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Mitigating the Effect of Pilot Contamination in Massive Multiple Input Multiple Output System  
Using Pilot Allocation Protocol

By

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**ABSTRACT**

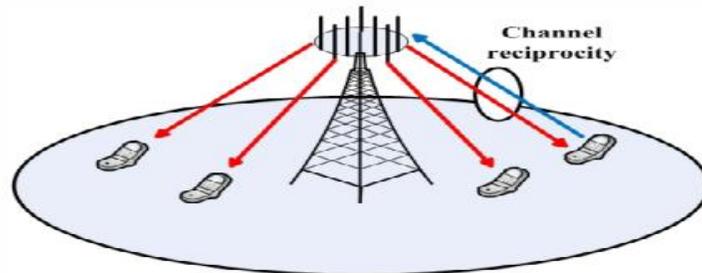
*Pilot Contamination (PC) is considered a major drawback of Time Division Duplexing (TDD) Massive Multiple-Input Multiple-Output (M-MIMO) systems because it limits their expected capacity. A Pilot Allocation Protocol (PAP) scheme is proposed in this letter to mitigate the effect of PC in order to improve the performance of users affected severely by PC. Specifically, the PAP technique is based on sectional pilot sequence initialization and sharing which allocate more than one user to share the same orthogonal pilot sequence within a cell which then creates intra cell interference between the users sharing the same pilot sequence but suppresses inter cell interference between users sharing the same pilot sequence in other cells and mitigate the effect of PC. Simulation results verify the performance gain of the proposed scheme over that of conventional schemes in a typical M-MIMO system.*

Keywords: Massive MIMO, Pilot Contamination and Pilot Allocation Protocol

**INTRODUCTION**

Massive Multiple Input Multiple Output (M-MIMO) has been identified as a promising technology to cater for the high data rate demand of the next generation wireless devices also known as 5G, in this technology, large number of antenna arrays concurrently is used to serve many user terminals (UTs), each having a single antenna, in the same time frequency resource (Jose *et al.*, 2009). Asymptotic analysis based on random matrix theory (Elijah *et al.*, 2016) shows that both the intra cell interference and correlated noise can be mitigated efficiently as the number of Base Station (BS) antennas tends to infinity. Furthermore the energy consumption of cellular BSs can be considerably reduced (Yin *et al.*, 2013), M-MIMO systems are robust, since failure in one or a few antennas would not appreciably affect the overall system performance. In addition, simple linear processing/detection schemes based on Zero Forcing (ZF) and Matched Filter (MF) can be used for approaching the optimal performance, when the number of BS antennas tends to infinity. Similar to standard MIMO systems, each base station requires accurate estimation of the CSI and this can be done either through reciprocity that is Time Division Duplex (TDD) or feedback as in Frequency Division Duplex (FDD) schemes (Elijah *et al.*, 2016). TDD is preferred as a better mode to obtain timely CSI in wireless systems in place of FDD due to the fact that the estimation requirement of TDD can be done in one direction and used in both directions as shown in figure 1, while in FDD estimation and feedback are required for both

forward and reverse directions (Guo *et al.*, 2017). Due to the popularity of FDD among existing networks (3G and 4G), it continues to attract more interest. The TDD scheme is based on reciprocity of downlink and uplink channels and has been considered to be a good choice because of these reasons. The forward channel is assumed to be equal to the transpose of the reverse channel and the needed information is obtained from transmitted pilots on the reverse link (Elijah *et al.*, 2016). However, due to the dense network deployment and limited orthogonal pilot sequences, multiple neighbour cells may use the same pilot sequence (non-orthogonal) and the pilot positions in pilot patterns of the multiple neighbour cells may overlap, which will directly affect the performance of the channel estimation. This is known as Pilot Contamination (PC) (Vardhan *et al.*, 2016b). Furthermore, the commonly used MF and ZF processing schemes will impose intercell interference on the DL transmission, which cannot be reduced by increasing the number of antennas at the BSs. In an effort to address the problem of PC in a multi-cell architecture, different schemes have been proposed, which are grouped into (1) Pilot-based estimation approach and (2) Sub-space estimation approach (Elijah *et al.*, 2016). In the pilot-based approach, channels of users are estimated using orthogonal pilot sequence within the cell and non-orthogonal pilot sequence across the cells and this lead to maximum Inter-Cell Interference (ICI) while in the sub-space estimation approach, the channels of users are estimated with limited or no pilots sequence which depends on high order statistical parameters that are susceptible to error in the estimation of user channels.



