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# Impact on Capacity Bounds under Higher Order Hardware Impairments for MIMO Configurations: Novel Approaches

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**ABSTRACT: The massive dimension antenna arrays can lead to enhancement in the capacity and spectral efficiency of the mobile cellular networks. The major challenge of massive MIMO design is degradation in capacity bounds in the presence of hardware impairments caused due to distortion noise and non linear devices. Thus, system must be designed for the worst case of impairments loses. This paper considers the massive MIMO device for the transmission and reception of the individual data. Initially paper contribute to address major problem and challenges of large MIMO designing, which can reduce correlations between transmitting channels with increasing the antenna dimensions. Thus, this paper contributed to evaluate the performance of such Massive MIMO transceiver under the exposure of higher degree of the hardware impairments with different level of the signal to noise ratio (SNR). Paper also addressed number of reasons of hardware impairments in the massive MIMO system. The channel capacity bounds are examined against the N individual antennas to compare the system performance. The paper assume LMMSE channel estimation model for cellular mobile network to model up link and down link. As another contribution, performance of MIMO configurations are evaluated for distinctive degree of higher Kappa values for hardware impairments of every individual antenna. Finally the degree of overall performance degradation under worst case of hardware is evaluated for capability bounds. Higher performance loss is noted under the higher impairments level of the MIMO system model. But the capacity performance is increased by around the 4 times towards the optimum with the proposed massive MIMO structure with N=64.**

**Keywords:** Cellular Network, Channel Capacity, Channel Estimation, Spectral Efficiency, Energy Efficiency, Hardware Impairments, Kappa values, Massive MIMO.

## I. INTRODUCTION

The theoretical channel capacity bound is the finding out factor of the spectral efficiency (SE) of a wireless link [1], which relies only on the performance of Signal to Noise Ratio (SNR) of the system and its energy efficiency (EE) [2]. The efficiency is also proportional to the environmental prerequisites and spatial correlation of the Wireless propagation links between mobile stations (MS) and the base stations (BS) [1]. Another foremost contributing aspect for the increased power efficiency is the accuracy of the channel estimation algorithms. As the channel estimation is responsible for modeling the proper propagation scenario, it may be multi path or point to point. Improvement in the trans-receiver structure, signal processing performance and methodologies may additionally affects the energy efficiency of the mobile networks [3, 7, 10]. Nowadays, significant growth have taken place in the antenna applied sciences, in order to improve spectral efficiency and additionally to hold the higher channel capacities [4-6]. In this paper, various challenges of maintaining energy and spectral efficiency along with capacity of the massive MIMO antennas are considered under impairments. The performance of the spectral efficiency is evaluated for standard and normalized channel models considering the different level of impairments level.

The basic concept behind design of wireless MIMO systems is to process the space - time signals. In this, time dimension of digital signal or data is complemented with the other dimension i.e. spatial dimension which is possible because of multiple spatially distributed antennas located at different distant points. Therefore, logically MIMO is an extension of the smart antennas that have been used for many years to improve the Wireless communication system performance. MIMO antenna configuration is setup between the wireless transmitter and a receiver. This permits signal to travel through many paths. In addition, if the spatial position of antenna may move by even a small distance, the transmission paths change. This enhances the overall capacity and security of the signal transmission between the trans-receivers. In the Massive MIMO the array size of paths is significantly increased which causes number of objects to appear in the paths between the transmitter to receiver.This is an extension of the existing MIMO structures by grouping the antennas together at the base station (BS's) and user equipments (UE's) for enhancing channel capacity of the wireless communication systems. Numbers of $\mathrm{BS}$ antennas $(\mathrm{M})$ in massive MIMO are in huge numbers. Some key benefits of using massive MIMO studied in this section are:

— **Larger Capacity:** as the number of antennas at the BS and the UE, given by $(M, N)$, increases then the overall rank of the channel matrix $HH^H$ will increase that indicating the better capacity.

— **Larger Antenna Array Gain:** With the increase in the number of antennas closely situated at BS, the diversity gain or gain of array of the system is increased due to space time diversity arrangements. Consequently, effects of array gain in massive MIMO are more significant compared to conventional MIMO systems. This may increase the transmission or coverage range.

