Performance of Massive-MIMO OFDM system with M-QAM Modulation based on LS Channel Estimation

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***Abstract*—A Least Squares Channel Estimation (LSCE) method is designated for a Massive MIMO system combined with Orthogonal Frequency Division Multiplexing (OFDM) and higher order modulation technique. The performance of ZF and MMSE detectors is evaluated with ($Nt \times Nr$), (50×100) and (50×300) respectively antennas array, for various modulations techniques 16-QAM, 64-QAM, and 128-QAM , and for various OFDM sub-carriers 64, 256, 512 and 1024. The performance is determined in terms of Bit Error Rate (BER). Increasing the number of Bits/symbol provides an increase of BER both the ZF and MMSE detectors for an antennas array 50×100; Whereas increasing the number of OFDM sub-carriers provides a decreasing of BER. Combining 128-QAM modulation with 1024-sub-carriers and increase the receiver antennas array three times (i.e., 50×300), decreases more the BER both the ZF and MMSE detectors. Consequently the ZF and MMSE detectors provide a best BER so a best system performance.**

***Keywords*—Massive-MIMO, OFDM, Channel Estimation, Least Square, MMSE, ZF, QAM**

I. Introduction

Nowadays, in a world of great mobility, the speed and capacity of communication systems are essential elements in order to keep people from all over the world in communication. Massive-MIMO systems has become a promising technique for $5th$ generation cellular network, increasing the Base Station (BS) antennas and combining with OFDM technique Massive-MIMO can support very high throughput and/or performance of the links as well as spectral efficiency [1]. At the transmitter the data sequence is modulated into Quadrature Amplitude Modulation (QAM) symbols. Moreover, the symbols is converted into time-domain signals using the IFFT technique, in the same way, the converted data is sent across the channel. The received signal is deformed by channel phenomena (i.e., Multi-path channel). Hence, in order to recuperate the transmitted data sequence, the channel phenomena must be estimated [2]. The Least-Square (LS) approach is extensively practiced for channel estimation. The organization of this paper is as follow. In Section II, we illustrate a Massive-MIMO system for single cell network and define the high order modulation also know M-QAM and introduce the FFT/IFFT. In the Section III, we illustrate the model of the system, in which the received signal is contaminated by an Additive White Gaussian Noise (AWGN). In Section IV, we introduce the LSCE; the linear detectors (i.e., ZF and MMSE) are discussed in Section V. Section VI presents the simulation results. In the end of this paper, the conclusion is done in Section VII.

II. Massive-MIMO

Multiple-Input Multiple-Output (MIMO) tend to use four or eight antennas. Moreover, Massive-MIMO or Large-scale MIMO is based on a MIMO system with a higher antennas number figure 1 [3]. The denomination of Massive-MIMO is envisaged on 5G technology. In particularly, the base station antennas is assumed to be larger than the number of users equipment [4].

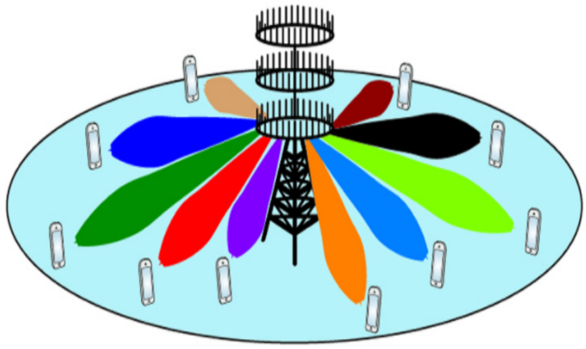

Fig. 1. Example of a Massive-MIMO system in the DownLink transmission.

A. M-QAM symbols

The high order modulation M-QAM is a technique used to modulate the data sequence into M-ary constellation. In this paper, the 16-QAM, 64-QAM, and 128-QAM modulation is used; their average power magnitude is done at the equation I [5]. In general, the M-QAM symbols with M constellation is noted by the following equation:

$$X^i = \beta.(x_i + jy_i) \tag{1}$$

where, $x_i, y_i \in \{\pm 1, \pm 3, \cdots, \sqrt{M} - 1\}$ and the average power normalization is defined by β. Hence, the Table I presents different value of β for the M-QAM used.

TABLE I. DIFFERENT VALUE OF β FOR M-QAM MODULATION

M-QAM	Bits/symbol	β
16-QAM	2	$\frac{1}{\sqrt{10}}$
64-QAM	6	$\frac{1}{\sqrt{42}}$
128-QAM	7	$\frac{1}{\sqrt{82}}$

B. Introduction to FFT/IFFT

The OFDM technique consist in transmitting digital data by modulating them on a higher number of carriers at the same time. The current interest is in the improvement brought by the increase of the spectral efficiency based on the orthogonalization of the carriers which makes it possible to implement modulation and demodulation using efficient Fourier transform circuits. fast. The principle is to transmit modulated parallel digital data over a large number of low-rate carriers. For this purpose, frequency division multiplexing packet digital data, which will be called OFDM symbol and module each data by a different carrier at the same time [6].

The Discrete-Fourier-Transform (DFT)and the Inverse-DFT (IDFT) of K-point data sequence can be given as

$$X(k) = \sum_{n=0}^{K-1} x(n)e^{-j2\pi kn/K}, \quad 0 \leq k \leq K-1 \tag{2}$$

$$x(n) = \frac{1}{N}\sum_{k=0}^{K-1} X(k)e^{j2\pi kn/K}, \quad 0 \leq n \leq K-1 \tag{3}$$

The DFT and IDFT of any given sequence of length N are $X(k)$ and $x(n)$, respectively. From Eqs. (2) and (3), it is clear that n and k are nth and kth samples of N data points, in this paper K can be 64/256/512/1024 points. The exponential term given in Eqs. (2) and (3) represents the twiddle factor needed for Fast-Fourier-Transform/Inverse-Fast-Fourier-Transform (FFT/IFFT) computation. The direct implementation of DFT demand K^2 and $K(K-1)$ complex multiplications and additions respectively [6].

III. MASSIVE-MIMO MODEL

We consider a Massive MIMO system in Uplink (Up) transmition from N_t terminals with single antennas to a single BS with N_r antennas. The considered system is presented in Figure 2. It's a Massive-MIMO-OFDM system with N_r and N_t receive and transmit antennas respectively. The length of sub-carriers and the cyclic prefix (CP) are defined by K and ν respectively. The CP is inserted on each transmit antenna to achieve a full OFDM symbol. In this paper, the CP is superior than the utmost multi-path delay [2], [7]. In the same way, at the reception the CP is removed on each receive antenna, taking for example the qth receive antenna, the received signal vector $y^q(n)$ is $K \times 1$ and expressed as follow:

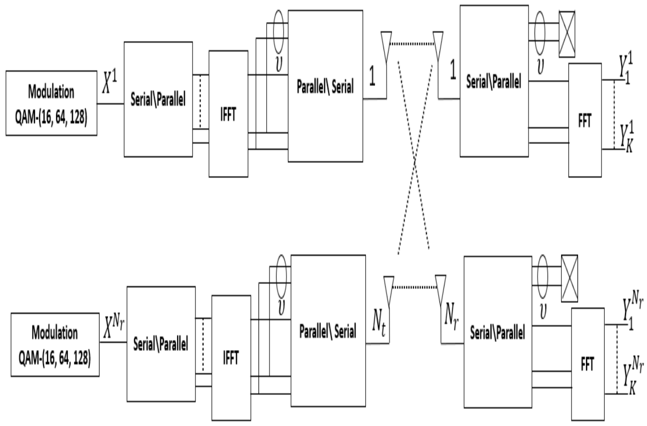

Fig. 2. System model.