**Figure 1:** Reciprocity in M-MIMO System (Tebe *et al.*, 2015)

Farhang *et al.*, (2014) looked into the problem of pilot contamination in cosine modulated multi-tone (CMT) based M-MIMO networks with the view to address the issue. The scheme takes the advantage of the special property of CMT, known as blind equalization property. It was evident that when the technique was extended from single user to a large-scale cellular M-MIMO system, channel estimation error due to (PC) removed without any coordination among the different base stations or transmission of more training information. Furthermore, it was proved that the proposed solution performed equally good as or even better compared to MF having perfect CSI and also the output SINR of the proposed algorithm converges towards that of the MMSE solution which has a perfect knowledge of CSI of the various users within its neighbouring cells. However, the scheme is highly computationally complex due to the high order statistical parameters needed to estimate the channels which could introduce serious error in the channels estimation.

A pilot contamination mitigation scheme based on Smart Pilot Assignment (SPA) to enhance the performance of users affected severely by PC was investigated in (Zhu *et al.*, 2015). It is done, particularly, by taking into consideration the characteristics of the channels large-scale fading. The base station measures the ICI of the individual training sequences produced from the users having the same training sequence in neighbouring cells. Contrary to the traditional way of allocating training sequences to users haphazardly, the SPA scheme allocates a training sequence that has the least ICI to a user with the poorest channel quality sequentially to enhance its performance. The scheme proves theoretically that the pilot allocation generated by it, is the answer to the optimization problem  $P^i$  in a greedy way that can approach the novel optimization problem  $P$  as the number of antennas tends to infinity. However, the scheme did not break away from the conventional way of initializing all training sequences for the training that leads to the re-use of the same training sequences in the adjacent cells, thereby causing ICI.

An in-depth survey of pilot contamination in M-MIMO system was presented in (Elijah *et al.*, 2016). Possible sources of pilot contamination such as hardware impairments and non-reciprocal transceivers have been identified. The paper gave an extensive detailed analysis of the effect of pilot contamination on the performance of M-MIMO systems in accordance with the established theories. Different mitigation techniques (pilot-based approach and sub-space-based approach) have been proposed. Research windows such as deployment platform, training overhead, channel reciprocity and computational complexity associated with pilot contamination have also been brought to the surface. The paper however, presented a broader or general review of the concept of pilot contamination and its possible effect on the performance of M-MIMO system. There was no evidence what so ever an attempt to address any of the issues militating against the performance or rather deployment of the M-MIMO system as highlighted therein.

The problem of pilot contamination in M-MIMO systems, for cell-edge and-cell centre user terminals (UTs) was investigated in (Zhu *et al.*, 2016). A novel scheme based on soft pilot reuse (SPR) and multi-block diagonalization (MBD) was used to address this issue. It has been established that users at the cell edge suffer from severe PC than their centre cell counterparts, in view of this development SPR is used in enhancing the quality of service (QoS) of cell edge users by re-using a cell-centre pilot group for all centre-cell users and a cell-edge pilot group for all cell edge users in the adjacent cells which is determined by their large-scale fading coefficients. The MBD pre-coding is utilized for a multi-cell scenario, to mitigate ICI and enhanced the QoS for cell-edge users. However, the enhanced rates of the UL and DL throughputs of the proposed scheme was achieved at the expense of more pilot sequence requirement for channel state information estimation as a trade off with resources for data transmission within the coherence interval in comparison to conventional methods and also the scheme is still based on full pilot sequence initialization and reuse of non-orthogonal pilot sequence in different cells in multi-cell scenario which is the major source of PC.

Motivated by the concept of pilot reuse and Soft Pilot Reuse (SPR) particularly, which allocates orthogonal pilot sequence to cell-edge users, we proposed Pilot Allocation Protocol (PAP) decontamination scheme for Time Division Duplex (TDD) mode Massive Multiple Input Multiple Output (M-MIMO) system based on sectional pilot sequence initialization and sharing with a pilot sequence reuse factor of  $1/3$  which can allocate more than one user to share same

orthogonal pilot sequence within a cell which then creates Intra Cell Interference and mitigates the effect of PC by separating the users using distinct codes unique to each of the interfering users.

**Review of Massive MIMO System Model**

Considering M-MIMO system, which consist of one BS and one  $K$  active users. The BS is equipped with  $M$  antennas, while each user has a single antenna as shown in figure 2. Assuming that all  $K$  users share the same time-frequency resource and the BS and the users have perfect CSI. The channels are acquired at the BS and the users during the training phase.

Let  $H \in \mathbb{C}^{M \times K}$  be the channel matrix between the  $K$  users and the  $M$  BS antenna array, where the  $K_{th}$  column of  $H$ , denoted by  $h_k$ , represents the channel  $M \times 1$  vector between the  $K_{th}$  user and the BS. Assuming that the elements of  $H$  are identically independent distributed (i.i.d) Gaussian distributed with zero mean and unit variance.

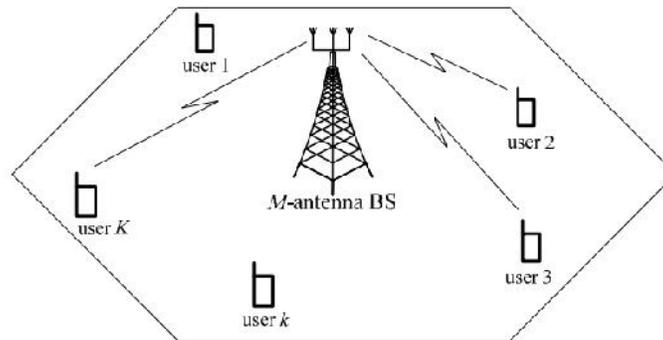


Figure 2. Massive MIMO System (Ul mulk, 2015)

**Uplink Transmission**

Uplink transmission is the process whereby  $K$  users transmit signals to the BS. Let  $s_k$ , where  $\mathbb{E} \{ |S_k|^2 \} = 1$ , be the signal that is transmitted from the  $K_{th}$  user. Since all  $K$  users share the same frequencies resource, the  $M \times 1$  received signal vector at the BS is the combination of all signals transmitted from all  $K$  users.

$$y_{ul} = \sqrt{\dots_u} \sum_{k=1}^K h_k s_k + n \tag{1}$$

Where,  $\dots_u$  is the average signal to noise ratio (SNR),  $n \in \mathbb{C}^{M \times 1}$  is the additive noise vector, and  $s = [s_1 \dots s_k]^T$ . Assuming the elements of  $n$  are i.i.d. Gaussian random variables (RVs) with zero mean and unit variance, and independent of  $H$ .

From the received signal vector  $y_{ul}$  combined with the knowledge of the CSI, the BS will coherently detect the signal transmitted from  $K$  users. The channel model in figure 2.13 has the sum capacity as (Saxena *et al.*, 2015):

$$C_{uls,um} = \log_2 \det(I_K + \dots_u H^H H). \tag{2}$$

The aforesaid sum capacity can be achieved with linear detectors such as Zero Forcing (ZF), Matched Filter (MF) and Minimum Mean Square Error (MMSE).

**Linear Processing Schemes**

To obtain optimal performance, complex signal processing schemes must be employed. The BS can use linear processing techniques (linear receivers in the uplink), to reduce the signal processing complexity. However, if the number of BS antennas tends to infinity, it is shown that the linear processing is nearly optimal (Vardhan *et al.*, 2016a). The details of Linear Processing Schemes are discussed in the following subsections.

**Linear Receivers (in the UPLINK)**

With linear equalization schemes at the BS, the received signal  $y_{ul}$  is separated into  $K$  streams by multiplying it with a  $M \times K$  linear equalization matrix,  $A$ :

$$y_{ul} = A^H y_{ul} = \sqrt{\dots}_u A^H H_s + A^H n \tag{3}$$

Each stream is then decoded independently. From the aforementioned equation the  $K_{th}$  stream (element) of  $\tilde{y}_{ul}$ , which is used to decode  $S_k$  is given by:

$$\tilde{y}_{ul,k} = \underbrace{\sqrt{\rho_u} a_k^H h_k S_k}_{\text{desired signal}} + \underbrace{\sqrt{\rho_u} \sum_{k' \neq k} a_k^H h_{k'} S_{k'}}_{\text{interuser interference}} + \underbrace{a_k^H n}_{\text{noise}} \tag{4}$$

Where  $a_k$  denotes the  $K_{th}$  column of  $A$ . The interference plus noise is treated as effective noise, and hence, the received signal to interference plus noise ratio (SINR) of the  $K_{th}$  stream is given by (Joham *et al.*, 2017):

$$SINR_K = \frac{\dots_u |a^H h_k|^2}{\dots_u \sum_{K^i} |a_k^H h_{k^i}|^2 + \|a_k\|^2} \tag{5}$$

**Maximum Ratio Combining Receiver.**

With MRC, the BS aims to maximize the received signal-to-noise ratio (SNR) of each stream, ignoring the effect of multiuser interference. From equation (2.7), the  $K_{th}$  column of the MRC receiver matrix  $A$ , the received SINR of the  $K_{th}$  stream for MRC yields:

$$\begin{aligned}
 SINR_{mrc,k} &= \frac{\dots_u \|h_K\|^4}{\dots_u \sum_{K' \neq K}^K |h_K^H h_{K'}|^2 + \|h_K\|^2} \tag{6} \\
 &\rightarrow \frac{\|h_K\|^4}{\sum_{K'=K}^K |h_K^H h_{K'}|^2} \\
 &as \dots_u \rightarrow \infty
 \end{aligned}$$

The signal processing is very simple since the BS just multiplied the received vector with the conjugate transpose of the channel matrix  $H$ , and then detects each stream separately. At low  $\dots_u$ , the SNR reduces to:

$$SINR_{mrc,k} \approx \dots_u \|h_k\|^2. \tag{7}$$

This implies that at low SNR, MRC can achieve the same array gain as in the case of a single-user system. However, since MRC neglects the effects of multi user interference, it performs poorly in interference limited scenarios, as shown in the last equation, where the SINR is upper bounded by a constant (with respect to  $\dots_u$ ) when  $\dots_u$  is large.

**Zero Forcing**

By contrast to MRC, zero forcing (ZF) receiver’s takes the inter-user interference into account but neglect the effect of noise. With ZF, the multi-user interference is completely nulled out by projecting each stream onto the orthogonal complement of the inter-user interference (Larsson *et al.*, 2014). The ZF receiver matrix, which satisfies  $K$  users, is the pseudo-inverse of the channel matrix  $H$ . With ZF, we have:

$$\tilde{y}_u = (H^H H)^{-1} H^H y_u = \sqrt{\rho_u} s + (H^H H)^{-1} H^H n \tag{8}$$

This scheme requires that  $M \geq K$  (so that the matrix  $H^H H$  is invertible). Thus, the received SINR of the  $k_{th}$  stream is given by:

$$SINR_{zf,k} = \left[ (H^H H)^{-1} \right]_{kk} \tag{9}$$

The ZF signal processing is very simple and works well in interference limited scenarios. The SINR can be made as high as desired by increasing the transmit power. However, it performs poorly under noise-limited scenarios. If the channel is not well conditioned then the pseudo inverse amplifies the noise to a large extent and hence, the performance is very poor. In comparison to MRC, ZF has a higher implementation complexity due the computation of the pseudo inverse of the channel gain matrix (Ul mulk, 2015).

**PILOT CONTAMINATION**

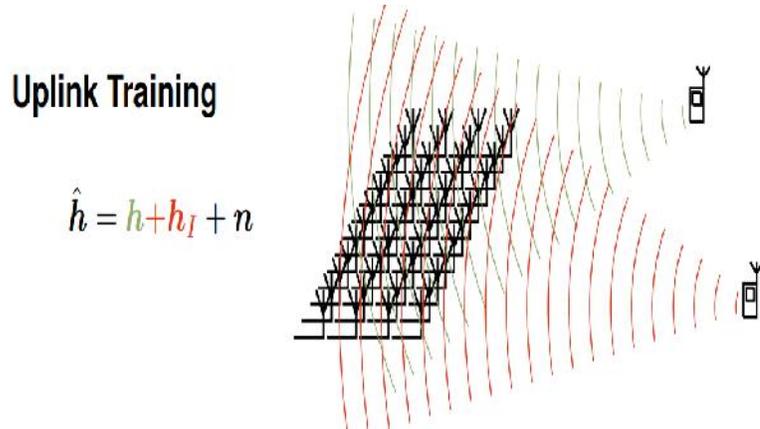


Figure 3: Uplink training

By considering UL training, before the transmitter can send information to the receiver, the receiver sends information to the transmitter at the BS, but the transmitted symbols are known on both sides so that it could train the symbols. Based on this known and properties of its symbols, then the transmitter can estimate the unknown channel vector  $h$  added with some noise  $n$  of user<sub>1</sub>, which leads to the corrupted version of the right channel vector  $\tilde{h}$  user<sub>1</sub>. However, at the same time there might be a second user (user 2) which also wants to have access to the BS and it also sends training symbols to the BS. If the BS at the transmitter is not aware of this it might happened that it considers the signal coming from the second user (user 2) as part of the original user (user 1), and that will have automatic effect on the downlink when the BS is transmitting data to the first user (user 1). Where  $h_i$  is the channel vector of user 2, this effect is called

Pilot Contamination (PC), because the interfering part of the channel vector of user 2 ( $h_i$ ) contaminates the channel information of user 1. Multi cell Architecture of M-MIMO system is shown in figure 4.

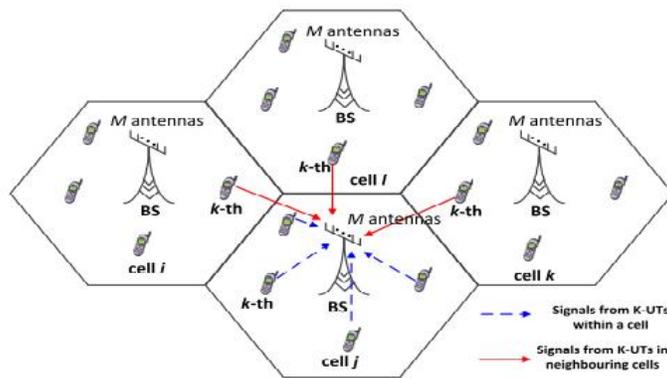


Figure 5: Multi-Cell Architecture of M-MIMO

**Pilot Allocation Protocol**

In this scheme the orthogonal pilot sequences are divided into 3 groups and allocated to three different cells, that is to say that within each cell and at least the next neighbouring cells the

pilot sequence are orthogonal to each other, so when orthogonal pilot sequences within a particular group are exhausted by users, then sharing starts between users which then creates an intra cell interference between users sharing the same pilot sequence which are then separated (made orthogonal to each other) by employing a property of hardmard matrix, which assigns distinct codes to the interfering users sharing the same pilot sequence in each coherence interval as against discarding or queuing the users for the next available pilot sequence in the conventional technique. The concept was able to mitigate the effect of pilot contamination to a large extent and also increase the number of users that can use the available resources without increasing the number of the orthogonal pilot sequences. Figure 6, depict the multi-cell architecture of the developed PAP technique.

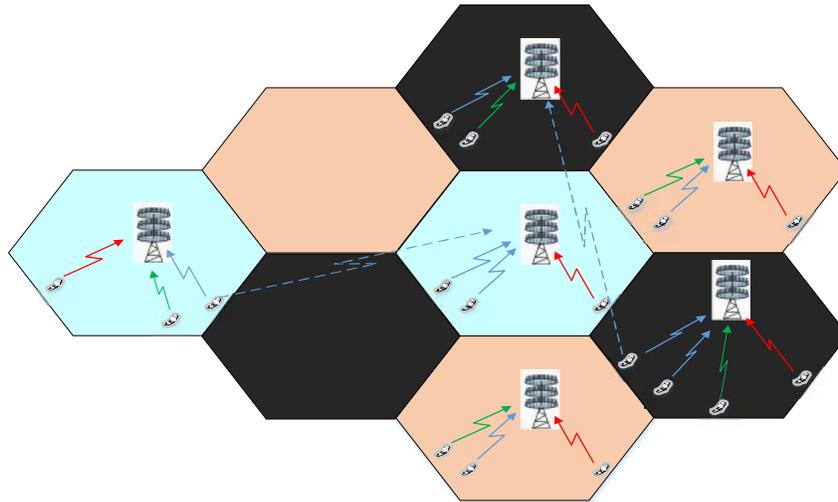


Figure 7: PAP Technique

Figure 6, shows the pilot sequence allocation and sharing pattern of the developed PAP scheme based on sectional initialization and pilot sequence sharing between users, each colour in Figure 6, represents a particular group (a section) of the total orthogonal pilot sequences while cells having the same colours uses the same type of orthogonal pilot sequences with a minimum reuse distance of one kilometre since the cell radius considered is 500m. furthermore the green, blue and red coloured signals emanating from the user equipment's to the base stations represents the individual pilot sequences in each cell, users transmitting same colour of signals are sharing the same pilot sequence but then are separated using distinct signs of hardmard matrix while the broken signals in blue colours represents interfering signals from far cells and they formed part of the additive white gaussian noise.

#### **METHODOLOGY AND SIMULATION**

The following methodology was adopted in carrying out the research work:

A TDD M-MIMO channel model with a varying number of base station antennas, number of users per cell, and power of user equipment was developed based on Rayleigh fading channel taking into consideration pilot allocation protocol.

PAP was implemented based on sectional initialization and pilot sequence sharing, which allocates pilot sequence to many users within a cell and their training was conducted using different codes. Users were grouped into cell centre and cell edge based on their large-scale fading coefficient.

A signal detection scheme based on matched filter and zero forcing, for equalizing the signals was implemented. The UL Signal to Interference plus Noise Ratio (SINR) of cell edge users was then calculated and the average UL cell throughput determined. Validation of the results was done by comparing the results obtained from the Pilot Allocation Protocol (PAP) technique and that of conventional schemes in terms of average uplink cell throughput and bit error rate as performance metrics.

