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Downlink Massive MIMO Systems: Reduction of Pilot Contamination for Channel Estimation with Perfect Knowledge of Large-Scale Fading

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Abstract: Abstract: Massive multiple-input multiple-output (MIMO) technology is considered crucial for the development of future fifth-generation (5G) systems. However, a limitation of massive MIMO systems arises from the lack of orthogonality in the pilot sequences transmitted by users from a single cell to neighboring cells. To address this constraint, a proposed solution involves utilizing orthogonal pilot reuse sequences (PRS) and zero forced (ZF) pre-coding techniques. The primary objective of these techniques is to eradicate channel interference and improve the experience of end users who are afflicted by low-quality channels. The assessment of the channel involves evaluating its quality through channel assessment, conducting comprehensive evaluations of large-scale shutdowns, and analyzing the maximum transmission efficiency. By assigning PRS to a group of users, the proposed approach establishes lower bounds for the achievable downlink data rate (DR) and signal-to-interference noise ratio (SINR). These bounds are derived by considering the number of antennas approaches infinity which helps mitigate interference. Simulation results demonstrate that the utilization of improved channel evaluation and reduced loss leads to higher DR. When comparing different precoding techniques, the ZF method outperforms maximum ratio transmission (MRT) precoders in achieving a higher DR, particularly when the number of cells reaches $\Upsilon_p = 7$.

Keywords: Massive MIMO, fifth generation (5G), SINR, MRT

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1. Introduction

Massive multi-input multiple-output (MIMO) technology Hugely improves the capacity of 5G networks by decreasing interference between neighboring cells (NCs) and mitigating multi-user interference. However, in multi-cell massive MIMO systems, a significant challenge arises due to pilot contamination (PC), which directly affects the Data Rate (DR). To tackle this issue, channel estimation (CE) techniques can be employed, especially in time division duplex (TDD) systems, where training the channel is crucial. By transmitting pilot reuse sequences (PRS), the use of PRS between NCs offers increased gains and effectively reduce adjacent cells interference. This approach helps alleviate the impact of PC and contributes to improving the overall system performance. [1]. PC poses a significant challenge in multicellular massive MIMO systems, and it influences DR. Nevertheless, utilization of CE techniques can effectively tackle this concern. In TDD systems, channel training can be performed using (PRS), which offer several advantages, including increased benefits from PRS utilization between neighboring cells and the elimination of interference among neighboring cells. This approach enables improved channel quality and mitigates the negative effects of PC on system performance [2]. The incorporation of estimates for large-scale fading (LSF) in joint channel processing is a critical technique for accurately assessing system performance. It facilitates the assessment of attainable data rates by considering the efficient SINR [3]. However, when dealing with varying antennas numbers at the base station (BS) and received training signals, a challenge arises in formulating the linear precoding problem effectively. In scenarios with low power, MRT precoding becomes essential as it maximizes the SNR for each user, focusing on the desired signal. Optimizing precoding techniques and considering various factors are key to achieving improved performance and higher data rates in the system design [4]. A crucial aspect is understanding large-scale fading, which encompasses signal strength variations due to factors like distance, shadowing, and path loss. By accurately estimating and accounting for these fading effects, the system can adapt and optimize its transmission strategies accordingly [5].

Mitigating (PC) is also vital. PC occurs when pilot signals from neighboring cells interfere with each other, leading to degraded channel estimation and overall system performance. Effective techniques, such as allocating appropriate pilot reuse sequences (PRS) and employing interference management strategies, can minimize interference between adjacent cells and enhance the accuracy of CH [6]. In light of these considerations, the base station (BS) employs advanced techniques to precode data signals. Precoding involves manipulating transmitted signals to follow optimal paths and reach intended users. By carefully designing precoding paths based on channel conditions, interference levels, and LSF characteristics, the system can maximize signal quality for users while minimizing interference from neighboring cells [7]. By integrating comprehensive knowledge of large-scale fading, mitigating pilot contamination, and establishing effective precoding paths from the BS to users, the system achieves improved performance and higher data rates. This optimizes resource utilization, resulting in enhanced connectivity, throughput, and reliability for users. Numerous studies [8-10] have conducted extensive research on the effects of pilot signals exchanged between neighboring cells, with a particular focus on simultaneous transmission. The findings from these studies have highlighted the considerable advantages associated with simultaneous pilot transmission, leading to enhanced accuracy in channel estimation and improved performance in pre-coding. Simultaneous transmission of pilot signals enables the system to gather more comprehensive and reliable information about the wireless channel. This increased information allows for improved accuracy in estimating crucial channel characteristics, such as channel gains, fading, and spatial correlations. The availability of precise channel estimates empowers the system to optimize its pre-coding techniques effectively, thereby enhancing the quality of transmitted signals and mitigating interference [11]. By leveraging simultaneous pilot transmission, researchers have achieved notable advancements in pre-coding performance. Pre-coding algorithms, which manipulate transmitted signals to exploit spatial diversity and minimize interference, greatly benefit from accurate channel estimation. The improved accuracy obtained through simultaneous pilot transmission enables more efficient pre-coding, resulting in enhanced signal quality, increased spectral efficiency, and improved overall system performance [16].

These studies have shed light on the significant positive impact of simultaneous pilot transmission on both EC accuracy and pre-coding performance. By harnessing the benefits of simultaneous pilot signals, future wireless communication systems can maximize their capacity, optimize resource utilization, and deliver a superior quality of service to users [12]. This approach enables a deeper understanding of the characteristics of the wireless channel, which in turn facilitates the optimization of transmission strategies. Accurate assessment of the wireless channel, including factors such as fading, multipath propagation, and interference, empowers researchers to devise effective techniques that enhance the performance of the system [13]. Simultaneously, other researchers [19] have dedicated their efforts to addressing the challenge of (PC) in multi-cell environments. Their studies have introduced the concept of employing orthogonal pilot sequences (OPS) between adjacent cells, a technique that substantially reduces interference and mitigates the negative impact of PC [14]. By utilizing orthogonal pilot sequences, neighboring cells can transmit pilot signals that are orthogonal to one another, effectively minimizing the interference caused by PC. This approach significantly improves the accuracy of channel estimation and enhances the reliability of the system's performance. By addressing the issue of PC through the use of OPS, researchers have paved the way for improved communication systems with enhanced capacity and reduced interference levels. By leveraging the insights derived from comprehending the characteristics of the wireless channel and integrating them with the implementation of OPS, future wireless communication systems can optimize their transmission strategies. This optimization leads to improved performance, higher data rates, and more efficient utilization of resources, ultimately enhancing the overall quality and reliability of wireless communication systems [15].

