# A Novel Vision to Mitigate Pilot Contamination in Massive MIMO-based 5G Networks

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# A Novel Vision to Mitigate Pilot Contamination in Massive MIMO-based 5G Networks

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***Abstract*—Massive multiple-input multiple-output (MIMO) is one of the promising technologies to be used in the future fifth generation (5G) wireless networks for its capability to increase the system throughput, improve spectral efficiency and energy efficiency. To achieve these benefits of the massive MIMO, there are many challenges that need to be handled. One of these challenges is the pilot contamination problem that arises from reusing pilot sequences among the system cells. Since this problem is considered as a bottleneck of the system performance, it attracted many researchers who proposed schemes to solve it. In this paper, we propose a new scheme that mitigates its effect by adopting both asynchronous pilot transmission (APT) and fractional pilot reuse (FPR). We compare the performance of our proposed scheme with other schemes using computer simulations and show that our proposed scheme enhances the performance of the time division duplex (TDD) multi-cell massive MIMO systems in terms of the signal to interference and noise ratio (SINR) and capacity.**

***Keywords*—*5G Networks, Massive MIMO, Pilot Contamination.***

## I. INTRODUCTION

Due to the continuous increase in the demand for higher data rates and larger capacity and the emergence of new services beyond personal communications, massive multiple-input multiple-output (MIMO) has been proposed as a key technology for the future fifth generation (5G) wireless networks that is capable of increasing the system throughput without purchasing additional bandwidth or increasing the transmitted power [1].

Massive MIMO technology refers to the idea of equipping the base station (BS) with a very large number of antennas to simultaneously serve a smaller number of single antenna terminals using the same time-frequency resources. It has been shown that massive MIMO provides large gains in terms of link reliability, spectral efficiency, and energy efficiency through using simple linear processing techniques [2]. To get the benefits of massive MIMO in practice, the BS must use accurate channel state information (CSI) for uplink (UL) in signal detection phase and for downlink (DL) in precoding phase. There are many ways to get the CSI, namely, training methods [3], semi-blind methods [4], and blind methods [5]. All the training methods require pilot sequences transmission which is considered an efficient way to get the CSI in the channel estimation phase. Channel estimation can be performed in either frequency division duplex (FDD) or time division duplex (TDD) modes.

In FDD mode, the CSI for uplink is different from that of downlink because they use different frequency bands. For downlink, the number of pilot sequences to acquire the CSI is proportional to the number of BS antennas which is very large in massive MIMO system. In addition, since the terminals send the estimated CSI for the downlink to the BS, this pose a large overhead on the system (i.e., time-frequency resources may be exhausted in channel estimation phase leaving fewer or no resources for data transmission). Therefore, the use of massive MIMO in FDD mode is a challenging issue. In TDD mode, with the assumption of channel reciprocity (i.e. the CSI for uplink is the transpose of the CSI for downlink), only the CSI for the uplink which is proportional to the number of terminals is required and it can be used for both uplink and downlink channels. This makes the TDD mode better to be used in massive MIMO systems.

The number of terminals in the system is limited by the number of orthogonal pilot sequences which is limited by the coherence interval regardless of the type of pilot arrangement. To serve more terminals and increase the system throughput, we can reuse the same set of orthogonal pilot sequences in neighboring cells. However, identical pilot sequences from neighboring cells may interfere with each other causing pilot contamination [6]. Contaminated pilot sequences causes inter-cell interference during data transmission phase in both uplink and downlink.

In massive MIMO, as the number of BS antennas tends to infinity, the channel vectors of different terminals can be considered orthogonal, hence the effects of fast fading, uncorrelated noise and intra-cell interference vanish. The only remaining limiting factor is the inter-cell interference caused by pilot contamination which does not vanish even with an unlimited number of BS antennas [6]. Thus, pilot contamination is an important issue that limits the performance of massive MIMO.

In this paper, we propose a novel scheme to mitigate the effect of pilot contamination. Our proposed scheme is based on the idea of decreasing the number of system terminals that use the same pilot sequence simultaneously in the channel estimation phase, specially for cell edge terminals that are severely affected by pilot contamination. Thus, decreasing the number of interfering terminals in data transmission phase and obtaining improved signal to interference and noise ratio (SINR) and capacity.

