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Review Article

Contemporary Approaches to Mitigate Pilot Contamination in Massive Mimo Systems

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Abstract

Massive Multiple Input Multiple Output (MIMO) is a promising technology for meeting the demand of high data capacity for mobile networks in the future. Obtaining channel state information (CSI) in MIMO systems provides energy and spectrum efficiency. Hence, the accuracy of the CSI is very important. Time Division Duplexing (TDD) is a good alternative method to obtain CSI in Massive MIMO systems. Pilot sequences are used to obtain CSI. In practice, it is not possible to assign a different pilot sequence to each user terminal. In particular, the use of the same pilot sequences in different cells in Massive MIMO systems causes the problem of pilot contamination. Many studies have been conducted in an attempt to mitigate this problem. In this study, the reasons for pilot contamination are discussed and the methods proposed in the literature for eliminating or mitigating pilot contamination are presented. In addition, the case of pilot contamination-related security in Massive MIMO and other related issues that may be important in future systems are highlighted.

Keywords: Pilot Contamination (PC) Mitigation, Massive MIMO Systems, Channel State Information (CSI), Time Division Duplex (TDD), Frequency Division Duplex (FDD).

Büyük Ölçekli Mimo Sistemlerde Pilot Kirliliğini Azaltmaya Yönelik Çağdaş Yaklaşımlar

Öz

Büyük Çoklu Giriş Çoklu Çıkış (MIMO), gelecekte mobil ağlar için yüksek veri kapasitesi talebini karşılamak için umut verici bir teknolojidir. MIMO sistemlerinde kanal durum bilgisinin (CSI) elde edilmesi, enerji ve spektrum verimliliği sağlar. Bu nedenle, CSI'nin doğruluğu çok önemlidir. Zaman Bölmeli Çift Yönlendirme (TDD), Massive MIMO sistemlerinde CSI elde etmek için iyi bir alternatif yöntemdir. CSI elde etmek için pilot diziler kullanılır. Pratikte, her kullanıcı terminaline farklı bir pilot dizisi atamak mümkün değildir. Özellikle Massive MIMO sistemlerinde farklı hücrelerde aynı pilot dizilerin kullanılması pilot kontaminasyonu sorununa neden olmaktadır. Bu sorunu azaltmak için birçok çalışma yapılmıştır. Bu çalışmada, pilot kontaminasyonunun nedenleri tartışılmakta ve pilot kontaminasyonunu ortadan kaldırmak veya azaltmak için literatürde önerilen yöntemler sunulmaktadır. Ayrıca, Massive MIMO'da pilot kontaminasyonla ilgili güvenlik durumu ve gelecekteki sistemlerde önemli olabilecek diğer ilgili konular vurgulanmıştır.

Anahtar Kelimeler: Pilot Kirliliğini Azaltma, Büyük Ölçekli Çok Girişli Çok Çıkışlı Sistemler, Kanal Kestirimi Bilgisi, Zaman Bölmeli Çift Yönlendirme, Frekans Bölmeli Çift Yönlendirme

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1. Introduction

One of the biggest reasons for developing wireless communications is the constantly increasing user demand. The existing systems are not sufficient to meet these needs. To meet these demands, the next-generation 5G technology is expected to make improvements in issues such as latency reduction, data rate increase, energy saving, cost reduction and spectrum efficiency. The usage of wireless Massive MIMO systems is very important for these improvements in 5G systems. The Massive MIMO system is a technology with many users and with many antennas in the receiver and/or transmitter. This technology promises hope for the future and recently, studies in this area have increased.

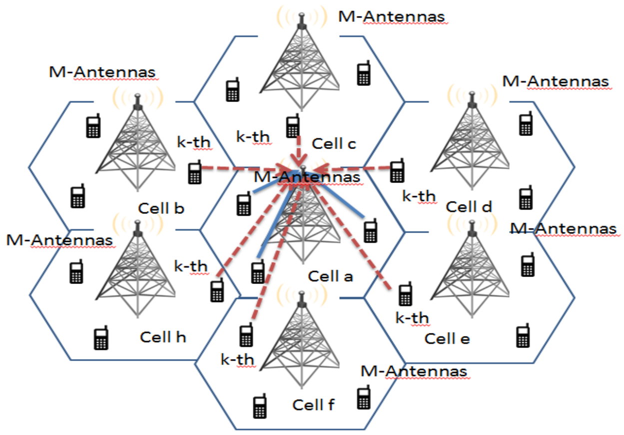

Fig. 1 Pilot contamination problem in Massive MIMO systems (Pilot reuse factor: 1).

This paper also presents the advantages and challenges of Massive MIMO systems. Major advantages of Massive MIMO systems include increased energy and spectral efficiency, reduced cost and air interface latency, a simplified multiple access layer, wireless communication robustness, and the simplicity and optimality of radio frequency (RF) linear pre-decoders and detectors. For this reason, the number of base station (BS) antennas is greater than that of the users (UTs) [1]. In contrast to these advantages, there are also some challenges. These include requiring transceiver calibration, obtaining channel state information (CSI) in a timely manner, fast processing algorithms aganist pilot contamination and RF chains, and orthogonality of radio propagation and responses [1].

This study especially focuses on the problem of pilot contamination. Pilot contamination limits the performance of Massive MIMO systems.

It is difficult to obtain CSI in the channel estimation phase due to the pilot contamination problem, as seen in Figure 1. Therefore, it would be very difficult to determine the advantages of a system in which accurate CSI cannot be obtained. There are many ways to obtain CSI, including pilot methods, semi blind algorithms and blind methods. Various successful methods proposed to date are presented in the overview in this study. In this study, more recent research and security-related works are also included in the examination of the pilot contamination problem. At the same time, topics for consideration in future studies have been suggested.

