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Effect of Non-ideal behavior of transceiverhardware on massive MIMO system

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***Abstract*—An aim of this paper is to study the Massive MIMO technology under transceiver hardware impairments and its effect on the system's performance. As we know that in a massive MIMO system, multiple antennas are used at the transmitting and receiving side and hence generates the need of using low cost and power efficient hardware devices in order to make this technology economical and widely accepted. But the usage of inexpensive hardware devices lead to the generation of hardware impairments due to the non-ideal behavior of the hardware devices which result in the inaccurate estimation of the channel response and degrade the overall system's performance. In this paper, we have used MATLAB software tool to study the effect of hardware impairments on the performance of the massive MIMO system.**

***Index Terms*—Capacity, LMMSE, Massive MIMO, Spatial multiplexing, Transceiver hardware impairments, Time division duplexing.**

I. INTRODUCTION

The present wireless communication system is facing many challenges like spectrum scarcity, multipath fading, increased data traffic etc. which has generated a need for such a technology which can help in mitigating these problems. Massive MIMO technology seems to be a solution to combat these problems as it can not only provide higher data rate and strong reliability compared to existing technologies but also appears to be a key technology in the future wireless communication system like 5G. Massive MIMO system is also known as Hyper MIMO or Large scale antenna system due to the use of hundreds or thousands of antennas which are arranged in uniform array distribution. The reason behind Massive MIMO technology gaining so much attention is that it can boost the performance metrics of the wireless communication system like capacity, energy efficiency etc. to manifolds. But Massive MIMO technology seems to be having some drawbacks as well because not much research has been done in this field. As we know that in Massive MIMO technology, hundreds or thousands of antennas are used, so to make it economical there is a need of using low cost and less power consuming hardware devices but it resultsin the distortion and noise in the signal and thus, have a negative impact on the overall performance of the system.

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II. CHALLENGESTOMASSIVEMIMOTECHNOLOGY

- Need of power efficient and medium cost hardware devices which produce minimum hardware impairments.
- Accurate estimation of the channel state information is still a difficult task to attain.
- The signal processing complexity which makes it difficult to accurately diagnose the faults and problems in the hardware circuitry.
- Development of more efficient and effective technique for reducing interference due to pilot contamination.
- Need of feasible and less complex compensation algorithms for minimizing hardware impairments.

III. BENEFITSOFMASSIVEMIMOTECHNOLOGY

- Increases the system's capacity, energy efficiency and provides higher data rates and a reliable communication and hence, can be an effective solution of problems like call drop.
- Provides more coverage area and increased range as a larger area can be served due to high antenna gain and transmitting directivity.
- Reduces the losses which occur due to multipath fading effectively.
- Will act as a basis for the emerging wireless technologies like 5G.

IV. PROBLEMFORMULATION

Massive MIMO technology has numerous benefits over the existing technologies and is being considered to play a great role in the development of the future technologies. As we already discussed that in Massive MIMO systems, multiple antennas are used both at the transmitting and receiving side. So, in order to make this technology economically profitable and widely accepted, there is a need of using low cost, compact and less power consuming hardware devices. But the usage of inexpensive hardware devices result in impairments because low cost hardware devices are prone to many errors like quantization errors during analog to digital conversions,non-linearity in power

amplifiers, phase noise etc. which damages the signal accordingly and thus, degrade the overall performance of the system. In this paper, we will study the overall impact of hardware impairments on the performance of the Massive MIMO system.

V. WorkingOfMassiveMIMOSystem

Massive MIMO technology is a multi-user system where large number of users are served at the same frequency and same time by the hundreds or thousands of antennas installed at the transmitting base station and at the receiving user end terminal. Instead of using FDD, it uses time division duplexing mode (TDD) because of the channel reciprocity property in which the channel state information obtained for the uplink can also be used for the downlink as both uplink and downlink uses the same carrier frequency. The diagram [2] representing its working is depicted as –

