POLİTEKNİK DERGİSİ

JOURNAL of POLYTECHNIC

ISSN: 1302-0900 (PRINT), ISSN: 2147-9429 (ONLINE)

URL: http://dergipark.gov.tr/politeknik

A new approach to pilot contamination in massive mimo systems for 5G communication networks with butterfly optimization algorithm

5G haberleşme ağlarındaki büyük mimo sistemlerinde pilot kirlenmesi için kelebek optimizasyon algoritması yaklaşımı

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Bu makaleye şu şekilde atıfta bulunabilirsiniz(To cite to this article): Altiraiki S., Tezel N. S., "A new approach to pilot contamination in massive mimo systems for 5G communication networks with butterfly optimization algorithm", ***Politeknik Dergisi***, 25(4): 1753-1759, (2022).

Erişim linki (To link to this article): http://dergipark.gov.tr/politeknik/archive

DOI: 10.2339/politeknik.726354

A New Approach to Pilot Contamination in Massive MIMO Systems for 5G Communication Networks with Butterfly Optimization Algorithm

Highlights

- *Increasing output and communication power in fifth generation networks.*
- *Use butterfly optimization algorithm to reducing the pollutions.*
- *Improving of the signal-to-noise ratio and the rate of network-connected users of similar communication methods such as Random, SPRS, WGC-PD and SPRS + WGC-PD.*
- *Increase communication efficiency and reduce energy consumption.*

Graphical Abstract

Butterfly optimization algorithm is used to increase the output and communication power in the 5G networks.

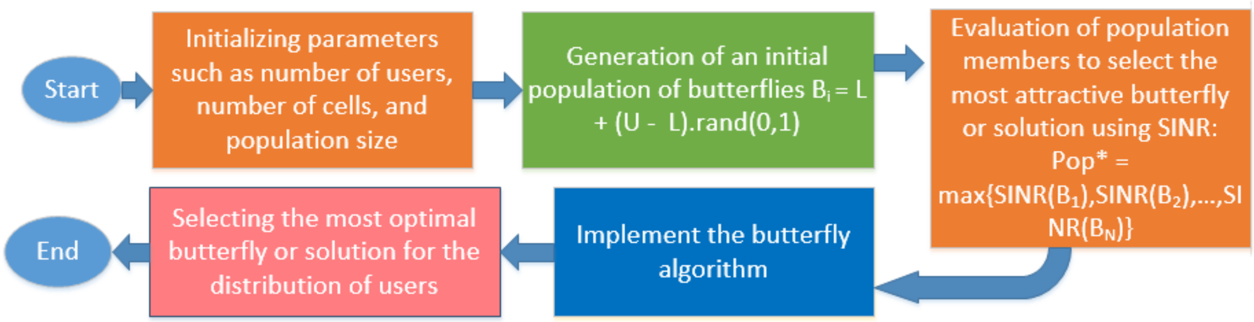

Figure. Flow chart of the proposed method

Aim

An important challenge in the 5G network is the problem of environmental pollution that a user can use multiple cell services simultaneously and make the system unbalanced. Therefore, in the proposed method to solve this challenge, the problem is assumed to be optimized with using of butterfly optimization algorithm, an attempt has been made to reduce and modify this challenge.

Design & Methodology

We designed the optimization algorithm which is name is butterfly to 19 cells, that each of them with a base station and a number of active users. In the proposed method, by implementing the license optimization algorithm, it is possible to optimize user-related vectors for service in a single cell, and the average signal-to-noise index can be maximized throughout the network, and the most optimal license is actually It is a butterfly that has the maximum signal to noise.

Originality

In this paper, in order to increase the output and communication power in the fifth generation networks, the problem has been considered from the perspective of optimizing the problem and the impeller optimization algorithm has been used for it. There is no any similar paper that represented proposed method before.

Findings

The proposed method is more efficient than other methods such as Random, SPRS, WGC-PD and SPRS+WGC-PD.