Moreover, another noteworthy study [16] has made a valuable contribution to this field of research by delving into alternative approaches for pilot signal management and interference mitigation in multi-cell environments. The insights gained from this study have unveiled novel techniques and methodologies that can be employed to more enhance the performance of pilot-based CE and pre-coding strategies. The study explores innovative methods to optimize the allocation and utilization of pilot signals in multi-cell scenarios. By carefully managing the transmission and reception of pilot signals, researchers have identified strategies to minimize interference and improve the accuracy of channel estimation. These strategies encompass intelligent pilot assignment, adaptive power control, and advanced interference cancellation techniques [17]. Additionally, the study investigates the efficacy of new pre-coding algorithms that exploit the enhanced channel estimation obtained through these alternative pilot signal management approaches. These algorithms leverage the refined knowledge of the wireless channel to optimize the transmission of data signals, mitigating interference and enhancing signal quality [18]. The findings of this study open up exciting avenues for further enhancing the performance of pilot-based channel estimation and pre-coding strategies. By incorporating these alternative approaches, future wireless communication systems can achieve even higher levels of accuracy, efficiency, and capacity, leading to improved overall system performance and user experience [19]. These collective studies have made significant strides in advancing our knowledge regarding the impact of pilot signals exchanged between neighboring cells and have provided valuable insights into mitigating pilot contamination. By incorporating the findings and recommendations from these studies, future wireless communication systems can effectively harness the potential of pilot signals to achieve higher accuracy in channel estimation, improved pre-coding performance, and overall enhanced system efficiency [20]. Extensive research has been conducted on the effects of (PC) in both uplink (UP)and downlink (DL) scenarios [21]. These studies have extensively investigated the impact of PC, considering scenarios with and without pilot signals and the practical implementation of array-based (MIMO) systems, which aim to achieve high (DR).

The insights gained from these studies have shed light on the complexities and challenges associated with PC and have provided valuable guidance in developing effective solutions. By understanding the factors influencing PC and considering various pilot signal strategies, such as OPC and optimal allocation techniques, researchers have devised approaches to minimize interference and improve the accuracy of channel estimation. These efforts have paved the way for the practical implementation of MIMO systems that can achieve higher data rates and improved system performance [22]. By leveraging the findings from these studies, future wireless communication systems can optimize their transmission strategies and allocation of pilot signals. This optimization, in turn, enables more accurate channel estimation, enhanced pre-coding performance, and overall improved system efficiency. By mitigating the effects of pilot contamination, wireless communication systems can effectively utilize available resources, maximize capacity, and provide users with enhanced connectivity, throughput, and quality of service [23] In this research, we address the challenge of PC for edge users by proposing the adoption of pilot reuse sequences (PRS). By utilizing PRS, we aim to mitigate the interference caused by PC, leading to improved system performance. Our approach involves evaluating the wireless channel while considering a comprehensive understanding of large-scale fading, which encompasses variations in signal strength resulting from factors such as distance and shadowing [24]. The use of PRS enables neighboring cells to transmit pilot signals that are orthogonal to each other, thereby minimizing the interference caused by PC. This orthogonalization of pilot signals allows for more accurate channel estimation, leading to enhanced reliability and improved performance of the system. By incorporating knowledge of LSF into our evaluation process, we can effectively account for variations in signal strength and optimize the allocation of PRS, further enhancing the accuracy of channel estimation [25]. Through our proposed approach, we can mitigate the negative impact of PC on edge users and improve the overall system performance. By reducing interference and improving channel estimation accuracy, we can enhance the data rates and reliability for users located at the network edge. This, in turn, enables more efficient utilization of resources and improved connectivity, resulting in an enhanced user experience. By adopting PRS and considering LSF effects, our research contributes to the development of advanced techniques for PC mitigation. It opens up possibilities for future wireless communication systems to optimize their transmission strategies, achieve higher performance, and provide seamless connectivity to users, even in challenging environments with PC [26].

Our research proposes an approach that combines the use of PRS and considers the effects of LSF during channel evaluation to significantly improve data rates for edge user scenarios. By effectively managing pilot contamination (PC) and optimizing system capacity, our aim is to enhance connectivity and increase throughput for users located at the network edge. We conducted a thorough examination of LSF utilizing MRT and ZF precoding approaches to assess the performance of our methodology. By investigating scenarios with increased antenna elements and users, we gained comprehensive perceptions into system performance, highlighting advantages, limitations, and power consumption in massive MIMO systems. [27]. By leveraging a CE equipped with deep knowledge of large-scale fading, we can efficiently minimize PC while achieving exceptional data speeds through pilot reuse. This approach tackles a primary obstacle encountered in massive MIMO systems and opens doors to improved performance and increased data rates. Furthermore, by optimizing the allocation of PRS and leveraging our knowledge of large-scale fading, we can enhance overall system efficiency and deliver an enhanced user experience [28]. In conclusion, our research focuses on addressing the challenges of PC in massive MIMO systems. Through the use of PRS. we strive to maximize achievable data rates for edge users. This approach has the potential to significantly improve connectivity and throughput at the network edge, contributing to advancements in wireless communication systems [29]. In order to obtain high-quality CE, the base station (BS) establishes a connection between the training signal and a predefined PRS specific to each user equipment (UE), leveraging comprehensive knowledge. Additionally, orthogonal PRS is employed to mitigate PC for edge users, whose channel quality tends to degrade [30]. The multicellular array provides a high degree of freedom, allowing the BS to accurately evaluate channels by utilizing enhanced pilot sequences from neighboring cells. [31]. By employing comprehensive knowledge of the channel and exploiting orthogonal PRS, the proposed approach enables the BS to generate high-quality channel estimates. This, in turn, enhances the capacity and data rates of the network in 5G mobile systems. By mitigating pilot contamination and leveraging optimized pilot sequences, the system can accommodate more users, leading to increased network efficiency and improved overall performance. To address this, a relative channel evaluation technique was employed, taking into account a comprehensive understanding of LSF [32]. This approach involved employing precoding schemes with reduced spatial dimensions, which effectively mitigated interference from nearby cells, particularly for the most vulnerable user equipment's (UEs). This approach considered the characteristics of LSF and effectively tackled interference issues. By cancelling interference using optimized precoding techniques, the system could enhance the data rates and reliability, especially for UEs located in challenging interference scenarios [33].

