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Analysis of Precoding Algorithms and Pilot Contamination Problem for massive MIMO System- Review

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ABSTRACT: Massive MIMO has been designed to enhance the capacity, data rate, spectral efficiency and maximal energy efficiency as well system sensitivity towards propagation environment which meets demand of future wireless communication. Using an asymptotic argument of random matrix theory, linear signal processing can be used to achieve the optimal performance of the massive MIMO. So what are the optimal numbers of antennas, actives users, and power transmitted in system? Is the one fundamental question needed to be answered, in this work we shall describe the effect of these parameters using Ergodig achievable rate and energy efficiency. In practice channel state information CSI in each base station needs to be estimated accurately, either through feedback (FDD) or channel reciprocity (TDD) schemes to achieve the benefits of massive MIMO. The major problem that encounters the implementation of massive MIMO multi-cell TDD network system is called pilot contamination due to limitations of coherence time. In this paper, massive MIMO along with linear precoding algorithms and pilot contamination are described. The research work presented by the researcher on this topic has summarized which also includes source and possible solution to this problem.

KEYWORDS: Massive MIMO, pilot contamination linear precoding, channel state information (CSI), single-cell, multi-cell, erodig achievable rate, energy efficiency (EE).

I. INTRODUCTION

Massive MIMO is multi-user MIMO technology where each base station (BS) equipped with M active antennas elements and utilizes these to communicate with k single antenna terminals-over same time and same frequency band (1) also can be defined as $\frac{M}{K}$>> 1 constant. By coherent processing of the signals over the array antennas, downlink able to use transmit pre-coding.to focus each signal to its desired terminal and receive combing can be used in uplink to discriminate between signals sent from deferent terminals (1). The more concentration beam or fine spatial beam to the terminals is achieved by using more antenna elements in the system thus more spectral and energy efficiency can be obtained. As in (2) it is shown that single-antenna user in massive MIMO system can scale down its transmit power proportionally to the number of antennas at the BS with perfect channel state information (CSI) or to the square root of the number of BS antennas with imperfect CSI (3).

Massive MIMO is one most candidate system to use in 5G, actually there are many reasons behind one of these is ,cellular system generally deployed in urban area where many obstructions are there, thus system suffer from the propagation environment such as small scale fading and large-scale fading, fortunately, massive MIMO does not or less sensitive from the such problems. The authors in (1)has intensively investigated and made a comparison of the system behavior with i.i.d. Raleigh fading and line-of-sight (LOS) propagation; the authors had shown that the system gives very good performance under Raleigh fading channel. The second feature of massive MIMO as we mentioned above it is provide very high energy and spectral efficiency and high system capacity as well as inherit all advantages of MIMO (4). But the key aspect point of the massive MIMO is frequency operation rage that provides is exactly which required in 5G, this frequency can be designed according to antennas array configuration used, in the array system, the space between antenna elements should be $\lambda_{c/2}$, where the λ_c is wavelength of the intended frequency carrier f_c.larger

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spacing provide less correlated channel response over the antennas and thus more spatial diversity, so that smaller λ_c higher frequency carrier therefore it's possible to extend our system to operate in millimeter band thus many advantages retained along with added features (1). The other good advantage of massive MIMO taken from the a asymptotic arguments of random matrix theory (5) as number of antennas increase make possible to use simplelinear signal processing approaches, such as zero-forcing ZF, matched filter MF, maximum ratio combing MRC/MRT to achieve an optimal performance of massive MIMO , and then simplicity of the system.

In massive MIM communication scenario all users share same frequency at the same time thus interference between the terminals (multiuser interferences) will be suppressed (making diagonal elements zero) by simple linear pre-coding technique mentioned above, hence more users can be serve, it remains only one major problem faced massive MIMO is the pilot contamination issue which limits the system performance we discussed in section **IV**