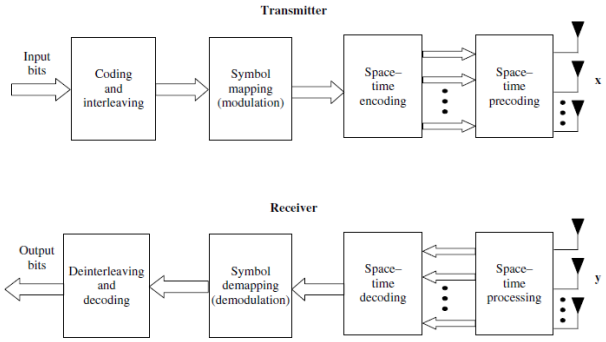

Fig. 1 Block diag. representation of the Massive MIMO System

In it, the technique of spatial multiplexing is used where data streams of high bit rate are divided into multiple data sequences of lower bit rate and are then transmitted by multiple antennas from the transmitting base station to the receiving user end terminals. This transmission takes place at the same time and at the same frequency band and thus gives a high spectral efficiency. At the receiving side, the individual data bit streams, which got mixed while travelling in the wireless channel at the same frequency band, are detected and combined to form the original transmitted signal of higher data rate.

VI. SystemModel

To study the impact of the transceiver hardware impairments on the performance of the massive MIMO system, a model is considered having M number of transmitting antennas at the base station and N number of receiving antennas at the user end terminal. Here, the overall impact of hardware impairments on the system is considered and it is assumed that the channel is following Rayleigh block fading structure where a channel remains constant for a particular period of time. The signal received in massive MIMO system under ideal hardware conditions [3] is shown as –

$$Y_d = \sqrt{\rho_d}\, X_d\, H + V_n \qquad (1)$$

where Y_d is the received data signal matrix of order $T * N$, H is the channel response matrix connecting M transmitting antennas to N receiving antennas, X is the transmitted signal matrix of order $T * M$ and V_n is the additive distortion noise added by the channel. Generally, in systems where few antennas are used it is considered that the system is working under ideal conditions. But in case of massive MIMO system

wherehundreds or thousands of antennas are used, the non-ideal hardware behavior cannot be ignored as the losses generated due to it degrade the system's performance severely. So, the actual signal obtained at receiver under non-ideal hardware behavior is as follows –

$$Y_d' = \sqrt{\rho_d}\, X_d\, \hat{H} + \underbrace{\sqrt{\rho_d}\, X_d\, \tilde{H} + V_n}_{V_d'} \qquad (2)$$

Here, the received data signal suffering from hardware impairments is depicted as Y_d', $\hat{H}$ is the estimate of the channel response, $\tilde{H}$ is the error occurred while estimating the channel response due to the time-varying nature of the channel and distortions caused by the transceiver hardware impairments in the transmitted signal which is equal to $\tilde{H} = H - \hat{H}$, where V_d' represents distortions in the received signal due to noise and errors generated due to transceiver hardware impairments in the transmitted signal and inaccurate channel estimation. From the above equation, it has been found that the accuracy in the estimation of the channel state information is also affected by the hardware impairments as estimation of the channel response depends on the transmitted signal. In other words, the original transmitted signal which is distorted by the hardware impairments result in the estimation of a channel response which is different from the actual one which should come and this way, not only the transmitted signal but the channel state information is affected by the hardware impairments. It can be seen in the channel estimate calculated by the Linear Minimum Mean Square Estimator [5] which is representedas-

$$\hat{H} = \sqrt{\frac{1}{\rho_d}} \left(\frac{1}{\rho_d} I_M + X_d^* X_d \right)^{-1} X_d^* Y_d \qquad (3)$$

We can clearly see that the estimate of the channel state information depends on both the transmitted and received data signal which suffer from the transceiver hardware impairments and gives an inaccurate estimation of the channel response. Now we will study the effect of the inaccurate channel response and distorted transmitted and received signal due to impairments on the capacity of the Massive MIMO system. We know that capacity of a system is defined as the maximum value of the mutual information between the transmitted and received signal given that the channel state information is known. So, the capacity of Massive MIMO system is as follows [5] –

$$C_\tau \geq E \frac{T - T_\tau}{T} \log\det \left(I_M + \rho_{eff} \frac{H H^*}{M} \right) \qquad (4)$$

Where $\rho_{eff}$is the effective signal to noise ratio, I_M is the identity matrix, T is the total time interval for which the

channel remains constant, T_t is the training time interval used for transmission of pilot or training signal. So from the aboveequation it is observed that the capacity of a Massive MIMO system is logarithmically proportional to the estimate of the Channel state information which means that a decrease in the accuracy of the channel estimate results in the decrement in the value of capacity of the Massive MIMO system as well.

VII. SIMULATIONRESULTS

In this section, MATLAB software tool is used to analyze the effect of transceiver hardware impairments on the capacity of the Massive MIMO system.

Case-1: M = 1 - 100, SNR = 18db, No. of BS antennas = 10

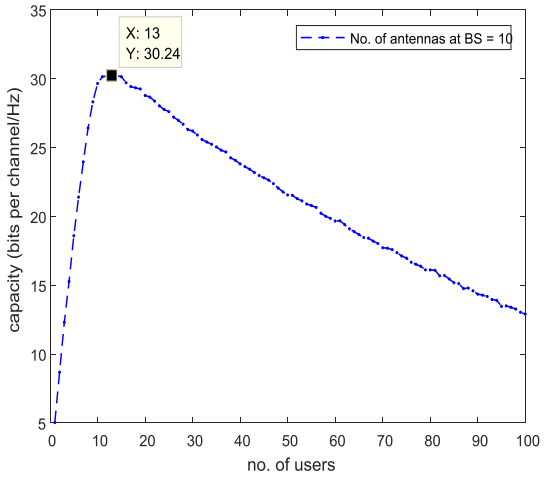

Fig. 2 - Capacity of MIMO system

Firstly, we have calculated the capacity of a MIMO system where the number of antennas taken at the base station are 10 and M represents the number of users varying from 1 to 100. From the above result, it is observed that the maximum capacity in a MIMO system is obtained at 30.24 decibel and the optimum number of users at that capacity are 13.

Case-2: M= 1 to 200, SNR= 18db, No. of BS antennas = 124

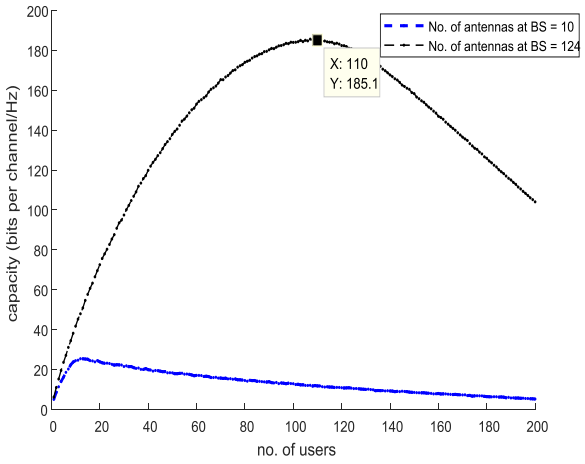

Fig. 3 – Comparative analysis of capacity in a Massive MIMO system and a MIMO system

In this case, the capacity of a massive MIMO system is calculated and compared with the capacity of a MIMO system which is obtained above. In the massive MIMO system, thenumber of antennas taken at the base station are 124 and M represents the number of users varying from 1 to 200.In this result, we found that the capacity of the massive MIMO system is 185.1 decibel for the optimum number of users equal to 110 at the user end terminal. It is quite evident from this result that capacity obtained in a massive MIMO system

is much larger than the capacity obtained in a MIMO system and also, a massive MIMO system provides services to a large number of users at the user end terminal.

Case-3: T = 300, Hardware impairment value = $(0.05)^2$

In this case, the impact of hardware impairments on the capacity of the massive MIMO system is observed. The value of SNR taken is equal to 18db, number of BS antennas are 124 and the number of users at user end are varying from 1 to 200. Here T represents the total time for which channel remains constant and is equal to 300 and the value of hardware impairments is taken as $(0.05)^2$ [6].