1.1. Channel Estimation and Duplexing Methods

In Massive MIMO, CSI acquired by the BS provides superior performance in energy and spectrum efficiency [2]. The CSI describes the characteristics of the channel. It is very important to determine the channel coefficients and obtain accurate CSI using channel estimation (CE). The channel estimation is made in the receiver and provides the channel impulse response. For this reason the estimated value is sent to the transmitter. This involves the use of system resources (time, bandwidth, spatial size, power level, etc.) [3]. The CSI needs to be obtained by the transmitter. Channel estimation is intended to reduce the effects that limit system performance such as inter-symbol interference (ISI), inter-carrier interference (ICI) and multi-path fading. Obtaining the accurate CSI provides high network efficiency, which is also important in the channel estimation phase.

The notations and definitions used here are given in Table 1.

Channel state information is needed in the Massive MIMO system BS. For this reason, two types of communication schemes, TDD and FDD, are mentioned with further details.

Table 1. Notations and definitions [4].

Notation	**Description**
$(.)^T$	Transpose operation
$(.)^H$	Hermitian of matrix
$(.)^*$	Conjugate of matrix
var(.)	Variance operation
Bold font upper case	Matrices
Bold font lower case	Vectors
C	Set of complex numbers

1.1.1. TDD Scheme

In the time division duplex (TDD) systems, data are transmitted between the BS and the UT in the same frequency band in different time slots. In TDD protocol, data transmission is divided into uplink (UL) and downlink (DL) parts, as in Figure 2. The UL and DL data transmissions use the same frequency band at different times. Moreover, the TDD system data are transmitted in half the time period needed by the FDD system. In addition, TDD systems do not require frequency multiplexing [5].

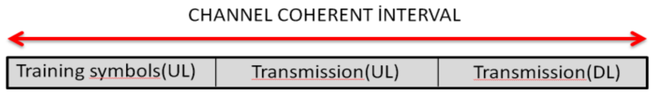

Fig.2 TDD transmission protocol.

Thus, the TDD scheme is a good option for obtaining CSI in Massive MIMO systems. Pilot sequences are used to find the CSI at the CE phase, which increases overhead. Based on the mutuality of the channels in TDD mode, obtaining only one CSI is enough for each terminal, so it can be used in both links and the process overhead is reduced [6].

1.1.2. FDD Scheme

In the frequency division duplex (FDD) scheme, UL and DL data between the base station and the users are transmitted in different frequency bands in the same time slot. The UL and DL data do not interfere with each other when they are transmitted. In addition, a multiplexer is needed [5]. In Massive MIMO systems, the TDD scheme is a much better way to obtain CSI compared to the FDD transmission scheme. Different CSI obtained in the UL and DL parts increases the processing load in Massive MIMO systems and feedback is needed for the downlink [6]. However, due to the limited resources of this feedback load, it is difficult to implement it in practice. The TDD or FDD modes can be used during the CE phase. There are advantages and disadvantages with both modes. When a study for a Massive MIMO system is planned, selection of the TDD mode is more advantageous because it reduces the feedback load.

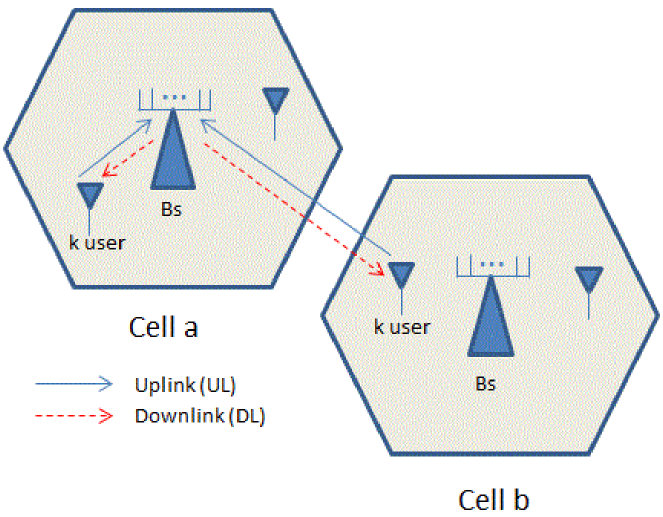

Fig. 3 Occurrence of pilot contamination in Massive MIMO system uplink and downlink transmission.

1.2. Commonly Used System Models

In the literature, a Massive MIMO system consists of L number of cells (number of BSs) and M ≥ K antennas (K = number of single antenna users) [2].

As seen in Figure 3, when pilot contamination occurs, the propagation factor from the user *k* in cell *b* to the antenna *m* in cell *a* is given as Equation (1):

$$g_{a,b,k,m} = \sqrt{\beta_{a,b,k}}\, h_{a,b,k,m}. \quad (1)$$

where $h_{a,b,k,m}$ is the small-scale fading factor and independent and identically distributed (i.i.d) and circularly symmetric complex Gaussian *CN* (0.1) random variable; $\beta_{a,b,k}$ is the large-scale fading factor. Channel matrices of all the BS antennas in cell *a* and all K users in cell *b* are expressed as Equations (2), (3) and (4) [2]:

$$\mathbf{G}_{a,b} = \sqrt{\mathbf{D}_{a,b}}\,\mathbf{H}_{a,b} = \begin{pmatrix} g_{a,b,1,1} & \cdots & g_{a,b,k,1} \\ \vdots & \ddots & \vdots \\ g_{a,b,1,m} & \cdots & g_{a,b,k,m} \end{pmatrix} \quad (2)$$

where

$$\mathbf{H}_{a,b} = \begin{pmatrix} h_{a,b,k,m} & \cdots & h_{a,b,k,m} \\ \vdots & \ddots & \vdots \\ h_{a,b,k,m} & \cdots & h_{a,b,k,m} \end{pmatrix} \quad (3)$$

and

$$\mathbf{D}_{a,b} = \begin{pmatrix} \beta_{a,b,1} & & \\ & \ddots & \\ & & \beta_{a,b,k} \end{pmatrix} \quad (4)$$

1.2.1. Uplink (UL) Training Phase

The CSI is obtained by the pilot sequences with the length of τ transmitted over the uplink to the base station from the users. It is shown as in Equation (5):

$$\varphi_b{}^H \varphi_b = \tau \boldsymbol{I}, \quad (5)$$

where $\boldsymbol{\varphi_b}$ represents pilot sequences and the orthogonal matrix, as shown in Equation (6) [2]:

$$\varphi_b = [\varphi_{b,1}\,\varphi_{b,2} \ldots\ldots\, \varphi_{b,K}]_{\tau \times K} \quad (6)$$

The received signal from the base station in cell *a* is expressed as Equation (7):

$$\boldsymbol{Y_a} = \sqrt{p_u}\sum_{j=1}^{L} \boldsymbol{D}_{a,j}^{1/2}\boldsymbol{H}_{a,j}\boldsymbol{\varphi}_{a,j}^{\boldsymbol{T}} + \boldsymbol{N}_a \quad (7)$$

where $\boldsymbol{N}_a$ is the additive noise matrix whose elements are *CN*(0.1) random variables and p_u is the average transmission power of each user on the UL [2].

