Improving BER Performance of Massive MIMO Scheme over Rayleigh Fading Channel

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Abstract — In massive multiple input multiple output (mMIMO) scheme, the system capacity can be improved without additional bandwidth or transmit power by using a huge antenna array at base station with as much separation between antenna elements as possible. Unfortunately, its performance depends on having a perfect channel state estimate between the base state and the users. In this paper, the bit error rate (BER) performance of a mMIMO scheme is improved using genetic algorithm-based optimization with simulation performed in MATLAB software environment. The genetic algorithm used selects the best signal required for effective transmission. Four different antenna configurations in the order of 2x2, 4x4, 8x8 and 16x16 were considered for the simulation. The encoding and decoding were done using an STBC coded. Also, filter bank multicarrier-offset quadrature amplitude modulation (FBMC-OQAM) scheme was used and simulation was carried out for 4-FBMC-OQAM, 16 FBMC-OQAM, and 64 FBMC-OQAM order. The BER is computed for both the optimized and un-optimized mMIMO schemes, and the performance of both schemes is compared. Simulation results show a significant improvement in the BER of the optimized mMIMO compared to the normal (coded) MIMO scheme. The overall results show that the optimized mMIMO experience a reduced BER when compared to the normal mMIMO. In both cases, the BER reduces gradually as the number of antenna increases.

Keywords — Antenna array; bit error rate; data traffic; genetic algorithm; MIMO; massive MIMO.

I. INTRODUCTION

The number of mobile subscribers has increased drastically in recent years due to improvement in wireless technology for GSM (3G, LTE and LTE-A). Consequently, the use of real-time traffic oriented applications for voice, video and data rises sharply [1]. Now with the introduction of 5G, the number of mobile communication subscribers is anticipated to be more than double [2], [3], increasing the need for data traffic. As shown in Fig. 1, the data traffic demand for voice, video, audio, amongst others, experience an explosive growth over the years. This demand is due to the development of high data rate applications and the expected increase in traffic from intelligent sensor devices utilized in Internet of Things (IoT), machine-to-machine

communication (M2M), cyber-physical systems, industrial IoT, vehicular technology and many other applications [4]-[6]. Therefore, the demand for data traffic will increase dramatically over the next few years, a threat to current and future wireless communications.

Fig. 1: Global data traffic [7]

Future wireless communication systems, known as 5G communication networks, aimed at addressing the capacity constraints of current networks: range, data rate, connection reliability, latency and energy efficiency. Future wireless communications will require new technologies that can serve vast number of consumers simultaneously albeit high throughput. Therefore, the new framework for wireless communication has brought about a new technology in which several antennas on a base station serve multiple user devices with a single antenna. This technique is considered a massive multi-input multi-output (mMIMO) scheme. Massive MIMO technology is capable to cater the needs of the 5G wireless communication systems and is keen to be a core technology for 5G and beyond [8], [9], to meet the ambitious goal of a thousand-fold rise in data traffic [10]. To achieve very high data rates and better connection reliability, several antenna elements are installed in mMIMO base stations instead of a small number of antenna units, as shown in Fig. 2. Thus, in a mMIMO system, a large number of antennas is installed at a base station (BS) and are used to serve many users at the same time. As illustrated in Fig. 2 for instance, hundreds of antennas at the BS communicate with tens of users. In most cases, the of BS antennas is much greater than that of the users. This is a completely different configuration of base transceiver station (BTS) design as compared to the current standards where up to 8 antennas are used in sectorized topologies. Many active antenna units are used to continuously focus energy on the user equipment (UE) within the target using a variety of precoding schemes.

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Fig. 2. An illustration of a massive MIMO scheme.

Strictly speaking, mMIMO schemes can improve system capacity without additional bandwidth or transmit power by using a huge antenna array at the BS with as much separation between antenna elements as possible. The research studies in [11-15] proved that this scheme has the capabilities to improve the spectral and energy efficiencies significantly with a relatively simple processing. However, the accuracy of the mMIMO scheme is dependent upon the channel state information (CSI) [16]-[18]. Under an imperfect channel estimate, the accuracy of such system is greatly affected. Therefore, a good CSI must be maintained at both downlink and uplink side (that is at BTS and UE). The imperfect channel estimation and time-variant channel produces impairment and consequently limit the performance in terms of the BER. In this paper, the BER performance of a mMIMO scheme is improved using genetic algorithm-based optimization.

