Ant Colony-based Optimization algorithm to overcome the pilot contamination issue within multi-cell Massive MIMO systems

Abdelfettah BELHABIB, [1,*], Jamal AMADID [1], Asma KHABBA [1], and *Abdelouhab ZEROUAL* [1]

[1] I2SP team Group, Faculty of Sciences Semlalia, Cadi Ayyad University, Marrakesh 40000, Morocco

Abstract. the pilot contamination (PC) issue still faces and limits the promising massive MIMO (mMIMO) technology, to unleash the high benefits of mMIMO, we provide here a new decontaminating strategy, which exploits the large-scale fading coefficients' characteristics to construct a search space for the Ant colony-based optimization (ACO) algorithm. This algorithm is employed to find the best pattern in which each UE is linked to its most concurrent UEs of the adjacent cells; specifically, each UEs has an enemy UEs that if they are allocated with the same pilot, the severity of the PC upon the two UEs become subversive for the quality-of-service of the two UEs. Hence, the ACO algorithm finds for each UE its enemy UE, which leads to construct a Hamiltonian graph. This graph is exploited during the assignment of the pilot sequences to the overall UEs; specifically, the linked UEs are successively allocated with the available OPSs, which leads to address the PC problem within multi-cell mMIMO systems.

1 Introduction

The increased requirements for such better performances has pushed the wireless communication systems to a new level, which is more mature than the current LTE-advanced pro. Accordingly, the next five generation (5G) standards, requires the use of new technologies and a new band of frequencies to meet the challenges of high connectivity and high system throughput. Since the LTE is already in the market, the switching to the new 5G requires a smooth bridge that will enable this transition from LTE 4G to 5G; accordingly, the first steps of deploying 5G needs the core network of the current LTE 4G, so the 5G will work in its first steps under the non-standalone option; when 5G become mature enough to work with its core network, here we say that it is in the stand-alone option; hence it can meet its promises of a latency (<1ms), data rat >10 GB/s and 10^6 connection per kilometer square. The band of millimeter-waves (band of high frequencies >20 GHz) is suggested for deploying the 5G; but still need more sophisticated/base stations to exploit these band of frequencies, so as to be able to serve -through multiplexing techniques- multiple user equipments (UEs) using the same resources. Massive multiple-input multiple-output (mMIMO) is the main pillar of the next 5G [1]. The concept of mMIMO stands on deploying each base stations (BS) with a large number of antennas; hence, the BSs become capable to serve, simultaneously, many UEs; consequently, the fulfilled achievable rate (AR) become, greatly, enhanced where both the spectral, and energy efficiency are boosted [2-5].

The benefits of mMIMO technology are related to the exactitude of the estimated channel state information (CSIs). Since the available pilot resources are very limited, mMIMO is desired to operate with the time-division duplex (TDD) protocol instead of the frequency division duplex (FDD), which requires a huge amount of the pilot resources. Specifically, the reciprocity characteristic of TDD can derivate the downlink CSIs based on the estimated uplink CSI. Accordingly, based on TDD, BSs are susceptible to use a small number -compared to FDD- of the pilot sequences (PSs), which is explained by the reciprocity characteristic of the TDD in which the BSs are exempt from the estimation of the downlink (DL) CSIs; accordingly, the TDD is desired for mMIMO due to its susceptibility to reduce the cost of obtaining the CSI at the BSs [6] [7].

Contribution

The prime contributions of this paper are:

- The PC problem is analyzed within multi-cell mMIMO systems.
- A new strategy is proposed to overcome the PC problem.
- The proposed strategy is based on the UEs' large-scale fading (LSF) coefficients and the ant-colony based optimization algorithm.

Organization

The remaining of this manuscript is planned in the following way: Section.2 is devoted for some related works, while the adopted system model is provided in Section.3. The communication schemes that take place in mMIMO systems are presented in Section.4, whereas our strategy is provided in Section.5. In section.6, we evaluate the performance of our strategy; therefore, the last section is reserved to the conclusion.

2 Related works

* Corresponding author: abdelfettah.belhabib@edu.uca.ac.ma

Since the available amount of the pilot resources is limited, the reuse of the same PSs, within several cells, is inescapable [8]. This leads to the famous phenomenon called pilot contamination (PC), which has contributed, negatively, on the accuracy of the estimated CSIs [1]. Since the PC issue is the principal constraint that prevents the implementation of mMIMO, many strategies have been proposed in the past decade. A pilot-based assignment is proposed in [9], which assigns the available PSs to the UEs based on a graph of interference. this graph sizes the severity of the PC (SPC) problem between the UEs and through a specific pilot assignment strategy, the SPC is, greatly, decreased. The proposed strategy in [10] is mainly based on the exploitation of the game-theory to guarantee the fairness between UEs, however, a perfect CSI is assumed, which is not always hold in such practical scenarios. The meta-heuristic based optimization algorithm is proposed in the work of [11]; and inspired from this work, the ACO-based algorithm is exploited here to find a pattern in which the available orthogonal PSs (OPSs) are, wisely, shared by the overall UEs, which helps to minimize the destructive influence of the PC within multi-cell mMIMO systems.

3 Channel model

Herein we provide the considered system model. This latter is composed of L hexagonal cells, each one of them is centered with a BS of M antennas that serve K UEs. The uncorrelated Rayleigh-fading channel model is adopted herein ([12]), and the channel $h_{i,j,k}$ between the k^{th} UE of the j^{th} cell (kj) to the BS of the i^{th} cell is given as in [1] as follows:

$$\mathbf{h_{i,j,k}} = \mathbf{g_{i,j,k}}\sqrt{\beta_{i,j,k}} \qquad (1)$$

where $\mathbf{g_{i,j,k}} \in \boldsymbol{C}^{M\times 1}$ represents the small-scale fading coefficients, which are statistically independent for the K UEs and they comply with a complex-Gaussian distribution of zero-mean vector and an identity covariance matrix $\boldsymbol{I_M}$ i.e $\mathbf{g_{i,j,k}} \sim \boldsymbol{NC}(\boldsymbol{0_M}, \boldsymbol{I_M})$, on the other hand, $\beta_{i,j,k}$ is the LSF which accounts for both the path-loss and the shadow-fading and it can be expressed [1] as :

$$\beta_{i,j,k} = \frac{z_{i,j,k}}{(r_{i,j,k}/R)^{\alpha}} \qquad (2)$$

where $z_{i,j,k}$ is a log-normal variable (i.e $10\ log_{10}(z_{i,j,k})$) of a zero-mean Gaussian distribution and it is characterized by a standard deviation σ_{shadow}, $r_{i,j,k}$ refers to distance between (kj) and the BS of the i^{th} cell, R=200m denotes the cell radius, and $\sigma = 3$ represents the path loss exponent.

The $M \times K$ channel matrix between the K users of the j^{th} cell to the BS of the i^{th} cell can be represented as :

$$H_{i,j} = [\mathbf{g_{i,j,1}}, \mathbf{g_{i,j,2}}, \dots, \mathbf{g_{i,j,K}}]D_{i,j}^{1/2} \qquad (3)$$

Where $D_{i,j}$ refers to a $K \times K$ diagonal matrix of the LSFs of the UEs, and it can be expressed as

$$\mathbf{D_{i,j}} = diag(\beta_{i,j,1}, \beta_{i,j,2}, \dots, \beta_{i,j,K}) \qquad (4)$$

The quality-of-service within a wireless communication system can be evaluated based on the fulfilled achievable rate (AR), which depends on the signal to noise-plus-interference ratio (SINR). The average AR for the UE (kj) is given as follows

$$C_{j,k} = (1-\mu)E\{log_2(1+SINR_{j,k}\} \qquad (5)$$

where μ assesses the loss of the spectral efficiency, while the UL SINRs is

$$SINR_{j,k} \xrightarrow{M\to\infty} \frac{\beta_{j,j,k}^2}{\sum_{i\neq j,i=1}^{L}\beta_{j,i,k}^2} \qquad (6)$$

whereas the DL SINR is given by the following equation

$$SINR_{j,k} \xrightarrow{M\to\infty} \frac{\beta_{j,j,k}^2}{\sum_{i\neq j,i=1}^{L}\beta_{i,j,k}^2} \qquad (7)$$

4 Communication schemes

Based on the block-fading channel model, the communication between the UEs and their supported BSs is divided into coherence blocks, in which the channel responses remain static. In each coherence block, we distinguish between four phases [12][13] :

- Pilot transmission : UEs transmit/uplink (UL) their pre-allocated pilot sequences.
- channel training: BSs exploites the received pilot signals for estimating the CSIs. These channels are used to build both detectors and precoders.
- data detection: UEs UL their data symbols, which are received at the BSs' side based on the constructed detectors.
- data precoding: BSs exploit the constructed precoders to beam-form, in the DL phase, the data symbols toward the targeted UEs.