1.2.2. Downlink (DL) Transmission

The received signal by the *k*th user cell *b* is expressed as Equation (8):

$$\boldsymbol{Z_b} = \sum_{l=1}^{L}\sqrt{\boldsymbol{p_d}}\,\boldsymbol{D}_{b,l}^{1/2}\boldsymbol{H}_{b,l}\boldsymbol{A}_l\boldsymbol{s}_l + \mathbf{n_b} \quad (8)$$

where $\boldsymbol{p}_d$ is the average transmission power at the *k*th user of the BS on the DL, $\boldsymbol{A_l} = f(\widehat{H_l})$ *as* the M×K precoding matrix and $\widehat{H_l}$ represents the channel estimate; s_a is the transmitted information signal to the *k*th user from the BS in cell *a* and $s_a = [\, s_{a,1} s_{a,2} \ldots s_{a,k}\,]^T$ is shown transposed, where $\boldsymbol{n_b}$ is the additive noise matrix whose elements are *CN(0.1)* random variables and shown as $n_b = [n_{b,1} n_{b,2} \ldots n_{b,K}]$ [2].

1.3. Commonly Used System Models

Although there are advantages in using Massive MIMO systems with multiple antennas, some difficulties arise in this system. One of these is pilot contamination. During the UL training phase, each user transmits pilot sequences at τ length to the BS [7]. The orthogonal pilot sequences are proportional to the number of system terminals. Large pilot sequences affect the data rate due to the channel coherence interval. Hence, it is necessary to reuse the pilot sequences to serve more terminals and increase the efficiency of the system. Since there is a limited number of bandwidths and constraints such as coherence intervals, an unlimited number of pilot sequence assignments cannot be achieved, i.e., the pilot reuse factor is 1. When the worst case scenario is considered, the same pilot sequences are transmitted to all BSs by all users at the same time in L cells. The transmitted pilot signals are contaminated at the BS. However, since the pilot sequences in the same cell are orthogonal to each other, they are ignored. On the other hand, the signals received by the BS from neighboring cells do not show orthogonality and accordingly, pilot contamination occurs in the system, as seen in Figure 3. Ideally, the Massive MIMO system is expected to perform well; however, in practice, it is only occasionally possible as transceiver equipment may be impaired. In this case, the transmitted signal is different from the signal received by the transceiver [8]. Hardware impairments are known to include quadrature imbalance, quantization error, phase noise and non-linearity of the amplifier and phase noise which affects channel estimation [9]. Hence, they mitigate the performance of the pilot contaminated system and affect the presence of CSI, which causes the channel estimation to be incorrectly calculated. Thus, pilot contamination affects system performance and reduces efficiency [9]. However, compensation algorithms are being developed that will improve system performance for each component, taking into account any hardware impairment [8]-[10].

2. Material and Method

2.1. Studies for Mitigating Pilot Contamination

It is assumed that the number of antennas used in Massive MIMO systems is infinite, the channel vectors of the terminals of different channels are orthogonal and noise vectors are also unrelated to channel vectors. Many studies have been conducted on mitigating or eliminating pilot contamination. A list of some of the proposed mitigation methods is presented in Table 2 under the titles of the studies, their assumptions and the applied channel estimation. The proposed methods in these studies were compared with each other and their disadvantages and advantages pointed out in Table 3.

In [11], the proposed method is a time-shifted, pilot-based two-stage channel estimation algorithm to reduce pilot contamination. In the first stage, users in the target cell remain silent over a certain N symbol and the received beamforming vectors are determined in order to reduce the pilot interference and the beamforming is then performed. In the second stage, channel estimation is carried out based on time-allocated pilots. The length of the pilots is set as KL in order that all users will be orthogonal. In this way, the pilot overhead occupies a large part of the coherence time and the data rate is reduced.

In the proposed scheme in [12], pilot sequences are divided into parts and these parts are transmitted in a certain order during the training phase. The most suitable pilot sequence length for a BS is found via coordination among the BSs, thus reducing the mean square error (MSE) sum of all BSs to a minimum. Each base station calculates the MSE by setting different τ sections. These operations create computational complexity at the BS.

In [13], the pilots in the target cell are transmitted in all time periods, while pilots in interfering cells are divided into two parts in the time domain. The proposed scheme considers a compromise solution by implementing partial pilot power control. These operations are based on cooperation among the BSs and therefore cause operational complexity.

Studies [14] and [15] propose a time-shifted, pilot-based scheme in which pilots of interferer cells do not overlap with the target cell. The pilot frames in the cells are replaced by a controller. When compared to the proposed method in [11], the length of the pilot frames is not changed, but only the pilot frame has been replaced. Therefore, while the pilot signal is transmitted in one cell, the other cells transmit downlink data. The downlink data in these interferer cells can partly cause pilot contamination in the target cell. Thus, pilot contamination is not completely eliminated and there is much more cost because of the need for a controller. There are L + 1 transmission phases. Each BS is silent in one phase and in the other phases the pilot signals are transmitted repeatedly [16]. In this proposed scheme, pilot lengths in the L cells orthogonal to each other are sacrificed and the data rate is reduced.