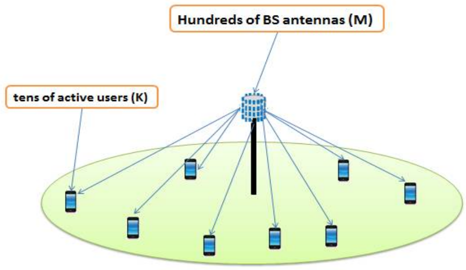

Figure 1: MU-MIMO System

II. RELATED WORK

In (1) ,this overview paper ,the authors had identified ten myths :they asked and answered : is it Massive MIMO only suitable for millimeter wave bands?, is Massive MIMO only works in rich-scattering environments ?, is it Massive MIMO performance can be achieved by open-loop beamforming techniques ?, is it Massive MIMO requires an order of magnitude more antennas than users ?, is it too much performance is lost by linear processing?, is it a new terminal cannot join the system since there is no initial array gain?, is it Massive MIMO requires high precision hardware? , is it the with so many antennas, resource allocation and power control is hugely complicated?, is it with so many antennas, the signal processing complexity will be overwhelming?. Practically they have made simulation using ZF, and MF to test the Comparison of system behaviour under i.i.d. Rayleigh fading respectively line-of-sight propagation. They have found that massive MIMO less sensitive to Rayleigh fading. In (2), this paper, authors had investigated the Ergodic sum rate and required transmit power of a single-cell massive multiple-input multiple-output (MIMO) downlink system. The system considered in this paper is based on two linear beam-forming schemes, that is, maximum ratio transmission (MRT) beam-forming and zero-forcing (ZF) beam-forming. Moreover, they have used minimum mean square error (MMSE) channel estimation to get channel information of imperfect channel state information (CSI). Then they compared with the perfect CSI case. Simulation results show that the system performance is different when the imperfect CSI is taken into account.In (3), in this paper authors provided an overview of the proposed approaches in mitigating and the effect of pilot contamination in massive MIMO systems. Different methods in mitigating pilot contamination problem proposed by various authors have reviewed in this article. Then they categorized the proposed methods based on the approach used in estimating channel information, i.e, pilot-based and subspace-based approach.In (4), In this paper authors had overviewed of TDD and FDD schemes in massive MIMO systems is presented. they had analyzed the impact of pilot contamination in TDD massive MIMO systems through published work. Different methods for mitigating pilot contamination due to limited coherence time proposed by various authors are reviewed. They had also categorized the proposed methods based on the approach used in estimating channel information, i.e, pilot-based and subspace based approaches. It is observed that majority of the proposed mitigation methods assume channel reciprocity, whereas in practical system hardware impairments and non-reciprocal transceivers can be sources of pilot contamination. In addition they had explored some broader perspectives, such as pilot contamination in in-band full-duplex system and HetNet. they have also discussed the open issues in pilot contamination and possible future direction of research in pilot contamination in TDD massive MIMO systems .In (5)authors have presented a comprehensive

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overview of state-of-the-art research on the massive MIMO, which has recently attracted considerable attention,particularly focus on the potential impact of pilot contamination caused by the use of non-orthogonal pilot sequences by users in adjacent cells.it also analyzed the energy efficiency achieved by massive MIMO systems, and demonstrated how the degrees of freedom provided by massive MIMO systems enable efficient single-carrier. In (6) this paper, authors has considered zero-forcing (ZF) and maximum ratio transmission (MRT) For downlink transmitter options, while for uplink receiver options it considers ZF and maximum ratio combining (MRC) and they derived simple closed-form formulas of sum rate of each. they have proposed power allocation to the users to be equally or unequally, they observed that, for the downlink, vector normalization is better for ZF while matrix normalization is better for MRT. Also they studied performance analysis of MIMO, power normalization methods, and the trade-off between ZF and MRT/MRC.In (7), authors have analyzed the performances of zero-forcing (ZF) and maximum ratio transmission (MRT) uplink and compared with a downlink massive MIMO system. The achievable sum rate and the required downlink transmit power using each of the precoding schemes are derived, analysed and compared under the same conditions and assumptions. Simulation results are found to coincide with the theoretical results, and show that ZF performs better than MRT under the same conditions. ZF is more power efficient than MRT to achieve high data rate. Therefore, they concluded that ZF is the best choice in a single-cell downlink massive MIMO system.In (8), this article authors have studied a practical massive MIMO DL system with or without pilot-aided coherent detection under the scenario of pilot contamination, and they derived closed-form approximate achievable DL rate expressions for both maximum ratio combining (MRC) and zero forcing (ZF) precoders. For the case with DL pilot, a corresponding DL effective channel estimator is also developed. also they showed performance characteristics of pilot-contaminated massive MIMO DL systems with MRC and ZF precoders.

