A Novel Pilot Decontamination Method for Massive MIMO Systems Using Social Spider Optimization Algorithm

Ali Mundeth Ahmed[1] and Erakkath Abdu Jasmin[2]
[1]Department of Computer Applications, Government Engineering College, Thrissur, Kerala, India
[2]Department of Electrical and Electronics, Government Engineering College, Thrissur, Kerala, India
Email: {mundethali, eajasmin}@gmail.com

Abstract —The promising capacity and data rate brought by massive MIMO communication systems lead to consider it as a very prominent fifth generation mobile technology. Pilot contamination is identified as the most significant impairment that limits the exploitation of its optimum capacity. It is caused by the re-use of the same, or at least non-orthogonal pilot sequences, among different cells that degrade the performance of channel estimation. In order to mitigate this issue, we propose a partial re-use of pilot sequences among users in the adjacent cells, which are close to the base station (BS) and also possesses minimum movement velocity. A novel multi factor social spider optimization algorithm (MSSOA), which imitates the cooperative behavior of social spiders, is used for selecting the eligible users for this pilot reuse in the neighboring cells. The algorithm tries to maximize the lowest SINR value for every user in the cell. The performance of the proposed method is evaluated through simulations and it is confirmed that the proposed method gives a better bit error rate (BER), sum-rate, and normalized mean square error (NMSE), over the conventional pilot assignment schemes.

Index Terms—Massive MIMO, Pilot decontamination, cellular networks, channel state information, social spider optimization algorithm

I. Introduction

The deployment of several antenna elements at the transmitter and/or receiver of a communication link enhances wireless communication to an extra dimension in space. This means that the advantages that come with MIMO are very similar to the benefits we have with two ears instead of a single ear, which allow us to distinguish sounds from different directions. It means that the technique allows exploiting the directivity of the signal as an extra dimension of resource on top of bandwidth in wireless communications systems. This exactly is the reason for considering MIMO as the most prominent technology for the present cellular mobile communication standards, known as Long Term Evolution (LTE) and LTE advanced [1]-[2]. For future 5th generation mobile communications, we are still seeking solutions for keeping pace with the ever increasing demand and for higher and higher data rates in a more and more connected world of already today and even more on tomorrow. Here lies the relevance of massive MIMO, which is MIMO with very large number of antennas, 100s to 1000s, at the BS transmitters [3]. Obviously, this will change the shape of future antennas dramatically.

Massive MIMO is not just a scaling up of standard MIMO, on the contrary, in order to obtain the potentials and benefits from massive MIMO, we have to reinvent and rethink lots of concepts and algorithms from standard MIMO, and this poses a variety of very interesting and challenging research questions for the researchers in Academia and Industry.

In order to appreciate the real benefits of using massive MIMO, a very accurate CSI has to be made available to BSs, using appropriate channel estimation methods [4]. When using a very large number of antennas at the BS of a massive MIMO system, reusing the pilot signal is quite inevitable, due to the limited spectrum availability. Pilot reuse will, in turn, make the CSI estimation process very challenging due to pilot contamination, and it is the main limiting factor to exploit the enormous benefits supplemented by massive MIMO [5].

The proper pilot assignment is an effective mechanism to reduce the negative effects of pilot contamination. In this paper, we propose a pilot reuse strategy and a pilot assignment algorithm, based on multi-factor social spider optimization (MSSO). The situations under which the pilot contamination becomes predominant are studied and techniques to mitigate their effects are carried out. For this purpose, a multi cell multiuser massive MIMO network in TDD architecture with the proposed pilot assignment algorithm is simulated and performance is evaluated under different conditions.

The remaining part of this paper is arranged as follows: Section II discusses the recent research works carried out in the related area. Section III explains the system model and Section IV gives a detailed analysis of the social spider optimization algorithm. Section V throws light upon the fitness function and MSSO algorithm. Simulation results and discussions are the focusing areas in Section VI, and Section VII reveals the concluding notes about the work.

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Corresponding author email: mundethali@gmail.com
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II. Related Works

Right from the beginning of massive MIMO concept applied for cellular mobile communication to the present, researchers are working hard to trace out the adverse effects of pilot contamination and methods to mitigate it. Research shows many proposals for reducing the inter-cell interference through the removal of pilot contamination in the CSI estimation process. Most of the work has identified non-orthogonal pilot reuse as the main cause of pilot contamination in massive MIMO systems [6]-[8], but few authors have discussed the effects of hardware impairments as well as non-reciprocal transceivers on pilot contamination [9]-[13].

In [14]-[15], the cells are divided into several clusters and an asynchronous time shifted algorithm was proposed for reducing the effect of pilot contamination. When the user terminals in one cluster transmit pilots, BSs from other clusters transmit downlink data, which will eliminate the pilot contamination problem between users of different clusters. The drawback of this method is that since the transmitted power of downlink data is much higher than that of the pilot signals, precise channel estimation may not be possible.

A decontamination method based on multi cell cooperation for Massive-MIMO systems, with a limited number of antennas was suggested in [16]-[17]. The BS linearly combines the data meant for different users from different cells, which use identical pilot sequence, and an outer cellular precoding is performed on the combined data. It works satisfactorily only for BSs with less number of antennas.

In [18]-[20], it has been shown that by using covariance matrices a BS can have a better estimate on the CSI which in turn improves the system performance by mitigating the effect of pilot-contamination. Though the calculation of the covariance-matrices of all the channels is not so easy, the papers focus on different practical methods to do the same for a massive MIMO system.