2. System Model

Massive MIMO systems deploy multiple cells, each with a BS equipped with M antennas, to ensure wireless communication coverage. The BS transmits signals to and receives signals from UEs within its coverage area. Using massive MIMO technology, the BS utilizes multiple antennas to enhance signal strength, reduce interference, and increase data rates, providing reliable and high-performance communication in a multi-cell environment K, ($M \gg K$), multicellular massive MIMO systems, multiple cells are deployed to provide wireless communication coverage in a given area. Each cell is equipped with BS that operates at the same frequency and serves as the central hub for transmitting and receiving signals to and from UEs within its coverage area. The channel model used assumes that the correlated Rayleigh fading channel matrix is independent and identically distributed. Additionally, the properties of MMSE are considered in the analysis to optimize the system's performance. MMSE for channel $h_{ljk} \in \mathbb{C}^{M\times 1}$ could assign. However, the channel reciprocities, which indicate the symmetry between the UP and DL channels, are assumed to be the same. This assumption ensures that the characteristics of the channel remain consistent in both the UP and DL directions. In $\Theta_{ljk} \in \mathbb{C}^{M}$, $M \times 1$ is the small-scale fading (SSF) channel refers to the rapid fluctuations in the received signal power caused by factors such as multipath propagation, reflection, and diffraction. These fluctuations occur over short distances and short time intervals, resulting in variations in the signal strength and phase. The SSF channel is often characterized by statistical models such as Rayleigh fading or Rician fading, which capture the random nature of the signal fluctuations and $\Omega_{ljk} \in \mathbb{C}^{M\times M}$ The LSF channel takes into account the correlation matrix associated with the spatial characteristics of the wireless channel. It captures the effects of signal propagation over longer distances and considers factors such as path loss, shadowing, and antenna patterns. The correlation matrix reflects the spatial correlation between different antenna elements and provides insights into the channel's behavior in terms of signal strength and spatial variations. By considering the related channel correlation matrix, we can better understand and model the LSF characteristics of the wireless channel. In $\left[D_{lj}\right]_{k,k} = \sqrt{\Omega_{ljk}}$, D_{ljk} is the diagonal matrix whose diagonal elements are $\sqrt{\Omega_{lj}} = \left[\sqrt{\Omega_{lj1}}, .., \sqrt{\Omega_{ljK}}\right]$. The channel between BS l and the Kth user in cell j is given by

$$g_{ljk} = \sqrt{\Omega_{ljk}}\ \Theta_{ljk} \tag{1}$$

In our study, we considered the BS to operate with imperfect channel state data (CSI), implying that the BS has incomplete or inaccurate information. This assumption accounts for the realistic scenario where CSI estimation errors are present in practical wireless communication systems. The Kth user's received signal z_{jk} inside the jth cell can be written as

$$z_{jk} = \underbrace{\sqrt{\rho_d} g_{jjk}^{H} x_{jk} b_{jk}}_{desired\ signal} + \underbrace{\sqrt{\rho_d} \sum_{i=1, i\neq k}^{K} g_{jjk}^{H} x_{ji} b_{ji}}_{intra-cell\ interference} + \underbrace{\sqrt{\rho_d} \sum_{l=1, l\neq j}^{L} \sum_{i=1}^{K} g_{ljk}^{H} x_{lk} b_{lk}}_{inter-cell\ interference} + n_{jk} \tag{2}$$

where g_{ljk}^{H} .The notation H symbolizes the Hermitian transpose of the channel matrix, which is utilized to assess the channel of K user equipment (UEs) in each cell by employing an orthogonal pilot signal.. $g_{jjk} = \left[g_{jj1} \ldots . g_{jjK}\right] \in \mathbb{C}^{M\times K}$is the DL channel between BS j and user K in its cell. The transmit signal vector of BS is $y_{lk} = x_{lk} b_{lk} \in \mathbb{C}^{M}$, $b_{lk} \in \mathbb{C}^{M\times K}$ is the linear precoding matrix, $x_{lk} \in \mathbb{C}^{K} \sim \mathcal{CN}(0, I_K)$ is the data transmitted from BS in cell l to the UEs, ρ_d is the DL transmit power, and $n_{jk} \sim \mathcal{CN}(0_{M\times 1}, I_M)$ is the received noise vector.