The rest of the paper is organized as follows. Sec. II presents and categorizes the related work to the pilot contamination problem. Sec. III, presents the TDD multi-cell massive MIMO system model and discusses the problem of pilot contamination. In Sec. IV, we present our proposed scheme. In Sec. V, we present our simulation results which show improvement in terms of SINR and capacity. Sec. VI concludes the paper.

Notations: The transpose of a matrix is denoted by $^T$, the conjugate of a matrix is denoted by $^*$ and the conjugate transpose (Hermitian) of a matrix is denoted by $^H$.

## II. RELATED WORK

The problem of pilot contamination has been recently attracting many researchers who tried to eliminate/reduce its effect on TDD multi-cell massive MIMO systems. We categorize the methods in literature into three categories:

### *A. Methods that try to mitigate the problem while considering full pilot reuse factor of* 1

In [7], [8], a time shifted protocol (TSP) is proposed, in which the system cells are partitioned into groups and the same set of orthogonal pilot sequences is reused among those groups. However, a TSP is used in each group such that terminals from cells in one group transmit pilot sequences to their BSs, while terminals from all other groups receive DL data from their BSs and so on. It has been proved that in the asymptotic regime (i.e. the number of BS antennas tends to infinity), the interference between the pilot sequences and DL data vanishes, and only the terminals using the same pilot sequence in the same group interfere with each other. This results in better performance compared to the synchronous pilot transmission from all system terminals. It has been shown in [8] that using power allocation algorithms (i.e., instead of using the same uplink and downlink transmit powers for all terminals, optimized individual powers can be used for each terminal) provides a more improved performance. This method in [8] seems to be promising, but its performance can be enhanced if a better pilot sequences allocation strategy is used to enhance the low capacity terminals.

Precoding-based methods are proposed in [9], [10]. In [9], a multi-cell minimum mean square error (MMSE)-based precoding scheme is proposed, which takes into account the set of pilot sequences assigned to all the terminals (i.e., takes into account that the channel vectors to terminals in a cell are contaminated by channel vectors to terminals in other cells) to mitigate the pilot contamination effect. The precoding matrix at each BS is designed as the solution of an optimization problem to minimize the sum of the mean-square error of the signals received at the terminals of its own cell and the mean-square interference received at the terminals of all other cells. It has been shown that the proposed method reduces both intra-cell interference and inter-cell interference, and thus providing better performance than conventional single cell precoding methods like zero forcing (ZF) and single cell MMSE precoding. However, the proposed method is suited to be used, if the sum rate is the main performance metric as it assumes that all the terminals are the same without differentiating them based on their channels.

In [10], A. Ashikhmin and T. Marzetta proposed a pilot contamination precoding (PCP) method which requires a collaboration between BSs. The collaboration is based on the following assumptions that all the source signals to all the terminals are accessible to all BSs of the system and the slow fading coefficients can be accurately estimated by each BS and transmitted to all BSs or to a network hub. The network hub computes the PCP precoding matrices and sends to each BS its matrix to use it in beam-forming the transmitted signals. A similar approach is used in UL to detect the received signals. This method allows us to build noise and interference free system in the asymptotic regime. However, there is information exchange overhead due to collaboration between BSs and the effectiveness of this method depends on the accuracy of shared information by BSs and computations made by the network hub.

Angle of arrival (AOA)-based methods are proposed in [11]–[13] and it has been shown that terminals with mutually non overlapping AOA probability density functions hardly contaminate each other even if they use the same pilot sequence. Hence, a coordinated scheme is proposed in [13] to assign identical pilot sequences to those terminals. This scheme reduces the inter-cell interference, and thus increases UL and DL SINRs. However, it requires second order statistics of all the UL channels, so it might be difficult to be implemented in practice.

### *B. Methods that try to mitigate the problem by considering less aggressive pilot reuse factor*

In [6], reuse factors of 3 and 7 are used. Although using less aggressive reuse factors reduces the pilot contamination effect and provides higher SINRs, they provide reduced cell throughput compared with a reuse factor of 1. In [14], a pilot sequence allocation strategy is proposed, where identical pilot sequences sets are assigned to center terminals (i.e., reuse factor of 1) and mutually orthogonal pilot sequences sets are assigned to edge terminals (i.e., reuse factor of 3) in different cells. The simulation results in [14] show that this proposed strategy provides higher system capacity compared to uniform reuse strategies. This method seems to be promising, but its performance can be highly enhanced if we use asynchronous pilot transmission (APT).