— **Sharp Beam-Forming:** A Massive MIMO antenna array is capable of forming the sharp beams adaptively. This is possible by adjusting the phases of radio frequency signals of each antenna element of the array. The multiple beams can be formed or achieved using the number of antennas and combining methods of beam forming as shown in the Fig. 1 (a) for massive MIMO antenna array. It can be observed that the vertical and horizontal beams are different. Usually by varying the phase multiple beams are formed to communicate to multiple users in the network. The basic structure of the antenna unit installed at the BS in Massive MIMO is as shown in the Fig. 1 (b). It can be observed that there are bidirectional multiplexed paths between the BS and UE. As structures of the antennas used for massive MIMO system are huge, therefore, they are slightly more expensive and bulkier to install. It is worth here to mention that the power and the modulation techniques used at the up-link and down-link for any communication between BS and the UE are different. At the up-link low power and efficient MSK modulation is used and at the down-link relatively higher power M-FSK may be used. The dimensions of the antenna also depend on the size of the transmitter and receiver structures. Thus at BS huge antenna size may be used but at UE it is not possible at present due to small size of UE, but in future it may improve with on chip integrated antennas.

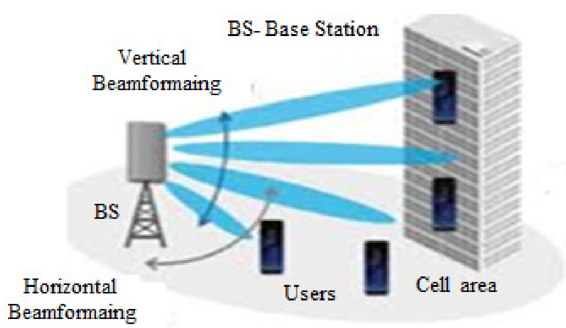



**Fig. 1** (a) Beam forming concept of the Massive MIMO.

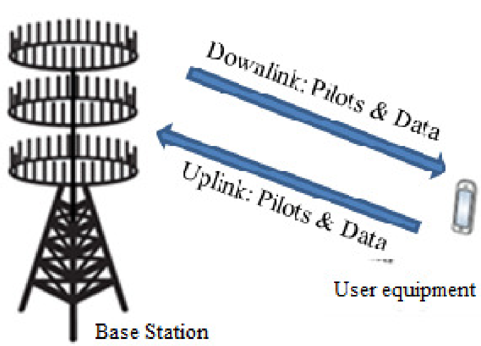
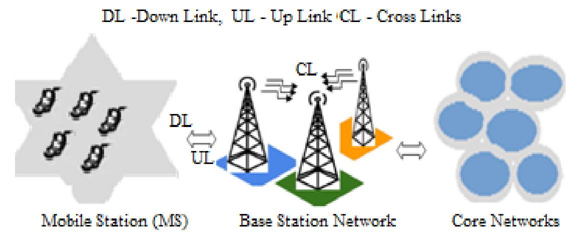



**Fig. 1** (b) Links and Massive MIMO tower antenna unit at BS.

The wireless system must be designed to consume minimum power. The Fig. 2 shows the power consumption by network at different parts. It can be observed from the Fig. 2, that the consumption of power over mobile network at Uplink (UL), Downlink (DL) and Cross link between MS and UE reaches to the level of Giga Watts. This consumption is directly proportional to the number of users and is therefore expected to increase in the near future. This is great motivation factor to minimize the energy utilization. The Massive MIMO systems are designed in such a manner that it improves the overall $EE$ of the cellular networks.




$P_{MS} = 0.7GW \qquad P_{BSN} = 10GW \qquad P_{CoreN} = 0.1GW$

**Fig. 2.** Basic minimum power comparison and connectivity of the cellular network [14].

## II. REASONS FOR HARDWARE IMPAIRMENTS

The major challenge before communication technologist is to serve the extra demand over the limited bandwidth. To serve the purpose massive MIMO with huge size of channel matrix is used frequently. Due to large setup it is essential to use low cost small hardware devices for implementation. Hardware Impairments terminology represents all reasons of losses introduced due to presence of non-ideal hardware during the design of Massive MIMO system. The major and most important factors contributing to the hardware impairments are:

— **Phase Noise:** This noise is major factor which causes frequency offset between hardware's of the MIMO transmitter and receivers. Phase noise is most essential and important factor for the designing of the oscillator due to the reason that it may create the disturbance in harmonica balance. Presence of phase noise can distort the signal data and hence reduces the efficiency of the channel estimation. Thus this factor is to take care in early designing to minimize the phase noise.