III. MASSIVE MIMO SYSTEM

Practically, it's not possible to equip the user terminal with large numbers of antenna so the term multi-user MIMO is used in practical scenario which equips the base station with large number of antenna M to serve simultaneously set of single antenna users K as shown in fig.1.The signal received by the k^{th} user after using the linear pre-coding/ beam-forming scheme is given by as in(6):

$$y_k = \sqrt{p_t}\, {h_k}^T g_k s_k + \sum_{l=1,l\neq k}^{k} \sqrt{p_t}\, {h_k}^T g_l s_l \; + \; n_k \ldots\ldots\ldots\ldots\ldots [1]$$

Where h_k is channel matrix,g_k precoding matrix, $\sqrt{p_t}\, {h_k}^T g_k s_k$is the desired signal, $\sum_{l=1,l\neq k}^{k} \sqrt{p_t}\, {h_k}^T g_l s_l$ is multiuser interference and $n_k$is the Noise power.

$$SINR_k = \frac{p_t \left| {h_k}^T g_l \right|^2}{\sum_{l=1,l\neq k}^{K} p_t {h_k}^T g_l s_l + 1} \ldots\ldots\ldots\ldots\ldots [2]$$

When increasing the number of antenna elements in the analysis, the Tx power will be scaled as 1/M in order to compensate for the increased array gain. As a result, a constant signal-to-noise ratio (SNR) operating point is maintained.

IV. LINEAR SIGNAL PROCESSING

By using an asymptotic argument of random matrix theory, linear signal processing can be used to achieve all of these above features. In this work we are taking zero-forcing (ZF), and maximum ratio combing MRC/MRT I the analysis, while and minimum mean square ratio MMSE take for channel estimation.

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$$\mathbf{G} = \begin{cases} ZF = H(HH^{H})^{-1} & \text{, for zero forcing} \\ MRC = H & \text{, for MRT/MTC} \\ MMSE = (HpH^{H} + \sigma^{2} I_{M})^{-1} H & \text{, for MMSE} \end{cases}$$

V. CHANNEL ESTIMATION

Inpractice, full CSI may not be directly available due to pilot contamination and feedback delay, In order to get finite CSI, we use MMSE channel estimation. The channel matrix can be estimated as in(2)

$$H^{*} = \zeta H + \sqrt{1-\zeta^{2}}E \qquad \text{[3]}$$

Where ζ is the reliability of the estimation, and **E**~$\mathcal{CN}$ (0,1) represents the error matrix

$$\mathbf{V} = \begin{cases} F = H^{*} & \text{, for MRT/MTC} \\ F = H^{*}(H^{*}H^{*H})^{-1} & \text{, for zero-forcing} \end{cases}$$

Where H^{*}represents the complex conjugate transpose of the estimated channel matrix. Generally, we used to set **V** = **G**, since it reduces the computational complexity.

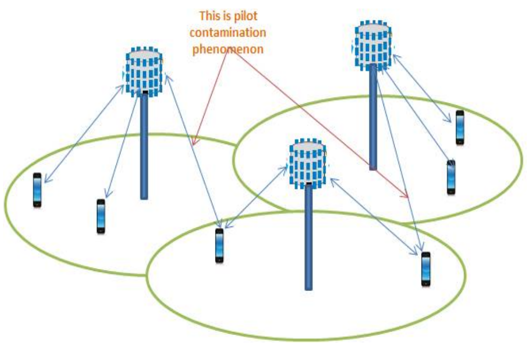

Figure 2: Pilot contamination problem

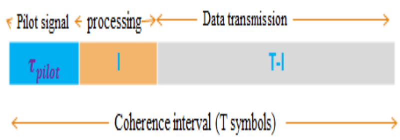

Figure 3: TDD frame

VI. LIMITATIONS OF TDD MASSIVE MIMO

In this section, we define the major problems of the TDD massive MIMO.

