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Optimization of the Deployment of Relay Nodes in Cellular Networks

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ABSTRACT Significant and continuous contributions related to 4G/5G cellular networks are still accelerating the investigation of the approaches that can boost the cell characteristics following the new aspirations of the users. The challenge of achieving sufficient coverage at the cell edge; represents a constant concern for both users and operators; in addition to ensuring a reasonable cost, are the most important search fields and in our scope of interest. As relay nodes can provide a solution, a scenario for a plan of relay nodes deployment at the cell edge is proposed, taking into account the interference due to the relay nodes. Since optimization algorithms are effective in terms of planning, an advanced hybrid particle swarm optimization and gravitational search algorithm (PSOGSA) is applied to the proposed scenario to detect the optimum solution. The optimum solution represents the optimum plan that attains the best coverage with the minimum cost. We submit cost analysis depends on three trails of construction cost, power and channel cost efficiency. To highlight that the optimal plan has been revealed, another recently developed optimization algorithm, a simplified adaptive bat algorithm based on frequency (FSABA) and a classic particle swarm optimization (PSO) algorithm are also applied to the suggested scenario. The obtained results are compared with the related findings of the PSOGSA. From the simulations, it is found that the PSOGSA achieves better performance than the other two algorithms with fruitful and promising results, and the optimal plan featuring great coverage at the cell edge and cost-saving is attained.

INDEX TERMS A simplified adaptive bat algorithm based on frequency (FSABA), cell edge, particle swarm optimization and gravitational search algorithm (PSOGSA), relay nodes.

I. INTRODUCTION

The coverage area still plays a pivotal role in cellular network studies. In addition, in the most exhaustive section, the users on the cell edge suffer from the instability and interruption of the service due to the coverage deficiency. Therefore, a solution for the coverage absence at the cell edge is needed. One of the important and useful features that represents a leap in the telecommunication domain and can be employed to improve the coverage at the cell edge is the relay node.

Relay nodes (RNs), which are low-power nodes, can offer a solution to improve the coverage at the cell edge by supporting the connectivity between the evolved node-B (eNB) and the users. Nevertheless, planning the deployment of relay nodes and choosing their numbers, power and locations in the cell still needs to be investigated, especially to realize the combination of enhancing the coverage area at the cell edge and harnessing the benefits of the RNs as it is low-cost technology due to its flexible installation.

From the numerous studies associated with cellular planning over time, we mention some of the researchers' efforts related to this field. In [1], the authors proposed a concept of cell zooming that adaptively adjusts the cell size according to traffic conditions. The authors in [2] proposed a mixed integer programming model of the Pareto front and a multi-objective Tabu search for a network configuration. Other authors have suggested dividing a region into sub-regions with almost equal traffic when the balance degree of the network is broken [3]. Another component of the search is mathematical analysis, but this may be difficult and complicated, like in [4], where the authors proposed an O (log R) approximation algorithm to plan the macro-cell only and then

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developed an O (log $\tilde{R}$) approximation algorithm for HetNet cell planning.

The papers of [5]–[8] belong to a group of researchers that have contributed to this area, and their contributions shall be described hereinafter. In [5], the authors proposed an enhanced tree (E-tree) algorithm to place the eNB and relay stations (RSs) at the location with the lowest construction cost compared with the tree algorithm; while in [6], a super-graph tree algorithm was proposed to place base stations (BSs) and relay stations at the lowest cost positions, and then the authors proposed another interference aware algorithm (IA) that considers the interference between BSs in the network. In [7], the authors suggested a set covering algorithm to achieve better network coverage and performance for LTE-Advanced relay networks. This algorithm reduced the number of uncovered users, but it had a higher construction cost generated from the S-tree algorithm and IA. Then, in [8], the authors deployed two types of RNs as in-band and out-band RNs in the LTE-A network with the eNB and compared the deployment results with their proposed interference coordination (IC) algorithm. These proposed algorithms depend on graph theory, but in the case of using an optimization algorithm, we believe that they will yield better results.

In [9], two site planning strategies were formulated in terms of SNR- and SINR-based selection criteria to analyze the effects of site planning on the backhaul link, but the authors mentioned the usage of the RNs as a low-cost feature only [10]. Presented a comparative simulation study for various suburban macro-only and macro-relay deployment scenarios in emerging markets. In [11], the authors proposed a partially combinatorial optimization algorithm that exploits a channel quality indicator (CQI), which segments the total number of possible locations into smaller randomly selected groups and performs an exhaustive search for each smaller group. In [12], the authors discussed developing the coverage probability due to deploy the decode-and-forward relays according to a Poisson point process model.