The proposed scheme is shown as an alternative to the time-multiplexed pilot and data symbols. This study assigns a special training sequence to each user in the system in order to estimate the channel vectors in the BS. In this proposed method, the training and data symbols are transmitted side by side throughout the entire uplink data period. A "hybrid system" that uses both time-multiplexed and superimposed trainings is also suggested [17],[18].

The method proposed in [19] is based on a small number of uplink data samples and a limited number of BS antennas. A subspace estimation is inaccurate; therefore, in this case, a more systematic method based on the maximum a-posteriori (MAP) criterion is proposed. Considering the effect of pilot contamination on system performance, in [6], the cells are divided into two parts as edge and center, based on the idea of the reduction of the used system terminal during the channel estimation phase of the same pilot sequence. The advantages of the asynchronous pilot transmission (APT) and fractional pilot reuse (FPR) methods are recognized and these methods proposed in this scheme. Thus, the number of interfering terminals in the data transmission phase is mitigated and system performance, SINR and capacity are improved.

In some cases it may be difficult or even impossible to obtain a method that completely divides user channels. For this reason, in [20], a predetermined angular adjustment method is used to match the desired users and an optimal spatial area method using a beam pattern with angular adjustment is proposed. Although the pilot contamination is mitigated with the scheme in this study, pilot contamination can be further reduced. The study was also conducted to improve system performance [20].

The study in [4] was done to mitigate pilot contamination using a method based on fast channel estimation and diagonal jacket matrices. In this study, jacket matrices are created to

Table 2. Summary of some proposals for training methods.

References	Proposed Method	Assumptions	Applied Channel Estimation
[11], [14], [15]	Time shifted scheme in which the pilot sequences in all cells do not overlap	The users in the interference cells are receiving the DL data while the target user transmits the pilot sequence.	NMSE, LMMSE
[12]	The training phase is divided into several parts and the pilot transmission sequence is staggered	By coordinating among the base stations, the optimal length of the pilot sequences can be found by reducing the channel estimation MSE sum of all base stations to the minimum.	MSE
[13]	Improved partial pilot power control scheme.	A compromise solution by implementing partial pilot power control.	MMSE
[16]	Consists of consecutive pilot transmission phases	Each base station composed of L + 1 phases is kept silent in one phase and transmits the pilot sequence continuously in the other phases.	NMSE
[17],[18]	Superimposed pilot scheme	Each user in the system has a unique pilot sequence to estimate the channel vectors in the base station.	Non-iterative Data - Aided
[19]	Conventional pilot scheme	This method is applied if there are a small number of uplink data samples and a limited number of base station antennas	MAP

improve system performance and channel accuracy and to reduce energy consumption and computational complexity.

In [21], covariance-aided channel estimation is proposed in the context of a limited interference, multi-cell and multi-antenna system. Bayes estimation is developed and the analytical effectiveness of this approach demonstrated. A coordinated pilot assignment strategy is proposed. The proposed co-ordinated channel estimation method involves exchange of information among BSs, and although statistical data from the 2nd level will change slowly from the instantaneous CSI, the BS covariance information will need to be updated to maintain performance.

In [22], a game-theoretical approach is proposed that models pilot assignment methods. Selection of BS pilot interactions in Massive MIMO systems is proposed. The problem is modeled as an optimization problem. It was shown that total contamination was significantly reduced in Massive MIMO systems by using the game-theoretical pilot selection method to increase the accuracy of the channel estimation phases.

A pilot assignment algorithm is proposed in [23] that can maximize the achievable minimum level in the target cell by monitoring the information obtained. When the number of interfering cells is large, the proposed algorithm was shown to be superior compared with both the sum-product algorithm (SPA) and random allocation.

In [24], the effects on the security performance of pilot contamination with artificial noise were examined by introducing a different perspective to the pilot contamination effect. This aspect has not been emphasized and is worthy of study. In the established scenario, an eavesdropper is added and it appears that the CE is influenced by the reverse training phase. A power allocation scheme is proposed against pilot contamination and noise jamming. As MIMO systems deal with security issues, it was reported that reducing the clamping force to reduce the generated pilot contamination led to increased privacy in pilot contamination, while also improving noise reduction performance.

The authors of [25] developed a new security attack using reverse training for a precoder design in the case of pilot contamination. In the reverse training, the eavesdropper transmits the same pilot sequence to spoof the correct channel transmitter to be estimated. It is also important to synchronize the intended receiver with the eavesdropper. For this reason, in the reverse training phase, the eavesdropper transmits the pilots at the same time as the intended receiver transmits. However, there is no information on when and how synchronization occurs. It was shown that the isolation of user channels was very difficult or impossible in some cases.

Table 3. Some proposed methods compared.

Reference	Proposed Method	Remarks
[22]	Game-theoretical approach that models pilot assignment method	Channel estimation accuracy and reduced total pilot contamination
[23]	Proposes a pilot allocation scheme for the pilot sequences	Improved spectral efficiency and performance and the lowest achievable rates were developed with the proposed method. When the number of interfered cells was large, it was seen as superior.
[24]	Considers the power allocation scheme	The effects on security performance of pilot contamination with artificial noise were examined.
[25]	A new security attack using reverse training to obtain the CSI at the transmitter for precoder design	Efficient use of transmission energy and strengthened signal reception at the eavesdropper were observed.

System performance is improved with less complexity against pilot contamination by suggesting a practical temporal domain-based method without coordination, which is the strongest channel impulse response (CIR) as effective channel information. The flexibility of the proposed method is seen when compared to the pilot contamination coordination-based schemes in [26].

In [27], the Adaptive Pilot Approach (APA) algorithm is proposed to counteract the problem of pilot contamination by using the training sequences in different cells. With this proposed algorithm, the system users are divided into two and normal pilot allocation is made to the users who have low interference while allocating the orthogonal pilot to the users who cause high interference. The number of normally used orthogonal pilots is 18, which is reduced to 11 thanks to this algorithm, for a scenario in which the number of pilot symbols used is 6. The APA algorithm provides more system performance for the CR period and at the same time provides about three times the minimum achievable rate compared to the conventional allocation method for 50% of the time. Hierarchical pilot reuse schemes to mitigate the pilot contamination problem most effectively are proposed by the method in [28], which aims to improve system performance. In [29], the effects of signal/noise ratio (SNR) and the user channel fading coefficients on the approximation ratio of a multiuser Massive MIMO system are analysed and the influence of the signal-to-interference-plus-noise ratio (SINR) convergence ratio on pilot contamination are examined when the number of antennas in the BS is approaching infinity. The SINR value was seen to increase directly in proportion to the number of antennas without the effect of pilot contamination. It was demonstrated that if the pilot contamination is less, when the variance is greater than one, the SINR in the base station is less.