— **Non-Linear Power Amplifiers:** the nonlinear characteristic of the high power amplifiers in the MIMO system may cause distortion in digitally transmitted data and requires more power for transmission. This reduces the energy efficiency (EE) of the Massive MIMO systems.

— **Analog-to-Digital Converter (ADC) Resolution:** It requires the higher ADC resolution of 10 to 12 bits of ADC due to huge channel array size. Thus any kind of quantization noise in the ADC process may leads to error and affects spectral efficiency.

— **I-Q imbalance**: this is the hardware error produced in the massive MIMO systems using the Quadrature modulations via QAM or QPSK. Since these techniques are having In-phase (I) and Quadrature phase (Q) components. The imbalance between I and Q channels may leads to serious hardware impairments.

## III. PAPER CONTRIBUTION

There are two major contributions of the current paper to understand the impact of the hardware impairment over massive MIMO performance:

(i) The impacts of MIMO antennas configurations under hardware impairments for the Massive MIMO are evaluated to assess capacity bounds.

(ii) Examined the impact of various degrees of impairments on channel capacity performance with respect to size $N$ of massive MIMO system.

In the remaining part of this paper: initial review of the existing work done in the field of massive MIMO system presented in section IV. The major benefits of using MIMO system are explained in section V. The modelling of the channel and capacity bounds for MIMO configurations is explained in the section VI. Calculation of the capacity at lower bound is presented. The hardware impairment transceiver structure is shown in section VII, followed by results and conclusion. The impact of changing the degree of impairment is evaluated on capacity bounds.

## IV. REVIEW OF WORK

Many researchers have worked for improving energy efficiency (EE) of present mobile cellular network. This section reviews various previous works implemented on massive MIMO under the presence of hardware impairment.

X. Zhang, S. Wu *et al.*, [1] represents the study focusing on Spectral-Efficiency (SE) in a massive MIMO wireless cellular network considering pilot contamination. They considered a downlink pre-coder for minimizing error in signal detection and leakage of power with spatial correlation consideration has been derived for low complexity. They have proposed an estimation technique in which covariance matrix is used. They have demonstrated that growing number of antennas may leads to small number of the pilot symbols.

Anuj Singal *et al.*, [2], have analyzed the antenna selection technique in Massive MIMO system with OFDM in which the schemes such as antenna selection for per subcarrier and selection of the bulk antenna were used under the presence of hardware impairments. An equation was derived for EE by using antenna selection under hardware impairment. Hence it has been stated that EE is 75% greater with lower circuit power values. They observed that the EE decreases amount of hardware impairments increases.

Emil Bjornson *et al.,* [3] have proposed to evaluate the capacity and accuracy of massive MIMO channel estimation system under the lossy (non-ideal) transceiver hardware's. Each antenna is modeled with hardware impairment for analyzing the capacity performance with new system model. They have demonstrated that massive MIMO System can achieve higher transmission gain, SE and EE relatively. They have mathematically modeled and derived the various theorems considering the Massive MIMO model under the hardware impairment. They have demonstrated that the capacity is degraded with loss or impairments in the system.

A He, L. Wang *et al.*, [4] they represented the account of power control in uplink for the D2D under-lay MIMO large mobile networks. They have demonstrated a well-mannered approach of providing the correct area SE expression for user of the cell or D2D transmitter. Expression They derived expression for evaluating the EE. They additionally represented the numerical results for their suggested power control design to verify the efficiency.

P. Patcharamaneepakorn *et al.,* [5] validated a simple spatial domain modulation method for multi cells and users massive MIMO system to achieve higher promising throughout. They analyzed the probability of antenna combination detection and used it for approximating overall performance of sum-rates. They have additionally analyzed overall performance of economic efficiency in terms of the economic profitably measures.

N. P. Le, *et al.*, [6] has completed the energy efficiency analysis with PAPR reduction in MIMO OFDM system.

X. Lin. *et al.*, [7] has studied SE of the perfect and imperfect CSI for D2D under-laid MIMO massive system. They verified that massive MIMO handles D2D cellular interference efficiently.

E. Bjornson *et al.*, [8] have studied the effect of hardware impairments effect in MISO for capacity limit. They also studied the interplay in massive MIMO and underpaid D2D network in a multi-cell setting. They also investigate under both, perfect and imperfect channels state information at the receiver.

Parish *et al.*, [9] have analyzed the impact of the hardware impairments over the capacity bounds of the various MIMO antenna configurations. They have restricted the work for the small impairments and stick to MIMO system only. They showed that the presence of the impairments may reduce the performance of MIMO system in terms of capability bounds.

Z. Fang, *et al.*, [10] analyzed the application of massive MIMO on spectral efficiency in Full Duplex Two Way Relay Networks. It was demonstrated that massive MIMO is capable to suppress self loop interference and small scale fading, thus improves the spectral efficiency of Full Duplex Two Way Relay Networks.

M. M. Badr *et al.*, [11] presented massive MIMO system as promising research to be implemented for (5G) cellular network for its extended capacity, improved throughput and spectral efficiency.

Xinlin *et al.*, [12] have presented study of MIMO capacity bounds. While in [13-16] the various wireless MIMO systems are presented.

Amjad *et al.*, [18] have analyzed MIMO capacity evaluation. Chirag et al [19] have presented the capacity comparison for various MIMO antenna configurations. [20-22] has given different MIMO antenna design methodologies.

Vijay *et al.*, [21] presented the review of MIMO-OFDM for the OFDM performance.

The summary of review work is given in Table 1 for impairments consideration.

**Table 1: Summary of the review ff related work on MIMO.**

| S. No. | Authors | Methodology | Descriptions |
|---|---|---|---|
| 1. | X. Zhang *et al.*, [1] | Study of spectral efficiency of the massive MIMO system under pilot contamination. | Demonstrated that increasing the number of antennas may relatively leads to small number of the pilot symbols. |
| 2. | Anuj Singal *et al.*, [2] | Investigated EE of the Massive MIMO-OFDM system with antenna selection in bulk | Observed that the EE is 75% more with the low circuit power. |
| 3. | Emil Bjornson *et al.*, [3] | Have assessed the capacity of Massive MIMO system under hardware impairments. | Inferred that capacity bound for massive MIMO degrades under hardware impairments considering Kappa value of 0.05. |
| 4. | Paresh *et al.*, [8]. | Investigation of the channel capacity of the massive MIMO system under hardware impairments. | Concluded reduction in the capacity under hardware impairments. Work was limited to MIMO and to the small amount of the impairments. |
| 5. | Our approach | Evaluating impact of the capacity bounds considering higher order impairments | Capacity bounds of Massive MIMO systems are evaluated under introduced higher hardware impairments with Kappa values of 0.1 and 0.15. |

## V. ADVANTAGES OF MIMO

The prime reasons of to work on massive MIMO are:
— Higher spectral efficiency due to better multiplexing and array gains.
— The radiated energy is more concentrated on UE's thus have more energy efficiency.
— Due to huge number of antennas the diversity gain is more thus is more reliable.
— Interference is low due to orthogonal UE's.
Therefore, this paper evaluates the performance under large antenna range and large range of hardware impairments in the massive MIMO transceiver hardware system.

## VI. CAPACIY IN MIMO CONFIGURATIONS

Based on number of the antennas utilized at transmitting and receiving end different MIMO configurations are available. The comparison of various popular MIMO antenna configurations is shown in the Fig. 3 Where Tx and Rx represents the transmitter and receiver blocks.

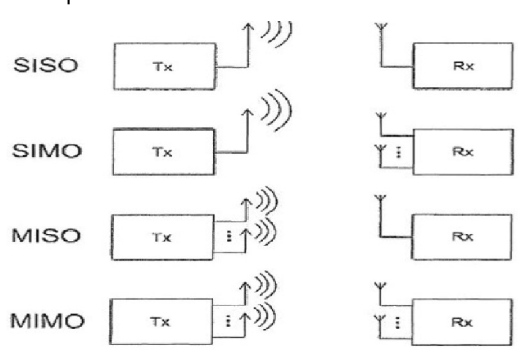



**Fig. 3.** The Basic Configuration of MIMO Systems.

These MIMO antenna configurations are abbreviated as;
1. SISO: Single Input Single Output
2. SIMO: Single Input Multiple Output
3. MISO: Multiple Input Single Output
4. MIMO.: Multiple Input Multiple Output.

In order to understand the effect of the hardware impairments over all MIMO configurations it is required to mathematically model the MIMO channel capacity mathematically. The common channel between the transmitter and receiver is modelled as the

$$\boldsymbol{y_n} = \boldsymbol{x_n} * \boldsymbol{h_n} + \boldsymbol{n} \qquad (1\text{ a})$$

Where $y$ is the output Chanel response, $x_n$ is the input response for nth sample. The $h_n$ is the random channel response matrix of the size $\boldsymbol{mxn}$ and is given as;

$$h = \begin{bmatrix} \boldsymbol{h_{11}} & \cdots & \boldsymbol{h_{1m}} \\ \vdots & \vdots & \vdots \\ \boldsymbol{h_{n1}} & \cdots & \boldsymbol{h_{nm}} \end{bmatrix} \qquad (1.b)$$

The channel state information CSI between Tx//Rx is estimated randomly in this paper for all these configurations as

$$hSISO = \frac{randn + j * randn}{sqrt(2)}; \qquad (2)$$

$$hSIMO = \frac{randn(mR,1) + j * randn(mR,1)}{sqrt(2)}; \qquad (3)$$

$$hMISO = (randn(1,mT) + j * randn(1,mT))/sqrt(2); \qquad (4)$$

$$hMIMO = \frac{randn(mR,mT) + j * randn(mR,mT)}{sqrt(2)}; \qquad (5)$$

It can be deduced from these equations that as the complexity of MIMO system increase as the size of Multi path components increases. Therefore probability of the hardware impairments can be more severe.

## VII. TRANSCEIVER HARDWARE IMPAIRMENTS

Radio transmitters and digital equipments are non linear devices which causes various kinds of distortion along with ideal transmitted signal. The majority of researchers consider ideal trans-receiver hardware for modelling massive MIMO system. However, practical transceivers suffer from various degrees of hardware impairments that
— Create a mismatch between the desired transmit signal and what is generated and emitted;
— Distort the received signal during the process of reception.
The basic channel model for the MIMO architecture is shown in the Fig. 4. It can be observed from the figure that the hardware impairments are introduced in the system at the transmitting well as at receiving antennas end. The non-linearity of modulation amplifiers may also cause the impairment loses. As an assumption, it is assumed that the same impairments are introduced at transmitter and receiver of the system. In this paper, we analyse how these various degrees of impairments impact the performance of massive MIMO systems and their key asymptotic properties. Physically transceiver consists of many different hardware components

implementations (e.g., amplifiers, mixers, converters, oscillators and filters [20]) and each one distorts the signals in its own way.

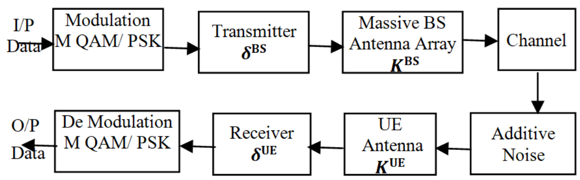



**Fig. 4.** Basic channel model and system of cellular LTE with hardware impairments.

The hardware impairments in the MIMO systems are unavoidable and level of such impairments highly depends on design decisions. Hardware impairments introduced due to compromise between larger introduced distortions and low hardware cost and minimum power consumption [7]. It can be observed from the Fig. 4 that most of impairments is introduced across the Transceiver and Antenna channel coupling mismatch and is represented by the Kappa values $K^{\mathrm{BS}}$ and $K^{\mathrm{UE}}$ at the BS and the UE. The paper is based on evaluating the capacity bounds under different level of Kappa values. The eq. (1) can be remodeled in the presence of impairments considering the Fig. 4 as;

$$\boldsymbol{y_n = x_n K^{\mathrm{BS}} h_n + h_n \delta^{\mathrm{BS}} + K^{\mathrm{UE}} + \delta^{\mathrm{UE}} + \mathrm{n}} \quad (6)$$

It is clear that more the impairments level more is the kappa values. Major cause of these values are loses in hardware of transmitter and receiver blocks. Where $\delta^{\mathrm{UE}}$ and $\delta^{\mathrm{BS}}$ are distortion noises.

## VIII. RESULTS AND EXPERIMENTAL ANALYSIS

In this paper it is aimed to calculate and evaluate the capacity bounds $C$ of the MIMO system. Various experiments are done via MATLAB simulation for performance evaluation. According to the Shannon the channel capacity for any random channel matrix $h$ is defined as the;

$$\boldsymbol{C_h = log_2\left(1 + \frac{S}{N_h}\right)} \quad (7)$$

where $C$ is the capacity, $S$ is signal strength and $N_h$ is noise in channel. Capacity of wireless channel is the measure of the average information transferred from Tx to Rx. Paper aims to evaluate the impact of hardware impairments on the channel capacity bounds but for Massive MIMO with large antenna sizes. The input parameters and ranges used for the experiment are shown in the Table 2.

**Table 2: Input simulation parameters**

| S.No. | Parameter | Range |
|---|---|---|
| 1. | Nt and Nr Number of Transmitting and receiving antennas | For all experiment varies from 4x4, 16x16 and 64x64 |
| 2. | $K^{\mathrm{BS}}$ and $K^{\mathrm{UE}}$ Kapa values | [ 0.05, 0.1, 0.15 ] |
| 3. | ITER Monte Carlo iterations | 1000 |
| 4. | SNR in dB | [0:25] |
| 5. | Channel State Information matrix. H | Relaying channel Multi path |

The size of the channel matrix is higher as the goal of the paper is to evaluate for Massive MIMO system. Till now 64 × 64 MIMO is tested practically, although it may improve in future. Initially paper validates the basic channel capacity for the Idle MIMO configurations for the basic channel size of 4 × 4. Then in further sections the effect of hardware impairments on different Massive MIMO sizes are evaluated.

**Experiment 1: Evaluating Capacity of Idle antenna Configurations Under hardware impairments.**

In this experiment the basic MIMO systems are validated for the four Idle MIMO antenna configurations. Under the idle condition channel is modelled randomly without any hardware impairments. The channel capacity of the wireless system for the different MIMO antenna configurations extending the eq. (6) are given in the equations below.

$$CSISO(K) = CSISO(K) + log2(1 + SNR(K) * norm(hSISO)^2); \quad (8)$$

$$CSIMO(K) = CSIMO(K) + log2(1 + SNR(K) * norm(hSIMO)^2); \quad (9)$$

$$CMISO\ (K) = CMISO\ (K) + log2\left(1 + SNR * \frac{norm(hMISO)^2}{mT}\right); \quad (10)$$

$$CMIMO(K) = CMIMO(K) + log2\left(abs\left(det\left(eye(mR) + SNR(K) * hMIMO * \frac{hMIMO'}{mT}\right)\right)\right) \quad (11)$$

The presentation of the limit of capacity at the MIMO reviver is given in the Fig. 5. The direct limit is determined in the Bits/Hz and plotted against the SNR measured in decibel (dB). It can be seen from the below Fig. 5 that MIMO offers significantly higher capacity compared to other configuration contrasted with different arrangements. The channel size was kept fixed to 4 × 4 in this examination.