A. *Pilot contamination*

In a multi-cell scenario as in fig.2, non-orthogonal pilots across neighboring cells are utilized, as orthogonal pilots would need a length of least K×L symbols (K= total number of Uses in a cell and L = a total number of cell in the system) owing to frequency reuse factor of one. The use of K×L symbols training sequence is not feasible in practice for multi-cell as a result of short channel coherence times due to the mobility of UTs. This causes a phenomenon known as pilot contamination and it has been considered as a major impairment in the performance of massive MIMO systems (3).

B. *Channel reciprocity*

Environment channel communication is continually change, so that this change affect the reciprocity of TDD protocol although in (5) described that the effect of Raleigh fading is reduced in massive MIMO, also the hardware chain in the

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base station many not work properly because of non-linear amplification, phase noise, quantization error (3), it means that uplink and downlink lose the reciprocal property. Under this condition, the performance of the system gets more degrades.

1. ***Sources of pilot contamination***

a. *Non-orthogonal pilot signals*:

As in fig.3, in multi-cell communication scenario the channel coherence time interval is very limit to accommodate large number of users (in full pilot reuse factor 1), there are two or more than two users in adjacent cells using same time slot this known as non-orthogonal pilot sequence, which lead to pilot contamination, therefore more increasing in intera-cell interference then degrade the performance of the system (3)(5).

a. Error in CSI estimation

One other source of pilot contamination is imperfection or error in CSI estimation, any error in channel state information estimation lead to pilot contamination

VII. MITIGATION METHODS OF PILOT CONTAMINATION

In this section, we reviewed the existing methods used to eliminate or reduce the impact of pilot contamination in multi-cell massive MIMO TDD system considering full pilot reuse factor 1.

A. Time-shifted protocol

This protocol reviewed in (3), which used to reduce the pilot contamination effect in multi-cell system, basically in this protocol scheme, transmission of pilot signals in the different cells of the system is accomplished by shifting the pilot positions in the frame such that users in different cells transmit at non-overlapping times as shown fig.4

Cell 1	**pilot**	**Processing**	**Downlink data**	**Uplink data**
Cell 2	**processing**	**Pilot**	**Downlink data**	**Uplink data**
Cell 3	**processing**	**Downlink data**	**pilot**	**Uplink data**

Figure 4: Time-shifted pilot scheme adapted

Eliminating of pilot contamination can be done using the proposed scheme, as long as the pilot does not overlap in time and applied appropriate power allocation algorithm. In practice may be difficult to implement this scheme, because It requires second order statistics of all the UL channels (3).

A. Subspace-Based Estimation Approach

Here Subspace estimation technique is applied using eigenvalue decomposition (EVD), the method is susceptible to error due to assumed channel between users and the BS are paired, they are orthogonally when the number of BS antennas M tends to be infinite. But in practical scenario the number of antennas finite, so in order to reduce these errors, the EVD algorithm is combined with iterative least squares and projection algorithm, in (3) results obtained described that the EVD method is not affected by pilot contamination and performs better than conventional pilot-based techniques but its accuracy depends on large number of BS antennas and increased sampling data within the coherence time.

B. Blind Technique

Blind techniques are based on subspace partitioning. Blind pilots purify technology for systems with power control switching handoff policies, and this technique can separate subspaces interference from the desired signal subspace, which can remove pilot contamination phenomenon. There is also precoding technique used for massive MIMO when systems having a limited number of antennas(5).

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VIII. CONCLUSION

In this paper, we highlight the great potential of large-scale MIMO systems as key technologies for future fourth-generation (4G) cellular systems; also we have described the features of massive MIMO and signal process (linear precoding algorithms) which can be used to achieve most massive MIMO benefits with optimal performance. using the channel reciprocity property of TDD protocol it makes system prone scalability feature in fact along with these advantages there are other problems degrade the performance of our system, one major problem is called pilot contamination due to limit in channel coherence length and error in CSI estimation as we discussed above. Source and solution of such problem also we have discussed through this paper, it was observed that many parameters need to be optimized during the implementation of massive MIMO based network structure. By optimized all terms that we described above the It would be possible to use an evolutionary approach to designing an optimal network.

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