Rayleigh fading with an infinite number of antennas needs to be considered with the effect of pilot contamination, which limits noise and system performances. It was found that the SINR value was saturated at a certain number of antennas. It was stated in [29] that this depends only on the fading coefficients of the desired user and the interacting channels.

The study in [30] aimed to reduce the problem of pilot contamination by aligning the power spectra of different users under doppler fading. The channel estimation is performed using the MSE method.

In [31], the authors propose a hybrid pilot assignment scheme. This hybrid structure was formed by combining soft. In this method, users are divided into two as cell centered and edge users. To reduce pilot contamination for the edge users especially, the authors added the weighted-graph-based method. The proposed hybrid structure was compared with SPRS, WGC-PD and random pilot assignments and significantly reduced pilot contamination.

In [32], authors attempted to achieve an optimal solution using the Hungarian Algorithm with minimum-weight multi-index assignment problem approach. In this article, a two-cell systems with optimal solution and multicellular systems with suboptimal solution have been identified. This study, which was conducted to reduce pilot contamination, showed a superior performance compared to some other conventional methods.
Authors of [33] propose the asynchronous scheduling, based on the fractional pilot reuse enables the users to be free from the pilot contamination throughout the uplink transmission. According to the level of interference between users, the users are divided into two groups are center users and edge users.

These Center users suffer from the mild pilot contamination while edge users suffer from severe pilot contamination. In this distinction, all center cell users reuse cell center pilot sequences while the edge users use cell edge pilot sequences in adjacent cells. That is to say cell edge users use ortgonol pilot sequences to each other. Thus the pilot sequences can be transmitted by the edge users any time. However, pilot sequences are transmitted in the non-overlapped time periods by the cell center users to prevent the pilot contamination. By using this schedule, each cell uses less orthogonal pilots sequences.

In [34], the pilot sequence users are divided into two groups. These are center users and edge users. Orthogonal pilot sequences are used for the edge users.

Table 4. Summary of some proposals for mitigating pilot contamination.

Reference	Proposed Methods	Assumptions	Performance Analysis
[21]	A scheme using the advantages of APT and FPR	A similar approach in UL for perceiving received signals allows the creation of a noisy and noise-free system in an asymptotic regime.	SINR and capacity
[20]	A scheme that uses a beam pattern with angular adjustment	To match the UL path, an angular, tunable predetermined beam pattern is used, and then used as the DL phase beam vector.	High performance is achieved with the proposed scheme to design the beam cover.
[4]	A study based on diagonal jacket matrix	The transmitter can trust the channel statistics: therefore, the receiver estimates the statistics and sends them back to the transmitter. In the TDD system, the transmitter can also rely on UL data.	Improved speed and performance and reduced complexity
[26]	A practical temporal domain-based method	One user per cell, unless otherwise stated	Method flexibility and SNR to total capacity comparison
[33]	Asynchronous scheduling, based on the fractional pilot reuse	According to the level of interference between users, the users are divided into two groups. Pilot sequences are transmitted in the non-overlapped time periods by the cell center users to prevent the pilot contamination.	By using this schedule, each cell uses less orthogonal pilot sequences.
[34]	A scheme based on Hungarian algorithm	find a solution to pilot assignment ,the hungarian algorithm is applied in each divided area	elimanetes the pilot contamination and the sum rate in the system is maximized.
[35]	Deep Learning Based Pilot Allocation Scheme	learning the relationship which is between the pilot assignment and location pattern of users.	achieves almost 99.38% theoretical upperbound performance and shows less complexity.
[36]	Hybrid pilot assignment	large-scale fading coefficients are assumed to change slowly in order to have block fading	offers a reduction in the number of users that cannot be improved on the basis of pilot contamination
[37]	Pilot assignment using ant colony optimization method	edge users‘ pilot sequences are assigned orthogonal to each other	higher SINR-CDF and user transmit power performance are achieved
[38]	Combines pilot allocation with semi-blind channel estimation methods	sector-based pilot allocation	enhances the system achievable rates and the normalized mean square error performance
[39]	An efficient pilot allocation scheme using a weighted graphic framework	mapping to the Max k-Cut problem	important improvement in throughput with low complexity
[40]	Formulating max-min sum spectrum efficiency per user optimization	for cellular Massive MIMO systems with correlated Rayleigh channels	preferable minimum sum SE per user

After that, in order to find a solution to pilot assignment, the hungarian algorithm is applied in each divided area. By this way this method elimanetes the pilot contamination and the sum rate in the system is maximized. The researchers of [35] proposed Deep Learning Based Pilot Allocation Scheme (DL-PAS) based on learning the relationship which is between the pilot assignment and location pattern of users. In this method, input features are the locations of users in all cell and output labels are pilot assignment. Researchers analyze training data for optimal pilot assignment and use a commercial deep multilayer perceptron system to implement this method. The proposed scheme achieves almost 99.38% theoretical upperbound performance and shows less complexity. In [36], hybrid pilot assignment method is proposed. The hybrid scheme proposed here is created by combining SPRS (Soft Pilot Reuse Scheme) and Munkres pilot assignment methods.

In that study, the cell is divided into two as edge and center to increase efficiency. This hybrid pilot assignment method offers a reduction in the number of users that cannot be improved on the basis of pilot contamination. Authors of [37] propose pilot assignment using ant colony optimization (ACO) method. In this method, edge users' pilot sequences are assigned orthogonal to each other but for the center users, pilot sequences are assigned using ACO in order to get minimum pilot contamination.