2.1 Channel Estimation

In the DL phase, we employed channel estimation based on channel interactions in TDD. The primary objective was to enhance the maximum data rate (DR) by leveraging comprehensive knowledge of LSF to eliminate PC. To achieve this, we investigated the maximum DR through relative channel estimation using the training received signal, considering the full knowledge of LSF. Furthermore, we selected an optimal antenna configuration with a limited number of radio frequency chains (RF), taking into account transmit power allocation and channel quality. We made the assumption that channel reciprocity could be established by matching the properties of the uplink and downlink channels. UEs in cell j of the downlink G^{G}_{jjk}, which is the Hermitian transposition of the uplink G^{G}_{jjk}, due to the reciprocity of the electromagnetic waves in the transmission signal at the uplink. A significant limitation of massive MIMO systems is PC, which adversely affects the data rate. PC arises due to the non-orthogonality of pilot reuse sequences (PRS) transmitted by users within a cell and neighboring cells. In the estimation of the channel, the received training signal is used, with identical pilot sequences employed by neighboring cells

$$A_{jk} = g_{jjk} + \sum_{l \neq j}^{K} g_{ljk} + \frac{n_{jk}}{\rho^{1/2}} \tag{3}$$

The training transmit power denoted by ρ, is proportional to the effective pilot SNR. The length of the training transmit power is denoted by T and determines the duration of the training phase.

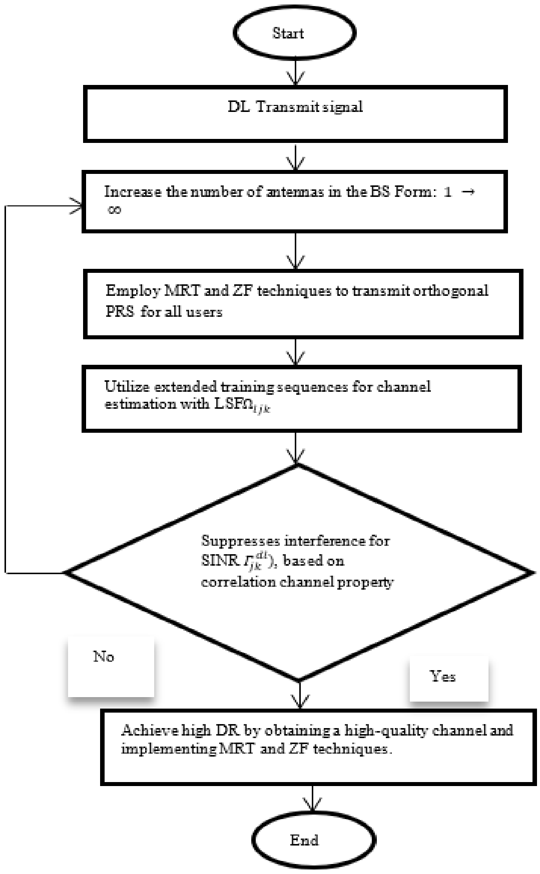

Fig. 1 - Illustrates the flow chart for achieving high data rates

In the downlink, users in different cells experience incorrect channel estimates due to the reuse of the same PRS. To improve SINR, active user evaluation aligns path loss with the required pilot signal. The number of PRS is determined to optimize achievable DR. High SINR is essential for accurate channel estimation, which is obtained using a correlated received pilot matrix with low complexity.$\hat{g}_{jjk}$ is convenient for a large number of M [5],[23],[26] at multiple $\hat{g}_{jjk}$ by A^{tr}_{jk}

$$\hat{g}_{jjk} = \Omega_{jjk}\varphi_{jk} \sum_{l \neq j}^{K} g_{ljk} + \frac{n_{jk}}{\rho^{1/2}} \tag{4}$$

2.2 Downlink Transmission

With LSF, the proposed approach achieves high data rates by utilizing relative channel estimation, full knowledge of LSF and PRS to mitigate pilot contamination. Performance analysis of MRT and ZF precoding methods, along with increased antenna elements and users, leads to improved achievable DL DR and SINR. The mitigation of PC enables more users to share bandwidth without requiring additional time-frequency resources. The base station transmits pilot sequences to each UE, allowing them to estimate their own channels. $K \times L$ Extensive training sequences were utilized to satisfy the requirement of orthogonal pilot sequences in the multi-cell scenario. This allowed for accurate channel estimation, with the channel variance expressed as a result of the training.

$$\varphi_{jk} = \left(\frac{I_M}{\rho} + \sum_{l=1}^{L} \Omega_{ljk}\right)^{-1} \tag{5}$$

A pilot sequence(PS) of $\Upsilon_p = K = \infty$ in which the orthogonal PRS number is increased and the user equipment's (UEs) number increased within the cell contributed to the creation of the PC K users during the UL training phase, the users within the same cell transmitted an orthogonal PS to ensure appropriate CE and avoid interference. The received signal at the BS is obtained from the DL PS symbol, represented by Υ_p, corresponding to the desired channel as shown in the equation (6)

$$\xi_{ljk} = \sqrt{\rho_d \Upsilon_p} \sum_{l=1}^{L} g_{ljk} + n_{lk} \tag{6}$$

The PS, denoted by Υ_p, is allocated within each coherence interval and can be used for both the UL and DL transmission. For the EC, the properties of MMSE $g_{\tilde{ljk}} = \hat{g}_{jlk} - g_{ljk}$ the EC between users K and BS cells L was originate, where $g_{jjk} \sim \mathcal{CN}(0, \varphi_{jk})$ is the uncorrelated estimation independent of $g_{\tilde{jjk}} \sim \mathcal{CN}(0, (\varphi_{jk} - \mathrm{O}_{ljk}) I_M)$, and $\mathrm{O}_{ljk} = \Omega_{jjk} \varphi_{jk} \Omega_{ljk}$, which is also independent of antenna M for LSF [6-10],[22-28]. The MMSE of the Kth UEs can be expressed as