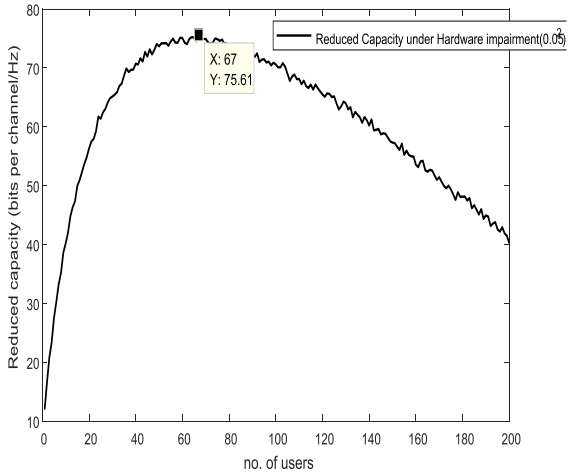

Fig. 4 - Effect of hardware impairment on the capacity of Massive MIMO System

From the above result, it is observed that capacity under hardware impairments effect reduces to 75.61 decibel which is nearly half of the capacity obtained under ideal conditions and also limits the number of users to 67. The above result shows that the hardware impairments not only degrade the capacity of the massive MIMO system but also limit the optimum number of users for using the services provided by massive MIMO system and hence results in degradation of the overall system's performance.

VIII. CONCLUSION

This paper has discussed the effects of transceiver hardware impairments on the capacity of the massive MIMO

system. We have found that hardware impairments generated due to the non-ideal behavior of the hardware devices not only distort the transmitted and received signal but gives inaccurate estimation of the channel response and thus, results in the degradation of the system's capacity. Also, it has been observed that hardware impairments at the user end terminal do more damage as compared to the impairments at the base station. So there is a need of using such hardware devices which are compact, inexpensive, power efficient and produce minimum hardware impairments. It is also noticed that despite having these limitations and complexities, massive MIMO technology seems to have a great potential in the development of the future wireless communication system. So more research needs to be done in this field in order to mitigate these problems and to exploit this technology for a better use.

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REFERENCES

[1] F. Rusek, D. Persson, B.K. Lau, E.G. Larsson, T. L. Marzetta, O. Edfors and F. Tufvesson, "Scaling up MIMO: Opprotunities and challenges with very large arrays,"IEEE Signal Process. Mag., 2012.

[2] X Zhu and R.D. Murch,"Layered space-frequency equalization in a single-carrier MIMO system for frequency-selective channels,"IEEE Transactions on Wireless, 2004 - ieeexplore.ieee.org

[3] U. Gustavsson, C. Sanchez-Perez, T. Eriksson, F. Athley, G. Durisi, P. Landin, K. Hausmair, C. Fager and L. Svensson,"On the impact of hardware impairments on massive MIMO," in Proc. IEEE GLOBECOM, 2014.

[4] L. Lu, G. Y. Li, A. L. Swindlehurst, A. Ashikhmin, and R. Zhang, " An Overview Of Massive MIMO: Benefits and Challenges," IEEE J. Sel. Topics signal process., vol. 8, no.5, pp. 742-758, 2014.

[5] B. Hassibi, B.M. Hochwald, "How much training is needed in multiple antenna wireless links"IEEETrans.Inf. Theory, vol.49, no.4, pp. 951-963, 2003.

[6] E. Bjornson, J. Hoydis, M. Kountouris and M. Debbah, "Massive MIMO Systems with Non-Ideal Hardware: Energy Efficiency, Estimation and Capacity Limits,"IEEE Trans. Inf. Theory, vol. 60, no. 11, pp. 7112 – 7139, 2014.

[7] E. G. Larsson, F. Tufvesson, O. Edfors, and T. L. Marzetta,"Massive MIMO for Next Generation Wireless Systems,"IEEECommun. Mag., vol. 52, no. 2, pp. 186-195, 2014.

[8] E. Bjornson, J.Hoydis, M. Kountouris and M. Debbah,"Hardware impairments in large-scale MISO systems: Energy efficiency, estimation and capacity limits", 2013.

[9] D. Aktas, M N Bacha, J S Evans, S V Hanly," Scaling results on the sum capacity of cellular networks with MIMO links,"IEEE Trans. Inf. Theory, vol.52, v no.7, pp. 3264-3274,2014.

[10] M. Biguesh, A. B. Gershman, "Training based MIMO Channel Estimation: A Study of Estimator Tradeoffs and Optimal Training Signals,"IEEETransactiona on signal processing, vol. 54, no. 3, 2006.

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