The authors introduced in [13], two relay cell range extension techniques; a bias to cell selection and handover thresholds, with decreasing the power of the eNB. Genetic algorithm scheme was proposed in [14] to find the minimum number of positions to place sensor nodes in the network to achieve k-coverage and m-connectivity. In [15], the authors focus on the employment of relay nodes and small cells to enhance the energy efficiency of the network. Reference [16] introduced a deployment scheme called four-stage fuzzy logic-based cost and power effective to determine the type, number and placements of the HetNet Nodes to meet an expected coverage. The authors in [17] submitted an approach called adaptive cost-based RS deployment to form a cost function that leads to finding the relay station location with minimum network cost. Two hop links treat with the low or null coverage locations and enhance the physical layer were suggested in [18]. The authors' work in [19] is concerned with the relay node deployment in LTE-A networks to increase the coverage with energy-efficient constraints. In [20], a cross-layer routing for secondary multihop was examined following the signal to interference noise ratio (SINR) constraints.

As the cost question should be taken into consideration for all researchers interested in optimization, it can be noted that each researcher examines the cost issue through his perspective. For instance, some papers focus on the construction cost like [21]–[25]. Where in [21], the authors considered in the cost equation the deployment of the most expensive components for their proposed system architecture, and also [22] which relied basically on the deployment cost. The authors in [23], set a total budget constraint of the system so as the deployed relay nodes is not exceeded [24]. Depended on CAPEX and OPEX, which represent the deployment cost and the operational cost respectively; but [25] connected the CAPEX and OPEX with the energy consumption. Whereas other researchers interested in linking the calculation of the cost with the data rate of the network as in [26]–[29]. In which the authors in [26] connected between the number of infrastructures deployed and the downlink throughput in the network [27]. Calculated the cost based on the data delivery and the successful transmission between two sensors. The authors in both [28], [29] associated between the deployment cost of the nodes and the cell throughput. The authors in [30] were concerned with increasing requirement for high data rates in order to make the network able to continue its normal operation when the breakdowns occur in a HetNet.

Earlier, we have introduced an initial scenario of the cell plan through the relay nodes where two stages of the relay nodes are deployed; edge relay nodes and the supporting intermediate relay nodes. Furthermore, to increase the efficiency of the cell, we applied the PSO optimization algorithm to the said scenario to reach an optimum plan in [31]. Consequently, in this work, we continue to improve the cell plan through the relay nodes deployment under a robust environment, following the advanced optimization algorithms.

Our proposal consists of two phases: a cell planning phase and an optimization phase that examines the variables within a specific criterion to investigate their optimal values that produce outstanding cell characteristics. In cell planning, we impose a cell plan that introduces an approach that permits studying several variables, which enhances the coverage area at the cell edge where the interference between the eRNs is considered and saves cost. The use of optimization algorithms is also expected to experience rapid growth as it yields an optimum solution. Therefore, with the help of global optimization algorithms, we intend to reach the optimum cell plan. Hence, our suggested strategies are:

- Deploy a number of relay nodes and alter their related particular variables within a specific range according to the proceedings of the proposed plan.
- As the cost dilemma is also paramount for operators considering the principle of cost savings in each plan, we present a coverage to cost index, which is an objective function proposed to sift through the plans.

- The particle swarm optimization and gravitational search algorithm (PSOGSA) is proposed to sweep the search space of variables, and then we compared results with those of its counterpart FSABA and PSO algorithm to determine the optimum plan that realizes a trade-off target between a large coverage area and a low cost.

This paper is organized as follows: Section II judiciously explains the proposed system model. Section III expounds a description of the optimization analysis of the cell planning problem for the introduced scenario. The optimization phase is presented in section IV. The concept of all the suggested optimization algorithms is described, and the proposed algorithm is connected to our deployment scenario. The results of the discussion and comparative study are presented in details in section V. Finally, the conclusions are presented in section VI.

II. SYSTEM MODEL

We consider a square area represents a macro cell containing one eNB placed at the centre of the cell with an omnidirectional antenna. A set of in band (both its backhaul and access links operate on the same frequency) edge relay nodes *eRNs*, N_e, is initially deployed in fixed positions by a uniform distribution at the cell edge, that we define as the area located out of the eNB effect on the users toward the cell borders.

To estimate the performance of the links in the cell plan, we mainly depend on both the signal-to-noise ratio ***SNR*** equations for the link between the user and the particular eRN and concurrently, on the signal-to-interference plus noise ratio ***SINR*** equations between the user and the interfered eRNs on the correlated link.