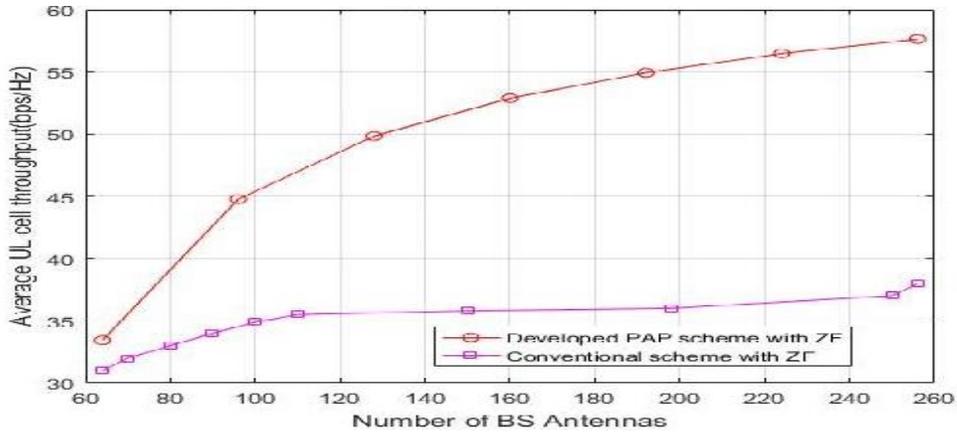
Simulation was carried out using MATLAB environment, with 50% of the bandwidth for data transmission allocated to Uplink data transmission. Table 1 showed the parameters used for the simulation.

**Table 1:** Model Parameters used.

Parameters	Units
Number of cells $L_{Total}$	19
Number of antenna in BS $M$	$32 \leq M \leq 256$
Number of users in the $i_{th}$ cell $K_i$	16
Number of pilot resource $K_{cs}$	10
Cell radius $R$	500m
Average transmit power at users $\rho_p$ $\rho_u$	10dbm
Average transmit power at BS $\rho_d$	12dbm
Pathloss exponent $\alpha$	3
Log normal shadowing fading $\sigma_{show}$	8db
Carrier frequency	2GHz
System bandwidth	10MHz
Minimum distance between user and BS	30m

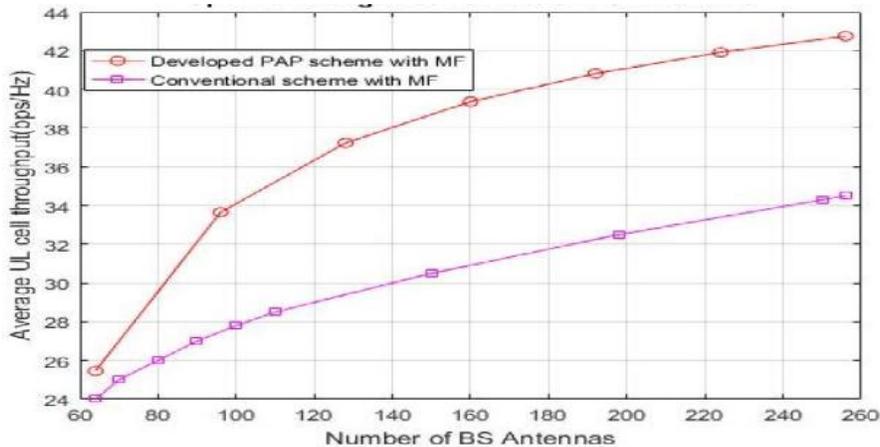
## RESULTS

The PAP simulation results obtained using simulation parameters highlighted in Table 1 were plotted for the PAP technique using Zero (ZF) and Matched Filter (MF) linear detectors.



**Figure 8:** Uplink Rate against Number of BS Antennas for the two Schemes

Figure 8, shows the average Uplink (UL) cell Throughput against the Number of Base Station (BS) Antennas for the developed PAP and conventional schemes all with ZF detector, with number of BS antennas ranging from 60 to 256 antennas and 50% of the bandwidth for data transmission allocated to UL data transmission. From simulation results in Figure 8. When the number of BS antennas is at 64, the conventional schemes offer an average UL throughput of 31 b/s/Hz while the developed PAP offers an average UL cell throughput of 33 b/s/Hz improvement, which is 2 b/s/Hz more than the conventional scheme when ZF detector was used. At 250 BS antennas the conventional and scheme offers an average cell throughput of 37 b/s/Hz while the developed PAP offers an average UL cell throughput of 57.5 b/s/Hz, which is 20.5 b/s/Hz more than the conventional scheme. This shows that the performance improvement of the interfering users (cell edge) users of the developed PAP schemes is better than that of the conventional scheme as the number of BS antennas increases. It can be seen that when the number of BS antennas was set at 256 the conventional scheme offers an average cell throughput of 37.5 b/s/Hz while the developed PAP offers an average UL cell throughput of 42.5 b/s/Hz, which is 5 b/s/Hz more than the conventional scheme. The PAP scheme out performs the conventional scheme and hence further proved that the performance improvement of the interfering users (cell edge users) of the PAP is better than that of the SPR scheme as the number of BS antennas increases.



**Figure 9:** Uplink Rate against Number of BS Antennas for the two Schemes

Figure 9 shows the Average Uplink (UL) Cell Throughput against the Number of Base Station (BS) antennas for the developed PAP and conventional scheme all with MF detector, with number of BS antennas ranging from 64 to 256 antennas and 50% of the bandwidth for data transmission allocated to UL data transmission. From simulation results in Figure 9, when the number of BS antennas is at 64, the conventional scheme offers an average UL throughput of 24 b/s/Hz while the developed PAP offers an average UL cell throughput of 25.5 b/s/Hz improvement, which is 1.5 b/s/Hz more than the conventional scheme when MF detector was used. At 250 BS antennas the conventional scheme offers an average cell throughput of 34.5 b/s/Hz while the developed PAP offers an average UL cell throughput of 42.5 b/s/Hz, which is 8 b/s/Hz more than the conventional scheme. At 256 BS antennas the conventional scheme offers an average cell throughput of 34.5 b/s/Hz while the developed PAP offers an average UL cell throughput of 43 b/s/Hz. This shows that the performance improvement of the interfering users (cell edge) users of the developed PAP schemes is better than that of the conventional scheme as the number of BS antennas increases. It can be seen that when the number of BS antennas was set at 256 the PAP scheme outperforms the conventional scheme and hence further proved that the performance improvement of the interfering users (cell users) of the PAP is better than of the conventional scheme as the number of BS antennas increases with MF detector.

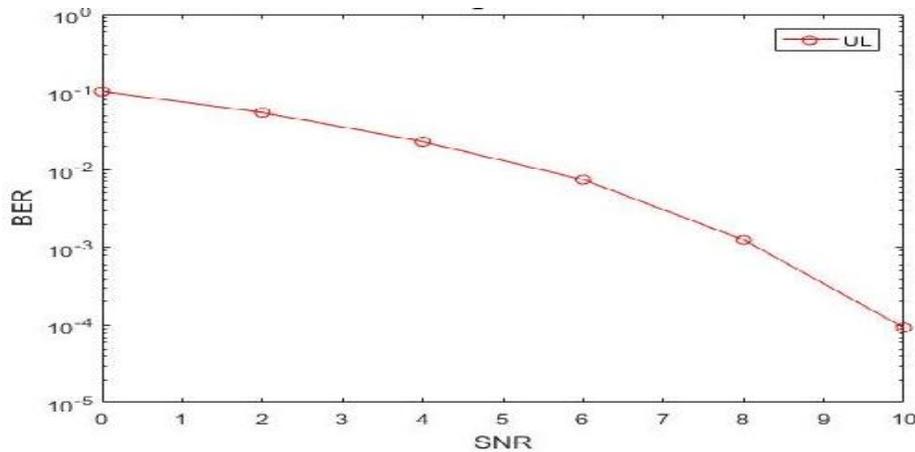


Figure 10: A plot of BER Performance for the PAP Scheme with ZF

It can be observed from Figure 10 that, as the SNR increases the BER also increases and the developed PAP using ZF for both UL and DL met the BER requirement for audio signal that is  $10^{-3}$  of BER in digital communications at SNR of 8 dB, which means in every 1000 bit you have 1 error.