In [21]-[22], a new precoder/detector combination was designed by using multiple cell linear preorders in the downlink path, and strong decoders for the uplink channel of massive MIMO networks. In [23], effects of pilot contamination were addressed by avoiding the simultaneous use of same pilot sequences in adjacent cells. Asymptotic orthogonality among different wanted channels and interference affected channels were effectively used in [24]-[25] for the pilot decontamination.

In [26] the pilot decontamination methods in massive MIMO under crowded scenarios were analyzed. Here a small set of pilot sequences were shared by users within a single cell causing intracellular pilot contamination. It is considered as a random access problem and the solutions proposed were very efficient. The main drawback in this was higher error rate by building up of errors in the algorithm.

Two novel channel estimation schemes were proposed in [27] for the effective removal of pilot contamination. The new scheme consists of repeated transmission stages of pilot symbols, where the BS stay idle in one stage and successively send pilots symbols in other stages. The performance gain of the suggested estimation schemes was demonstrated through simulation.

Pilot allocation based on graph coloring has been proposed in [28] for effective pilot decontamination. An interference graph is first prepared to show the possible inter-cell interference relationships of every user terminal. With the aid of this graph, the fully orthogonal pilot-sequences are allocated to the potential users to avoid the interference and pilot contamination. The improvement in the spectral efficiency has been verified through simulations.

In [29], authors have shown that the spectral efficiency can be increased without any limit even in the occurrence of pilot contamination by providing a simple condition of linear independence in the covariance matrices. Thus, they have derived the analytical proof for the same for a simple two user MIMO and then extended that to multi cell scenarios.

A novel algorithm for mitigating the pilot contamination problem was designed in [30]. The new pilot design with arbitrary length based on alternating minimization approach was used and tested using simulations. Thus, the main attraction of the approach was flexibility in designing the pilot sequences for maximizing the spectral efficiency.

Under these conditions, we propose a new strategy for the pilot reuse among users in the center area of all the cells by considering their movement velocity and closeness to the BS. The MSSO algorithm, which mimics the cooperative behavior of social spiders, is used for selecting such eligible users for pilot reuse in neighboring cells. Thus, the main cause of performance deterioration through pilot contamination is identified, as the signal to interference plus noise ratio (SINR) saturation due to inter cell interference. So far, there has been no study towards the reduction of pilot contamination through proper pilot assignment strategy, according to the users' position related to the BS and users' mobility. Therefore, a social spider optimization algorithm, which makes use of the foraging behavior of community spiders, is used for solving the pilot assignment problem. It is to be noted that the existing SSO algorithm is working with single decision making metric. Hence, in this paper, the existing algorithm is modified so as to make it suitable for multi-factors. Significantly, the considered multi-factors are time varying metrics, which are optimized by the proposed MSSO algorithm. These metrics are obtained from the CSI during the uplink training process. Using this modified MSSO algorithm, one can easily assign the pilots based on the present position, and the mobility of the user.

III. The System Model

Consider a Massive-MIMO mobile cellular-network given in Fig. 1, which consists of multiple hexagonal-cells with a BS at the center, having an antenna array with M number of elements and K number of simultaneous users equipped with single transmit/receive antenna. All the users and the BSs are synchronized based on a time division duplex (TDD) protocol. In TDD, each frame consists of two phases, namely uplink (UL) training period and downlink (DL) data transmission. The channel reciprocity is assumed between the UL and DL. The BS needs to estimate the CSI of each user using pilot sequences, and then use the estimated-CSI to detect uplink data and to establish the downlink transmissions. All the pilot signals used by the individual users in a cell are assumed to be mutually orthogonal.

In the DL communication system (Fig. 2) the information symbols to different users are first multiplied by the conjugate of the estimated channel, and then these products are added together and fed to the transmitting antenna. The process is repeated for every antenna in the BS and hence the signals intended for the nth user from all the antennas will arrive in phase at user n, and arrive out of phase at all the other users. The precoding and beam forming technique used is Zero Forcing (ZF) which is considered as the simplest possible one and also very effective. Hence, for the downlink, the signal transmitted from the nth antenna can be written as in equation (1).

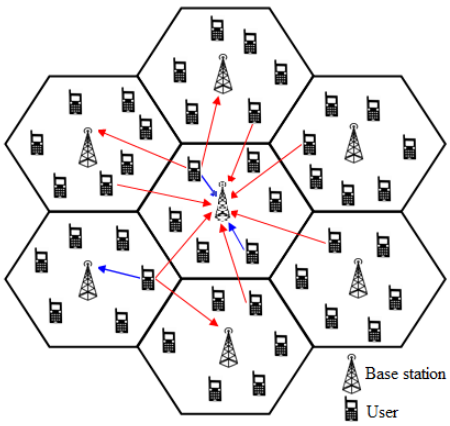


Fig. 1. System model

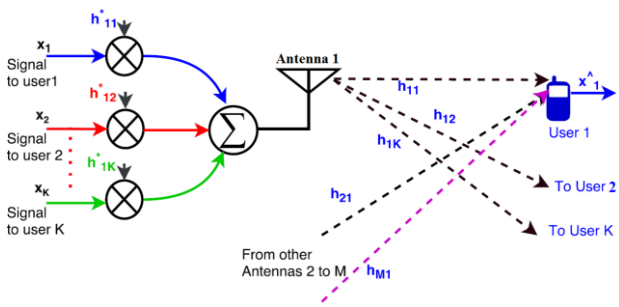


Fig. 2. Downlink communication

$$T_n = x_1 h_{n1}^* + x_2 h_{n2}^* + x_3 h_{n3}^* + \ldots\ldots + x_k h_{nk}^* \qquad (1)$$

where x_1 to x_k are the signals intended for k active users in the cell and h^*_{nk} his the conjugate of the channel estimate between *the* n^{th} antenna and k^{th} user.