$$\begin{aligned}
\tilde{g}_{ljk} &= \mathbb{E}\left\| \hat{g}_{ljk} - g_{ljk} \right\|^2 \\
&= \mathbb{E}\left\{ \left| \varphi_{jk}(\xi_{ljk} +) - g_{ljk} \right|^2 \right\} \\
&= \mathbb{E}\left\{ \left| (\varphi_{jk} - I_M)(\xi_{ljk}) + n_{lk} \right|^2 \right\} \\
&= \left\{ \Omega_{ljk} (\varphi_{jk} - I_M)(\varphi_{jk} - I_M)^G (\xi_{ljk}) + \sigma^2 I_M \right\} \\
\tilde{g}_{ljk} &= \left\{ \Omega_{ljk} (\varphi_{jk} - I_M)(\varphi_{jk} - I_M)^G \left(\Theta_{ljk} \left(\rho_d \Upsilon_p \textstyle\sum_{l=1}^{L} \Omega_{ljk}\right) \Theta_{ljk}^G \right) \xi_{ljk} + \sigma^2 I_M \right\} \\
\tilde{g}_{ljk} &= \{ \Omega_{ljk} ((\frac{I_M}{\rho} + \sum_{l=1}^{L} \Omega_{ljk})^{-1} \\
&\quad - I_M)((\frac{I_M}{\rho} + \sum_{l=1}^{L} \Omega_{ljk})^{-1} - I_M)^G ((\Theta_{ljk} (\rho_d \Upsilon_p \sum_{l=1}^{L} \Omega_{ljk}) \Theta_{ljk}^G) \xi_{ljk}) \\
&\quad + \sigma^2 I_M \}
\end{aligned} \tag{7}$$

The impact of PC resulting from the correlated precoding channel matrix and multiple user equipment's (UEs) can be calculated using equation (8), where $\Theta^G{}_{ljk} \xi_{ljk}$ is determined by $\Theta_{ljk} \Theta^G{}_{ljk} = 1$[26]. CE, represented by $\Theta^G \xi_{ljk}$, is related to the channel response $\Theta^G \xi_{ljk}$, as described by equations (4) and (8)

$$\tilde{g}_{ljk}^G / \left\| \tilde{g}_{ljk} \right\| = \frac{\Theta^G{}_{ljk} \xi_{ljk}}{\left\| \Theta^G{}_{ljk} \xi_{ljk} \right\|} \tag{8}$$

The impact of PC during signal transmission from BS to UEs can be calculated using equation (8),where $\mathbb{E}[g_{ljk} a_{lk}] = \mathbb{E}\|\tilde{g}_{ljk}^G\|$[26]. CE, represented by g_{ljk}, is associated to the channel response g_{ljk}, as described by equations (4) and (8)

$$\tilde{g}_{ljk} = \frac{\rho_d \Upsilon_p \Omega_{ljk}}{1 + \rho_d \Upsilon_p \sum_{i=1}^{L} \Omega_{lik}} \Theta^G{}_{ljk} \xi_{ljk} \tag{9}$$

2.3 Achievable Data Rate

The channel quality of users can be improved by assigning orthogonal PRS taking into account various levels of PC based on the LSF. This approach effectively mitigated the negative effects of PC and resulted in enhanced channel performance for all users. The objective of improving the channel quality was to enhance system performance by achieving more accurate EC and reducing inter-cell interference. However, the DR in massive MIMO systems is limited by PC resulting from the non-orthogonal PRS transmitted by users in the same cell and neighboring cells. The challenge of PC addressed and EC improved, we proposed a method that utilizes orthogonal PRS and considers the effects of LSF.To address the problem of PC, we assigned pilot PRS to specific user groups, which helped mitigate the issue as the number of antenna elements increased [29-33]. In addition to maximizing the SNR for each user equipment (UE) K, MRT precoding technique also addressed power constraints, which helped mitigate interference. By optimizing the precoding scheme, we aimed to enhance the overall system performance. of $\mathcal{A}_j = [b_{1,MRT}, .., b_{K,MRT}] = [\tilde{g}^G_{lj1}, .., \tilde{g}^G_{ljk}] = \tilde{G}^G_{ljk}$. The zero-forcing (ZF) precoding technique allows for scheduling up to K users in the system, enabling the delivery of one data stream per user. Additionally, the achievable DR depends on the condition of the channel inverse, which further contributes to optimizing the system performance. inverse $b_j = \tilde{G}_{ljk}(\tilde{G}^G_{ljk}\tilde{G}_{ljk})^{-1} / \left\| \tilde{H}_{ljk}(\tilde{G}^G_{ljk}\tilde{G}_{ljk})^{-1} \right\|^2$. The lower bound of the achievable DR was derived as follows:

$$\mathcal{R}_{jk} = \sum_{l=1}^{L}\sum_{i=1}^{K}(1 - \partial)\left[\log_2(1 + \Gamma^{dl}_{jk})\right] \tag{10}$$

The channel response was predicted to account for mitigated PC. The received signal was decomposed, where $(1 - \partial)$represents the loss of pilot signaling for the pre-log factor, and $0 < \partial < 1$ indicates the potential DR.

$$\mathcal{Y}_{jk} = \sqrt{\rho_d \Upsilon_p}\mathbb{E}\{g^G_{jjk}b_{jk}\}\mathrm{x}_{jk} + \sqrt{\rho_d \Upsilon_p}\sum_{i=1,i\neq k}^{K}(g^{\,G}_{\,jjk}b_{jk} - \mathbb{E}\{g^G_{jjk}b_{jk}\})\mathcal{V}_{jk} + \sqrt{\rho_d \Upsilon_p}\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} g^G_{ljk}b_{lk}\,\mathrm{x}_{lk} + n_{jk} \tag{11}$$

From equation 10, we were able to evaluate the achievable DR of the transmit signal from BS,

$$R_t = \sum_{l=1}^{L}\sum_{i=1}^{K}(1 - \partial)\, log_2\left(1 + \frac{\mathbb{E}|DS\,|^2}{\mathbb{E}|Uncorrelated\ noise\ \,|^2}\right) \tag{12}$$

