ISSN: 0974-5823 Vol. 7 No. 5 May, 2022

International Journal of Mechanical Engineering

Comparative Analysis of Techniques for Pilot Contamination in Massive MIMO Systems

Ratnaprabha Chavan,
PhD Scholar, SOET, Sandip University, Nashik.

Mortha Sureshkumar,
HOD Aerospace Engineering, SOET, Sandip University, Nashik.

***Abstract* –** With high data demands for mobile networks, massive multi-input multi-output (MIMO) systems (MMS) has been recognized as a promising technology. The MIMO systems suffer from pilot contamination as a result of sharing non-orthogonal pilots among users. This paper presents a comparative analysis of various techniques for preventing pilot contamination in MIMO systems. We initially brief about the broad categories of approaches for pilot decontamination in MMS. A comparison and analysis of existing approaches is used to examine the impact of pilot contamination on the performance and achievable rates of massive MIMO systems. Important concepts of various decontamination techniques are also highlighted. PD schemes addresses and solves the contamination problem significantly and offer various advantages at appropriate levels.

***Index Terms* -** pilot contamination, massive MIMO, multicell, 5G Wireless Communication

INTRODUCTION

Smart terminals, such as smart phones, computers, and tablets, require multimedia services that are quick and easy to use. Over the past few decades, there has been a significant demand for faster data rates for wireless communications [1]. To guarantee the quality of service demanded by mobile applications, the capacity of wireless communication networks must be increased. By utilizing various degrees of freedom, such as time and frequency, significant advancements have been made throughout the most recent mobile generation of systems. However, the trend is currently to use several antennas at both transmitter and receiver ends so that spatial dimensions can be investigated and the channel features can be further used to fulfil the current service requirements of the market [2]. This method is frequently known as Multiple-Input-Multiple-Output (MIMO).

One of the important 5G technologies is massive MIMO system, which significantly increases connection density, spectrum efficiency, and channel capacity by deploying a huge number of antennas at the base station (BS).

TABLE I
ACRONYMS

Acronyms	Terms
2D-SCE	two-dimensional smoothed channel estimation method
BS	Base station
BT-PCP	beamforming training pilot contamination precoding
DR	Data rate
ES-PA	efficient sectorization-based pilot allocation
MIMO	Multi-input, multi-output
MMS	Massive Multi-input, multi-output systems
MMSE	Minimum mean squared error

PC	Pilot Contamination
PD	Pilot Decontamination
PRS	pilot reuse sequence
SR	Sum rate
SE	spectral efficiency
SINR	Signal-to-interference-plus-noise ratio

In order to conserve bandwidth, the same pilot sequences are frequently assigned to users in various cells, which creates the issue of pilot contamination. The inter-cell interference caused by pilot contamination severely restricts the system capacity as the number of BS antennas reaches infinity. Pilot pollution is becoming one of the key causes of performance degradation in huge MIMO systems [3].

Fig.1 demonstrate the situation of two cells I and II, where users $U_{1,1}$ and $U_{2,1}$ are the first users of respective cells. Let $H_{i,j,k}$ be the channel representation from the i^{th} base station to user $U_{j,k}$. If $U_{1,1}$ and $U_{2,1}$ sends the pilot to respective base stations simultaneously with the same pilot sequence, a base station in each cell will receive the pilot sequence from both $U_{1,1}$ and $U_{2,1}$ to give $h = h_{1,1,1}+h_{1,2,1}$. Therefore, the targeted signal from a user may get be contaminated by that from another.

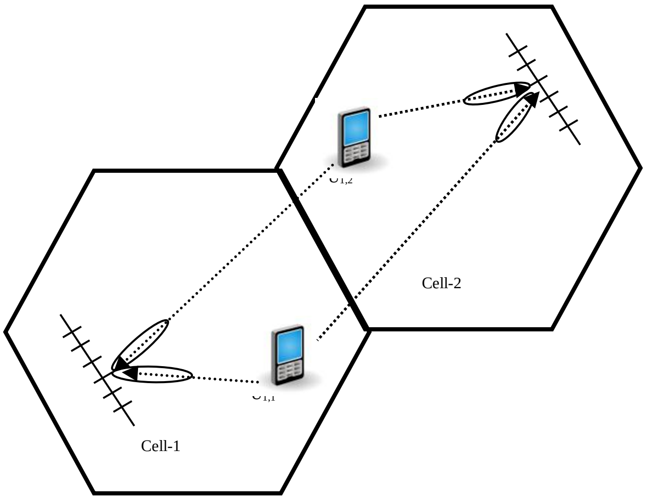

FIGURE 1
PILOT CONTAMINATION IN TWO CELLS

MMS' current pilot contamination reduction strategies majorly fall into three categories:

- Channel estimation,
- Precoding, and
- Pilot assignment and scheduling

CHANNEL ESTIMATION BASED TECHNIQUES

[4] has proposed a multi-cell MMSE-based precoding that is dependent on the user-assigned training set of sequences. Such schemes are suitable for maximizing the lowest rates that all users may attain. This precoding can be used in conjunction with power control, scheduling, and other similar strategies where the performance metric is sum rate. The precoding matrix is given by (1). This precoding technique reduces inter- and intracellular interference [4].

$$\mathbf{A}_l^{\mathrm{opt}} = \frac{1}{\beta^{\mathrm{opt}}}\begin{pmatrix}\hat{\mathbf{G}}_{ll}^{\dagger}\hat{\mathbf{G}}_{ll} + \eta^2 \sum_{j\neq l} \hat{\mathbf{G}}_{jl}^{\dagger}\hat{\mathbf{G}}_{jl} + \\ \left(\delta_{ll} + \eta^2 \sum_{j\neq l} \delta_{jl} + K\right)\mathbf{I}_M\end{pmatrix}^{-1} \hat{\mathbf{G}}_{ll}^{\dagger} \qquad (1)$$

TABLE I
COMPARISON OF VARIOUS TECHNIQUES FOR PILOT CONTAMINATION IN MASSIVE MIMO SYSTEMS

Reference	Category	Approach	Advantage
[4]	Precoding	multi-cell MMSE-based precoding	significant performance gains over single-cell precoding methods.
[5]	Channel Estimator	coordinated pilot assignment	Near interference-free
		2D-SCE	eliminates pilot contamination, lesser pilot overhead,
[6]	Channel-Estimation	pilot design-based channel estimation using Chu sequences with perfect auto-correlation	outperforms random pilot method and equivalent to the exhaustive search method
[7]	Precoding	beamforming training pilot contamination precoding (BT-PCP)	higher spectral efficiency than the conventional Pilot contamination precoding
[8]	minimum-weight multi-index assignment	SPR scheme,	minimum uplink SINR 99%
	Pilot Assignment	SPR	minimum uplink SINR 75%
	Pilot Assignment	SPA scheme	minimum uplink SINR 56%
	Pilot Assignment	PA scheme	minimum uplink SINR 14%
[9]	Pilot Scheduling	asynchronous fractional pilot scheduling scheme (AFPS)	Minimum pilot overhead and inter-cell interference (ICI)
[10]	Pilot Scheduling	edge weighted interference graph (EWIG)	improves SE and SR of the overall system by using HOS
[11]	Channel Estimation	estimation of large-scale fading and performance analysis of maximum ratio transmission and zero forcing precoding	improved channel estimation and reducing performance loss, a high DR

[5] used a virtual channel representation using a two-dimensional smoothed channel estimation method (2D-SCE), which can jointly predict the multi-user channels of the target cell and the interference links from neighboring cells by avoiding pilot contamination. The predicted channel is given by (2),

$$\hat{\boldsymbol{H}}_j = (\hat{\boldsymbol{G}} \boldsymbol{A}_R)^T \qquad (2.a)$$

$$\hat{\boldsymbol{G}} = \boldsymbol{X}^{\dagger}\boldsymbol{Y}(\boldsymbol{A}_R)^{\dagger} \qquad (2.b)$$

$\boldsymbol{G}$ denotes the coupling gain from a terminal to the virtual receive angle and $\boldsymbol{A_R}$ represents a unitary discrete Fourier transform matrix. This technique potentially eliminates pilot contamination-related performance limitation and requires lesser pilot overhead than the classical least square (LS) technique.