In the uplink communication system (Fig. 3), each of the antennas at the BS collects signals arriving from all the users and multiply that individually by the conjugate of the channel estimate. Therefore in the UL the signal received by the nth antenna from all the users can be expressed as

$$R_n = x_1 h_{n1} + x_2 h_{n2} + x_3 h_{n3} + \ldots\ldots + x_k h_{nk} \qquad (2)$$

To get good estimates of CSI, the number of orthogonal pilot sequences should be equal to the number of users. Moreover, in order to maintain orthogonality of each pilot sequence, the length of the sequence must increase and that, in turn, will increase the time required for transmitting the pilot sequences. However, in a practical wireless system, the coherence interval is limited, and only a fraction of this interval can be devoted to pilot symbols, the rest being reserved for the data. So the length of the pilot sequence cannot be too long, which implies that the maximum number of orthogonal pilot sequences is limited. However, for massive MIMO networks, since the number of users in the system is very large and all users send pilot sequences to BSs simultaneously, the required number of orthogonal pilot sequences is also large. The practical number of available orthogonal pilot sequences is much less than the requirement and therefore, the same or partially correlated pilot sequences are reused in different cells causing pilot contamination. The proposed MSSO algorithm assigns these reused pilots in such a way that it will not create any inter channel interference.

System model described in Fig. 1 also explains the pilot contamination effect. Consider the center BS as an example, where it receives a combination of pilot sequences from all users. The blue color arrows represent the pilot sequences from own cell and the red color arrows represent the pilot sequences from a neighboring cell. If the neighboring cells reuse the pilots used by the center cell, then the pilot sequences received by the center cell will interfere each other and cause contamination. The channel estimate of a user in the center cell is contaminated by those users sharing the same orthogonal pilot sequence located in adjacent cells.

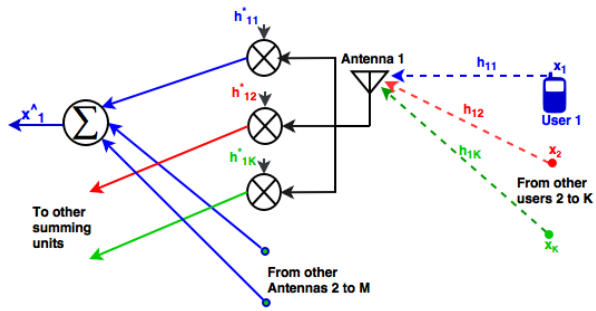


Fig. 3. Uplink communication

Fig. 4 shows the standard pilot reuse pattern with a $\beta=3$, where the integer $\beta \geq 1$, represents the number of subsets of pilots used in the system and S_1 to S_3 represent the different subsets of orthogonal pilot sequences. The concept of pilot reuse advocates the use of orthogonal pilot subsets in nearby cells thereby minimizing the actual number of subsets of pilot sequences required [31]. This, in turn, maximizes the spectral efficiency for both downlink and uplink communication links.

In the proposed model, the pilot sequences are partially reused in adjacent cells, and for that, the available set of orthogonal pilot sequences are divided into $\beta+1$ orthogonal subsets. Integer $\beta\geq1$ represents the pilot reuse factor between the adjacent cells and an extra subset of pilots is reused in the center area of all the cells. This scenario is depicted in Fig. 5(a) (only 3 cells are shown for simplicity). For the example shown in Fig. 5(b), $\beta = 3+1$, i.e. four subsets of pilot sequences, $S_1=\{f_3, f_4, f_5, f_6\}$, $S_2=\{f_7, f_8, f_9, f_{10}\}$, $S_3=\{f_{11}, f_{12}, f_{13}, f_{14}\}$ and $S_4=\{f_1, f_2\}$ are used. The subset S_4 is reused in all the cell centers without causing any inter-cell interference and subsequent pilot contamination problem.

Fig. 6(a) describes this situation where the interfering pilot signal from adjacent cell centers are very week compared to the own pilot signals giving rise to high SINR. But if the same sequences are reused in the cell boundary area as shown in Fig. 6(b), the interfering pilot signals from adjacent cells will be equally strong as the own pilot signal giving rise to a poor SINR and pilot contamination.