This proposed method provides higher SINR-CDF and user transmit power performance.

In [38], combining pilot allocations with semi-blind channel estimation method is proposed. To reduce the search complexity for optimal pilot allocation under conditions of large number of users per cell, the authors also added a sector-based pilot allocation. The average uplink achievable rate is enhanced, and the system NMSE is abated with this method.

The researchers of [39] proposed an efficient pilot allocation scheme using a weighted graphic framework for the cell-free massive MIMO systems. Transforming to the Max k-Cut offers solution and important improvement in throughput with less complexity.

In [40], maximizing the minimum weighted sum of the uplink and downlink spektrum efficiencies (SE) subject to the transmit powers and pilot allocation sets method is proposed. It is indicated that important enhancements of pilot allocations to the minimum sum SE per user compared with the other related works.

A summary of some of the proposed methods formitigating pilot contamination is given in Table 4.

2.2. Open Issues

Since pilot contamination is due to interference of other neighboring cells at the training transmission phase, high-frequency reuse factors are used during this phase to reduce this problem. Along with this, the spectral efficiency is reduced by decreasing the pre-registration factor. For this reason, cell size needs to be increased.

Here, because of path loss, with a large-sized cell the power of the desired signal in a particular target cell is much stronger than the power of the interferer from other cells. Due to the large cell size and path loss, service for users at the cell edge is not good. In the training phase, a power control scheme should be investigated to increase the battery life and to reduce the frequency reuse factor and consequently, the problem of pilot contamination [10].

2.2.1. Training Overhead

Uplink training sequences are needed when CSI is obtained during the channel estimation phase. However, since the training sequences are continuously transmitted, the training overhead is generated at the BS. This suggests that system performance should be improved.

2.2.2. Cost

Some of the studies have proposed that the number of antennas must be higher than the number of users in order to reduce training contamination. This is a cost burden, even though the number of antennas in the BS is considered unlimited. Methods of working with fewer base stations and antennas should be researched.

2.2.3. Energy Consumption

Studies should be carried out to reduce the transmission power consumption used by the training sequences during the channel estimation phase in order to obtain the CSI.

2.2.4. Processing Complexity

Attempts should be made to simplify the processing by reducing the processing complexities of the methods used in the channel estimation step and the mathematical operations used in obtaining the system channel coefficient of the transmitted data and symbols.

2.3. Future Trends

In the future, researchers wishing to work in this field should carry out further investigations of pilot contamination and security issues in Massive MIMO systems. In future studies, a special training design should be created to learn second order statistical information [6]. As mentioned in [4], single-carrier transmission is recommended in Massive MIMO systems and the scheduling process should be further simplified. It should not be forgotten that the amount of interference caused by other BSs and the amount of interference caused by the mobile terminal (MT) on its own BS is not the same. Pilot processing via a central control unit has already met the latest wireless communication standards and has facilitated the implementation of the method used in [21].

3. Conclusions and Recommendations

Although there is still no certainty about TDD and FDD modes in 5G networks at present, that no feedback is required in the TDD scheme was seen as more advantageous for Massive MIMO systems. The topics of TDD and FDD were addressed on these points. With the aim of identifying pilot contamination and reducing or eliminating this problem, literature reviews were carried out and studies investigated. A number of topics such as advantages, disadvantages and channel estimation using the proposed methods were examined. The topics that should be studied in the future were emphasized. Reducing the problem of pilot contamination, however, must be achieved in conjunction with new studies.

References

ELIJAH, O. LEOW, C. Y. THAREK, A. NUNOO, S. ILIYA, S.Z. Mitigating Pilot Contamination in Massive MIMO System - 5G: An Overview. In: *IEEE 10th Asian Control Conference (ASCC)*. Kota Kinabalu, 2015, pp. 1–6. ISBN 978-192210721-3.

[1] ELIJAH, O. LEOW, C. Y. THAREK, A. NUNOO, S. ILIYA, S.Z. A Comprehensive Survey of Pilot Contamination in Massive MIMO-5G System. In:*IEEE Communications Surveys & Tutorials*. 2016, vol. 18, iss. 2, pp. 905 – 923.**ISSN** 1553-877X. **DOI:** 10.1109/COMST.2015.2504379.

[2] SOYSAL, A. MIMO Systems with Non-exact CSI. In: *IEEE 18th Signal Processing and Communications Applications Conference (SIU).* Diyarbakir 2010, pp. 531 – 534. **ISBN** 978-1-4244-9671-6. **DOI:** 10.1109/SIU.2010.5653390.

[3] SARKER, M.A.L., LEE, M.H. A fast channel estimation and the reduction of pilot contamination problem for Massive MIMO based on a diagonal Jacket matrix. *IEEE 4th International Workshop on Fiber Optics in Access Network (FOAN)*. 2013, pp 26-30. ISSN 2378-8488. **DOI:** 10.1109/FOAN.2013.6648821.

[4] BANDIRMALI, N. ÇEKEN, C. BAYILMIŞ, C. ERTURK, İ. Kablosuz Erişim Yöntemlerinin Karşılaştırmalı İncelenmesi. *Elektrik, Elektronik, Bilgisayar Mühendisliği 11. Ulusal Kongresi EMO* , İstanbul ,2005 pp 95-98.

[5] BADIR, M.M., FOUDA, M.M., TAG ELDIEN, A.S. A novel vision to mitigate pilot contamination in Massive MIMO-based 5G networks. *IEEE 11th International Conference on Computer Engineering & Systems (ICCES)* . Cairo,2016, pp366-371. **DOI:** 10.1109/ICCES.2016.7822031

[6] SAXENA, V. *Pilot Contamination and Mitigation Techniques in Massive MIMO Systems*. LTH, 2014. PhD thesis. Department of Electrical and Information Technology Lund University. Supervisor: Dr. Eleftherios Karipidis, Dr. Gábor Fodor

[7] BJÖRNSON, E., HOYDIS, J. KOUNTOURIS, M. Massive MIMO Systems With Non-Ideal Hardware: Energy Efficiency, Estimation, and Capacity Limits. *IEEE Journals & Magazines, IEEE Transactions on Information Theory*. 2014, vol. 60, iss.11, pp.7112-7139. **ISSN:** 0018-9448. **DOI:** 10.1109/TIT.2014.2354403.