$$y^q(n) = \sum_{r=1}^{N_t} H_{cir}^{q,r} F^H X^r(n) + z^q(n) \tag{4}$$

From the equation 4, the circulant matrix $H_{cir}^{q,r}$ has a rst column defined by $[h^{q,r^T}, 0_{1\times(K-L)}]^T$, in addition to that L is the length of the channel impulse response and $h^{q,r}$ presents $L \times 1$ vector. The OFDM vector that is transmitted on each transmit antenna is defined by $X^r(n)$ with $K \times 1$ dimension, r and n are the index of the number of transmit antenna and time respectively, as shown in the figure 2 and $z^q(n)$ is additive gaussian noise at Time Index (TI) n with zero mean and variance of σ_n^2. Moreover, the unitary DFT matrix the dimension $K \times K$ is presented by F; from the eigenvalue decomposition of the circulant matrix, it can rewrite by $H_{cir}^{q,r} = F^H diag\{\sqrt{K}F[h^{q,r^T}, 0_{1\times(K-L)}]^T\}F$ [7]. Finally the FFT of the received signal $y^q(n)$ is given as follow:

$$Y^q(n) = \sum_{r=1}^{N_t} diag\{\sqrt{K}F[h^{q,r^T}, 0_{1\times(K-L)}]^T\} \times X^r(n) + \Xi^q(n) \tag{5}$$

where $\Xi^q(n) = Fz^q(n)$.

IV. Massive-MIMO Estimation

Based on the same system presented in figure 2, the LSCE scheme is presented. Then, the equation (5) becomes:

$$Y^q(n) = \sum_{r=1}^{N_t} diag\{X^r(n)\}\mathbf{F}h^{q,r} + \Xi^q(n) \tag{6}$$

From the equation (6), $\mathbf{F}$ is $\sqrt{K} \times l$ of F, where l is the $1st$ column of F. Noting $X^r_{diag}(n) = diag\{X^r(n)\}$. Hence the equation (6) becomes:

$$Y^q(n) = \sum_{r=1}^{Nt} X^r_{diag}(n)\mathbf{F}h^{q,r} + \Xi^q(n) \tag{7}$$

Assuming training over g consecutive OFDM symbols, e.g.,over the time indices $n \in \{0, \cdots, g-1\}$, we consider the data model

$$Y^q = Ah^q + \Xi^q \tag{8}$$

where $Y^q = [Y^{q^T}(0), \cdots, Y^{q^T}(g-1)]^T$, $\Xi^q = [\Xi^{q^T}(0), \cdots, \Xi^{q^T}(g-1)]^T$,

$$A = \begin{bmatrix} X^1_{diag}(0)\mathbf{F} & \cdots & X^{Nt}_{diag}(0)\mathbf{F} \\ \vdots & & \vdots \\ X^1_{diag}(g-1)\mathbf{F} & \cdots & X^{Nt}_{diag}(g-1)\mathbf{F} \end{bmatrix} \tag{9}$$

and $h^q = [h^{q,1^T}, \cdots, h^{q,Nt^T}]^T$. The LSCE technique minimize the noise defined in equation (8), basing on the cost function (equation 10), to obtain the estimated channel noted by $\hat{h}^q$.

$$\begin{aligned} J(\hat{h}^q) &= ||Y^q - A\hat{h}^q||^2 \\ &= (Y^q - A\hat{h}^q)^H(Y^q - A\hat{h}^q) \\ &= Y^{q^H}Y^q - Y^{q^H}A\hat{h}^q - \hat{h}^{q^H}A^HY^q \\ &\quad + \hat{h}^{q^H}A^HA\hat{h}^q \end{aligned} \tag{10}$$

In the next taking the derivation of the equation (10) relative to $\hat{h}^q$ variable,

$$\frac{\partial J(\hat{h}^q)}{\partial \hat{h}^q} = -2(A^HY^q)^* + 2(A^HA\hat{h}^q)^* = 0 \tag{11}$$

Finally, we have $A^HA\hat{h}^q = A^HY^q$ and the solution of the LSCE, is given by the following expression:

$$\hat{h}^q = A^+Y^q \tag{12}$$

where A^+ is the pseudo-inverse that equal to $(A^HA)^{-1}A^H$ if $gK \geqslant LN_t$. Because $rank(A) = min(gK, LN_t)$, the necessary and sufficient condition to have unique LSCE is $gK \geqslant LN_t$. This LS method presents a low complexity and a high simplicity, in addition to that also taking the information about the channel and the noise are not necessary [7]–[9].