II. MASSIVE MIMO MODELLING

Consider a mMIMO scheme having a single BS with M number of antenna and serving N number of active user equipment (see Fig. 3). As shown in Fig. 3, it is assumed that each UE has a single antenna. Also, the same time-frequency resources are shared among the N UEs, and that the BS and UEs have a perfect channel state information (CSI).

In a general MIMO scheme, the relationship between the signal received and that transmitted is expressed as

$$y = Hx + \xi \quad (1)$$

where x denotes the transmitted signal, ξ is the noise, and H denotes the channel matrix. The channel matrix may be decomposed as:

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} & \dots & h_{1,N} \\ h_{2,1} & h_{2,2} & \dots & h_{2,N} \\ \vdots & \vdots & \dots & \vdots \\ h_{M,1} & h_{M,2} & \dots & h_{M,N} \end{bmatrix} \quad (2)$$

Assuming a Rayleigh channel matrix, each entry in Rayleigh channel matrix may be represented as

$$h_{i,j} = \alpha + j\beta$$

$$h_{i,j} = |h_{i,j}| e^{j\phi_{i,j}} \quad (3)$$

In (3), α and β denote randomly distributed variables while $|h_{i,j}|$ is a Rayleigh distributed random variables. In

the channel matrix $H \in \mathbb{R}^{(M \times N)}$, the n^{th} column of H , that is, h_n is used to denote the M by 1 channel vector between the n^{th} UE and the BS.

Fig. 3. A massive MIMO system.

A. Uplink Transmission

This is a situation where the N UEs transmit signals to the BS. If the transmitted signal from the n^{th} UE is denoted by s_n where

$$E\{s_n^2\} = 1 \quad (4)$$

Since it is assumed that N UE shares the same resources, the M by 1 vector of the signal received at the BS consist of all the signals transmitted from all n UEs. Thus,

$$y_{ul} = \sqrt{\rho_{ul}} \sum_{n=1}^N h_n s_n + \xi \quad (5)$$

That is,

$$y_{ul} = \sqrt{\rho_{ul}} Hs + \xi \quad (6)$$

In both (5) and (6), ρ_{ul} denotes the signal to noise ratio (SNR) during uplink transmission, $\xi \in \mathbb{R}^{(M \times 1)}$ denotes the noise vector while $s \equiv [s_1, s_2, \dots, s_N]^T$ and $y_{ul} \equiv [y_{ul,1}, y_{ul,2}, \dots, y_{ul,M}]^T$ denote a single column vector of the transmitted signal by the UEs and that received at the BS.

Using the knowledge of the CSI, the BS will coherently detect the transmitted signals from the N UEs. The sum-capacity of the channel model during uplink transmission $C_{ul,sum}$ may be expressed using (7) [19], [20]:

$$C_{ul,sum} = \log_2 \Delta [I_N + \rho_{ul} H^* H] \quad (7)$$

where I_N is the N by N identity matrix while H^* denotes the conjugate transpose of matrix H and Δ is the determinant of a matrix. It is pertinent to mention that the $C_{ul,sum}$ may be

achieved by successive interference cancellation where user's signals are decoded and subtracted out of the received signal [19].

B. Downlink Transmission

In this case, the BS transmits signals to all the N UEs. If the vector of the transmitted signal from the BS antenna to the UEs is represented by x where:

$$x \in \Re^{(M \times 1)} \text{ such that } E\{|x|^2\} = 1$$

The received signal vector at the UEs may be expressed as

$$y_{dl} = \sqrt{\rho_{dl}} H^T x + w_N \quad (8)$$

where ρ_{dl} is the average SNR during downlink transmission, and w_N is the noise present at the N UE end. It is always assumed that the noise added during this transmission is Gaussian distributed with zero mean [19]. From (8),

$$y_{dl} = \begin{bmatrix} y_{dl,1} \\ y_{dl,2} \\ y_{dl,3} \\ \vdots \\ y_{dl,N} \end{bmatrix}, w = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \\ \vdots \\ w_N \end{bmatrix}, H = \begin{bmatrix} h_1 \\ h_2 \\ h_3 \\ \vdots \\ h_N \end{bmatrix}$$

The sum-capacity is given as [19]

$$C_{dl-sum} = \max_{\{q_k\}} \log_2 \Delta [I_M + \rho_{dl} H^* D_q H^T] \quad q_k \geq 0, \sum_{n=1}^N q_n \leq 1 \quad (9)$$

where D_q is a diagonal matrix whose n^{th} diagonal element is q_n .