[8] ABBOUD, A. (2017). *Interference Mitigation in 5G Mobile Networks Uplink Pilot Contamination in TDD Massive MIMO Scheme*. France, 2017. PhD thesis, Université de Limoges.. Supervisor: Jean-Pierre Cances, Ali Jaber et Vahid Meghdadi.

[9] ALQAHTANI, A.H. SULYMAN, A.I. ALSANIE, A. 2016. Rateless space–time block code for mitigating pilot contamination effects in multi-cell Massive MIMO system with lossy links. *IET Journals & Magazines, IET Communications*. 2016 vol .10, iss. 16, pp 2252-2259. **ISSN:** 1751-8636**DOI:** 10.1049/iet-com.2016.0283

[10] WU, L. ZHANG, Z. DANG, J. Enhanced Time-shifted Pilot based Channel Estimation in Massive MIMO Systems with Finite Number of Antennas. *2017 IEEE International Conference on Communications Workshops (ICC Workshops)*. Paris, 2017. pp 222-227. **ISBN:** 978-1-5090-1525-2.DOI:10.1109/ICCW.2017.79 62661.

[11] WANG, H., YANG, L., ZHU, H. Pilot contamination reduction based on MSE performance of channel estimation. *IEEE International Conference on Wireless Communications & Signal Processing (WCSP),* Nanjing, 2015. pp 1-5. **ISBN:** 978-1-4673-7687-7 DOI: 10.1109/WCSP.2015.7341048

[12] MA, S., JIANG, S., LONG, T. Pilot contamination reduction based on improved power control in M-MIMO systems. *IET Conferences, 11th International Conference on Wireless Communications, Networking and Mobile Computing (WiCOM)*, Shanghai 2015.pp1-6.**ISBN:** 978-1-78561-035-6 **DOI:** 10.1049 /cp . 2015.0705

[13] APPAİAH, K., ASHİKHMİN, A., MARZETTA, T.L. Pilot Contamination Reduction in Multi-User TDD Systems. *IEEE Conferences, 2010 IEEE International Conference on Communications*, Cape Town, 2010. pp 1-5. **ISBN:** 978-1-4244-6404-3.**DOI:** 10.1109/ICC.2010. 5502810

[14] MAHYIDDIN, W.A.W.M., MARTIN, P.A., SMITH, P.J. Pilot Contamination Reduction Using Time-Shifted Pilots in Finite Massive MIMO Systems. *IEEE Conferences, 2014 IEEE 80th Vehicular Technology Conference (VTC2014-Fall).* Vancouver, 2014 pp1-5. **ISBN:** 978-1-4799-4449 **DOI:** 10.1109/VTCFall.2014.6966130

[15] VU, T.X., VU, T.A., QUEK, T.Q.S. Successive Pilot Contamination Elimination in Multiantenna Multicell Networks. *IEEE Journals & Magazines, IEEE Wireless Communications Letters*. 2014 vol. 3, iss. 6, pp 617-620. **ISSN:** 2162-2345. **DOI:** 10.1109/LWC.2014.2361518.

[16] UPADHYA, K., VOROBYOV, S.A., VEHKAPERA, M. (2016). Superimposed pilots: An alternative pilot structure to mitigate pilot contamination in Massive MIMO. *IEEE Conferences, 2016 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP)*. Shanghai 2016. pp 3366-3370. **ISBN:** 978-1-4799-9988-0 **DOI:** 10.1109/ICASSP.2016.7472301

[17] UPADHYA, K., VOROBAYOV, S.A., VEHKAPERA, M. Superimposed Pilots Are Superior for Mitigating Pilot Contamination in Massive MIMO. *IEEE Journals & Magazines, IEEE Transactions on Signal Processing*, vol. 6, iss. 11, 2017 pp 2917-2932. **ISSN:** 1941-0476. **DOI:** 10.1109/TSP.2017.2675859.

[18] NEUMANN, D., JOHAM, M., UTSCHICK, W. Suppression of pilot contamination in Massive MIMO systems. *IEEE Conferences, 2014 IEEE 15th International Workshop on Signal Processing Advances in Wireless Communications (SPAWC)*, Toronto 2014 pp 11-15. **ISBN:** 978-1-4799-4903-8 **DOI:** 10.1109/SPAWC. 2014.6941307.

[19] WANG, H., PAN, Z., NI, J. A spatial domain based method against pilot contamination for multi-cell Massive MIMO systems. *IEEE 8th International Conference on Communications and Networking in China (CHINACOM).* Guilin 2013 pp 218-222. **ISBN:** 978-1-4799-1406-7. **DOI:** 10.1109/ChinaCom.2013.6694594

[20] YIN, H., GESBERT, D., FILIPPOU, M. A Coordinated Approach to Channel Estimation in Large-Scale Multiple-Antenna Systems. *IEEE Journal on Selected Areas in Communications* ,vol. 31, iss. 2, 2013. pp 264-273. **ISSN:** 1558-0008 **DOI:** 10.1109/JSAC.2013.130214.

[21] AHMADI, H., FARHANG, A., MARCHETTI, N. A Game Theoretic Approach for Pilot Contamination Avoidance in Massive MIMO. *IEEE Journals & Magazines, Wireless Communications Letters* 2016. vol. 5, iss. 1, pp 12-

15. **ISSN:** 2162-2345 **DOI:** 10.1109/LWC.2015.2487261.

[22] ALKHALED, M., ALSUSA, E., HAMDI, K.A. A New Allocation Algorithm for Pilot Contamination Mitigation in TDD Massive MIMO Systems. *2017 IEEE Wireless Communications and Networking Conference (WCNC)*. San Francisco 2017. pp 1-6. **ISBN:** 978-1-5090-4183-1. **DOI:** 10.1109/WCNC.2017.7925938.

[23] LIN, S., HUANG, K., LUO, W. Analysis of Pilot Contamination on the Security Performance of Artificial Noise in MIMO Systems. *2015 IEEE 81st Vehicular Technology Conference (VTC Spring)*. Glasgow 2015. pp 1-5. **ISBN:** 978-1-4799-8088-8 **DOI:** 10.1109/VTCSpring.2015.7145701.

[24] ZHOU, X., MAHAM, B., HJORUNGNES, A. Pilot Contamination for Active Eavesdropping. *IEEE Transactions on Wireless Communications*, vol. 11, iss. 3,2012 pp 903- 907. **ISSN:** 1558-2248 **DOI:** 10.1109/TWC.2012.020712.111298.

[25] WANG, H. PAN, Z. NI, J. A Temporal Domain Based Method against Pilot Contamination for Multi-Cell Massive MIMO Systems. *2014 IEEE 79th Vehicular Technology Conference (VTC Spring)*, Seoul 2014. pp 1-5. **ISBN:** 978-1-4799-4482-8 **DOI:** 10.1109/VTCSpring.2014.7022799.

[26] ALKHALED, M. ALSUSA, E. HAMDI, K.A. Adaptive Pilot Allocation Algorithm for Pilot Contamination Mitigation in TDD Massive MIMO Systems. *2017 IEEE Wireless Communications and Networking Conference (WCNC)*, San Francisco 2017. pp 1-6. ISBN: 978-1-5090-4183-1. DOI: 10.1109/WCNC.2017.7925885.

[27] SOHN, J. Y. YOON, S.W. MOON, J. On Reusing Pilots Among Interfering Cells in Massive MIMO. *IEEE Journals & Magazines, IEEE Transactions on Wireless Communications*, vol. 16, iss. 12, 2017 pp 8092-8104. ISSN: 1558-2248. **DOI:** 10.1109/TWC.2017.2756927

[28] GOPALAKRISHNAN, B. JINDAL, N. An Analysis of Pilot Contamination on Multi-User MIMO Cellular Systems with Many Antennas. *Signal Processing Advances in Wireless Communications (SPAWC), 2011 IEEE 12th International Workshop on San Francisco*. 2011. pp 381-385. **ISSN:** 1948-3252. **DOI:** 10.1109/SPAWC.2011.5990435.

[29] LUO, X. ZHANG, X. Flexible Pilot Contamination Mitigation with Doppler PSD Alignment. ***IEEE Journals & Magazines,*** *IEEE Signal Processing Letters*, 2016 vol. 23, iss.10, pp 1449-1453. **ISSN:** 1558-2361. **DOI:** 10.1109/LSP.2016.2601270

[30] WEINA YUAN., XINKAI YANG., RUI XU. A Novel Pilot Decontamination Scheme for Uplink Massive MIMO Systems. *8th International Congress of Information and Communication Technology (ICICT-2018). Procedia Computer Science 131* 2018 pp 72–79. DOI: 10.1016/j.procs.2018.04.187.

[31] SHUAI MA., EASTON LI XU., AMIR SALIMI., SHUGUANG CUI. A Novel Pilot Assignment Scheme in Massive MIMO Networks. *IEEE Wireless Communications Letters*, 2018 Vol. 7, No. 2. pp 262-265 ISSN: 2162-2345. DOI: 10.1109/LWC.2017.2771285

[32] LIY, Y. CHENY, Y. HUANG, H. JING, X. On Massive MIMO Performance with a Pilot Assignment Approach Based on Hungarian Method. *2016 16th International Symposium on Communications and Information Technologies (ISCIT)*. Qingdao 2016. ISBN: 978-1-5090-4099-5. DOI: 10.1109/ISCIT.2016.7751694.

[33] ZHOU, R. FU, Y. WANG H. Uplink Asynchronous Fractional Pilots Scheduling in Massive MIMO System. *2018 18th IEEE International Conference on Communication Technology*. Chongqing 2018. pp 402 - 406 ISBN: 978-1-5386-7635-6. DOI: 10.1109/ICCT.2018.8600231

[34] KIM, K . LEE, J. CHOI, J. Deep Learning Based Pilot Allocation Scheme (DL-PAS) for 5G Massive MIMO System. *IEEE Communications Society* , 2018. vol. 22, iss.4, Pp 828 - 831. ISSN: 1558-2558 DOI: 10.1109/LCOMM.2018.2803054

[35] KOSE, E.C., KULAÇ, S. Effective Pilot Contamination Mitigation Approach with Hybrid Method in 5G and Beyond Systems. *3rd Scientific and Vocational Studies Congress BILMES 2019*, NEVŞEHİR, TURKEY, 2019

[36] YAYILKAN, A., KULAÇ, S. Effective Pilot Assignment Approach with Ant Colony Optimization in Pilot Contamination Mitigation in Next Generation Mobile Communication Systems. *International Symposium on Academic Studies in Science, Engineering and Architecture Sciences ISMS 2019*, ANKARA, TURKEY, 2019

[37] HU. C. WANG. H. SONG. R "Pilot Decontamination in Multi-Cell Massive MIMO Systems via Combining Semi-Blind Channel Estimation With Pilot Assignment," in *IEEE Access*, vol. 8, pp. 152952-152962, 2020, doi: 10.1109/ACCESS.2020.3015263.

[38] ZENG. W. HE.Y. LI. B. and WANG. S. "Pilot Assignment for Cell Free Massive MIMO Systems Using a Weighted Graphic Framework," in *IEEE Transactions on Vehicular Technology*, vol. 70, no. 6, pp. 6190-6194, June 2021, doi: 10.1109/TVT.2021.3076440.

[39] NGUYEN. T. H., CHIEN T. V., NGO. H. Q., TRAN. X. N., BJÖRNSON E., "Pilot Assignment for Joint Uplink-Downlink Spectral Efficiency Enhancement in Massive MIMO Systems With Spatial Correlation," in *IEEE Transactions on Vehicular Technology*, vol. 70, no. 8, pp. 8292-8297, Aug. 2021, doi: 10.1109/TVT.2021.3091020.