V. Linear Detectors

The channel estimation for the UpLink transmission is performed at the BS by the intermediate of Pilot Sequences (PS) that is transmitter from the users equipment. The necessary time for UpLink transmission is independent of the BS antennas number. Hence, to estimate the channel of each users in their cells the BS use these PS in the first, and in the second basing on the estimated channel the BS detects the UpLink data. The performance of linear detectors such as ZF and MMSE is evaluated [10], [12]. Linear MIMO detectors are based in general on a multiplication of the received signal by T (Figure 3):

$$d = Ty \tag{13}$$

In this case, the symbol T define the linear transformation matrix in which presented according to different specification [12]. The Figure 3 shows the basic principle of MIMO linear detectors.

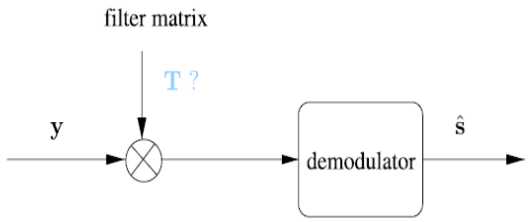

Fig. 3. Basic principle of MIMO linear detectors.

A. Zero Forcing Detector

Zero Forcing (ZF) is linear detection scheme which forces the interference to zero. However it may result in increase in noise level [10]–[12]. the linear transformation matrix is given by

$$T_{ZF} = \hat{H}^+ \tag{14}$$

where $\hat{H}^+ = (\hat{H}^H\hat{H})^{-1}\hat{H}^H$, the matrix $\hat{H} = [\hat{h}^1, \cdots, \hat{h}^q, \cdots, \hat{h}^{N_r}]^T$ satisfies $N_r > N_t$ and a complete column rank of N_t.

B. Minimum Mean Square Error Detector

From the equation (13), T can be defined for MMSE detector. Hence, the main goal is to minimize the MSE between the actual transmitted signal and the received signal multiplied by T. Hence, the T_{MMSE} expression is shown below [10]–[12].

$$T_{MMSE} = arg \min_{T_{MMSE}} E(||X^r - T_{MMSE}Y^q||_2^2) \tag{15}$$

Finally, transformation T_{MMSE} can be shown as

$$T_{MMSE} = (\hat{H}^H\hat{H} + 2\sigma_n^2 I)^{-1}\hat{H}^H \tag{16}$$

where σ_n^2 is the noise power and $Y = [Y^1, \cdots, Y^q, \cdots, Y^{N_r}]^T$ and $X = [X^1, \cdots, X^r, \cdots, X^{N_t}]^T$.

VI. Simulation Results

The performance of LSCE is evaluated for a Massive-MIMO system and the performance of ZF and MMSE detectors is evaluated also for different OFDM sub-carriers such as 64, 252, 512 and 1024, and for different QAM modulation such as 16, 64 and 128 with a massive-MIMO antennas given by $(Nt \times Nr)$ (50×100) and (50×300). We present the performance of MMSE detector and ZF detector associated with a Massive-MIMO antennas. The transmitter (terminals) and the receiver (BS) having an antennas array of $Nt = 50$ and $Nr = 100$ respectively, under the modulation 16-QAM, in which we vary the number of OFDM sub-carriers by calculating BER; Figure 4 shows a BER decrease if we increase the SNR for various number of sub-carriers such as 256, 512, 1024 although the 64 sub-carriers shows a bad BER; So an interpretation can be draw, the increase of OFDM sub-carriers increases the accuracy of the system consequently increase the bit rate of the link. The same consequence illustrates from ZF detector figure 5. The performance of the ZF detector is better than MMSE detector; taking for example, at an SNR of $8dB$ the $BER = (15.63)10^{-5}$ for ZF detector and $BER = (50.78)10^{-5}$ for MMSE detector for 1024 OFDM sub-carriers.