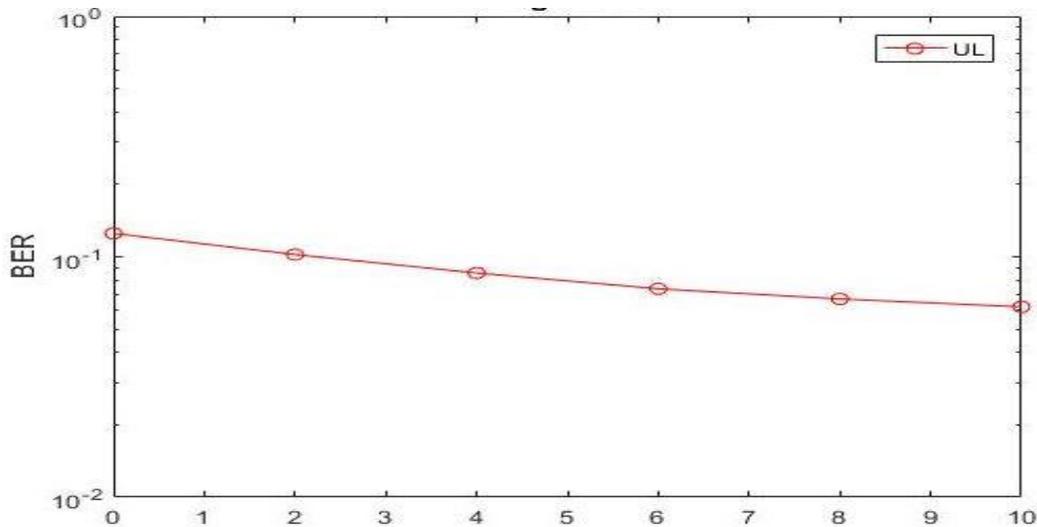


Figure 11: A plot of BER Performance for the PAP Scheme with MF

It can be observed from Figure 4.6 that, the developed PAP using MF for both UL and DL attained a BER of  $10^{-1.25} = 1/10^{1.25} = 1/17.8 = 1/18$ , which means in every 18 bits of transmission you have 1 error, at SNR of 8 db.

## DISCUSSIONS

From the simulation results obtained from the developed PAP scheme using the ZF and MF detection schemes evaluated at 64,250 and 256 BS antennas, the average cell throughput improvement of the developed PAP scheme outperforms that of the conventional scheme. The improvement occurred as a result of the pilot sequence allocation protocol adopted by the PAP technique and the way the interfering users (cell edge users) were efficiently separated after sharing of pilot sequence occurs between users. The PAP scheme creates intracell interference and suppressed the effect of Inter-cell Interference ICI to a large extent which is the major cause of Pilot Contamination during Uplink pilot transmission. Furthermore, it is important to have observed that, the average cell throughput improvement performance of the PAP technique is better than that of the conventional scheme with both ZF and MF detection schemes throughout the range of BS antennas considered (64,250 and 256), this is due to the fact that in the PAP technique pilot sequence of users within and across the neighbouring cells were made to be orthogonal to each other and when sharing occurs (when pilot sequence of users were made to be non-orthogonal) to each other, codes were used to separate the interfering users throughout the length of the coherence interval.

## CONCLUSION

Pilot Contamination (PC) is considered as the major drawback of Time Division Duplexing (TDD) Massive Multiple-Input Multiple-Output (M-MIMO) systems because it limits their expected capacity. Several mitigation techniques such as Eigenvalue Decomposition, Cooperative Bayesian Channel Estimation, Blind Equalization Technique, Time Staggering Pilot, Smart Pilot Assignment, etc. have been proposed in literature to address the issue of PC. This research work

focused on Pilot-based estimation approach, in the pilot-based approach, channels of users are estimated using orthogonal pilot sequences within the cell and non-orthogonal pilot (the same pilot) sequences across the cells. However, this technique is largely affected by Intercell Interference (ICI) which is the major cause of Pilot Contamination during UL pilot sequence transmission, therefore, we developed a Pilot Allocation Protocol (PAP) decontamination scheme for TDD mode M-MIMO system based on sectional pilot sequence initialization and sharing which allocates more than one user to share the same orthogonal pilot sequence within a cell which then creates Intra Cell Interference, suppresses Inter Cell Interference (ICI) and mitigate the effect of PC among the interfering User Terminals (UTs). The developed PAP scheme provides an average cell throughput improvement over conventional scheme of 2 b/s/Hz at 64 BS antennas, 20.5 b/s/Hz for uplink, at 250 BS antennas, and 20.2 b/s/Hz for uplink at 256 BS antennas with ZF detector at 64, 250 and 256 BS while with MF detector the developed PAP technique had an average uplink cell throughputs improvement of 1.5 b/s/Hz at 64 BS antennas, 8.1 b/s/Hz for UL at 250 BS antennas, and 8.1 b/s/Hz for UL at 256 BS antennas over conventional technique, thereby improving Bit Error Rate (BER) performance degradation and mitigate the effect of PC and hence improve the performance of M-MIMO technology. The performance of the developed PAP technique was evaluated using average UL cell throughputs, and BER as performance metrics and results showed that the developed technique was efficient with substantial improvement of average UL cell throughputs.

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