To enhance the performance of the system, [6] introduced the pilot assignment and pilot design-based channel estimate scheme to undertake an exhaustive search strategy using large-scale properties of fading channels.

The estimated channel matrix is given by (3) as,

$$\hat{G} = \frac{\alpha}{\alpha + \frac{\sigma^2 K}{M\tau p}}\left(G + \frac{\varphi N}{\tau\sqrt{p}}\right) \tag{3}$$

In the next section we analyses PD scehemes based on precoding.

PRECODING-BASED TECHNIQUES

Different precoding matrices are used in precoding-based PD schemes. For example, [4,7] have used the precoding matrix given by the following equation (4),

$$W_l = \alpha_l \hat{G}_{ll} \mathbb{C}^{N\times L} \tag{4}$$

where, $\hat{G}$ is a channel matrix of cell *l for N* antennas and *L* users.

Based on the estimation of large-scale fading and performance analysis of maximum ratio transmission and zero forcing precoding, [11] have proposed an estimation method with information of large-scale fading and performance analyses of maximum ratio transmission and zero forcing precoding. As the number of antennas goes higher and higher to infinite, pilot reuse sequence (PRS) is assigned to a user grouping to mitigate this problem, resulting in lower bounds on downlink DR and SINR ratios. By improving channel estimation and reducing performance loss, a high DR can be achieved.

The grouping used is given by (5) as,

$$\boldsymbol{\varphi_{j,k,l} = a_i > \tau\mu_i \rightarrow \begin{cases} YES \rightarrow center \\ NO \rightarrow edge \end{cases}} \tag{5}$$

Here, $\boldsymbol{\tau}$ is the group parameter, $\boldsymbol{\varphi_{j,k,l}}$ channel fading, and $\boldsymbol{a_i}$ is the quality of a user's channel. Similarly [12] have proposed a grouping algorithm as given in Algorithm 1 for central and edge user allocation.

The equations used are given by (6) and (7) as,

$$Uc = \frac{3U - \epsilon}{2} \tag{6}$$

$$Ue = \frac{\epsilon - U}{2} \tag{7}$$

Here, Uc are the number of users in center and Ue denotes the set of edge users. K are the total number of users in the cell and ϵ represents the pilot length.

ALGORITHM I

CENTRAL AND EDGE USER ALLOCATION

Algorithm: Central and Edge User Allocation	
STEP 1.	Firstly, we need to make sure that the pilots in the pilot sequence set are orthogonal to one another
STEP 2.	Utilize equations (6) and (7) to identify the edge user $\mathbf{U_e}$ and the central user $\mathbf{U_c}$.
STEP 3.	The central user assigns pilots in the pilot set PC at arbitrarily.
STEP 4.	A set of pilot sequence Pe1, Pe2, and Pe3 is similarly assigned to the edge users in adjacent cells.

PILOT ASSIGNMENT TECHNIQUES

[9] proposed a pilot assignment strategy based on the harmonic signal-to-interference-plus-noise ratio at asymptotes (SINR) utility function to raise the minimum SINR across all users by reducing the total SINR inverses of all active users over all conceivable pilot assignments given by (8) as,

$$\min_{A} \sum_{i=1}^{N} \sum_{j=1}^{K} \frac{1}{\mathrm{SINR}_{i,j}}. \tag{8}$$

where, *i* is the cell and the *j* is the user.

The efficient sectorization-based pilot allocation (ES-PA) [10] scheme comprises two zones, namely a cell center zone as well as a zone on the edge of the cell, a zone with low interference and a zone with low noise, in order to optimize the pilot allocation. By using smart antenna technology, edge zones are further divided into N uniform regions. Pilot sequences are assigned to UEs in the cell center zone due to lower inter-cell interference (ICI), whereas pilot sequences are allocated to UEs in the edge zone due to reduced PC.

Based on simulation results, this approach effectively reduces PC strength, has a lower mean square error (MSE), higher data rate, and superior SE compared to conventional methods of pilot allocation.