In a massive MIMO system, M number of base station antennas is used to served N number of UEs in the service area with a large antenna array at each BS. Studies in [21], [22] showed that with perfect CSI and completely eliminated pilot contamination, a better SNR will be achieved with increasing the transmitting antenna. In this scheme $M \gg N$, then the bound of capacity, C , of mMIMO scheme with coefficient of the magnitude of propagation normalized to 1 [19], [22], is as under:

$$\log_2(1 + \rho M) \leq C \leq \min(N, M) \times \log_2 \left(1 + \frac{\rho \max(N, M)}{N} \right) \quad (10)$$

where ρ is the overall SNR.

C. Simulation Process for the Optimized Massive MIMO

The simulation of the system was carried out using MATLAB programming. Fig. 4 shows the flow chat for the massive MIMO over Rayleigh fading channel. Binary data are generated randomly, and these symbols were then

converted to bits, reshaped and modulated with FBMC-OQAM scheme. The FBMC is a combination of multiplexing and modulation which function by breaking the wideband channel into a number of narrowband sub channels [23]. The modulated symbols are split among the transmitters, and they are being sent to the channel where AWGN is added. This mimic the effect of many random processes that might occur and also added to the incoming noise that might be intrinsic to the information system. This is followed by Genetic Algorithm where the most fit signal is selected. The best fit signal is sent to the receiver and the message is detected with the aid of Zero forcing detector. This is repeated until the last SNR reached and BER value is generated.

Fig. 4. Flow chart for massive MIMO over Rayleigh fading channel.

Fig. 5 relays the block diagram of the optimized massive MIMO scheme. As may be observed in this figure, an encoder called the Space Time Block Code (STBC) is applied to the generated data. This corrects the symbol error in the block. STBC technique rely on the construction of matrices and the signal is to be transmitted at different period of time from multiple of antennas. After this stage, the signal is modulated with FBMC-OQAM and it is sent to the transmitter, and later to the channel. In the channel, scintillation and terrestrial fading distorted the signal and afterwards, Genetic Algorithm is applied. The resulting signal is then sent to the receiver. Demodulation takes place with the help of the FBMC-OQAM before the STBC decoder is finally applied. This gives the optimized BER. The process is carried out for the three different modulation orders which include order 4, 16 and 64 respectively. The results were compared for each modulation order and also for each antenna configuration.

Fig. 5. Block diagram for the optimized massive MIMO.

D. Genetic Algorithm-based Optimization

GA is an optimization technique that primitively reflects some of the process of genetics and natural evolution. It has three operators: the reproduction (selection), crossover and mutation. The former is utilized to take the chromosome from current population to form new solutions. The success rate of GA is dependent upon the parameters used in crossover and mutation operations. The following steps was used to achieve a GA based optimization.

- i. Represents the problem variables by a chromosome of fixed length. The chromosomes population size and the crossover probability are chosen.
- ii. Define the fitness function to measure the quality of a chromosome in the problem domain. The fitness function establishes the basis for selecting chromosomes that will be mated during reproduction.
- iii. Randomly generate the initial chromosome population of fixed size.
- iv. Calculate the fitness function for each individual.
- v. Select pairs of chromosomes for mating from the current population. The parent chromosomes are selected with a probability related to their fitness. The best chromosomes have a greater probability of being selected for mating.
- vi. Apply genetic operations (crossover and mutation) to create pairs of chromosomes solution.
- vii. Place the chromosomes solution in the new population.
- viii. Repeat steps v through vii until the size of the new population is equal to the initial population size.
- ix. Replace the original parent population by the new population.
- x. Repeat steps iv through ix until optimum solution is achieved.

After the simulation process, the BER plot of the massive MIMO and optimized massive MIMO was plotted and compared for each antenna configuration and modulation order.

