complexity this is due to the fact that MMSE depends on the channel and noise statistics. LS and MMSE provide better performance in term of BER using TxD scheme as compared with that when using OLSM, so this make the TxD scheme are useful only in case of low SNR values or for the requirements of lower BER.

ZF and SSD have the same impact on LS and MMSE when using TxD scheme, while SSD make the estimation techniques perform better in OLSM scheme.

For 8x1 LTE-A system, increasing the number of transmit-antennas to (8) due to an improvement on the system performance in term of BER while the throughput of the system remains as it is and not affected.

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