Conclusion

The proposed method based on butterfly algorithm has been able to increase the SINR level more than other methods such as Random, SPRS, WGC-PD and SPRS + WGC-PD. The bit rate for each user is better than the other methods that discussed inside of the paper.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission

5G Haberleşme Ağlarındaki Büyük MIMO Sistemlerinde Pilot Kirlenmesi için Kelebek Optimizasyon Algoritması Yaklaşımı

Araştırma Makalesi / Research Article

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(Geliş/Received : 24.04.2020 ; Kabul/Accepted : 15.06.2020 ; Erken Görünüm/Early View : 02.07.2020)

ÖZ

Haberleşme teknolojileri, özellikle beşinci nesil (5G) cep telefonları şu anda tüm dünyada gelişmektedir. Çok sayıda kullanıcının ağa bağlanabilmesi ve hizmetleri kullanabilmesi için, bu tür haberleşme ağlarında genellikle çok girişli çok çıkışlı (MIMO) sistemler kullanılır. Büyük MIMO sistemleri, haberleşme performansını artırmak için anten kullanan 5G iletişim ağları için iyi bir çözümdür. 5G ağlarında çıkış iletişim performansını artırmak için sistem kelebek optimizasyon algoritması (BOA) ile optimize edildi. Simülasyon sonuçlarına göre, önerilen yöntemin rasgele, SPRS, WGC PD ve SPRS + WGC PD algoritmaları gibi diğer yöntemlere göre sinyalin girişim artı gürültü oranı (SINR) ve kullanıcıların ağa bağlanma oranı açısından daha iyi performans gösterdi.

Anahtar Kelimeler : Beşinci nesil haberleşme ağı, büyük çok giriş çok çıkış sistemleri, kelebek optimizasyon yöntemi, pilot kirlenmesi.

A New Approach to Pilot Contamination in Massive MIMO Systems for 5G Communication Networks with Butterfly Optimization Algorithm

ABSTRACT

Communication technologies, in particular fifth-generation (5G) mobile phones, are currently developing around the world. Massive multi-input-multi-output (MIMO) systems are usually used in this type of communication network so that a large number of users are able to connect to the network and use its services. Massive MIMO systems are a good solution for 5G communication networks leveraging antennas to improve communication performance. To increase output communication power in 5G networks, the problem was optimized with the butterfly optimization algorithm (BOA). According to the simulation results, the proposed method outperformed other similar communication methods, such as the Random, SPRS, WGC PD and SPRS+WGC PD algorithms in terms of the signal-to-interference-plus-noise ratio (SINR) and rate of connection of users to the network.

Keywords : Fifth-generation communication network, massive multi-input-multi-output (MIMO) systems, butterfly optimization algorithm (BOA), pilot contamination.

1. INTRODUCTION

Internet of Things (IoT) is a technology in which everything can be considered a node or network member. Smart sensors and devices may be simple objects or wireless sensors or actor networks (WSAN). There are different technologies in IoT to achieve communications at such levels. IoT makes use of the communication technologies employed in WSAN and radio-frequency identification (RFID) [1]. There are many applications for IoT, including smart homes, smart cities and industrial and agricultural applications [2]. Smart devices are an integrated component of IoT and include various types of communication equipment and peripheral information collectors for data transfer and exchange among smart devices. Various communication technologies such as WiFi and Bluetooth are used for communication in the network nodes [3]. IoT includes a large number of nodes and devices in the network and it is capable of generating a high traffic volume called big data, the processing of which is carried out using cloud computing systems [4]. IoT can be used at a vast operational scale in which each node sends important information to the base station. To accelerate data processing, this network can be combined with big data processing models to analyze the data collected by the sensors. IoT networks are currently integrated with various communication infrastructures such as fifth-generation (5G) communication technology [5]. Wireless telecommunications are of great importance in today’s world with a great impact on various communication layers. The advent of wireless telecommunication networks has led to a high value adding for such networks. These technologies have been introduced as one of the most profitable industries in the

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world leading to a rapid growth and intense competition in this area. According to the literature, a new generation of mobile network is usually introduced to the communications market each decade. On the other hand, due to competition among large communications companies, a beta version of the technology is provided to the market prior to finalization [6]. In fact, this rapid development is mainly due to factors such as rapid growth in demand, customer acceptance, profitable trade and intense competition among large companies. Although 4G technology has been recently presented, the new 5G communications have already been emerging and are ready for use. Due to numerous factors, in particular considerable profit, communications research centers around the world have focused on mobile communications [7].

Due to the rapid growth of telecommunication networks and their various generations, the old generation of networks are slowly being replaced, further slowing down the integration of new generations with day-to-day applications. Another side effect is the diversity of the existing communication and telecommunication networks. On the other hand, similarly to IoT, 5G communication networks assume an intrinsic heterogeneous and unpredictable nature as it includes a large number of communication nodes and not all the connected devices are necessarily identical [8][9].

In this paper, a novel method based on pilot contamination in massive MIMO systems used in 5G communication networks is presented using metaheuristic algorithms to evaluate the problem from an optimization perspective. Given the fact that the butterfly optimization algorithm (BOA) is an exact metaheuristic algorithm with a higher accuracy than conventional metaheuristic algorithms, this algorithm is nevertheless used to eliminate pilot contamination in 5G networks. The prerequisites for 5G communication technology, such as IoT, are first discussed and then metaheuristic methods are reviewed. The butterfly optimization algorithm is then discussed and the proposed method is formulated. The algorithm is then implemented and the results are analyzed and discussed.

2. BUTTERFLY OPTIMIZATION ALGORITHM

Butterflies are insects capable of communicating through chemicals called pheromones. As shown in Figure 1, butterflies release pheromones into the air for various purposes such as finding food or to attract other butterflies. Butterflies usually move toward a pheromone source with the highest concentration. The Butterfly Optimization Algorithm (BOA) is a swam-based metaheuristic algorithm taking inspiration from the behavior of butterflies in releasing pheromones and its absorption by other butterflies. In this algorithm, each butterfly is a solution capable of releasing pheromones into the air according to its competence [10].

Figure 1. Pheromones are released by butterflies to attract other butterflies

A butterfly in the butterfly optimization algorithm is able to make two types of movements. First, it moves toward the source with the maximum pheromone concentration in the problem domain released by the most competent butterfly with a random probability. In fact, this leads to a local search around the optimal solution. A butterfly in the population then randomly selects two other butterflies, becoming attracted to their released pheromones. A global search, in fact, occurs in this case. Evaluations of the butterfly optimization algorithm indicate its higher accuracy and lower error rate in finding the optimal solution compared to genetic, swarm optimization, differential evolutionary, firefly, cuckoo search and artificial bee colony algorithms.

3. PROPOSED METHOD

Massive multi-input-multi-output (MIMO) systems are among the most important applied technologies to meet the demands of users in a 5G network. In a MIMO system, a communication device equipped with an antenna, which is used for the provision of services, contains one or multiple systems with multiple inputs and outputs. This base station is equipped with an array antenna the number which amounts to over 100 in some cases. In contrast, a mobile station contains a small number of antennas for communications. The main advantages of massive MIMO systems over other communication methods such as non-massive MIMO systems are as follows:

- Improved communication efficiency
- Improved communication productivity and reduced energy consumption
- High reliability in continuous communications
- Less interference in communications between users

In a particular type of MIMO system known as multi-user MIMO in the communications and telecommunications literature, a large number of mobile stations can be connected to a base station. In this system, the pilot channel considered for information and signal transfer between transmitter and receiver should be correctly modeled to improve their performance. The impulse and frequency responses in the transmission channel are among the most important specifications of these systems. The multi-path effects experienced by any given node while communicating with the base station can be modeled using random values in wireless telecommunication systems. In general, for signal detection at the receiver of massive MIMO systems in 5G networks, the specification of the channel between the users and all receivers in the base station should be completely specified. Communications in 5G networks should offer two important features:

- Increased network connectivity for users
- An increased data transfer rate

Multi-input-multi-output (MIMO) systems have been taken into consideration in this technology. To this end, each base station contains several antennas that are provided to the users, allowing them to connect to the optimal connection line. This in turn leads to a lower energy consumption in the base stations, reduced intercellular interference and noise, and improved strength. Despite the many advantages of 5G communication networks, they suffer from pilot contamination, which reduces their performance. Figure 2 shows pilot contamination in a 5G cellular communication network.

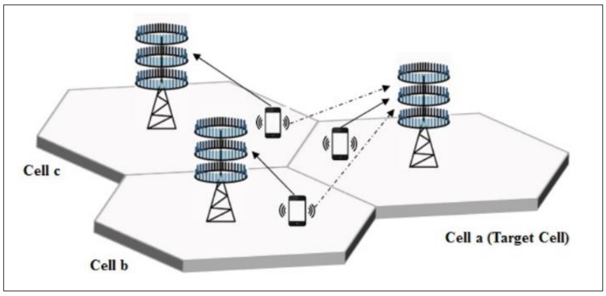

Figure 2. Pilot contamination in a 5G network

This problem occurs due to the reuse of the same set of test sequences (i.e., training sequences) by users of different cells. Wireless communications between users and their BSs occur in certain frames known as coherence intervals. In smooth fading mode, the specification of the channel between any user and the base station can be expressed by a random vector resulting from small-scale fading multiplied by a random coefficient induced by large-scale fading. The dimensions of this channel vector equal the number of antennas in the base station in this communication network. Channel estimation (CE) aims to find the channel vector. Channel estimation in massive MIMO systems differs from those in non-massive MIMO systems because of the larger number of base station antennas in the former, which leads to pilot contamination of the training data. Channel estimation is performed in both the uplink and downlink directions; however, the process is easier in the uplink direction given the large number of antennas in this direction. In contrast, there is a connection challenge in the downlink direction which includes a lower number of antennas. The time division duplex (TDD) technique can be used to solve this problem. To this end, in addition to channel estimation in the uplink direction, the channel should also be estimated in the downlink direction for signal detection in the user receiver. The training data is used in some methods for CE in the downlink direction of massive MIMO systems. Considerable effort has been made to solve this challenging problem. Therefore, channel estimation and pilot contamination in massive MIMO system have been evaluated. A simple practical channel estimator and data-assisted MMSE evaluation have been proposed, with both showing desirable performance without any previous knowledge. However, pilot reuse has not been considered in any of them because CE requires training resources while such resources are limited and should be used in multi-cellular scenarios. Various methods have been proposed to eliminate pilot contamination, one of which is the coloring graph and weighted coloring graph (WGC-PD) method [11]. This method not only reduces pilot contamination, but also reaches a high upstream. Moreover, a scheme called the soft pilot reuse scheme (SPRS) has been presented for the reuse of training data, where users are divided into *center users* and *edge users*.

Center users (probably exposed to partial pilot contamination) are able to use the same pilot contamination source while edge users (probably exposed to serious pilot contamination) apply other cellular pilot subsets in neighboring cells, which increases pilot contamination due to flexibility. A novel method is presented in this paper for pilot contamination elimination based on SPRS and WGC-PD with the help of the butterfly optimization algorithm. In the proposed scheme, SPRS is first applied to divide the users and then the cells, after which pilot contamination is emphasized. To solve this challenge among center users, WGC-PD is applied to achieve better performance in the upper band of the massive MIMO. A multi-cellular uplink MIMO system was considered in this study. It is assumed that the system contains J cells in which each cell has N antennas providing services to K users so that K is much smaller than N. The impulse response of the connection vector for the user k in cell j to the BS in cell i can be written as follows [12]:

$$h_{i,k,j} = b_{i,k,j}\sqrt{\gamma_{i,k,j}} \quad (1)$$

where $b_{i,j,k}$ and $\gamma_{i,j,k}$ respectively represents small-scale and large-scale fading coefficients and $h_{i,j,k}$ shows the channel response of the connection vector for user k in cell j. The objective function can be defined as follows to maximize the SINR in the 5G network cells [12]:

$$SINR = \frac{\left\|h^H_{<j,k>,j}\right\|^4}{\sum_{<j',k'>\in\Gamma<j,k>}\left\|h^H_{<j,k>,j}\right\|^4 + \frac{\sigma^2_{<j,k>}}{\delta^2}} \approx \frac{\gamma^2_{<j,k>,j}}{\sum_{<j',k'>\in\Gamma<j,k>}\gamma^2_{<j',k'>,j}} \quad (2)$$

This relation has been defined for a single cell and can be extended to other cells to obtain the following objective function [12]:

$$\max_{a_{k,j}}\left\{\sum_{<j,k>}\log_2(1+SINR)\right\} \quad (3)$$

Combining the above equation with the previous one gives the following objective function which should be maximized [13]:

$$\max_{a_{k,j}} \left\{ \sum_{<j,k>} \log_2 \left(1 + \frac{\gamma^2_{<j,k>,j}}{\sum_{<j',k'> \in \Gamma <j,k>} \gamma^2_{<j',k'>,j}} \right) \right\} \tag{4}$$

This objective function can be maximized using metaheuristic methods. The butterfly optimization algorithm is used in this study for this purpose. To obtain the maximum point of the objective function in the proposed method, the users connected to the cellular network are divided into *center users* and *edge users*.

A threshold is used to determine the type of user. According to the following relation, if the squared large-scale fading coefficient ($\gamma_{i,j,k}$) is larger than the considered threshold (ρ_i), then the user is considered a center user, otherwise ($\gamma_{i,j,k} \geq \rho_i$), the user is considered an edge user [12]:

$$\gamma^2_{i,k,i} > \rho_i \rightarrow \begin{cases} Yes \rightarrow Center\ Users \\ No \rightarrow Edge\ Users \end{cases} \tag{5}$$

The following equation can be used to define the threshold for dividing the users into two categories [12]:

$$\rho_i = \frac{\theta}{K} \sum_{k=1}^{K} \gamma^2{}_{i,k,j} \tag{6}$$

where θ is the convergence coefficient for the users and K is the total number of users. To maximize the objective function in this problem, each solution can be considered a vector of users, each of which making use of a cell in the 5G communication network in the equation below. In fact, each butterfly or solution in the D dimensional space in the proposed method can be formulated as follows:

$$B_i = \{B_i^1, B_i^2, \dots, B_i^D\} \tag{7}$$

where each solution or butterfly, B_i, can be randomly generated in the range of (L, U):

$$B_i = L + (U - L).rand(0,1) \tag{8}$$

Then a population of solutions can be considered as a population of butterflies in the problem space searching for an optimal solution:

$$Pop = \{B_1, B_2, \dots, B_N\} \tag{9}$$

where N is in the number of the initial population and Pop is the initial population of solutions or butterflies dispersed in the population. The best butterfly in this maximization problem can be calculated with the proposed algorithm:

$$Pop^* = max\{SINR(B_1), SINR(B_2), \dots, SINR(B_N)\}(10) \tag{10}$$

where f is the objective function to evaluate butterflies or initial solutions, N the butterfly population size, B_i a butterfly or solution, and $Pop*$ the most attractive (popular) butterfly or solution in the population. Each butterfly is capable of local searching at a probability of 50%:

$$B_i(t+1) = B_i(t) + (r^2 \times Pop^* - B_i(t)) \times f_i \tag{11}$$

Moreover, each butterfly is capable of global searching in the problem space with a probability of the remaining 50%:

$$B_i(t+1) = B_i(t) + (r^2 \times B_j(t) - B_k(t)) \times f_i \tag{12}$$

where $B_i(t+1)$ is the new position of the butterfly $B_i(t)$ and f_i the attractiveness of a butterfly when attracting other butterflies in proportion to the objective function. $B_k(t)$ and $B_j(t)$ are the current positions of two arbitrary butterflies, and r is a random number between 0 and 1. By executing the butterfly optimization algorithm in the proposed method, the user vectors can be optimized to receive services from a given cell. Moreover, the mean SINR can be maximized in the entire network and, in fact, the most optimal butterfly would be the one with the maximum SINR. Figure 3 shows the proposed method to maximize SINR using the butterfly optimization algorithm:

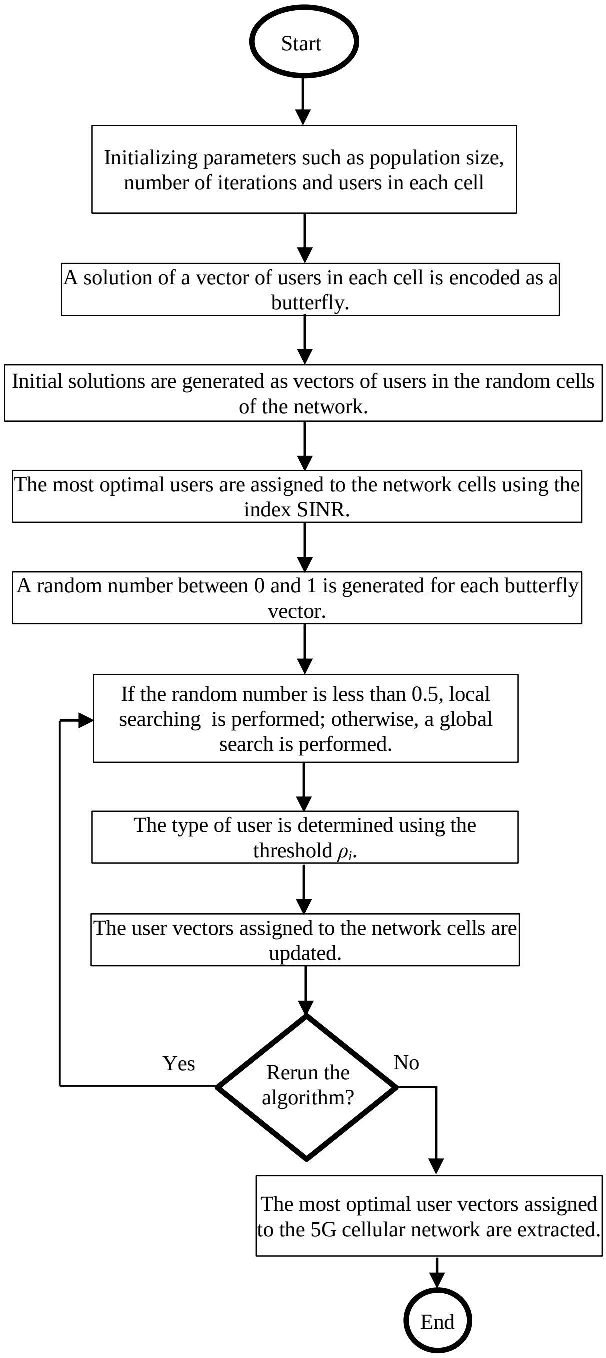

Figure 3. Flowchart of the proposed algorithm

The above flowchart can be represented with more details by adding the optimal user vector to the cellular network. The proposed flowchart to reduce pilot contamination is shown in Figure 4 below.

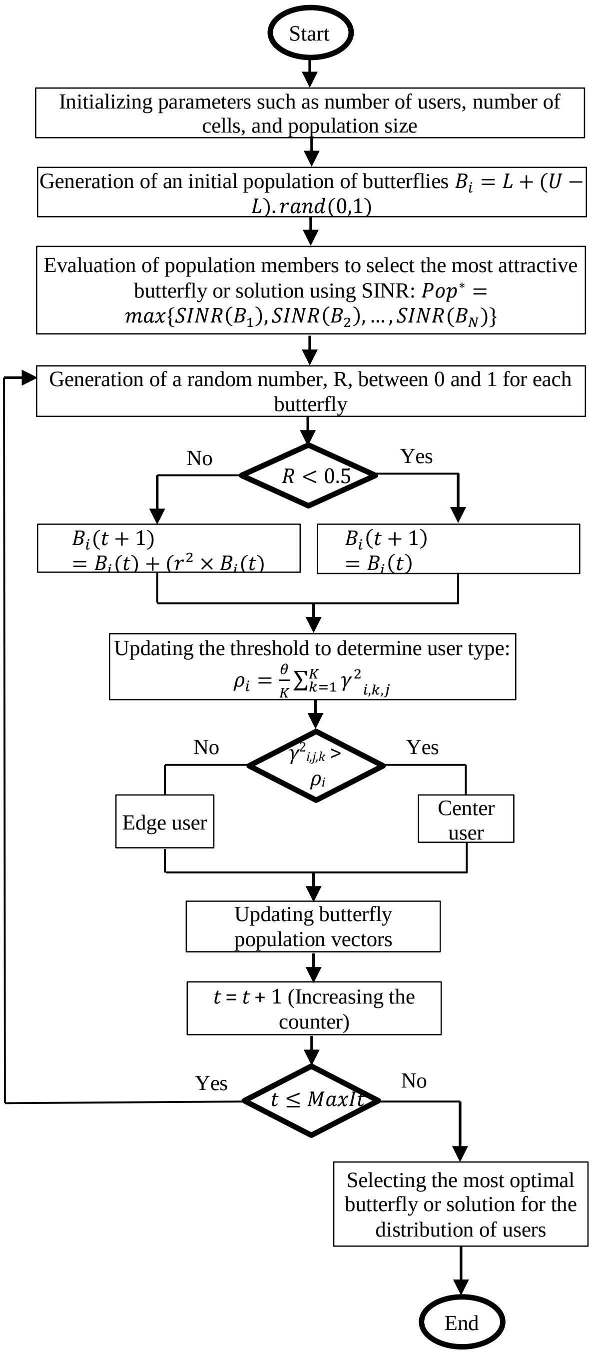

Figure 4. Proposed flowchart to reduce pilot contamination

4. IMPLEMENTATION AND ANALYSIS

The proposed algorithm is implemented and analyzed with the help of MATLAB 2015 using the scenario shown in Figure 5 with 19 cells, each with a base station and a number of active users:

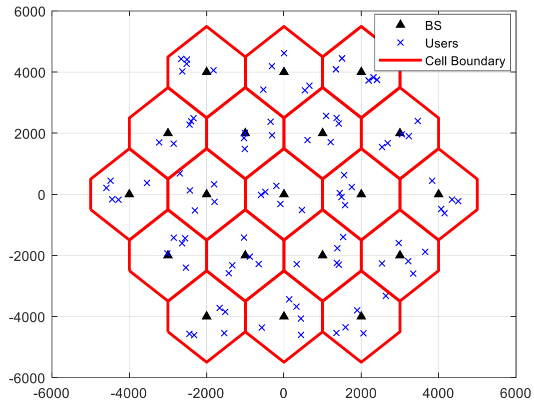

Figure 5. Implementation and simulation scenario

As can be observed, each cell has been able to provide services to a number of users. The parameters used in the algorithm implementation and simulation are initialized according to Table 1.

Table 1. Parameters used in the proposed method

Parameter	Description
nPop	Population size = 10
Maxiter	Maximum iteration number = 50
K	Number of users in each cell = 10
J	Number of cells = 19
μ	Spectral frequency coefficient = 0.5
θ	Initial threshold = 0.1
N	Number of antennas in each cell = 512

A cumulative distribution function (CDF) can be plotted as a function of the objective function (SNIR). In this case, the vertical and horizontal axes respectively show the CDF and SINR in terms of dB. Figure 6 compares the proposed method with the Random, SPRS[14], WGC-PD [11] and SPRS+WGC-PD [12] methods.

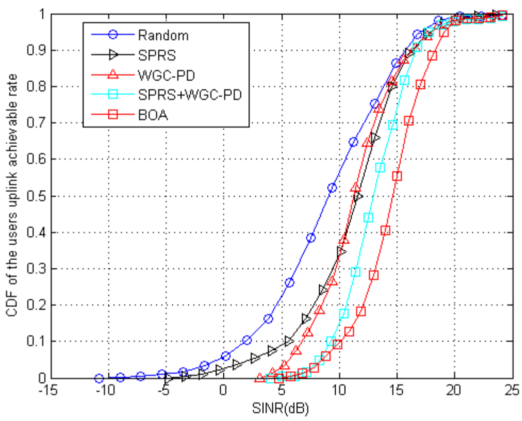

Figure 6. Cumulative distribution function (CDF) versus SINR in various scenarios

As can be observed, the proposed BOA shows a higher SINR than the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms. In fact, BOA has a greater ability to connect users and maximize the objective function SINR. BOA ranks first in terms of efficiency, followed by the SPRS+WGC-PD algorithm. The SPRS and WGC-PD algorithms show a relatively similar performance, while the Random algorithm performed the least well. The proposed algorithm and the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms show almost identical performance when the CFD equals 0 or 1. When the cumulative distribution function (CFD) is greater than 0.1, the proposed method outperforms the others. Figure 7 compares CFD and bit transfer rate (per sec) in the proposed algorithm and the SPRS, WGC-PD and SPRS+WGC-PD algorithms. As can be clearly seen, the proposed BOA shows a higher bit transfer rate than the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms.

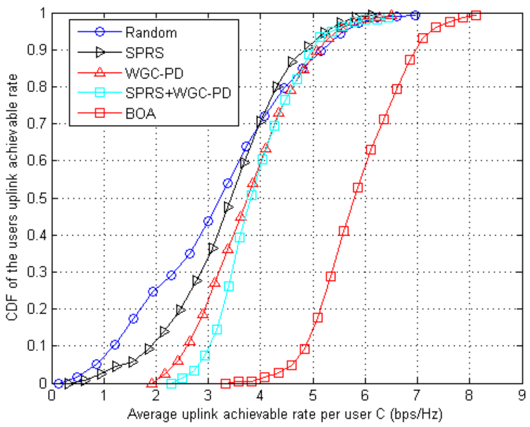

Figure 7. CFD versus average uplink achievable rate per user in various scenarios

According to the above diagram, the proposed method outperforms the other methods in terms of average uplink achievable rate per user. The SPRS+WGC-PD ranks second in this regard and WGC-PD and SPRS are placed in the third and fourth places. The Random algorithm shows the worst performance in terms of average uplink achievable rate per user. The average achievable uplink rate per user (R (bps/Hz)) in terms of the number of antennas in the BS is another important index. Figure 8 compares the average achievable uplink rate per user (R (bps/Hz)) in terms of the number of antennas in the BS in the proposed algorithm and the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms. An increase in the number of antennas improves the average achievable uplink rate per user, causing an increase in the diagrams for the proposed algorithm as well as the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms. Despite this ascending behavior, the average achievable uplink rate per user is further increased by increasing the number of antennas in the proposed method as compared to the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms. According to the above diagram:

- As the number of antennas increases, the quality of services is improved with different methods, but what is achieved in the proposed method is higher than the other methods;
- The average achievable uplink rate per user increases more sharply in the proposed method than in the other methods when increasing the number of antennas.

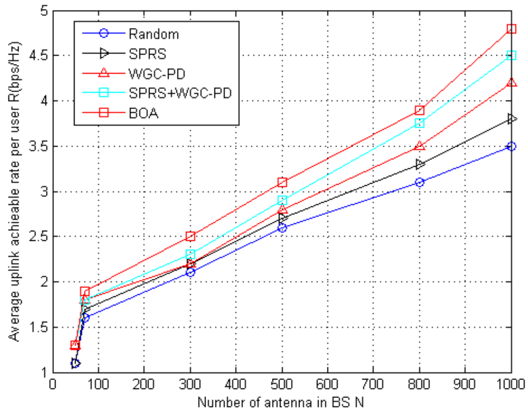

Figure 8. Average uplink achievable rate per user versus number of antennas in the proposed method and other methods

5. RESULTS

Fifth-generation (5G) mobile telecommunication is a new communication technology forming the next generation of communication services. Various technologies such as the Internet of Things (IoT) and novel computing models such as fog computing have been considered for 5G telecommunications. The main advantages of this generation of communication over its fourth generation counterpart include increased speed and higher rates of connection of users to the communication network. A number of mechanisms has been considered for this communication technology to increase the number of users connected to the network as well as to implement concepts such as IoT and offer diverse services to network users. When a user makes use of services in multiple cells simultaneously, the resulting pilot contamination may cause system imbalance, which is considered a great challenge in such networks. Accordingly, to deal with this challenge, the optimization problem was solved using the butterfly optimization algorithm (BOA). According to simulation results in MATLAB, the BOA caused a further increase in the SINR compared to the Random, SPRS, WGC-PD and SPRS+WGC-PD algorithms. The proposed algorithm also outperformed the other methods in terms of average uplink achievable rate per user. BOA also further increased the average uplink achievable rate per user by increasing the number of antennas. In future studies, a novel metaheuristic algorithm will be provided based on the intelligent behavior of living organisms to improve the connection of users to the 5G communication network.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Salah ALTİRAİKİ: Analysed the results. Wrote the manuscript.

Necmi Serkan TEZEL: Analysed the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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