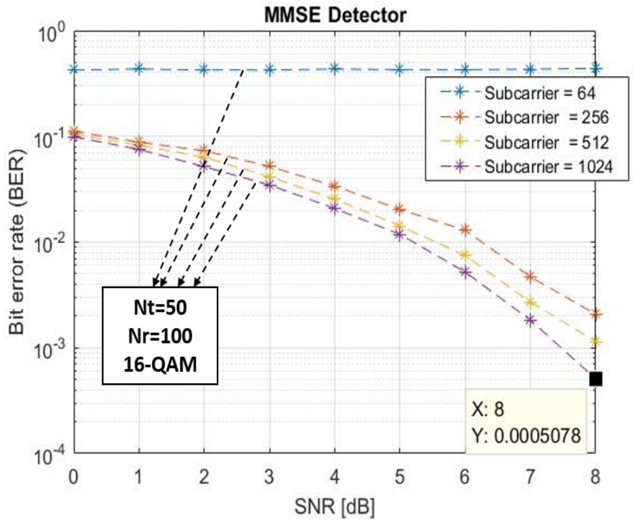

Fig. 4. BER vs SNR for different OFDM sub-carrier using MMSE detector.

The figure 6 and figure 7 show a plot of BER versus SNR for the number of antennas at transmitter and receiver equal to $Nt = 50$ and $Nr = 100$ respectively, and the number of OFDM sub-carriers equal to 1024. The BER decreases for different curve of various QAM modulation such as 16, 64 and 128. The 16-QAM modulation provides better BER compared to others modulation. From this result an interpretation can be draw, if we increase the bits/symbol we can increase the bit rate of the link but decrease in distance between the constellation points, which increases the

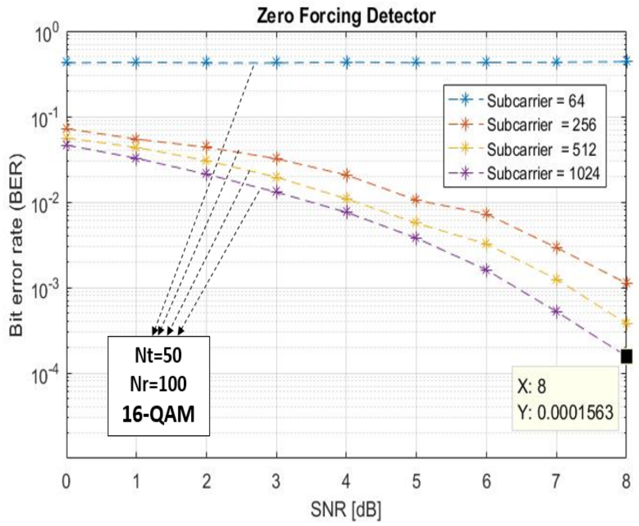

Fig. 5. BER vs SNR for different OFDM sub-carrier using ZF detector.

sensitivity of the system to noise. The ZF detector provides better performance compared to MMSE detector for example at SNR of 5 dB the BER equal $(22.22)10^{-3}$ and $(43.92)10^{-3}$ respectively for 128-QAM modulation.

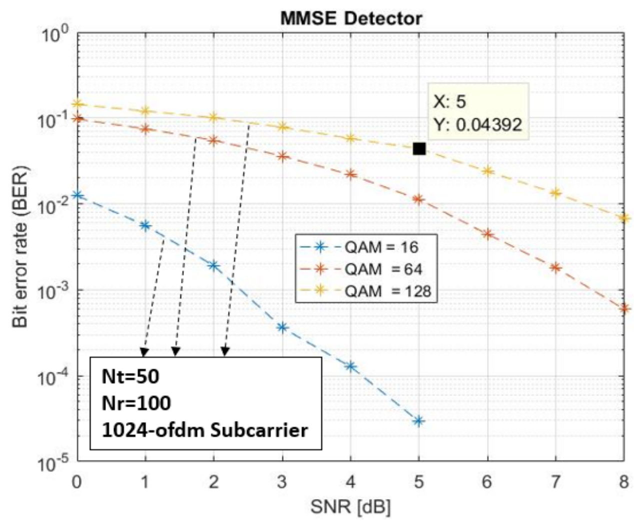

Fig. 6. BER vs SNR for different QAM-modulation using MMSE detector.