### *C. Methods that try to mitigate the problem by using no or limited number of pilots*

In [15], eigenvalue-decomposition (EVD)-based channel estimation is proposed which uses the statistics of the received data to estimate the channels (i.e., by implementing EVD of the covariance matrix of the received signals). In [16], [17], a blind pilot decontamination strategy is proposed which depends on separating the interference subspace from the desired signal subspace to eliminate the pilot contamination. However, methods used to eliminate pilot contamination have computational complexities and require particular channel characteristics.

## III. SYSTEM MODEL & PROBLEM STATEMENT

In this section, inspired by [2], [6], [8], [9], we build our TDD multi-cell massive MIMO system and describe pilot contamination problem.

### A. System Model

Our system model consists of $L$ hexagonal cells. Inside each cell, there are a BS having $M$ antennas and $K$ single antenna terminals, where($M \gg K$). The BS is located at the cell center and terminals are uniformly distributed in the cell region. The system has $B$ bandwidth that is shared by all system terminals.

BSs and terminals exchange data through Orthogonal Frequency-Division Multiplexing (OFDM) transmission technique that transforms a frequency selective wide-band channel into a group of flat fading narrow-band channels, thus the channel model for each OFDM subcarrier is given by:

$$g_{mikl} = h_{mikl}\sqrt{\beta_{ikl}}, \tag{1}$$

where $g_{mikl}$ is the propagation coefficient between the $m$-th antenna of the $i$-th BS and the $k$-th terminal of the $l$-th cell, $h_{mikl}$ is a complex term that accounts for the fast fading and $\sim CN(0,1)$ (i.e., it is a random variable with complex Gaussian distribution of zero mean and unit variance), and $\sqrt{\beta_{ikl}}$ is a real term that accounts for the geometric attenuation (GA) and the shadow fading (SF). we assume that $h_{mikl}$ is different for different antennas at each BS, but $\beta_{ikl}$ is the same regardless of the antenna index due to the slow variation of GA and SF with distance. $\beta_{ikl}$ can be represented by:

$$\beta_{ikl} = \frac{z_{ikl}}{r_{ikl}^{\gamma}}, \tag{2}$$

where $r_{ikl}$ is the distance between the $k$-th terminal in the $l$-th cell and the BS in the $i$-th cell, $\gamma$ represents the decay exponent, and $z_{ikl}$ represents SF and it is a log-normal random variable (i.e., $(10log_{10}(z_{ikl}))$ has Gaussian distribution of zero mean and $\sigma_{SF}$ standard deviation).

We consider TDD mode with channel reciprocity assumption (i.e., $g_{mikl}$ represents both UL and DL channels). We assume a block fading channel model in terms of time and frequency (i.e., the channel remains constant for a coherence time of $T$ OFDM symbols and it also remains constant for a coherence bandwidth of $N$ subcarriers), thus the channel needs to be updated only once for every $T$ OFDM symbols and only once for every $N$ subcarriers .

The BS and its terminals do not know the channels, and all CSIs are acquired by sending UL pilot sequences. If the number of OFDM symbols used to acquire CSIs is $\tau$, the maximum number of mutually orthogonal pilot sequences is $\Delta = \tau N$, each of length $\tau$. The set of pilot sequences can be represented by the $\tau x \Delta$ orthogonal matrix $\phi = (\psi_1, ..., \psi_k, ..., \psi_\Delta)$, where $\psi_k$ is the pilot sequence of the $k$-th terminal, thus $\phi^H \phi = \tau I$(as $\psi_{k1}^H \psi_{k2} = \tau$, if $k1 = k2$ and =zero, otherwise).

We assume that the system cells are non-cooperative and there is no power control.

### B. Problem Statement

In this section, we illustrate the problem of pilot contamination and show its effect on the system performance. Based on Eq. 1, The channel matrix from all $K$ terminals in the $l$-th cell to the $i$-th BS is $MxK$ matrix given by:

$$G_{il} = H_{il} D_{il}^{1/2}, \tag{3}$$

where $H_{il}$ is $MxK$ matrix of fast fading coefficients, whose entries are independent and identically distributed (i.i.d.), and $D_{il}$ is $KxK$ diagonal matrix whose diagonal elements represent $\beta_{ikl}, k = 1, ..., K$.

We assume that the number of terminals in each cell ($K$) is equal to $\Delta$. The system needs to assign unique pilot sequence to each terminal, so that BSs can accurately estimate CSIs, but due to limited coherence interval, the same set of orthogonal pilot sequences is reused among all system cells and we assume synchronous pilot transmission from all system terminals, which is the worst case for pilot contamination.

*1) pilot transmission:* After pilot transmission, the received signal matrix at the $i$-th BS is the $Mx\tau$ matrix given by:

$$Y_i = \sqrt{P_p}\sum_{l=1}^{L} G_{il}\phi^T + W_i, \tag{4}$$

where $W_i$ is the $Mx\tau$ noise matrix at the $i$-th BS added to the received pilot sequences, whose entries are i.i.d. and $\sim CN(0,1)$, and $P_p$ is the power of the transmitted pilot sequence. We can say that $W_i$ is white noise matrix whose entries are mutually uncorrelated and uncorrelated with the propagation matrices [6].

The $i$-th BS estimates the channel matrix by projecting its received matrix on $\phi^*$ and the estimated channel matrix is given by:

$$\hat{G_{ii}} = \frac{1}{\sqrt{P_p}\tau} Y_{il}\phi^* = G_{ii} + \sum_{l \neq i}^{L} G_{il} + \frac{1}{\sqrt{P_p}\tau} W_i \phi^*. \tag{5}$$

From this equation, we note that each $m, k$ element (i.e., $\hat{g}_{miki}$) of $\hat{G_{ii}}$ is not the channel coefficient between the $m$-th antenna and the $k$-th terminal of the $i$-th BS (i.e., $g_{miki}$), but a linear combination of the channel coefficients of all the terminals that use the same pilot sequence in the $L$ cells in addition to noise. This is what is referred to as the pilot contamination problem (while estimating the channel coefficient of a certain terminal, we obtain a linear combination of the channel coefficients of all terminals that use the same pilot sequence in the pilot transmission phase). Using this contaminated version of channel estimate by the $i$-th BS in signal precoding and detection processes, causes inter-cell interference in data transmission phase as shown in Sec. III-B2.

*2) Data Transmission:* After data transmission, the received signal vector at the $i$-th BS is the $Mx1$ vector given by:

$$y_i = \sqrt{P_d}\sum_{l=1}^{L} G_{il}\mathbf{x}_l + w_i, \tag{6}$$

where $w_i$ is the $Mx1$ noise vector at the $i$-th BS added to the received data symbols, whose entries are i.i.d. and $\sim CN(0,1)$, $P_d$ is the power of the transmitted data symbol and $\mathbf{x}_l$ is the $Kx1$ vector of Gaussian data-bearing symbols from terminals of the $l$-th cell.

We assume that the $i$-th BS uses maximum ratio combining to detect the received signal, thus the estimated data vector is given by the following equation:

$$\hat{\mathbf{x}}_i = \frac{1}{\sqrt{P_d}M} (\hat{G_{ii}})^H y_i, \tag{7}$$

$$\hat{\mathbf{x}}_i = \frac{1}{M}\Big(\sum_{l=1}^{L} G_{il} + \hat{V}_i\Big)\Big(\sum_{l=1}^{L} G_{il}\mathbf{x}_l + w_i\Big), \tag{8}$$

where $\hat{V}_i = \frac{1}{\sqrt{P_p\tau}} W_i\phi^*$.

Eq. 8 contains sums of inner products between $Mx1$ random vectors. According to [6] as the number of BS antennas ($M$) tends to infinity, the channel vectors of different terminals become asymptotically orthogonal, and noise vectors are mutually uncorrelated and uncorrelated with the channel vectors, thus the products of identical quantities remain and of different quantities vanish and we have:

$$G^H G = D^{1/2} H^H H D^{1/2} = M D^{1/2} I D^{1/2} = MD. \tag{9}$$

From Eqs. 8 and 9 we have:

$$\hat{\mathbf{x}}_i = \sum_{l=1}^{L} D_{il}\mathbf{x}_l. \tag{10}$$

From Eq. 10, the estimated symbol of the $k$-th terminal in the $i$-th cell which is the $k$-th component of $\hat{\mathbf{x}}_i$ is given by:

$$\hat{x_{ki}} = \sum_{l=1}^{L} \beta_{ikl} x_{kl} = \beta_{iki} x_{ki} + \sum_{l\neq i}^{L} \beta_{ikl} x_{kl}. \tag{11}$$

From this equation, we note that effects of fast fading, uncorrelated noise and intra-cell interference vanish. We note also that the estimated symbol of the $k$-th terminal by th $i$-th BS is not the actual transmitted symbol by that terminal, but it is a combination of transmitted symbols by all $k$-th terminals of all system cells the use the $k$-th pilot sequence in the pilot transmission phase (i.e., it is a combination of desired signal and interference). Thus, pilot contamination causes inter-cell interference that does not vanish even with unlimited number of BS station antennas. and the SINR of the $k$-th terminal in the $i$-th cell is given by:

$$SINR_k = \frac{\beta_{iki}^2}{\sum_{l\neq i}^{L} \beta_{ikl}^2}. \tag{12}$$

Using the SINR, we can calculate the capacity per terminal in (Mbits/sec) according to the following equation:

$$C_k = (B)\Big(\frac{T-\tau-1}{T}\Big)\Big(\frac{T_s - T_c}{T_s}\Big)\log_2(1 + SINR_k), \tag{13}$$

where $B$ is the total bandwidth in (MHz), $T_c$ is the cyclic prefix duration in seconds, $T_s$ is the OFDM symbol interval in seconds and 1 accounts for the OFDM symbol used in processing (i.e., channel estimation and signal detection).

## IV. PROPOSED SCENARIO

### A. Asynchronous Pilot Transmission (APT)

As mentioned above, synchronous pilot transmission is the worst case for pilot contamination. To mitigate this problem, a TSP is proposed in [8] to decrease the number of interfering cells. The cellular system is divided into groups and in each group a TSP is used as shown in Fig. 1 for three groups.

It has been shown in [8] that only cells of the same group interfere with each others and thus we obtain a higher SINR compared to the synchronous pilot transmission.

The SINR of the $k$-th terminal in the $i$-th cell is given by:

$$SINR_k = \frac{\beta_{iki}^2}{\sum_{l\in \textit{same group of } i,\ l\neq i} \beta_{ikl}^2}. \tag{14}$$

### B. Fractional Pilot Reuse (FPR)

Instead of a full pilot reuse, a FPR is proposed in [14] to mitigate the problem of pilot contamination. Each cell is divided into two regions, a cell center and a cell edge. For center terminals a reuse factor of one is used(i.e., the same set of orthogonal pilot sequences is assigned to all center terminals of all system cells), but for edge terminals a reuse factor of three is used (i.e., different pilot sequences are assigned to edge terminals of each three adjacent cells), because edge terminals are much affected by interference from adjacent cells than center terminals.

It has been shown in [14] that FPR provides better performance than traditional pilot reuse schemes of one and three.

Given that the total number of terminals in each cell is $K = K_c + K_e$, where $K_c$ is the number of center terminals and $K_e$ is the number of edge terminals, the minimum number of OFDM symbols required for channel estimation is given by:

$$\tau_f = \frac{K_c + 3K_e}{N} = \frac{K + 2K_e}{N}. \tag{15}$$

### C. Proposed Scheme

In this paper, we propose a scheme that combines the advantages of both APT and FPR. Using this scheme:

- The cellular system is divided into three groups: $G_1, G_2$ and $G_3$ as shown in Fig. 2, in each group a time shifted protocol is used as shown in Fig. 1 .
- The set of orthogonal pilot sequences $\phi$ is divided into 4 subsets: $S_c, S_{e1}, S_{e2}$ and $S_{e3}$ as shown in Fig. 3.

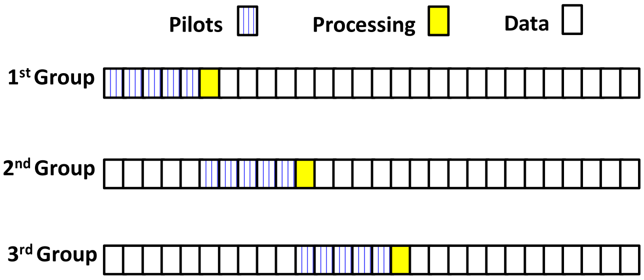

Fig. 1. Time shifted protocol.

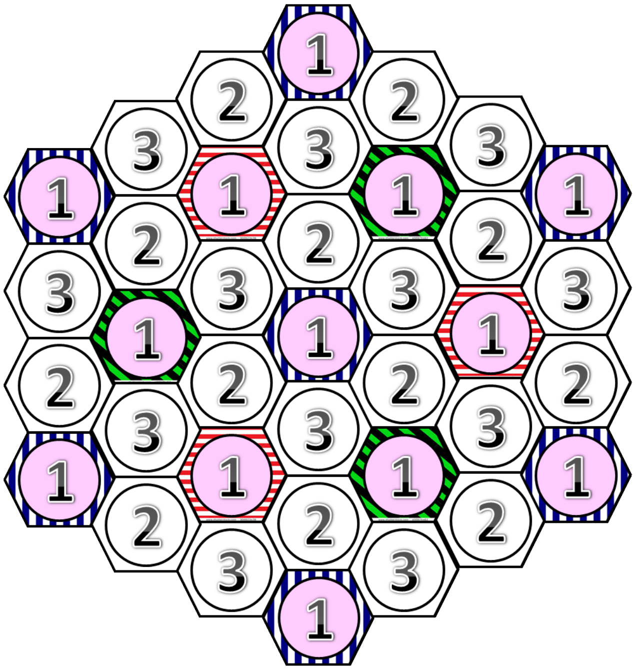

Fig. 2. Proposed scheme.

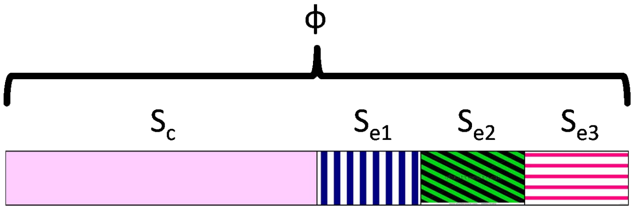

Fig. 3. Pilot sequences.

- Each cell is divided into two regions: center and edge. For center terminals of all cells, we use $S_c$ to assign pilot sequences to those terminals. For edge terminals of each cell we use $S_{e1} or S_{e2} or S_{e3}$ to assign pilot sequences to those terminals so that a pilot reuse factor of three is used for edge terminals of each group as shown in Fig. 2 for the $1^{st}$ group.

Our proposed scheme decreases the level of inter-cell interference to all the system terminals as follows:

- Center terminals of a cell only interfere with center terminals of cells of the same group of that cell, instead of all system cells as in [14]. The SINR of the $k_c$-th center terminal in the $i$-th cell of $G_1$ is given by:

$$SINR_{k_c} = \frac{\beta^2_{ik_ci}}{\sum_{l \in G_1, l \neq i} \beta^2_{ik_cl}}. \tag{16}$$

Using Eq. 13, $SINR_{k_c}$ can be translated to the capacity per center terminal as follows:

$$C_{k_c} = (B)(\frac{T-\tau_f-1}{T})(\frac{T_s-T_c}{T_s})\log_2(1+SINR_{k_C}). \tag{17}$$

- Edge terminals of a cell only interfere with edge terminals of cells of the same group of that cell which use same pilot sequences, instead of all system cells as in [14]. The SINR of the $k_{e_j}$-th edge terminal in the $i$-th cell of $G_1$ using the pilot sequence $j$ is given by:

$$SINR_{k_{e_j}} = \frac{\beta^2_{ik_{e_j}i}}{\sum_{l \in G_1, l \neq i} \beta^2_{ik_{e_j}l}}. \tag{18}$$

Using Eq. 13, $SINR_{k_{e_j}}$ can be translated to the capacity per edge terminal as follows:

$$C_{k_{e_j}} = (B)(\frac{T-\tau_f-1}{T})(\frac{T_s-T_c}{T_s})\log_2(1+SINR_{k_{e_j}}). \tag{19}$$

## V. PERFORMANCE EVALUATION

Using equations presented in sections III & IV, and the simulation parameters presented in Table I, in this section we evaluate the performance of our proposed scheme.

In Fig. 4, we show the Cumulative Distribution Function (CDF) of SINR for generic scenario (i.e., Synchronous pilot transmission with pilot reuse factor= 1), TSP of [8], FPR of [14] and our proposed scheme.The circles indicate the $50\%$ values, i.e., with a probability $50\%$, the SINR is greater than or equal to the indicated value. Using FPR instead of the generic scenario, increases the SINR by about 5dB. Using TSP instead of the generic scenario, increases the SINR by about 20dB.Using our proposed scheme instead of the generic scenario, increases the SINR by about 25dB. Simulation results show that in terms of SINR, our proposed scheme provides better performance than FPR as it adds an additional 20dB ,and TSP as it adds an additional 5dB.

In Fig. 5, we show the CDF of per terminal capacity for generic scenario, TSP of [8], FPR of [14] and our proposed scheme. Using FPR instead of the generic scenario, enhances the performance of low capacity terminals and achieves almost the same performance of high capacity terminals. Using TSP instead of the generic scenario, highly enhances the performance of all terminals. Using our proposed scheme instead of the generic scenario, highly enhances the performance of all terminals. Simulation results show that in terms of per terminal capacity, our proposed scheme provide better performance than FPR as it enhances the performance of all terminals compared with FPR ,and TSP as it achieves almost the same performance of high capacity terminals but it enhances the performance of low capacity terminals compared with TSP.

TABLE I. SIMULATION PARAMETERS

| parameter | value |
|---|---|
| $L$ | 39 cells |
| $R$ | $1600m$ |
| $\gamma$ | 3.8 |
| $\sigma_{SF}$ | 8dB |
| $\tau$ | 5 OFDM symbols |
| $T$ | 30 OFDM symbols |
| $T_s$ | $71.4\mu s$ |
| $T_c$ | $4.76\mu s$ |
| $B$ | $20MHz$ |
| $N$ | 14 subcarriers |
| $\tau_f$ | 7 OFDM symbols |

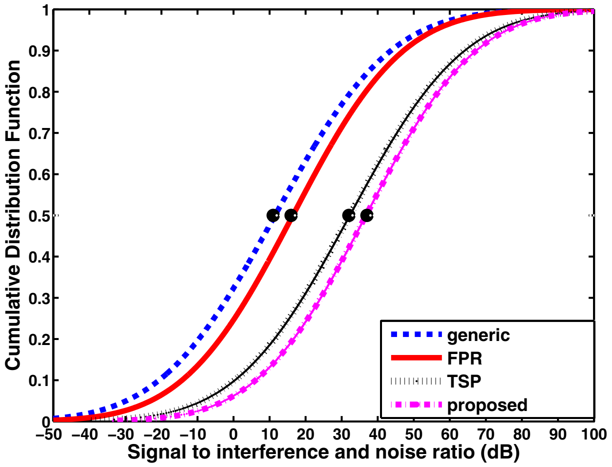

Fig. 4. Comparison between cumulative distributive functions of SINR of different schemes.

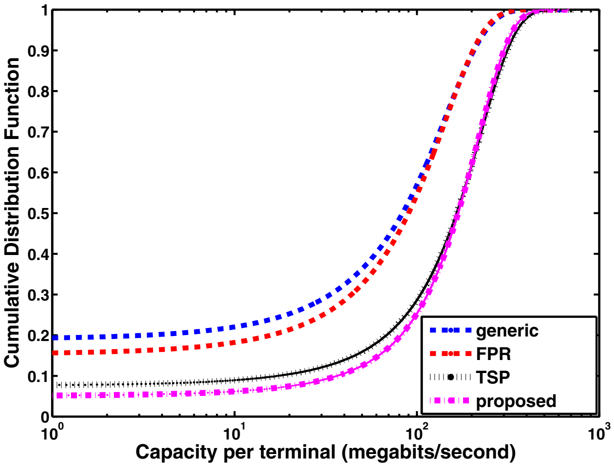

Fig. 5. Comparison between cumulative distributive functions of capacity per terminal of different schemes.

## VI. CONCLUSION

Massive MIMO is a very promising technology that can provide large gains in terms of spectral and energy efficiency, but it has a performance limiting factor that does not vanish even with unlimited number of BS antennas. This limiting factor is the inter-cell interference caused by the problem of pilot contamination. In this paper, we proposed a scheme to mitigate the pilot contamination effect, that takes the advantages of APT to enhance the performance of all terminals and of FPR to further enhance the performance of low capacity terminals. Simulation results show the effectiveness of our proposed scheme in enhancing the system performance in terms of SINR and capacity.

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