The PRS was observed to have a connection between the channel matrix $h^{\,H}_{\,ljk}$ and the precoding matrix $b_{lk}$of the neighboring cell. SINR at the kth UE was calculated [32-34], and the desired SINR signal can be expressed as follows:

$$\mathbb{E}|\mathrm{DS}\,|^2 = \rho_d \Upsilon_p \mathbb{E}\left[g^H_{jjk}b_{jk}\right]^2 \tag{13}$$

$$\mathbb{E}|\text{Uncorrelated noise }\,|^2 = \rho_d \Upsilon_p \sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K}\mathbb{E}\left[\left|g^{\,G}_{\,ljk}b_{lk}\right|^2\right] - \sum_{i=l}^{L}\rho_d \Upsilon_p\left|\mathbb{E}\left[g^{\,G}_{\,jjk}b_{jk}\right]\right|^2 + \sigma^2 \tag{14}$$

By employing MRT and ZF precoding techniques, we obtained significant SINR improvements for the kth UE. The derived SINR results demonstrate the effectiveness of these precoding methods.

$$\Gamma^{dl}_{jk} = \frac{\rho_d \Upsilon_p\left|\mathbb{E}\left[g^{\,G}_{\,jjk}b_{jk}\right]\right|^2}{\rho_d \Upsilon_p\sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K}\mathbb{E}\left[\left|g^G_{ljk}b_{lk}\right|^2\right] - \sum_{i=l}^{L}\rho_d \Upsilon_p\left|\mathbb{E}\left[g^G_{jjk}b_{jk}\right]\right|^2 + \sigma^2} \tag{15}$$

The average channel and interference power for MRT precoding were computed in closed form based on the received signal, resulting in the following representation:

$$\rho_d\left|\mathbb{E}\left[g^G_{ljk}b_{lk}\right]\right|^2 = \frac{d}{M\ var(g_{ljk})}\left|\left\{\mathbb{E}\left\|\tilde{g}_{ljk}\right\|^2\right\}\right|^2 \tag{16}$$

The noise variation was a direct consequence of the significant fading that occurred. $\left|\mathbb{E}\left[g^{\,G}_{\,ljk}b_{lk}\right]\right|^2$ from Kay [6]: $\rho_d\left|\mathbb{E}\left[g^{\,G}_{\,ljk}b_{lk}\right]\right|^2 = Mvar(g_{ljk})$. Channel CSI was conducted for MMSE when the diagonals of the parameter estimates demonstrated linear independence [32-34]. To mitigate the impact of power control (PC) on interference, correlated channels were utilized from the same cell to adjacent cells as stated in equation (14) [9]. In the case of MRT, the SINR can be expressed as follows.

$$\Gamma_{jk}^{dl-mrt} = \frac{Mvar(\tilde{g}_{jjk})}{Mvar(\tilde{g}_{ljk}) + \sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} var(\tilde{g}_{jjk}) + \frac{\sigma^2}{\rho_d}} \tag{17}$$

Based on ZF precoding $b_{lk} = \mathbb{E}\left|\tilde{G}_{ljk}\left(\tilde{G}_{ljk}^{G}\tilde{G}_{ljk}\right)^{-1}\right| / \mathbb{E}\left\{\left\|\tilde{G}_{ljk}\left(\tilde{G}_{ljk}^{G}\tilde{G}_{ljk}\right)^{-1}\right\|^2\right\}^{1/2}$, By employing orthogonal pseudo-random sequences (PRS), direct estimation of the user becomes feasible without interference from other users. This approach effectively reduces inter-user interference $b_{lk} = (M-K)var(\tilde{g}_{ljk})^{1/2} G_{ljk}\left(\tilde{G}_{ljk}^{G}\tilde{G}_{ljk}\right)^{-1}$. Subject on a number of $M \to \infty$, the variance channel is $var\{\tilde{g}_{ljk}^{G} b_{jk}\} \xrightarrow[M\to\infty]{} 0$.To achieve high performance in terms of achievable DR, it is crucial to determine the appropriate number of pseudo-random sequences (PRS). Additionally, obtaining a high SINR is essential for improved channel estimation performance. By considering the numerator and denominator of equation (15), we can simplify the linear precoding of ZF as follows.

$$\rho_d \left|\mathbb{E}\left[g_{ljk}^{H} b_{lk}\right]\right|^2 = \rho_{jk}(M-K)\ var(\tilde{g}_{ljk}) \tag{18}$$

The denominator of the expression can be used to represent the interference.

$$\begin{aligned} &\rho_d \sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} \mathbb{E}\left[\left|g_{ljk}^{H} b_{lk}\right|^2\right] - \rho_{jk}\left|\mathbb{E}\left[g_{jk}^{H} b_{jk}\right]\right|^2 + \sigma^2 \\ &\qquad = \rho_d (M-K)\ var(\tilde{g}_{ljk}) + \sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} \rho_d var(\tilde{g}_{ljk}) + \sigma^2 \end{aligned} \tag{19}$$

By utilizing ZF precoding at BS, we can derive the lower bound for the LSF channel by substituting equations (18) and (19) into equation (17).

$$\Gamma_{jk}^{dl-zf} = \frac{(M-K)var(\tilde{g}_{jjk})}{(M-K)var(\tilde{g}_{ljk}) + \sum_{l=1,l=j}^{L} \text{O}_{jk} + \sum_{l=1,l\neq j}^{L}\sum_{i=1}^{K} var(\tilde{g}_{jjk}) + \frac{\sigma^2}{\rho_d}} \tag{20}$$

2.4 The Proposed Methods

The possible SINR in equation (10) is proportional to the LSFΩ_{ljk}, depending on the location of UE K within each cell. In MIMO systems, where the training signal at BS cannot be directly constructed, the adoption of MRT and ZF linear precoding becomes necessary to enhance multi-cell interference without introducing additional time overhead. The estimation of LSF becomes feasible, leading to improved performance evaluation through the utilization of MRT and ZF precoding. Consequently, the accurate estimation of the LSFΩ_{ljk} for UEs in the ith cell is essential when sorting UEs based on their channel conditions, distinguishing between the best and worst. To enhance the channel quality for users, we assigned orthogonal pseudo-random sequences (PRS) to the edge user group, as expressed in equations (17) and (20), taking into account the LSFΩ_{ljk}. This approach allowed us to divide the users into two distinct groups, resulting in an improved user channel quality.