We supposed here that the UEs, synchronously, UL their pilot sequences, and we suppose that the BSs accept all the UEs that request the permission, the random access protocol is not considered her.

5 The proposed decontaminating strategy

From eq. 2, it can be noticed that the LSF coefficients of the UEs relies heavily on the distance between their geographical position and their supported BS; accordingly, we propose to exploit this information to assign the available OPSs to the overall UEs based on their positions within cells. Firstly, we build a matrix that arranges the distances between UEs of the overall cells. This matrix is considered as the database (i.e., the search space) of the ACO algorithm. In Fig.1 we depict the situation in which each UEs is linked to its closest UEs, while Fig.2 shows the pattern founded after applying the ACO algorithm, for more details about the input parameters of the ACO algorithm, we invite the interested readers to the book [11].

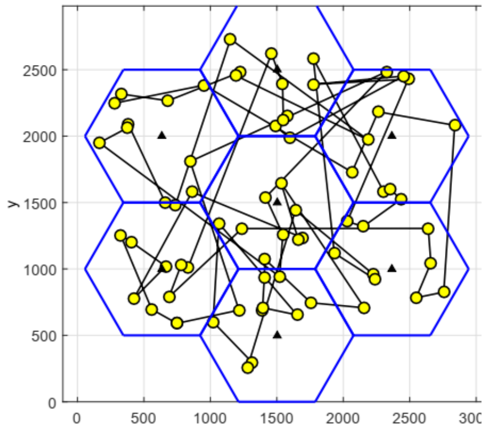

Fig. 1. Before applying the adapted ACO algorithm.

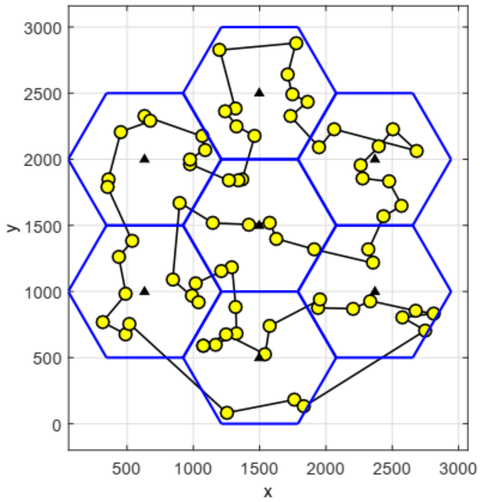

Fig. 2. After applying the adapted ACO algorithm.

Note : In Figs 1 and 2, the black triangles and the yellow circles represent, respectively, the BSs and the UEs' geographical position within the hexagonal cells.

At this level, each UE is connected to its most concurrent UE; otherwise, each connected UE must be allocated with orthogonal pilot sequences, if not they are subject to the highest destructive influence of PC. Accordingly, our strategy, shoes one UEs in a randomly chosen cell. Therefore, the UEs ars assigned, successively, with the available orthogonal pilot sequences. Specifically, let us consider the scenario of Section. 3, and that we are allowed to use K orthogonal pilot sequences. Thus, the ACO decontaminating strategy allocates K OPSs to the first K UEs of the constructed graph (i.e., the line that connects the UEs in Fig.2), therefore, the next K UEs are again allocated with the same set of K OPS, and so on for the overall KL UEs, where the k^{th} UE in each considered range is allocated with the k^{th} pilot sequence.

6 Simulation results

In this section, we aim to assesses the performance of the ACO-PD strategy. This based on a set of Monte-Carlo simulation. The system model of section. 3 is adopted, and the system parameters used in our simulation results are listed in Table.1.

Table 1. System parameters.