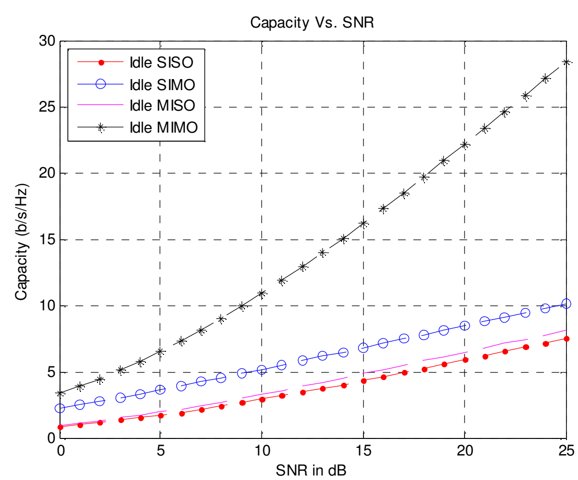



**Fig. 5.** Capacity bounds for idle hardware without Impairments, appraised performance over [18] for channel capacity of antenna configurations i. e. SISO, MISO, SIMO and MIMO with simple 4 × 4 sizes as a function of SNR in dB [19].

**Experiment 2: Impairments level effect on capacity of various antenna Configurations.**

In this experiment the effects of higher order hardware impairments over the capacity of vasrious antenna configurations are evaluated.

$$CSISO(K) = CSISO(K) + log2(1 + SNR(K) * KapaBS * norm(hSISO)^\wedge 2 + SNR(K) * KapaUE * norm(hSISO)^\wedge 2\,) \quad (12)$$

$$CSIMO(K) = CSIMO(K) + log2\big(1 + NR(K) * KapaBS * norm(hSIMO)^2 + log2(1 + SNR(K) * KapaUE * norm(hSIMO)^2)\big) \quad (13)$$

$$CMISO(K) = CMISO(K) + log2(1 + SNR(K) * KapaBS * \frac{norm(hMISO)^2}{mT} + SNR(K) * KapaUE * norm(hMISO)^\wedge 2/mT) \quad (14)$$

$$CMIMO(K) = CMIMO(K) + log2(abs(det(eye(mR) + SNR(K) * KapaBS * \frac{hMIMO * hMIMO'}{mT} + SNR(K) * KapaUE * \frac{hMIMO * hMIMO'}{mT}))) \quad (15)$$

The impairments level is raised by kappa values extending from 0.05 to 0.15 considered as impairments 5 to 15 % impairments lose. MIMO system Channel capacities are mathematically modelled for the antenna configurations considering the hardware impairments [18, 19] as given in the equations. Although these capacity equations are normalizes before plotting for Monte Carlo iterations

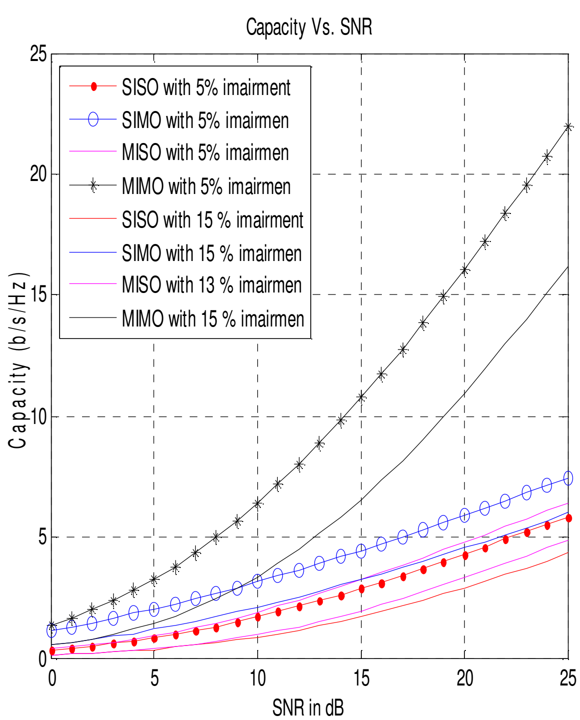



**Fig. 6.** Impact of higher order Impairments on channel capacity bounds for the non-idle hardware for impairments level of Kappa values of 0.05 and 0.15 respectively for 25 dB SNR [improvement over 18].

**Experiment 3: Massive MIMO Capacity under Different MIMO sizes.**

In this experiment the size of the MIMO is varied for evaluating the capacity performance of MIMO systems but under the worst case of impairments with fixed Kappa=0.15 at BS and UE. The Massive MIMO capacity performance is validated with the Idle MIMO ability for $N = 64 \times 64$. Under the idle condition channel is modeled without any hardware impairments. It can be discovered from the Fig. 7 that channel capacity will increase with dimension of MIMO, but there is a more effect of hardware impairments for Massive MIMO at higher sizes i.e. on 64 × 64.

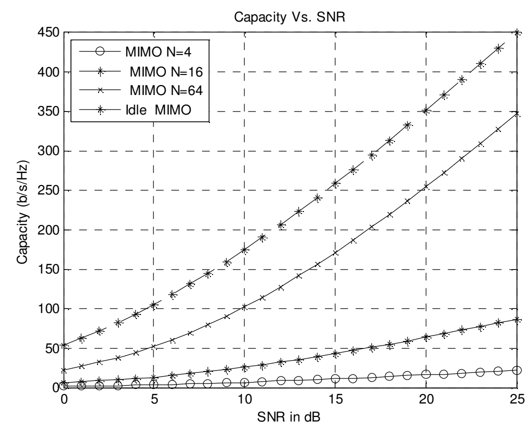



**Fig. 7.** The Channel Capacity bounds with worst case of Hardware impairments of Kappa=0.15 at the BS and UE with variable channel matrix size of 4, 16, and 64 at both side.

It can also observe from Fig. 7 that the Capacity degrades drastically from 450 to 350 for the 64x64 antenna size under this experiment.

## IX. CONCLUSIONS

In this paper, the impacts of different level of hardware impairments over the wireless communication systems are evaluated. Improving the capacity bounds and efficiency of the cellular networks is a challenging field of research. This paper is focused to simulate and evaluating the performance of massive MIMO transceiver under the presence of higher degree of hardware impairments. The capacity bound with respect to different order of the signal to noise ratios (SNR) is plotted for the different MIMO configurations. Paper also describes different causes of the hardware impairments that Massive MIMO system can have. Paper simulates the capacity bounds performance for the large size of Massive MIMO with 16 × 16 and 64 × 64 systems. As an experiment the impact of hardware impairments with the various massive MIMO size is evaluated for higher order impairments for the worst case of Kappa values of 0.15. Our experimental results suggest that in experiment one MIMO offers significantly higher capacity compared to other configurations. The channel size was kept fixed to 4 × 4 in this experiment. This experiment was to validate the MIMO communication capacity model.

In experiment two the impact of higher hardware impairments on MIMO configurations with Kappa values of 0.05 and 0.15 are evaluated for channel capacity bounds under the non-idle hardware for 25 dB SNR. It is found that for MIMO the significant reduction in capacity bound of around 6 dB at 25 dB SNR is observed in case of 15% impairments compared to 5% impairments. In the experiment 3 impact of the higher order hardware impairments over the channel capacity bounds under the worst case of Kappa=0.15 are evaluated for the Massive MIMO system.

The Massive MIMO system is modelled by considering the impairments at BS and UE with variable channel matrix size of 4, 16 and 64 at both side..As the size 16 × 16 and 64 × 64 are representing the Massive MIMO system. It is concluded that although channel capacity increases with size of MIMO but on the other side there are more effect of hardware impairments for Massive MIMO at higher sizes as on 64x64, it is calculated that the efficiency of capacity bounds at 64x64 massive MIMO for kappa value of 15% is reduced to around 350/450=77.7 % while at 4 × 4 MIMO the capacity efficiency reduces to around 16/28=57.14%. Thus over all paper concluded that as the size of massive MIMO increases then the performance is degraded due to the hardware impairments. Hence, it is better to limit the impairments for even better performance.

## X. FUTURE SCOPE

Energy Efficiency, Spectral Efficiency may further be computed considering the power scaling law with Kappa values. Capacity bound for higher order of impairments i.e. increasing Kappa Values may also be evaluated for two way relaying.

**Conflict of Interest.** The authors, hereby, declare that they do not have known competing financial interests and also do not have any personal relationship which could have appeared to influence the work reported in this paper.

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