$$\Omega_{ljk} = \mathscr{b}_i \geq \tau\mu_i \to \begin{cases} Yes \to center\ users \\ No \to edge\ users \end{cases} \tag{21}$$

The user's channel quality, corresponding to Ω_{ljk}, plays a significant role in determining the grouping parameter for enhancing the achievable data rate (DR). By selecting a suitable grouping threshold value, $\tau\mu_i$ the edge users can be effectively grouped to improve their channel quality. As a result, this user grouping strategy, denoted by $\mathscr{b}_i$ facilitates the attainment of acceptable channel quality levels.

$$\mu_i = \sum_{k=1}^{K} \frac{\max[\mathscr{b}_{i1}, \mathscr{b}_{i2}, \ldots, \mathscr{b}_{iK}] + \min[\mathscr{b}_{i1}, \mathscr{b}_{i2}, \ldots, \mathscr{b}_{iK}]}{2} \tag{22}$$

where $K_{ic} = \text{card}[k: \ldots, \mathscr{b}_i > \mu_i]$ represents the number of center users and $K_{ie} = \text{card}[k: \ldots, \mathscr{b}_i \leq \mu_i]$ represents the number of edge users. In multi-cell massive MIMO systems, the perfect orthogonality pilot reference signals (PRS) play a crucial role. This research focuses on examining the impact of power control (PC) and investigating the effectiveness of MRT and ZF precoders in conjunction with PC.

This limitation arises in massive MIMO systems. Nevertheless, the perfect orthogonality PRS in massive MIMO. The connected precoding vector matrix within the same cell, along with the channel characteristics of users in neighboring cells, significantly contribute to achieving high DR through mitigated PC. Both ZF and MRT precoding techniques offer different achievable DR levels, which are as follows:

$$\mathcal{R}^{mrt,\ zf}{}_{jk} = \sum_{l=1}^{L}\sum_{i=1}^{K}\left(1-\frac{\partial}{K}\left(\sum_{l=1}^{L} LK_{ie} + \max\left[K_{ic}, K_{ic}\ldots, K_{ic}\right]\right)\right)\log_2(1+\Gamma_{jk}^{dl-mrt,zf}) \tag{23}$$

The data rate (DR) in equation (23) is affected by LSF, resulting in some losses. By increasing the antenna count, we can enhance the overall system performance and minimize the impact of LSF on the DR. Similarly, ensuring that users move uniformly helps in maintaining a more stable communication environment, reducing the variations caused by fading and improving the overall DR.

3. Numerical Results

The results are depicted in Figure 2, which highlights the benefits of having a uniform distribution of users within each cell and accurate EC, providing comprehensive information on LSF at higher spatial resolutions. By increasing the grouping value to M = 256 and K = 10, the target cell was able to achieve a significantly higher data rate (DR). This improvement is highlighted in Figure 2. Additionally, the figure illustrates that increasing the number of PRS from 1 to 3 further enhanced the achievable DR. Furthermore, due to its high SINR capabilities, (ZF) precoders outperformed the MRT precoders when utilizing a large pilot reuse scheme. This superiority of ZF over MRT resulted in a greater DR. This flexibility allows for optimization and improvement in the achievable DR. Furthermore, increasing the number of antennas in the multi-cell system ensures that the channels become orthogonal to those in neighboring cells, effectively reducing interference. This orthogonality contributes to a significant reduction in interference between adjacent cells, resulting in a higher attainable DR. When comparing ZF precoding with extensive pilot reuse to MRT precoding, it was observed that ZF precoding effectively mitigated inter-cell interference between neighboring cells, leading to a higher achievable DR. This superiority of ZF over MRT precoding in handling interference resulted in a significant improvement in the DR. In Figure 2, it can be seen that the average DR for all curves exhibited a nonlinear relationship with the number of UEs. Therefore, it is crucial to select the optimal number of UEs (K) in order to achieve a high DR. Furthermore, a high DR was achieved by considering the impacts of bandwidth and the correlation between the transmit pilots. The available user capacity also imposes limitations on the transmission of orthogonal PRS based on bandwidth constraints. Taking these factors into account contributes to the achievement of a high DR.