CONCLUSIONS

In this article, we have analyzed and compared various schemes for PD. Different schemes proposed incudes approaches based on channel estimation, precoding, pilot assignment and scheduling. These schemes offered several advantages including significant performance gains over single-cell precoding methods, near interference-free transmission, lesser pilot overhead, outperforming over random pilot method, equivalent to the exhaustive search method, higher spectral efficiency than the conventional improved uplink and downlink SINR, minimum pilot overhead and inter-cell interference (ICI), improved SE and SR of the overall system, improved channel estimation and reducing performance loss, and high DR etc.

These schemes are suitable in scenarios as proposed and are found to be significantly useful in pilot decontamination. Some limitations of theses schemes include degradation in the performance with the number of cell users. Also certain assumptions in obtaining the channel estimation and matrices like channel reciprocity does not suit well in practical scenarios, thus throwing issues in the deployment. PC remain a bottleneck for performance in MMS, these PD schemes addresses and solves the contamination problem significantly.

ACKNOWLEDGMENT

Authors would like to thank Sandeep University for providing necessary resources and support extended for this research work.

REFERENCES

[1] K. Tachikawa. A perspective on the evolution of mobile communications. IEEE Commun. Mag., pages 66–73, Oct. 2003.

[2] E. Dahlman, S. Parkvall, J. Skold, and P. Beming. 3g evolution: Hspa and lte for mobile broadband, 2nd edition. Elsevier, 2008.

[3] Wu, Y., Liu, T., Cao, M. et al. Pilot contamination reduction in massive MIMO systems based on pilot scheduling. J Wireless Com Network 2018, 21 (2018). https://doi.org/10.1186/s13638-018-1029-1

[4] J Jose, A Ashikhmin, TL Marzetta, S Vishwanath. Pilot contamination and precoding in multi-cell TDD systems, (2011), pp. 2640–2651.

[5] Ye, X., Zhang, A., Zheng, G. et al. Multicell multiuser massive MIMO channel estimation and MPSK signal block detection applying two-dimensional compressed sensing. J Wireless Com Network 2018, 238 (2018). https://doi.org/10.1186/s13638-018-1252-9

[6] Zhao, J., Ni, S., Gong, Y. and Zhang, Q. (2019), Pilot contamination reduction in TDD-based massive MIMO systems. IET Communications, 13: 1425-1432. https://doi.org/10.1049/iet-com.2018.5557

[7] J. Zuo, J. Zhang, C. Yuen, W. Jiang and W. Luo, "Multicell Multiuser Massive MIMO Transmission With Downlink Training and Pilot Contamination Precoding," in IEEE Transactions on Vehicular Technology, vol. 65, no. 8, pp. 6301-6314, Aug. 2016, doi: 10.1109/TVT.2015.2475284.

[8] Zahoor, M.I.; Dou, Z.; Shah, S.B.H.; Khan, I.U.; Ayub, S.; Reddy Gadekallu, T. Pilot Decontamination Using Asynchronous Fractional Pilot Scheduling in Massive MIMO Systems. Sensors 2020, 20, 6213. https://doi.org/10.3390/s20216213

[9] S. Ma, E. L. Xu, A. Salimi and S. Cui, "A Novel Pilot Assignment Scheme in Massive MIMO Networks," in IEEE Wireless Communications Letters, vol. 7, no. 2, pp. 262-265, April 2018, doi: 10.1109/LWC.2017.2771285.

[10] Farhad Banoori;Jinglun Shi;Khalid Khan;Ruiyan Han;Muhammad Irfan; (2021). Pilot contamination mitigation under smart pilot allocation strategies within massive MIMO-5G system . Physical Communication, (), –. doi:10.1016/j.phycom.2021.101344

[11] Qazwan Abdullah, Noorsaliza Abdullah, Adeb Salh, Lukman Audah, Nabil Farah, Abbas Ugurenver, Abdu Saif, Pilot Contamination Elimination for Channel Estimation with Complete Knowledge of Large-Scale Fading in Downlink Massive MIMO Systems, CoRR, abs/2106.13507, 2021, https://arxiv.org/abs/2106.13507