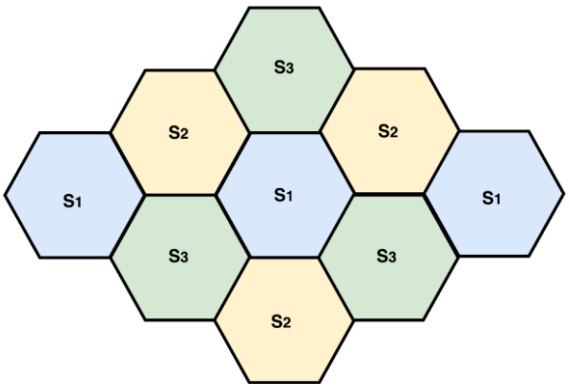
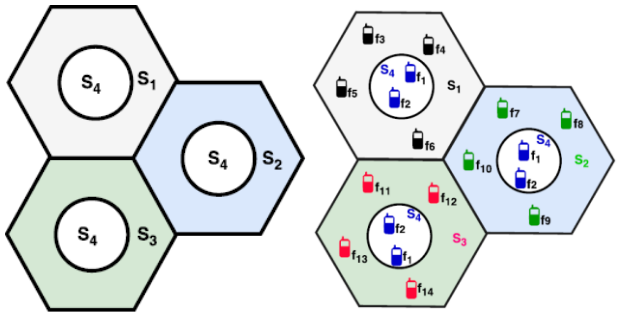
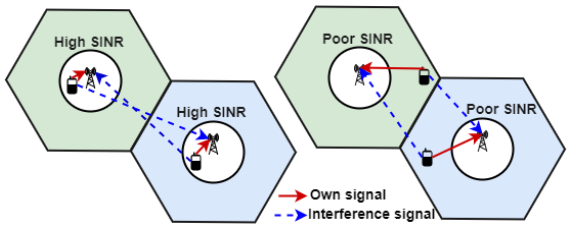


Fig. 4. Pilot reuse



(a) (b)

Fig. 5. Partial pilot reuse



(a). From cell center (b). From cell boundary

Fig. 6. Interference from adjacent cells

The proposed algorithm defines the radius of the cell centre area according to the received signal strength and SINR. Pilots are assigned to the users present in this area based on its distance from the BS and velocity of movement.

It is noteworthy that users with low mobility only are selected for assigning pilot sequences reserved for the cell center (S_4) because the probability of staying these user terminals (UT) within the cell center is much higher than the UTs with high mobility. The algorithm tries to maximize the minimum SINR value for all the K users in the cell.

IV. Social Spider Optimization Algorithm

Social spider optimization (SSO) algorithm is a Swarm intelligence algorithm proposed by researchers for optimization. It imitates the natural food/mate hunting phenomenon of social spiders to the optimization of a process [32]. The hyper dimensional spider web is considered as the search space in this problem of optimization and each point on this web is considered as a viable solution.

In addition to the space solution, the web acts as a communication media for the vibration produced by the spiders. Spiders are the primary functional agents in social spider algorithm. Every spider carries memory units which can store its present location on the web, fitness value corresponding to that position, and the vibration intensity experienced in the previous iteration. The algorithm uses the vibration intensity for determining the movement of the spider whereas the first two properties represent the features of the spider.

Biologically spiders are considered to be highly sensitive to vibrations. The position and intensity of the source of vibrations can be easily and accurately traced by spiders. They are also capable of differentiating separate simultaneous vibrations propagated through the web. These characteristics of social spiders are utilized in SSO algorithm [33]-[34]. Every time when a spider on a web makes a movement to a new location, it produces a new vibration which is communicated through the web to all the other spiders. The vibrations received by spider a_i from another spider or a prey a_j on the same web is given by

$$V_{a_{i,j}} = w_{a_j} e^{-d^2_{a_{i,j}}}; \quad d_{a_{i,j}} = \left\| x_{ai} - x_{aj} \right\| \qquad (3)$$

w_{aj} is the weight of the spider a_j given by equation (4), $d_{a,j}$ represents the distance between the spiders and x gives the position of the spider with respect to the center of the web.

$$w_{a_j} = \frac{FF - W_x}{B_x - W_x} \tag{4}$$

where $FF(a_j)$ represents the fitness function of the spider a_j, B_x and W_x are the best and worst cases of x and these are defined by the following equations.

$$B_x = \max_{k=1,\ldots,k} FF\left(x_k\right) \tag{5}$$

$$W_x = \min_{k=1,\ldots,k} FF\left(x_k\right) \tag{6}$$

Two methods are followed to learn the updated position of the spider which depend on the gender of the spider. Following equation gives the updated position for female spiders.

$$X_{FM_{a_i}}^{k+1} = \begin{cases} X_{FF_{a_i}}^{k} + r_1 \times \upsilon_{a_1} \times \left(a_1 - X_{FF_{a_i}}^{k}\right) + r_2 \times V_{a_2} \times \\ \left(a_2 - X_{FF_{a_i}}^{k}\right) + r_3 \times \left(\xi - 0.5\right); Random \geq M \\ X_{FF_{a_i}}^{k} - r_1 \times \upsilon_{a_1} \times \left(a_1 - X_{FF_{a_i}}^{k}\right) - r_2 \times V_{a_2} \times \\ \left(a_2 - X_{FF_{a_i}}^{k}\right) - r_3 \times \left(\xi - 0.5\right); Otherwise \end{cases} \tag{7}$$

where r_1, r_2, r_3 and ξ are random integers between 0 and 1, k is the number iterations made and M is the threshold value that makes the spider move either towards or away from the origin of vibration. a_1 is the spider with maximum weight and nearest to the spider a_i and a_2 is the best spider. V_a is the vibration intensity of the spider which is calculated by equation (3) and its weight is given by

$$W_{a_2} = \max_{k=1,\ldots,k} W\left(a_k\right) \tag{8}$$

When the female spider decides to travel to the origin of vibration, the first condition of equation (7) is used or else the second condition is used. The male spiders, on the other hand, update their current location according to the following equation.

$$X_{M_{a_i}}^{k+1} = \begin{cases} X_{M_{a_i}}^{k} + r_1 \times \upsilon_{a_3} \times \left(a_3 - X_{M_{a_i}}^{k}\right) + r_3 \times \left(\xi - 0.5\right); W_{M_{a_i}} \geq W_{median} \\ X_{M_{ai}}^{k} + r_1 \left(\left(\sum_{a_{j=1}}^{M_n} X_{M_{a_i}}^{k} \cdot \frac{W_{a_3+j}}{\sum_{a_{j=1}}^{M_n} W_{a_3+j}} \right) - X_{M_{a_i}}^{k} \right); \quad Otherwise \end{cases} \tag{9}$$

here W_{median} is the median weight calculated from all the male spiders and M_n gives the total number of male spiders. For dominant spiders, the weight value will be greater than the median weight or else it is considered as non-dominant. a_3 is the female spider nearest to the a_i^{th} male spider and V_{a3} is given by

$$V_{a_3} = W_{a_3} . e^{-d_{ai,a3}^2} \tag{10}$$

The SSO algorithm is executed in an iterative manner and the vibration intensity of the next iteration is calculated by the equation

$$V_{(i+1)} = V_{(i)} \times \alpha_a \tag{11}$$

where i and $i+1$ are the two successive iterations and α_a is the attenuation coefficient. The following equation gives the attenuation in intensity of vibration as it propagates over a distance of X.

$$V_{(D)} = V_O \times \exp\left(\frac{-X_{(O,D)}}{X_{max}\alpha_a} \right) \tag{12}$$

O and D are the originating and terminating positions, X_{OD} is the distance between them and X_{max} is the maximum distance between any two points on the web.

In SSO algorithm, three separate steps are involved; the first stage is the initialization phase which is then followed by the iteration stage, and then the final stage. All the optimization parameters search space and objective functions are initialized first and then, a number of spiders are generated and randomly placed on the search space. Then these positions are initialized as the current position with an intensity of zero; this completes the initial setup of the social spider algorithm and then it moves to the iteration stage where the optimization process is performed in an iterative manner. The fitness value of every spider in the web is calculated first and then the vibrations obtained in the previous phase are attenuated. Then according to equation (3), these spiders will generate vibrations in the present locations. These vibrations are transmitted using equation (12) to the entire web. Then each spider receives all the vibrations from other spiders from all sides of the web. Out of all these received vibrations, each spider selects one vibration with maximum intensity ($V_{\max}$) which is then compared with the value used in the previous iteration. Location of the spider is then calculated by the equation

$$X_{a(i+1)} = X_{a(i)} + (X_{\max(i)} - X_{a(i)})(.)\left(1 - R(.)R\right) \tag{13}$$

where $X_{a(i)}$ and $X_{a(i+1)}$ represents the location of the spider at iterations i and $i+1$ respectively, (.) is the elements wise multiplication. X_{max} is the source location of the spider with a maximum intensity of vibration V_{max}. R is a uniformly generated vector of random numbers from 0 to 1.

Finally, when a dominant male spider locates one or more female spiders within the specific range called as mating radius, it mates with all the females. The mating radius is given by

$$r = \frac{\sum_{j=1}^{n} (X_j^{max} - X_j^{min})}{2n} \tag{14}$$

where $J= 1, 2, \ldots..n$. and X^{max} and X^{min} are the boundary values of X.

In the proposed MSSOA, it first assigns random locations to each mobile user (spider), for that a

population of users is created and then its assigned locations are transformed to binary vectors of size M by the following equation.

$$TP\left(X_{a_i}^{a_j}(t)\right)=\frac{1}{1+e^{-X_{a_j}^{a_i}(t)}} \tag{15}$$

$$X_{a_i}^{a_j}(t+1)=\begin{cases}1; if\ TP\left(X_{a_i}^{a_j}(t)\right)>[0,1]\\ 0; Otherwise\end{cases} \tag{16}$$

where $X_{ai}^{aj}(t)$ is the user's value at iteration t. For each user a_i, The features selected correspond to 1s and the rests which are not selected correspond to 0s The multiple UL data metrics are used to compute the fitness function for the proposed optimization algorithm. The multi-factors obtained from the UL pilot sequences are *SINR*, received signal strength (*RSS*), the position of the user as a distance from the BS (X_n) and the velocity of user movement (v). The multi-factor metrics gathered from every user is considered as input and the proposed MSSO algorithm serves the pilot sequence request from multiple users according to its fitness function.

The suitability of the SSOA for a cellular network is demonstrated through the comparison shown in the following Table I.

TABLE I: COMPARISON BETWEEN SOCIAL SPIDER COLONY AND CELLULAR NETWORK

	Social spider colony	Cellular network
1	The web of social spiders is taken as the search space for the optimization problem and each point on this web is considered as a possible solution.	The entire area under a single hexagonal cell of a cellular network is considered as the search space and each point inside this cell can be a viable position for the UTs.
2	In the social spider colony, dominant male spider usually resides at the center of the web(hub) and female spiders are distributed over the entire web.	BS (equivalent to the dominant male spider) is located in the center of the cell and the UTs (equivalent to female spiders) are distributed in the entire cell area.
3	Male spider at the center receives vibrations from the female spiders through radial threads of the web and from those vibrations it identifies the location of the female spider.	BS receives CSI and other information from the mobile nodes through direct wireless links. Position and velocity of the mobile nodes are determined from the received information.
4	Male spider is capable of receiving and identifying simultaneous vibrations from multiple female spiders.	BS with massive MIMO antenna is capable of communicating simultaneously with the number of UTs through spatial diversity.
5	Male spider moves towards the female spider and mates with it when it comes inside the mating radius.	BS assigns a reusable pilot sequence to the UT if it is located in the center cell area and satisfies the speed condition.

SSO algorithm is based on swarm intelligence. Due to the use of mobile agents and stigmergy, it has got the following advantages over the existing solutions available in literature, when it is used for pilot assignment.

1. Scalability: The population of the mobile agents (UTs) can be changed to any value according to the cellular network requirement.
2. Adaptation: UTs can change its communication characteristics according to the change in communication environments.
3. Speed: System adapts to the network changes very fast and is very useful in a dynamic wireless environment.
4. Autonomy: The system automatically accepts all the changes and acts accordingly to get the best performance.
5. Parallelism: Mobile agent's function is essentially parallel which again increases the speed.
6. Fault tolerance: Failure of few nodes or links does not result in any disastrous failures.
7. Modularity: The mobile agents act independently of the other layers of the network.

All the above benefits are attained in a very simple and expeditious way. It requires only RSS and velocity of UTs to effectively assign pilot sequences in order to mitigate the effects of pilot contamination. These values will not change with the number of antennas used at the BS and also will remain constant within a considerable frequency and time interval. Hence implementation of the proposed pilot assignment scheme using MSSO algorithm for massive MIMO system is a definite possibility.

V. FITNESS CALCULATION USING MULTI-FACTORS

MSSOA performs the optimization on the basis of the time varying metrics calculated in each iteration. The fitness function (FF) for each user is calculated as per the following rule

$$FF=Min\left\{\frac{1}{RSS},\frac{1}{SINR},X_n,v\right\} \tag{17}$$

The steps for the proposed algorithm for pilot assignment are given in Table II. The FF is calculated individually for every user in the cell and is compared with the total best fitness value FF_{best}. If the present value of fitness function FF_i is better, then the FF_{best} is replaced with FF_i . This process is repeated until all the users are iterated. Finally, the pilot assignment is done for the user with FF_{best}.

A. Mobility with Received Signal Strength (RSS)

The energy consumption depends on both transmitter and receiver energy requirements. The energy consumed by any UT is directly proportional to the square of the distance (D^2) when the transmission distance is lesser compared to the threshold value (D_0) or else proportional to D^4. When a data packet carrying b number of bits is transmitted by the network and received by a UT the total energy consumed will be

$$E_T=E_{tx}(b,d)+E_{rx}(b) \tag{18}$$

where $E_{tx}(b,d)$ and $E_{rx}(b)$ are energy consumed by the transmitter and receiver.

$$E_{tx}(b,d)=\begin{cases} b\times E_d + b\times \varepsilon_{fs}\times D^2; if\ \ D<D_0 \\ b\times E_d + b\times \varepsilon_{mp}\times D^4; if\ \ D\geq D_0 \end{cases} \quad (19)$$

where E_d is the energy dissipated per bit to run the transmitter or receiver circuit. ε_{mp} and ε_{fs} are the energy consumed by the amplifier circuit under the multipath model and free space model respectively which depends on the amplifier model and threshold distance.

Received signal strength (RSS) is calculated from the linear average of the energy consumed considering the adjacent channel interference and thermal noise. RSS can be calculated from the transmitted energy and the distance between the source and destination. If a packet with b number of bits and energy $E_{tx}(b,d)$ is transmitted by a user the received signal strength at a distance D from the source is given by

$$RSS=\frac{E_{tx}(b,d)}{4\pi D^2}+T_{x,y/z} \quad (20)$$

where $T_{x,y/z}$ is the time taken by the UT to move to the new location x or y. The differential speeds of the transmitter and receiver and distance between them determine the actual speed of the node. Sample points are chosen in such way as to meet the condition $\Delta t_y = \Delta t_z = \Delta t$. In practice, a number of different sample points are selected for calculation of the actual signal strength of the user. Differential speed calculation is shown in Fig. 7. Assume x as the current location of the node and it can move to location y and z. D_x is the distance from the BS to the current location, D_y and D_z are the updated distances calculated by the cosine laws as given in equation (21) and (22).

$$D_y^2=D_x^2+\Delta_y^2-2D_x\Delta_y\cos(\alpha) \quad (21)$$

$$D_z^2=D_x^2+\Delta_z^2-2D_x\Delta_z\cos(\beta) \quad (22)$$

Since $cos(\pi-\theta) = -cos(\theta)$, $cos(\alpha)$ can be considered as $-cos(\beta)$, hence by adding equations (21) and (22) and assuming $\Delta_y = \Delta_z$ we get

$$2\Delta_y^2=D_y^2+D_z^2-2D_x^2 \quad (23)$$

Then the velocity of the node movement is given by

$$v=\frac{\sqrt{\left(D_y^2+D_z^2-2D_x^2\right)/2}}{\Delta_t} \quad (24)$$

where Δ_t is the time taken by the node to move from the present location to the new location y or z.

The proposed pilot allocation scheme is implemented as follows.

1. The BS is initialized in each cell and a fixed number of UTs are randomly placed across each cell
2. A pilot reuse pattern with a β of 4 as explained in Fig. 5 is selected and the users from all the cells transmit the pilot signals to their corresponding BSs
3. The BS calculates the position and velocity of UT movement as explained in section V-A.
4. SINR corresponding to each UT is also calculated by the BS from the received CSI.
5. Based on the above information the MSSO algorithm determines the best UT to assign a reusable pilot sequence.
6. The process is repeated until all the pilot sequences in set S4 are assigned to the best possible UTs which are selected by considering the *max(SINR)*, *min(Xn)*, *max(RSS)* and *min(v)* values.

Table II describes the proposed MSSO algorithm.

TABLE II: MULTI-FACTOR SOCIAL SPIDER OPTIMIZATION ALGORITHM FOR PILOT ASSIGNMENT

1	Input: RSS, β, SINR, No. of users, No. of cells, Cell radius
2	Output: Pilot sequence assignment
3	Initialize the number of users, number of cells, number of iteration(I_{max}) and best fitness function(FF_{best})
4	Initialize a population of n users a_{x_i}

5	I=0
	Repeat
	for all a_{x_i} do
	$FF=Min\left\{\frac{1}{RSS},\frac{1}{SINR},X_n,v\right\}$
	If ($FF_i<FF_{best}$) then
	$a_{x_{best}}=a_{x_i}, FF_{best}=FF_i$
	end *if*
	end *for*

6	Compute the worst and best FF using equation (5) and (6)
7	Compute the position and velocity of users using equation (13) and (24)
8	Discriminate the locations of the pilot requests using equation (14)
9	Perform the pilot assignment on the basis of FF
10	*I=I+1*
11	Repeat until $I<I_{max}$

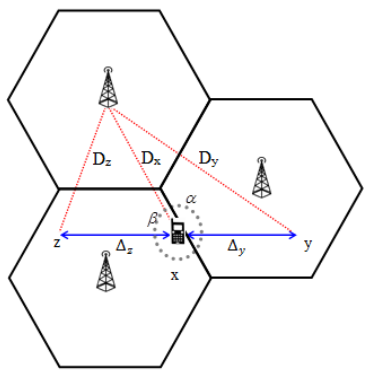


Fig. 7. Mobile nodes movement computation

B. Normalized Mean Square ERROR (NMSE)

NMSE is the estimator used for calculating the overall deviations between the predicted value and the actual measured value. In NMSE the variations (absolute values)

are added instead of taking the differences and hence NMSE always indicates the predominant differences in the simulation models. A simulation model having very less NMSE can be considered as well performing.

The performance of channel estimation in wireless communication networks are measured using NMSE and it is given by the following equation

$$NMSE = \frac{E\left\{\hat{H}_{i,i} - H_{i,i}{}^{2}\right\}}{E\left\{H_{i,i}{}^{2}\right\}} \tag{25}$$

where $\hat{H}_{i,i}$ represents the estimate of the wireless channel from the ith transmitter to the ith receiver and H_{ii}, is the corresponding measured value.

C. Sum-rate

If the CSI obtained is assumed as perfect then the BS correctly estimates the channel matrix and SNR of the nth user in the lth cell can be represented as [12]

$$SNR_{nl} = \frac{Mp_{dln\beta_{ln}^{2}}}{\sigma^{2}} \tag{26}$$

where σ^2 is the noise variance at the receiver, M is the number of BS antennas, β is the attenuation coefficient P_{dln} is the downlink power from the BS to the nth user in the lth cell. Then the total achievable sum-rate of the nth user in the lth cell is given by

$$R_{ln} = \left(1 + SNR_{nl}\right) \tag{27}$$

The total sum-rate of the lth cell is given by

$$R_{l} = \sum_{n=1}^{N} R_{ln} \tag{28}$$

where N is the total number of active users in the lth cell.

VI. Results and Discussions

The performance of the MSSO algorithm for the effective pilot assignment in massive MIMO cellular communication system was investigated through simulation. The proposed pilot decontamination in a time varying channel was implemented using MATLAB. The evaluation metrics used were NMSE, bit error rate and sum-rate. Simulations were carried out for two different modulation techniques, BPSK and 16-QAM, and the performance was analyzed under varying number of BS antennas as well as for varying number of mobile users.

Fig. 8 shows the variation NMSE with increasing number of BS antennas. As we increase the number of BS antennas it provides more spatial diversity and increased beam forming to make the communication more error free. The NMSE performance is improved more rapidly at the initial stage, and later, it becomes more or less saturated because the number of receiving nodes is kept constant at 50 and as the number of BS antennas increases it becomes sufficient to form the necessary spatial diversity and beam-forming for 50 UTs. The proposed method QAM(MSSO) and BPSK(MSSO) gives improved performance compared to standard QAM and BPSK irrespective of the number of antennas and is clearly due to the mitigation of pilot contamination by proper pilot assignment.

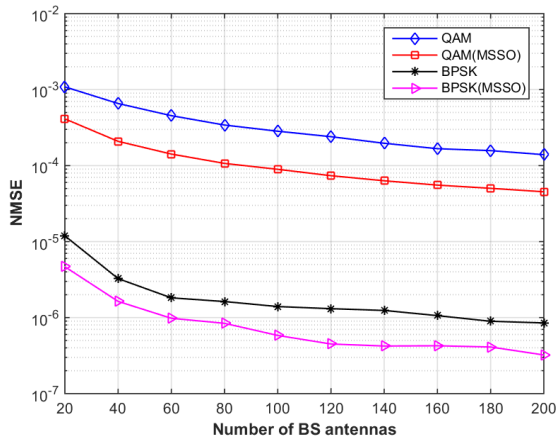


Fig. 8. NMSE Vs No. of BS antennas (log scale)

Fig. 9 shows the total sum-rate variation in a cell with increasing number of BS antennas. It gives the improvement in the sum-rate performance of the proposed scheme under two modulation schemes. The sum-rate degradation due to inter cell interference from nearby cells is minimized by using the MSSO algorithm for pilot assignment. The MSSO algorithm considers both mobility and position of the user node for selecting the pilot sequence and hence the contamination effect due to the high mobility of users is also reduced giving rise to better performance.

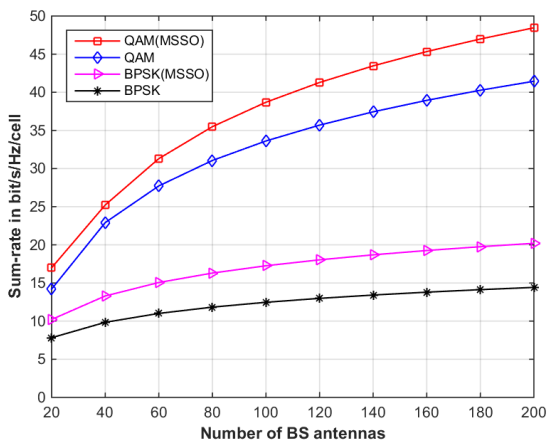


Fig. 9. Sum-rate Vs no. of BS antennas

Fig. 10 compares the BER of the system under the four different scenarios. The BER performance of the system is considerably improved by the use of MSSO algorithm for pilot assignment both in QAM and BPSK type of modulation. Here the number of user terminals is kept constant at 50 and system dimension is increased by increasing the number of BS antennas up to 200.

Fig. 11 shows the variation of NMSE with increasing number of UTs keeping the number of BS antennas as constant at 100. The spatial diversity and beam forming requirements of the system increase with the increase in the number of UTs, but since the number of transmitting

antennas was kept as constant, the system performance starts deteriorating and gives an increased error.

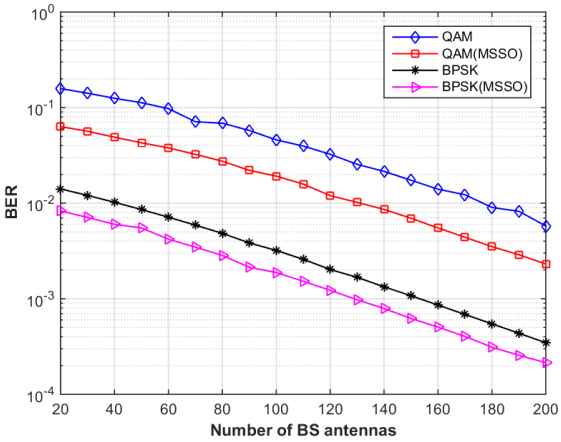


Fig. 10. BER Vs No. of BS antennas

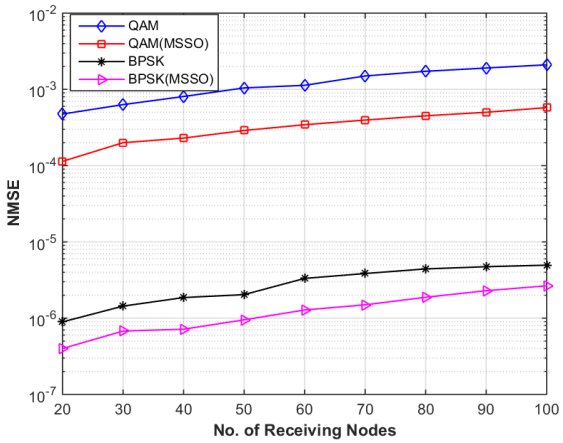


Fig. 11. NMSE Vs Number of receiving nodes

VII. Conclusion

This paper proposes a novel method for pilot decontamination in massive MIMO cellular communication system. In this method, each cell is divided into two sectors, and the users near to their respective BSs in all cells, get the same subset of pilot sequences based on their speed and distance from the BS. This is made possible by using the MSSO algorithm, which imitates the cooperative behavior of social spiders, for coordinating the pilot assignment for these mobile users. The algorithm was implemented using MATLAB and tested over a massive MIMO system employing ZF precoding and TDD architecture with two types of modulation techniques 16-QAM and BPSK. Further, the performance gain was measured by comparing BER, NMSE and system sum-rate under different scenarios. The yielded results proved that the effect of pilot contamination can be significantly reduced by proper pilot assignment strategy. Thus it becomes obvious that the proposed MSSO algorithm outperforms the regular pilot assignment method in terms of BER, NMSE and sum-rate.

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Ali Mundeth Ahmed obtained his Bachelor's degree in Electronics and Communications Engineering from Kerala University, India. Then he obtained his Master's degree in Fiber optics and light wave engineering from Indian Institute of Technology, Kharagpur, India. He is at present working as Associate Professor in the department of Computer Applications, Government Engineering College, Thrissur, Kerala, India. His current research interests are Wireless networking, OFDM, Massive MIMO, Channel estimation etc.

Erakkath Abdu Jasmin obtained her Bachelor's degree in Electrical and Electronics Engineering from Kerala University, Kerala in 1995. Then she obtained her Master's degree in Computer and Information Sciences and Ph.D. degree from Cochin University of Science and Technology, Kerala, India in 1997 and 2009 respectively. Currently, she is Associate Professor in the department of Electrical and Electronics, Government Engineering College, Thrissur, Kerala, India. Her current research interests are Optimization algorithms, Soft computing, Smart grid, Wireless networking etc.