Number of (NrO) cells	L = 7
NrO antennas BSs	$32 \leq M \leq 256$
NrO UEs per cell	*K=10*
NrO OPSs	*K=10*
Inner radius of the cell	*r=200 m*
Transmit powers ρ_p, ρ_u, ρ_d	*15dBm*
Log-normal shadow fading	$\sigma_{shadow} = 8\ dB$

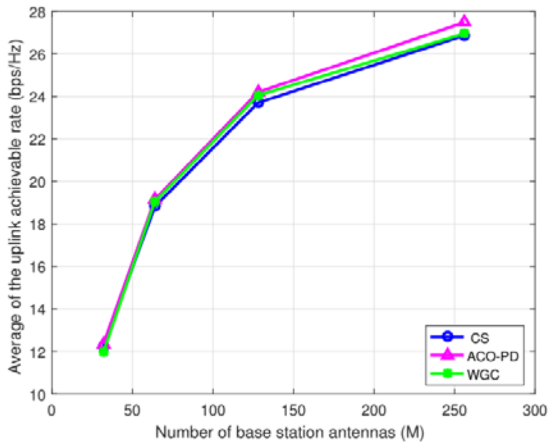

Fig. 3. Average of the UL AR as a function of *M*.

In Fig.3, we compare the fulfilled performance of our proposed strategy to those of two strategies i.e., the conventional strategy (CS) of [1] and the weighted graph coloring-based assignment strategy (WGC) of [9] in the UL phase. From the figure, it can be remarked that the three strategies perform similarly in the range $32 \leq M \leq 64$, while the proposed strategy begins to performs more efficiently than both CS and WGC from M=128 up to M=256. The main benefit of our strategy is its stability; in other words, the obtained performances are always the same, contrariwise, both CS and WGC are not stable and their reached performance can be good in specific scenarios, while it can reach low performance in other scenarios, especially, the WGC that can lose its efficiency in such crowded scenarios.

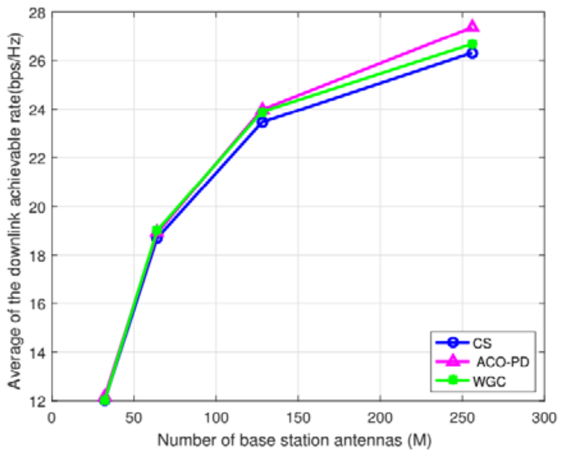

Fig. 4. Average of the downlink AR as a function of *M.*

The downlink achievable rate of ACO-PD is compared to that of both CS and to WGC in Fig.4. Here, the ACO-PD strategy outperforms the CS strategy for the whole range (i.e., $32 \leq M \leq 256$), but with a small gap ; while the proposed ACO-PD performs similarly to the WGC strategy from $M = 32$ up to $M = 128$; therefore, the proposed strategy starts to outperforms better than the WGC after *M*=128; As in the UL phase, the reached performances are good, and the good side of our proposed strategy is its stability and robustness, which is practically desired.

It should be noticed that the performance reached by the three strategies increases with M, which can be explained by the fact that deploying the BSs with a vast number of antennas lead to strengthening the transmitted signals; additionally, the beams of the transmitted signals are likely to become more narrow which helps to reach their targets without generating the disturbing interference.

7 Conclusion

In this manuscrit, we have analyzed the main issue that faces the mMIMO technology. Therefore, a novel decontaminating strategy is provided, which is based on the exploitation of the UEs' LSF coefficients to construct the search space for the ACO algorithm. Once, the search space is ready, it is exploited by the ACO algorithm to link each UE to its most concurrent UE; accordingly, a Hamiltonian graph is constructed. This graph is exploited during the assignment of the available OPSs to the overall UEs where orthogonal pilots are allocated to the concurrent UEs. This simple process can be considered as a cure to the destructive influence of the PC problem.

The first author would like to thanks Mr. Jy-yong Sohn from the University of Wisconsin-Madison for his valuable, immediate, and constructive answers.

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