E. Simulation Environment and Parameters

The simulation was conducted using MATLAB software. During simulation, four different antenna configurations were considered. This are 2×2 , 4×4 , 8×8 and 16×16 antenna configurations. The encoding and decoding were done using an STBC coded. Also, Filter Bank Multicarrier-Offset Quadrature Amplitude Modulation (FBMC-OQAM) was used, and simulation was carried out for 4 FBMC-OQAM, 16 FBMC-OQAM, and 64 FBMC-OQAM order. The BER is computed for both the optimized and un-

optimized (coded) mMIMO schemes, and the performance of both schemes is compared. Table I reports the simulation parameters.

TABLE I: SIMULATION PARAMETERS

Parameters	Description
Modulation Scheme	FBMC-OQAM
Channel Model	Rayleigh fading channel
Antenna Configuration	2×2 , 4×4 , 8×8 , 16×16
Carrier Frequency	2.5 GHz
Noise	AWGN
SNR	-5:2.5:20 dB

III. RESULTS AND DISCUSSIONS

Fig. 6 shows the BER plot for the optimized and un-optimized (coded) massive MIMO scheme with FBMC-OQAM for 4 modulation order. It can be observed that the BER due to the optimized scheme is relatively lower than that due to the coded (un-optimized) scheme. Also, the BER reduces as the antenna configuration increases. The BER due to the 16×16 antenna configuration is relatively lower than that due to 8×8 , 4×4 and 2×2 respectively. Considering the 16×16 antenna configuration for both optimized and un-optimized schemes, under perfect CSI with SNR of 0 dB, there is significant reduction in the BER due to the optimized scheme. As the SNR increases beyond 0 dB, there is a large reduction in the BER. About 65% reduction was observed due to the optimized scheme for the 16×16 antenna configuration. It is pertinent to mention that the large reduction in the BER occurs mostly with the large antenna configuration (that is, 16×16).

In Fig. 7, the BER plot for the optimized and un-optimized (coded) massive MIMO scheme with FBMC-OQAM for 16 modulation order is presented. In line with the results presented in Fig. 6, the BER also reduces as the antenna configuration increases. Also, for all the antenna configuration, the BER due to the optimized scheme is relatively lower compared to that of the coded (un-optimized) scheme.

Fig. 6. BER plot for massive MIMO with FBMC-OQAM for 4 modulation order.

Fig. 7. BER plot for massive MIMO with FBMC-OQAM for 16 modulation order.

When the modulation order was increased to 64, the results obtained is illustrated in Fig. 8. As may be observed, the BER due to the optimized scheme is relatively lower than that due to the coded or un-optimized scheme. In line with Fig. 6 and Fig. 7, the 16×16 antenna configuration has the least BER value for both the optimized and un-optimized scheme. It is observed that for the optimized scheme, almost 20 dB SNR is required to achieve error performance close to 10^{-4} . However, for un-optimized scheme, under the same SNR value, an error performance of about 10^{-3} was only achieved. This has proved that the optimized massive MIMO scheme has a good performance in terms of the BER.

Fig. 8. BER plot for massive MIMO with FBMC for 64 modulation order.

A general observation is that as the modulation order increases, there is a rise in the BER values for both optimized and un-optimized (coded) scheme, though that due to the optimized scheme is relatively lower. It is safe to say that the BER performance degrades for higher modulation order.

IV. CONCLUSION

Massive MIMO scheme allows the improvements in the system capacity without additional bandwidth or transmit power by using a huge antenna array at the BS. However, under an imperfect channel estimate, the BER performance of such scheme is greatly affected. In this paper, the BER performance of a massive MIMO scheme is improved using genetic algorithm-based optimization. Simulation results shows a significant improvement in the BER of the optimized massive MIMO compared to the normal (coded) MIMO scheme. The overall results show that the optimized massive MIMO experience a reduced BER when compared to un-optimized massive MIMO. In both cases, the BER reduces gradually as the number of antennas increases. A general observation is that as the modulation order increases, there is a rise in the BER values for both optimized and un-optimized (coded) scheme, though that due to the optimized scheme is relatively lower. It is safe to say that the BER performance degrades for higher modulation order. The research studies presented in this paper has shown that optimized higher antenna configuration coupled with FBMC-OQAM could provide a better solution for a reduced error.

CONFLICT OF INTEREST

Authors declare that they do not have any conflict of interest.

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