For a non-line of sight (NLOS) connections considered between the transmitter and the receiver, we can calculate the *SNR* equation $SNR = P_r/(P_n \cdot P_l)$ as a ratio between the received power P_r to the power of the noise P_n-due to the proposed additive white Gaussian noise (AWGN) distributed channel that expressed by $y(t) = x(t) + n(t)$ where $y(t)$ is the received signal, $x(t)$ is the transmitted signal and $n(t)$ is the AWGN added to this signal through the channel-and to the NLOS distance-dependent path loss P_l.

Accordingly,

$$\boldsymbol{SNR_{be}} = \frac{P_{eNB}}{P_n \cdot P_l} \tag{1}$$

where $\boldsymbol{SNR_{be}}$ is the signal-to-noise ratio from the eNB to each edge relay node, P_{eNB} is the eNB transmitting power, P_n is the noise power of the channel and P_l is the NLOS path loss power between the transmitter and the receiver.

$$\boldsymbol{SNR_{eu}} = \frac{P_{RN}}{P_n.P_l} \tag{2}$$

where $\boldsymbol{SNR_{eu}}$ is the signal-to-noise ratio from each edge relay node to each user, P_{RN} is the relay node transmitting power.

Considering the interference $\boldsymbol{I}$ that represents the interfered signals can be expressed by $I = \sum_{i' \neq i} P_t$ where i refer to the connected relay node, i' refers to the interfered relay nodes. So, *SINR* can be calculated as follow:

$$\boldsymbol{SINR} = \frac{P_t}{P_n.P_l + I} \tag{3}$$

where P_t is the transmitted power that represents the P_{RN} as we are concerned with the relay nodes affecting on the cell edge.

$$\boldsymbol{SINR} = \frac{P_{t_i}/P_l}{P_n + \sum_{i' \neq i} P_t/P_l} = \frac{P_{t_i}/P_l.P_n}{1 + \sum_{i' \neq i} P_t/P_l.P_n} \tag{4}$$

So, $SINR_{i,j}$ that represents the signal to interference plus noise ratio for the link between the *eRN* (*i*), and the user (*j*) will be as follows:

$$\boldsymbol{SINR_{i,j}} = \frac{SNR_{i,j}}{1 + \sum_{i' \neq i} SNR_{i',j}} \tag{5}$$

A. COVERAGE ANALYSIS

Check the links between the eNB and eRNs by calculating the *SNR* at each eRN. If the *SNR* received at the node from the eNB is more than or equal to the threshold line of the power *nSNRth*, referred to as the least accepted received power at the node, considering the link as a success link. So, we define the link from *eNB* to *eRNs* as $\boldsymbol{l_{be}(i)} = [l_{be}(1), l_{be}(2), \ldots\ldots\ldots\ldots, l_{be}(i)]$, where i represent the number of the *eRN*.

$$\boldsymbol{l_{be}(i)} = \begin{cases} 1 & if\ SNR_{be}(i) \geq nSNRth \\ 0 & otherwise; \end{cases} \quad i = 1, \cdots, N_e \tag{6}$$

In order to calculate the coverage area at the cell edge, we randomly distributed the number of users $\boldsymbol{N_u}$. To enhance the coverage area at the cell edge, we neutralize the impact of the *eNB* at the cell edge and study the effect of deploying the relay nodes. In the same time, we take into account the interference which is likely to result from dense relay nodes at the cell edge.

The links from the eRNs to the users $\boldsymbol{U}$ represented by the matrix $\boldsymbol{l_{eu}(i,j)} = \begin{bmatrix} l(1,1) & \cdots & l(1,N_e) \\ \vdots & \ddots & \vdots \\ l(N_u,1) & \cdots & l(N_u,N_e) \end{bmatrix}$, whereas *uSINRth* is the threshold power, referred to as the least received power accepted by the user.

$$\boldsymbol{l_{eu}(i,j)} = \begin{cases} 1 & if\ SNR_{eu}(i,j) \geq uSNRth \\ & and \\ & SINR_{eu}(i,j') \geq uSINRth \\ 0 & otherwise; \end{cases} \quad i = 1, \cdots, N_u, \quad j = 1, \cdots, N_e\ \&\ j \neq j' \tag{7}$$

We consider the user would be covered if he received a link from one eRN with a signal to noise ratio more than or equal the *uSNRth* and a signal to interference plus noise ratio from the others eRNs more than or equal the *uSINRth* at the same time. