Research on the Possibility of the Bee Colony Algorithm for Determining the Topology of the Wireless Network at the Marshalling Yard

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***Abstract*—** For railway marshalling yards of different power (low, medium, high), an optimal number of wireless base stations and their location were determined on a Python program based on a bee colony algorithm. Program input: marshalling yard parameters (area, number of clients); wireless network parameters (coverage radius and number of base station clients); parameters of the algorithm (number of bees, number of attempts). For example, to connect 300 clients at the medium-power marshalling yard, 93 base stations with a coverage radius of 50 m are required. The quality of solutions depends heavily on the choice of parameters of the bee colony algorithm. It is determined that increasing the number of bees (from 10 to 50) and the number of attempts to find the optimal bee solution (from 10 to 50) leads to an improvement in the quality of the optimal solution (reducing the number of base stations by an average of 6.5% and 9.3%, respectively). In addition, increasing the number of bees by 5 times leads to a decrease in the search time of the bee optimal solution by an average of 1.8 times, while increasing the number of attempts to find the optimal bee solution by 5 times will increase the search time of the solution by an average of 2.14 times. In particular, for the high-power marshalling yard, when the base stations coverage radius is doubled (from 50 to 100 m), their number decreases approximately twice (from 136 to 64), while the search time for the bee optimal solution is increased by 2.5 times (from 8.4 to 20.6 s).

***Keywords*—**marshalling yard; wireless network; base station; coverage radius; bee colony algorithm

I. Introduction

A wireless network is a combination of computers and other devices to exchange information without the use of wires; the connection is made through radio channels. The establishment of the wireless network is necessary when deployment of a cable system is impossible or economically impractical, in particular at railway marshalling yards, which confirms the relevance of the project theme.

The purpose of the project is to investigate the effect of the number of base stations and their coverage radius on the quality of the wireless network at the railway marshalling yard using the bee colony algorithm. According to the purpose of the project, the following tasks have been set:

1. Perform an analytical review of scientific sources on the topic.
2. Create a program to determine the number of wireless base stations at the marshalling yard and their location.
3. Determine the optimal number of wireless base stations for marshalling yards of different power.
4. Conduct research parameters of the bee colony algorithm for marshalling yards of different power in the created program.

The object of study is the process of functioning of the wireless network at the marshalling yard under various conditions of changing its parameters.

The subject of study is the influence of the number of base stations and their coverage radius on the quality of the wireless network.

The research method is an intelligent multiagent optimization method (bee colony algorithm) to determine the optimal number of wireless network base stations under given

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constraints, as a software implementation - Python language with a wide range of modern standard tools.

The presented project consists of an introduction, three mandatory sections, conclusions and a list of references. The first section presents the main findings of the analytical review of scientific sources on the subject of the project: classification and advantages of wireless over wired networks; choice of intelligent multiagent optimization method; current state (foreign and domestic) of development of wireless networks on the railway transport. The second section presents the formulation of the problem, the reasoned choice of the topology and methodology of wireless networks deployment, the general characteristic of the created program in the Python language according to the bee colony algorithm for determining the number of wireless base stations for marshalling yards and their location. In the third section for marshalling yards of different power, the optimal number of wireless base stations is determined under given restrictions using the created program. The implementation of the project is based on the use of 19 main sources, among which about 50% of scientific articles in the last 5 years.

Theoretical significance.

The study was made of the number of wireless base stations and the search time for bees solution by different numbers of bees and the number of attempts to find the bee optimal solution for marshalling yards of different power. It was determined that increasing the number of bees (from 10 to 50) and the number of attempts to find the optimal bee solution (from 10 to 50) leads to the specification of the optimal solution (reducing the number of base stations by an average of 6.5% and 9.3%, respectively. In addition, increasing the number of bees by 5 times leads to the decrease in the search time of the bee solution by an average of 1.8 times, while increasing the number of attempts to find the optimal bee solution by 5 times leads to increasing search time of the optimal solution by an average of 2.14 times.

Practical importance.

The algorithm and its software implementation have been developed, which allow determining the required number of wireless network base stations and their placement at the marshalling yard of different power.

Results were tested at the XIII International Scientific and Practical Conference "Modern Information and Communication Technologies on a Transport, in Industry and Education" held at the Dnipro National University of Railway Transport named after academician V. Lazaryan in December 2019.

II. Analytical Review of Literature

A. Wireless networks as an alternative to wired networks

Wireless networks have significant advantages over wired networks [2-4]: they allow deploying the network where it is impossible to use wires while maintaining sufficient data rates. Wireless networks also provide easy connectivity, user mobility, rapid fault detection and network equipment availability.

Wireless networks can be classified into four specific groups (Fig. 1) [2-4]: Wireless Personal Area Networks (WPAN) - up to 10 m; Wireless Local Area Networks (WLAN) - up to 100 m; Wireless Metropolitan Area Networks (WMAN) - up to 50 km; Wireless Wide Area Network (WWAN).