We now improve the performance of the linear detector presented above. 128-QAM modulation is used and 1024 OFDM sub-carriers , the transmitter antennas stay at $Nt = 50$ as describe above. In this part, we increase the received antennas at $Nt = 300$ three times by contribution to the previous number describe above $Nt = 100$ (figure 8). The BER of ZF and MMSE detectors decrease more for different value of SNR. For an example, of SNR at 5dB, the comparative results illustrates in the table II, for the number of antennas

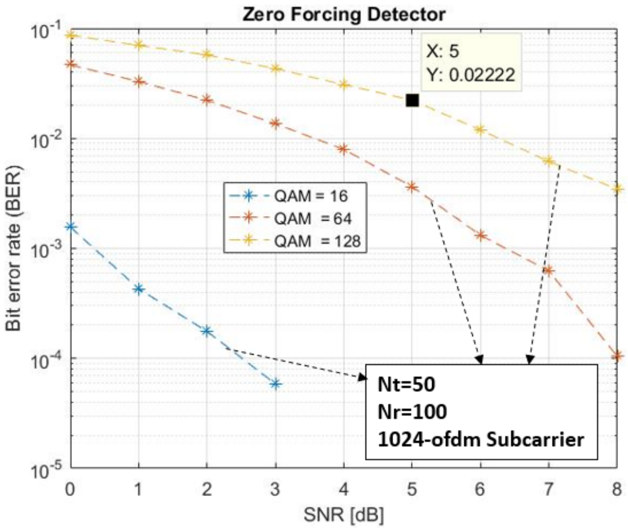

Fig. 7. BER vs SNR for different QAM-modulation using ZF detector.

arrays (50×100) the BER of the ZF detector more important than MMSE detector; increasing the receiver antennas three times (50×300) makes the BER more important than the previous one. The linear detector ZF provides more performance compared of the linear detector MMSE as the number of antennas grows.

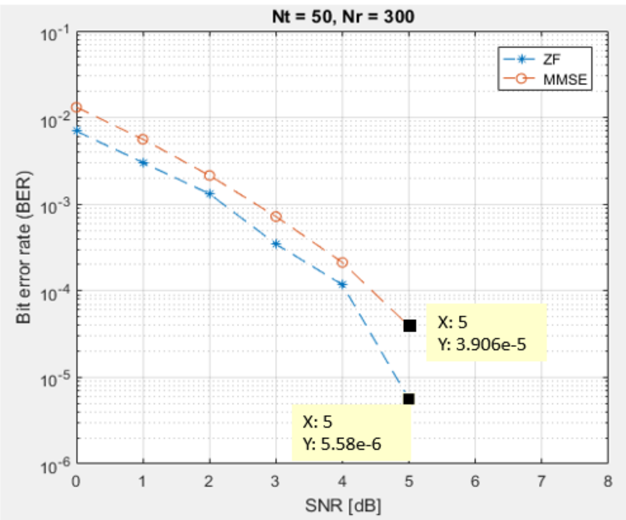

Fig. 8. BER vs SNR for ZF and MMSE detectors, with 128-QAM modulation and 1024-sub-carrier.

TABLE II. A COMPARATIVE TABLE FOR MMSE AND ZF DETECTORS AT SNR=5DB FOR (50×100) AND (50×300) MASSIVE-MIMO ANTENNAS WITH 128-QAM MODULATION AND 1024-SUBCARRIERS.

$Nt \times Nr$	ZF Detector	MMSE Detector
50×100	$BER = 22.22e^{-3}$	$BER = 43.92e^{-3}$
50×300	$BER = 5.58e^{-6}$	$BER = 39.06e^{-6}$

VII. CONCLUSION

The performance of the least squares channel estimation is successively evaluated of ZF and MMSE detectors for a Massive-MIMO systems combined with high order modulation and OFDM technique. Increasing the M constellation points in a high order modulation M-QAM increases the sensitivity of the system to noise. Therefore, with a higher antennas at the receiver (BS) the noise sensitivity compensated and the system performance increases.

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