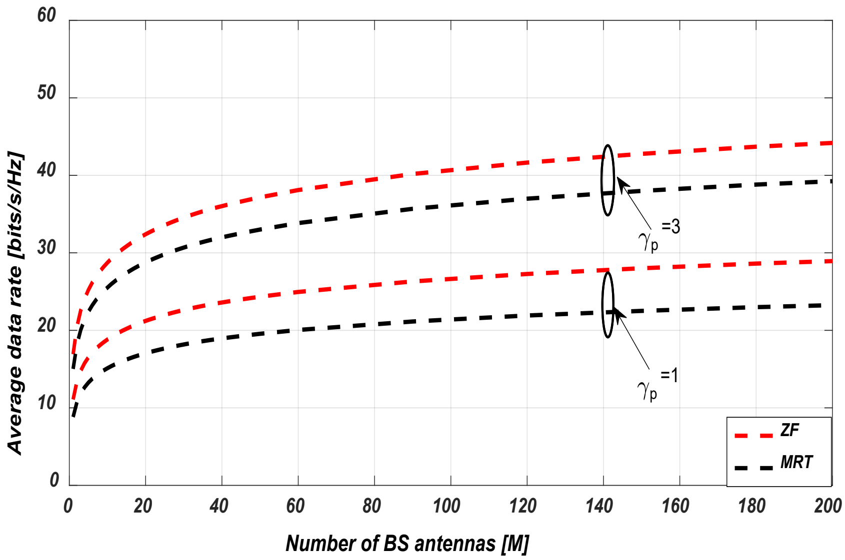

Fig. 2 - Achievable data rate with number of antennas *M*

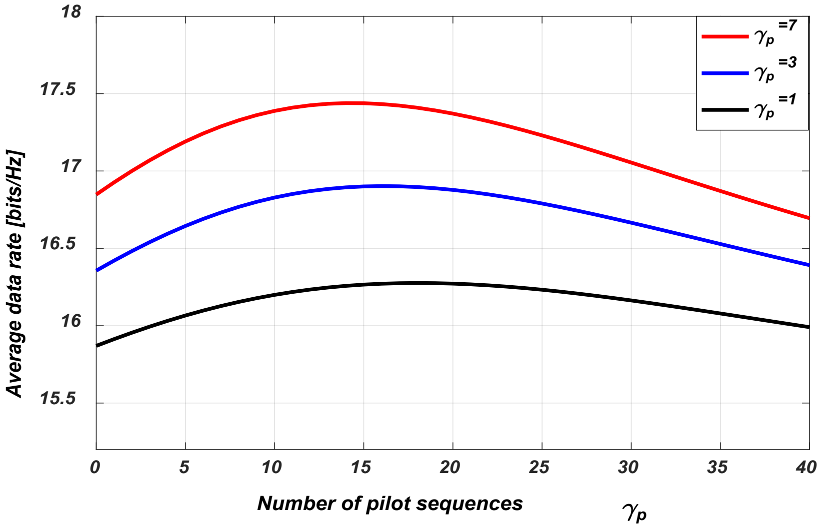

Fig. 3 - Average data rate with number of pilot sequences Υ_p.

By appropriately selecting the number of edge users in accordance with equation (23), it is possible to achieve a high feasible data rate (DR) while considering user grouping to minimize power control (PC) requirements for the edge users. Additionally, when the quantity of Υ_p= 7 was used, the system exhibited significantly improved DR performance compared to Υ_p= 1. This improvement highlights the importance of selecting an optimal value for Υ_p. Figure 3 provides insights into the relationship between the number of PRS and interference reduction due to PC implementation in each BS for channel estimation. It demonstrates that the number of PRS cannot grow arbitrarily, as this would result in increased interference and pose restrictions on coherent channel estimation, thereby limiting the DR capacity. Furthermore, Fig. 3 reveals that the average DR initially increases and then gradually decreases. This indicates that the increasing DR of edge users outweighs the decreasing DR of center users, resulting in an overall fluctuation in the average DR.

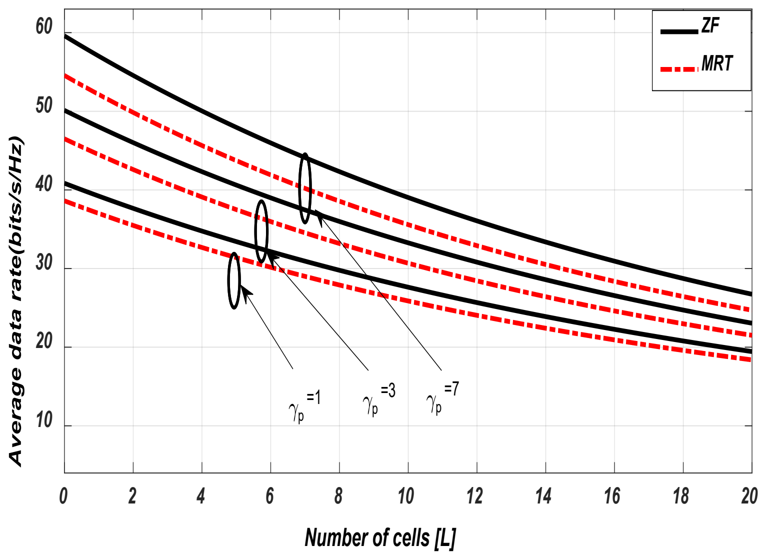

Fig. 4 - Average data rate with number of cells L

Figure 4 illustrates a decrease in the feasible average data rate as the number of cells increases. This reduction in data rate is primarily due to the occurrence of interference when the number of antennas is smaller than the number of cells $M < L$. In such cases, users from different cells utilize the same pilot sequence, resulting in contaminated channel estimation and interference. In order to mitigate the interference caused by pilot contamination, which affects the accuracy of channel estimation at all base stations (BSs), it is necessary to avoid arbitrarily increasing the number of pilot reuse sequences. Limiting the number of pilot reuse sequences helps to minimize the interference and maintain the quality of channel estimation across the BSs. Consequently, this imposed a significant limitation on the calculation of coherence channels, leading to a reduction in the data rate capacity. In multi-cell systems, the allocation of orthogonal PRS to all users in every cell is not feasible due to the limitation of channel coherence intervals. Particularly, for pilot sequences with short coherence intervals, channel estimation becomes more challenging. Additionally, as the number of cells increased, the average data rate declined due to the increase in pilot reuses, further exacerbating the interference and impacting the achievable data rate. For a system with two cells (L=2) and a pilot reuse factor of Y_p =7., the average data rates achieved using both zero-forcing (ZF) and maximum ratio transmission (MRT) precoders were $\mathcal{R}$ =(55.5, 50) bits/s/Hz. However, as the number of cells increased to eighteen (L=18) while maintaining the same pilot reuse factor, the average data rates experienced a decline due to the inherent constraint in coherence channel estimation. In this case, the average data rates dropped to $\mathcal{R}$ =(28.6, 26.2) bits/s/Hz.

4. Conclusion

This paper focuses on the investigation of channel evaluation using orthogonal PRS in a DL multi-cell massive MIMO system. The evaluation MRT and ZF precoders with power control (PC) is presented. In this system, it is crucial to accurately match the received pilot signal from each UE with the corresponding pilot signal associated with that UE for channel estimation. The study identifies the essential constraint in coherence CE, leading to a decline in the average DR. Specifically, with a higher number of cells (L=18), the average DRs were found to be $\mathcal{R}$ = (28.6, 26.2) bits/s/Hz. The numerical findings emphasize the benefits of employing orthogonal PRS in the downlink. These benefits include reduced performance loss, improved channel estimation quality, and increased data throughput.

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