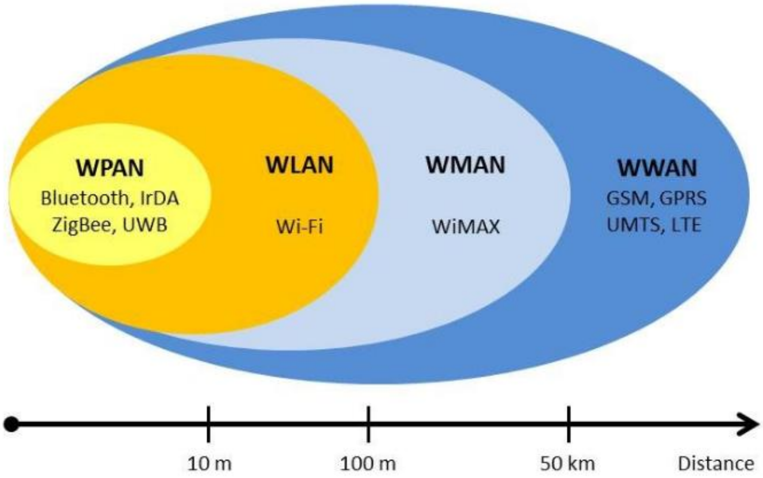


Fig. 1 Wireless networks classification

By topology, wireless LANs are divided into: Ad-Hoc (Independent Basic Service Set, IBSS) temporary networks; dependent networks (Basic Service Set, BSS); Extended Service Set (ESS) [2-4]. According to the IBSS topology (Fig. 2, a) [11, 18], the client stations interact directly with each other without an access point. Ad Hoc mode requires a minimum of hardware - a wireless adapter. This configuration does not require the creation of any network infrastructure. In this mode, each node participates in routing by forwarding data to other nodes, so determining which nodes send data is dynamically based on the network connection and the routing algorithm used. Ad-Hoc mode is mainly used to create temporary networks.

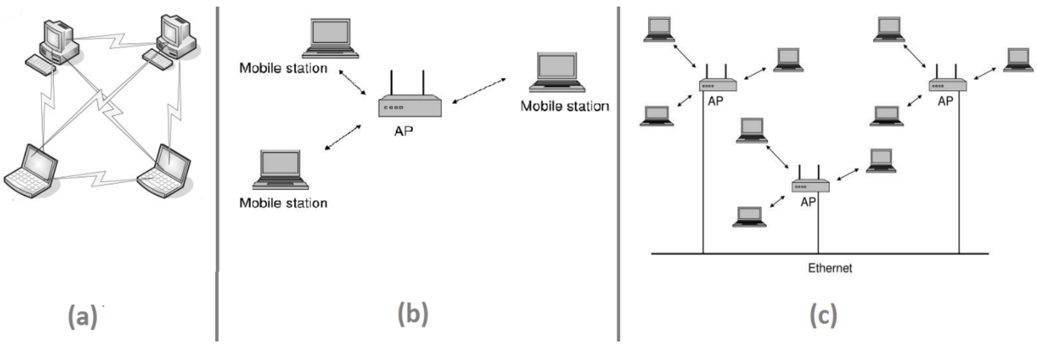
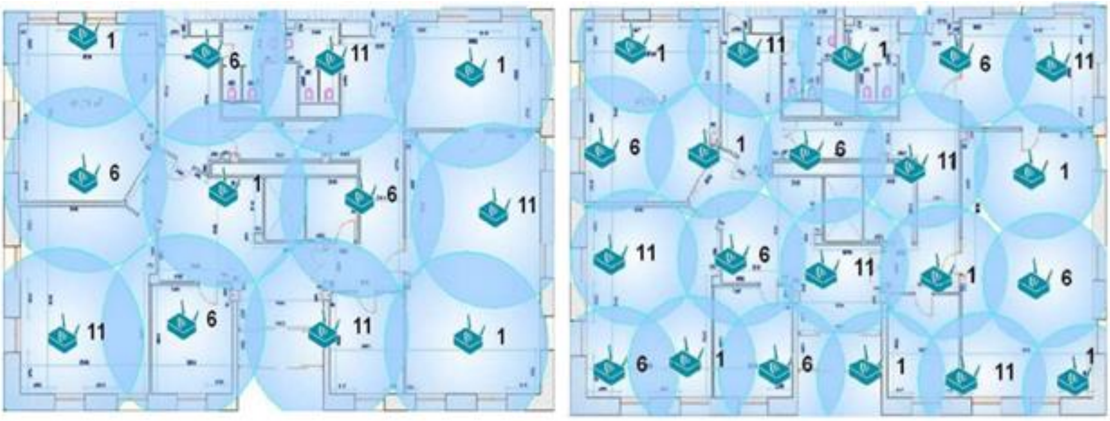


Fig. 2 Topology: (a) – IBSS; (b) – BSS; (c) – ESS

According to the BSS topology (Fig. 2, b) [11, 18], network nodes do not interact with each other directly but through an access point (Access Point, AP), which can act as a bridge to connect to an external cable network. All the base stations of the network are interconnected by means of a Distributed System (DS), which can be used as radio or infrared waves.

The ESS topology (Fig. 2, c) [11, 18] allows to combine several access points, that is, to integrate several BSS networks. In this case, access points can interact with each other. Such the topology is convenient when you need to combine multiple users into one network or connect multiple wired or wireless networks.

There are two main WLAN deployment methodologies available: wireless LANs with maximum service area; wireless LAN with maximum bandwidth [11, 18], Fig. 3. Service-oriented WLANs are designed with the emphasis on providing maximum coverage with as few access points as possible. A typical network-centric service provides a ratio of users to 25:1 access points. Some typical features of service-oriented WLANs are: the use of pulsating-type applications with a low packet rate, such as applications that query databases; low bandwidth requirements so that data rates can be reduced to as low as 1 and 2 Mbps; providing ease of maintenance as the WLAN service staff is small [18].



(a) (b)

Fig. 3 WLAN: (a) – Bandwidth Oriented Networks; (b) – Service Oriented Networks

In service-oriented networks, typical applications have a low packet rate and have low bandwidth requirements. This approach allows many users to immediately access WLAN services while retaining the latest sufficient features. Such options are common to small or medium-sized business affiliates when WLAN is selected as an alternative to Ethernet. Easy-to-deploy WLANs provide the basic LAN connections needed to share files and printers. Each WLAN access point serves approximately 25-30 users [18].

High bandwidth-oriented WLANs are required when: applications that require high packet speed are used; Delay-sensitive applications are used; smaller subnets are deployed (or multiple subnets are in the same service area); there is a high density of user placement. On such networks, the number of access points is several times the number of service-oriented WLANs. The service area of each access point is much smaller than when building a network focused on the maximum service area. Each access point serves about 12 users [18].

B. Choosing a method for organizing a wireless network

Nowadays, there are many different swarm algorithms [1, 8], which can be divided into: swarm algorithms based on the behavior of insects and animals; swarm algorithms based on bacterial behavior and inanimate nature. The first algorithms include: particle swarm algorithm; ant algorithm; bee colony algorithm; firefly algorithm; cuckoo search; bat algorithm. The second are: gravitational search algorithm; intelligent water drops algorithm; stochastic diffusion search; bacterial foraging optimization. It was determined [7] that the bee colony algorithm is most suitable for solving the problem of placement of wireless base stations. It should be noted that the bee colony algorithm is a new algorithm for finding global extrema of complex multidimensional functions. The advantages of the algorithm include: the ability to effectively allocate to parallel processes; high speed of work. The bee colony algorithm has some modifications [14], one of which is BCOi (Bee Colony Optimization based on the improvement concept), the peculiarity of which is that it deals with working with complete solutions of an optimization problem and not with partial ones, as in the classical BCO method [7].

Consider the biological basis of the bee colony algorithm. Bees in nature search for food by exploring the space around their hive (Fig. 4) [16]. As a rule, at the initial stage, several bee-scouts are exploring the environment. Upon completion of the search, the scout bees return to the hive and inform other swarm members about the location, quantity and quality of available food sources that they have found.

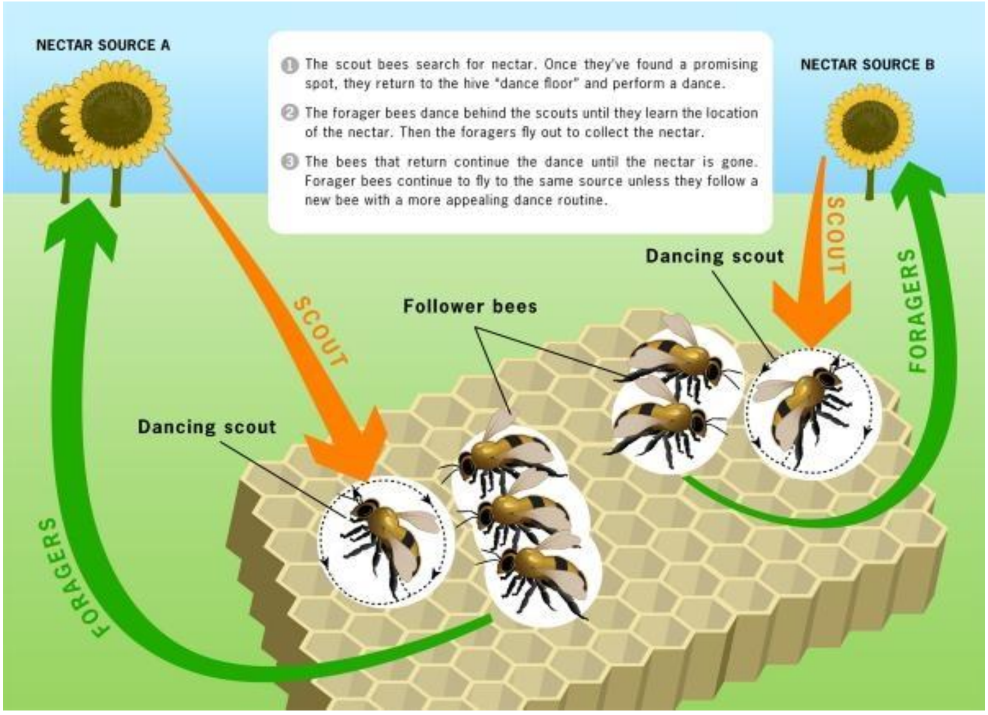


Fig. 4 Natural analogue

A review of sources [7, 13-14, 16] shows that bees share information through the waggle dance at a designated area. If a scout-watching bee decides to leave the hive and collect nectar, it will follow one of the scouts to one of the previously identified food sources. Such a bee becomes a busy forager, it deals with the collection of nectar, while specifying information on the amount of nectar in the vicinity of the source found. After collection, the forage returns to the hive and leaves the collected nectar there. He can then do one of the following things: Become an unoccupied forager by leaving his current source of nectar; continue to obtain nectar from its source without recruiting idle bees through dance; continue to extract nectar from its source while recruiting idle bees. The described process continues continuously, while the hive accumulates nectar and explores new areas with potential food sources.

C. The current state of the railway

Railways in Europe have been using the GSM-R (Global System for Mobile Communications - Railway) standard since 2008 to provide secure wireless communication between rail services and trains [9, 15]. The GSM-R network is used to provide the European Train Control System (ETCS) [9]. In the UK, the GSM-R network has been operational since 2015 [10]. To date, Europe is moving towards more advanced technologies such as 4G / LTE and 5G [17]. In the future, the following new services are expected on the railway: on-board and off-road HD video surveillance, multimedia control video streams, sensory information from the railway infrastructure, including bridges, viaducts, tunnels, road defects and more. With the help of infrared, sound and temperature sensors, information is collected and sent to a data center [12].

At the present stage, Ukraine is conducting research on the information and telecommunication system (ITS) of railway transport using artificial intelligence methods: neural and neural fuzzy networks, ant and genetic methods, in particular, at the marshalling yard [19]. However, the results of the implementation of wireless networks on the railway transport are not yet sufficiently presented. In [5-6], the authors considered the possibility of using WLAN technology for the implementation of mobile communication at railway stations, compiled a diagram of the states of the base station in the mode Distributed Coordination Function (DCF), which is mandatory and based on the protocol providing Carrier Sense Multiple Access with Collision Avoidance (CSMA / CA) multiple access. It is advisable to conduct an investigation of the optimal number of wireless network base stations, in particular, at the marshalling yard that reaches the lower level (linear enterprises) of the Ukrainian Railways.

III. Object, Subject and Methods of Study

A. Formulation of the problem

The railway marshalling yard (Fig. 5) includes an arrival park, a marshalling park and a hump, a departure park. The most important part of the technological object is the hump, whose capacity (small, medium, large and high) depends on the number of humps (2, 3, 4, 6-8, respectively).

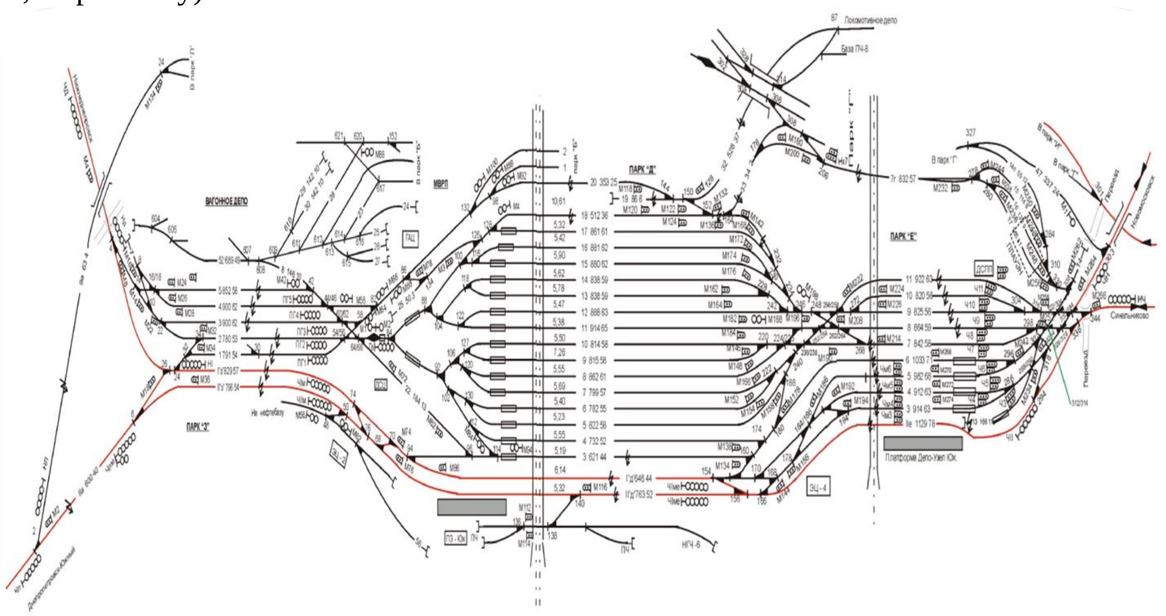


Fig. 5 Layout of the marshalling yard

Various technological sections are located at the investigated site: turn, speed and acceleration measurements in the area of 1-2BP (brake position) and 3-4BP, measurement of the parameters of the split, control of the cleavage, measurement of the mass of the split with various terrestrial equipment: travel sensors and photo sensors; rail circuits; weights; radar speedometers and others.

Let L be the set of clients (terrestrial marshalling yard equipment) that need to be connected to the WLAN base station at the marshalling yard. Known M - candidate places where base stations can be installed. In addition, all clients must be connected to base stations.

Introduce the notation $BS_i(r)^k$ – the *i*-th wireless base station with the coverage radius r to which *k*-clients are connected, where $i \in [1; M]$; $k \in [1; L]$. If $BS_i(r)^k = 1$, then the *i*-th wireless base station with k-clients connects to the wireless network, otherwise $BS_i(r)^k = 0$.

As a target function, consider the following function:

$$F = \sum_{i=1}^{M} BS_i\,(r)^k \rightarrow min, \qquad (2.1)$$

Moreover, there are following restrictions:

$$r \le r_{\max}, \;\; k \le k_{\max}., \tag{2.2}$$

$r_{\max}$ – the maximum coverage radius of the WLAN base station; $k_{\max}$ – the maximum number of clients that connect to the WLAN base station.

B. Deploying the wireless network at the marshalling yard

Based on a survey of scientific sources and subject topology (railway marshalling yard), it is appropriate to investigate an ESS network that uses multiple access points that interact with each other. In addition, there are wired networks at the marshalling yard that need to be exchanged, so it makes sense to use a WLAN deployment methodology that is focused on maximum bandwidth. The size of the cell-oriented WLAN bandwidth is smaller than that of the WLAN, which is focused on the maximum service area, respectively, the density of placement of access points above.

C. Bee colony algorithm

An enlarged scheme of the bee colony algorithm is presented in Fig. 6 [13]. Initially, the colony is initialized, followed by a search for a solution, after which the bees exchange information in the hive via dance, and then colony initializes again until an algorithm stop criterion is detected, and then the search for the optimal solution is performed.

D. Short description of the created program

Software implementation of the bee colony algorithm is executed in Python language using standard libraries: Os - is responsible for interaction with the OS; Sys - responsible for system functions; Random - responsible for random number generation; Math - is responsible for mathematical operations; Datetime - Responsible for time conversion; Matplotlib - responsible for charting.

The following classes of user are included in the program structure (Fig. 7): Log - used for debugging the program and displaying results, it is the parent for all classes; Field is a class for representing the marshalling yard where the location of the base stations is searched; Hive is the hive class where scout bees share information and choose the best solution; the parent class is Field; Bee is a reconnaissance class of bee-scouters looking for coordinates to house base stations, the parent class being Hive.

The location of the WLAN base stations (BS) on the marshalling yard is based on the bee colony algorithm. Firstly, all classes are initialized, the main variables include: bees_count - number of bees; max_retries_count - number of attempts to find the best solution; clients_count - number of clients; clients_list - a list of client coordinates; bs_max_clients_count - the maximum number of clients that can be connected to one station; bs_area_radius - base station coverage radius; field_width - the width of the marshalling yard field; field_height - the length of the marshalling yard field.

As an example in Fig. 8 shows a snippet of the program. The For loop (line 28) creates the required number of bees, according to the initial conditions. After creating everything you need for the program, the implementation of the algorithm begins. Line 30 starts the While loop until all clients are connected to the wireless base stations. Inside, a For loop (line 32) is performed, in which the values of the extremes and positions for each of the bees are cleared (lines 33-35). After specifying a search field (line 36), each bee makes a specified number of attempts to find the optimal location solution for the base station (line 37). As a result of the loop iteration, a global extremum may be found, where it is more expedient to place the base station, in which case it will be installed (line 40). Then client numbers that connected to the base station (lines 41-42) is deleted from the general client list and the loop is repeated.

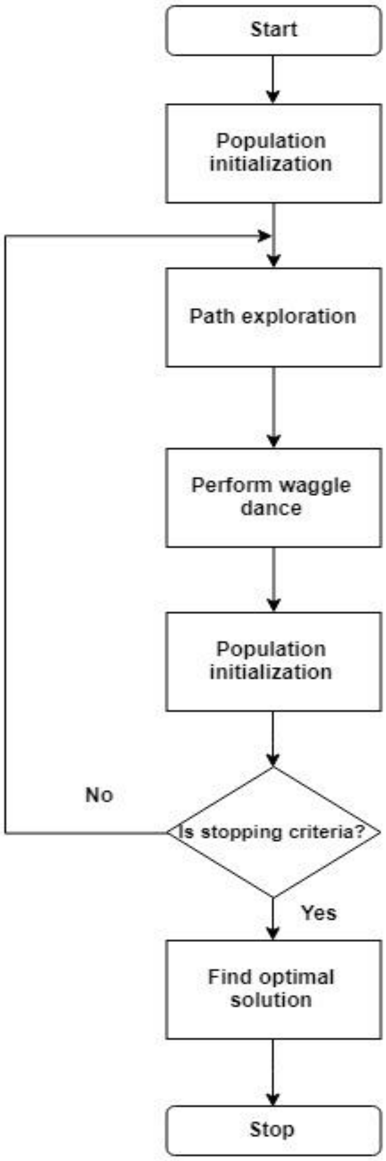


Fig. 6 Artificial Bee Colony Algorithm Flowchart

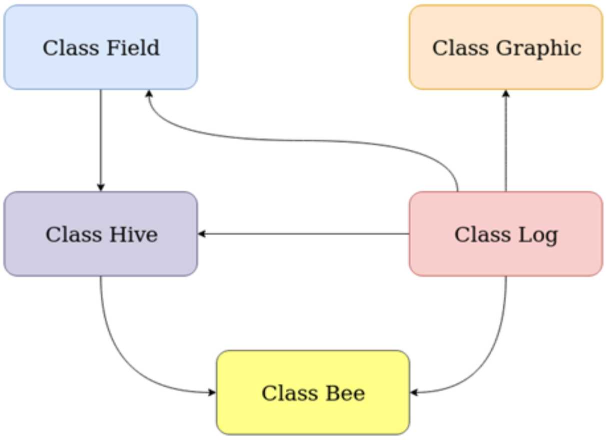


Fig. 7 Interaction of main classes of the program

```
bees = [bee(hive, log) for i in range(bees_count)]
iter_count = 0
while len(hive.clients_list) > 0:
log.stat("run".upper(), "### Iteration #"+ str(iter_count) +" started. ##
#")
for bee in bees:
bee.local_extremum = {}
bee.location = []
hive.global_extremum = {}
scouting_area = hive.set_scouting_area(field, bs_area_radius)
for _ in range(max_retries_count):
for bee in bees:
bee.scout(scouting_area)
bee.set_bs_location(hive.global_extremum)
for key, value in hive.global_extremum["clients_in_area_list"].items():
hive.modify_clients_list({key: value})
iter_count += 1
```

Fig. 8 Snippet of the program

IV. Research Results

A. Determining the number of base stations (BS) and their location

Determination of the number of BS at the low power marshalling yard

Input parameters of the program: number of bees (bees_count) = 10; maximum number of attempts to find the optimal solution (max_retries_count) = 10; number of clients (clients_count) = 250; maximum number of clients covered by one base station (bs_max_clients_count) = 12; coverage radius (bs_area_radius) = 50; field width (field_width) = 2000; field height (field_height) = 400. The results of the program are shown in fig. 9.

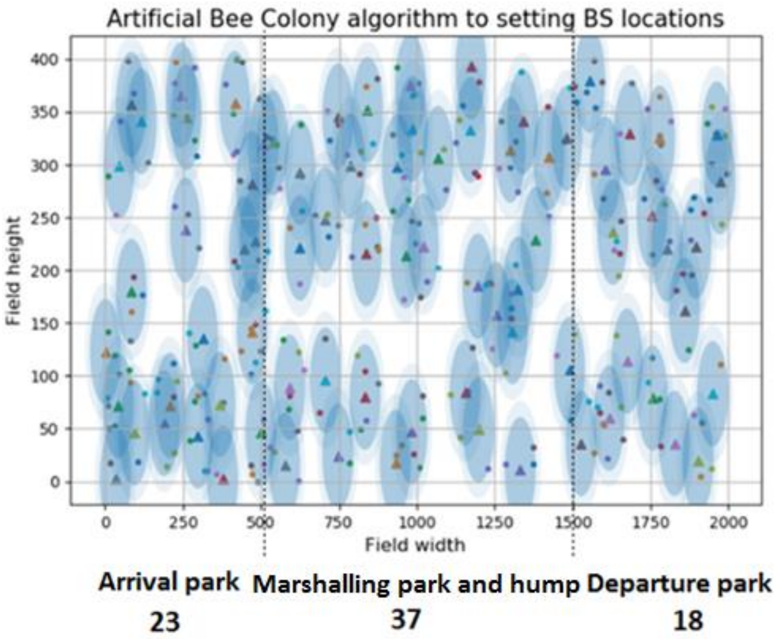


Fig. 9 BS location at the low power marshalling yard

Determination of the number of BS at the medium power marshalling yard.

Input parameters of the program: number of bees (bees_count) = 10; maximum number of attempts to find the optimal solution (max_retries_count) = 10; number of clients (clients_count) = 300; maximum number of clients covered by one base station (bs_max_clients_count) = 12; coverage radius (bs_area_radius) = 50; field width (field_width) = 2500; field height (field_height) = 500. The results of the program are shown in fig. 10.

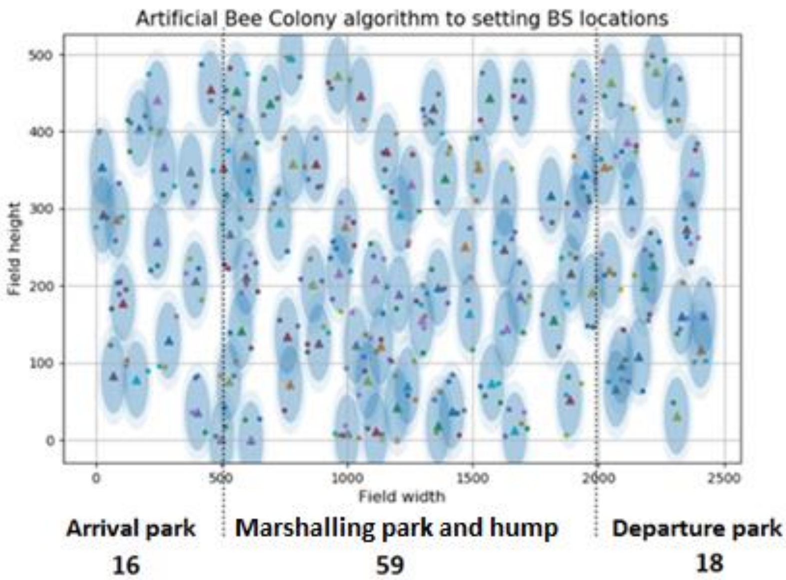


Fig. 10 BS location at the medium power marshalling yard

Determination of the number of BS at the high power marshalling yard.

Input parameters of the program: number of bees (bees_count) = 10; maximum number of attempts to find the optimal solution (max_retries_count) = 10; number of clients (clients_count) = 350; maximum number of clients covered by one base station (bs_max_clients_count) = 12; coverage radius (bs_area_radius) = 50; field width (field_width) = 3000; field height (field_height) = 600. The results of the program are shown in fig. 11.

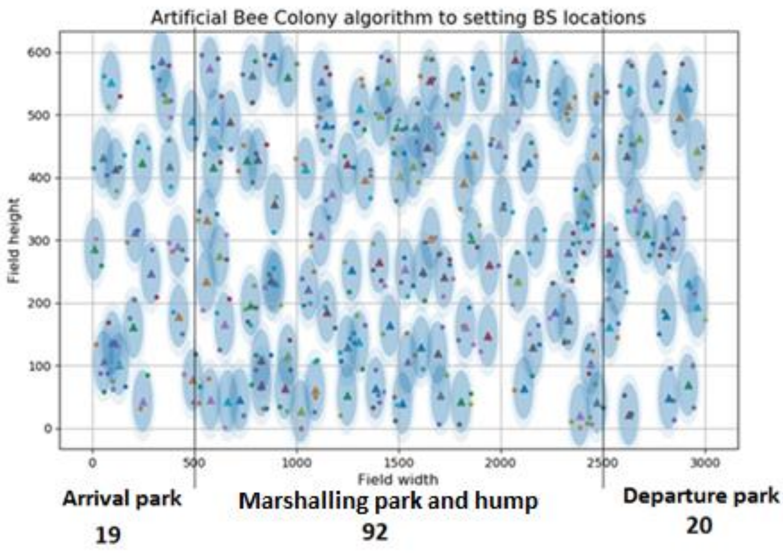


Fig. 11 BS location at the medium power marshalling yard

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B. Investigation of parameters of the bee colony algorithm

The quality of the obtained solutions depends on the choice of algorithm parameters. In addition, the speed of the algorithm depends on this choice. Therefore, a study was conducted to find out the dependencies of the optimization results (the number of BS of the wired network) and the time to find the optimal solution for low, medium and high power marshalling yards with different number of bees and the maximum number of attempts to find the optimal solution for each bee. The results are shown in Fig. 12-13.

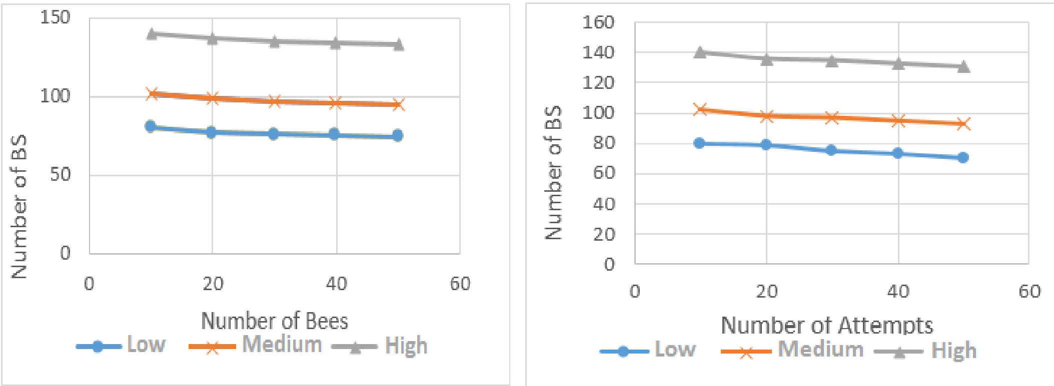

Fig. 12 Dependence of optimization results (number of BS) on different number of bees and attempts for different power marshalling yards

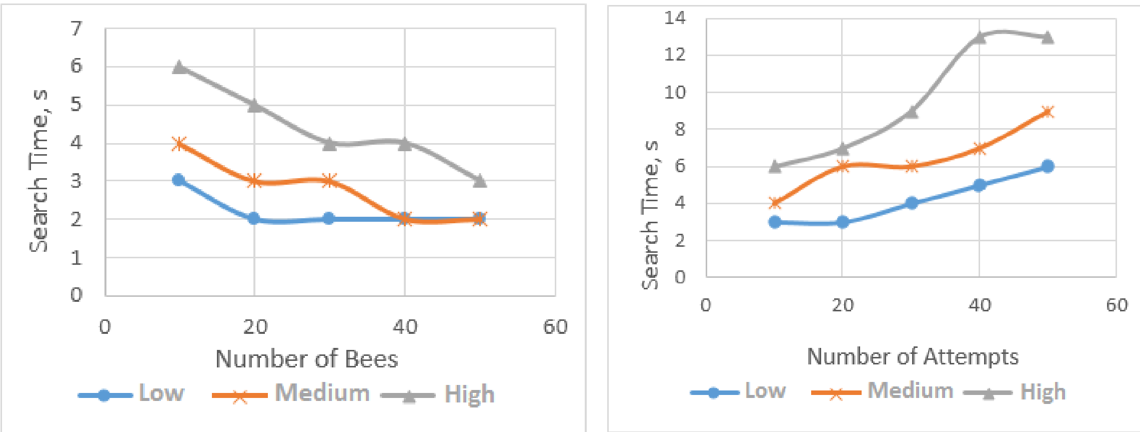

Fig. 13 Time dependency of finding the optimal solution for different number of bees and attempts for different power marshalling yards

From fig. 12 it can be seen that increasing the number of bees (from 10 to 50) and the number of attempts to find the optimal bee solution (from 10 to 50) leads to the decrease in the number of WLAN base stations by an average of 6.5% and 9.3%, respectively.

Increasing the number of bees (from 10 to 50) leads to the decrease in the search time of the bee solution by an average of 1.8 times, while increasing the number of attempts to find the optimal bee solution (from 10 to 50) will increase the search time of the solution by an average of 2.14 times (Fig. 13).

C. Investigation of base station coverage radius

An appropriate study was conducted for the high-power marshalling yard with the following parameters: number of bees (bees_count) = 10; maximum number of attempts to find the optimal solution (max_retries_count) = 10; number of clients (clients_count) = 350; maximum number of clients covered by one base station (bs_max_clients_count) = 12; field width (field_width) = 3000; field height (field_height) = 600. The results obtained in the program are summarized in table 1.

Table 1. Research results

Experiment №	BS Coverage Radius, m	Number of BS	Search Time, s	BS Coverage Radius, m	Number of BS	Search Time, s
1	50	135	22	100	67	8
2		135	20		61	7
3		133	19		62	9
4		140	22		63	9
5		138	20		66	9
Average:		136,2	20,6		63,8	8,4

The table shows that, when the WLAN base stations coverage radius is doubled (from 50 to 100 m), the number of BS decreases approximately twice (from 136 to 64), while the search time for the optimal bee solution is increased by 2.5 times (from 8.4 to 20.6 s).

Conclusion

To determine the optimal number of wireless base stations and their location at the marshalling yard, the bee colony algorithm was used, the advantages of which include the ability to effectively allocate to parallel processes and high speed of operation.

The Python program was created based on the bee colony algorithm, the input of which is: marshalling yard parameters (area, number of clients to be connected to the base stations); WLAN parameters (maximum coverage radius and maximum number of clients of base station); parameters of the bee colony algorithm (number of bees, maximum number of attempts to find the optimal solution for the bee). For example, to connect 300 clients at the medium-power marshalling yard with an area of 2500x500 m2, 93 base stations with the coverage radius of 50 m are required.

The quality of solutions depends heavily on the choice of bee colony algorithm parameters. The number of WLAN base stations (time to find the optimal solution) was investigated by different number of bees (number of attempts to find the optimal bee solution) for marshalling yards of different power. It is determined that increasing the number of bees (from 10 to 50) and the number of attempts to find the optimal bee solution (from 10 to 50) leads to increasing the quality of the optimal solution (reducing the number of base stations by an average of 6.5% and 9.3%, respectively). In addition, increasing the number of bees (from 10 to 50) leads to decreasing the search time of the bee solution by an average of 1.8 times. Increasing the number of attempts to find the optimal bee solution (from 10 to 50) leads to increasing the search time the bee optimal solution by an average of 2.14 times.

For the high-power marshalling yard, when the wireless base stations coverage radius is doubled (from 50 to 100 m), their number decreases approximately twice (from 136 to 64), while the search time the bee optimal solution is increased by 2.5 times (from 8.4 to 20.6 s).

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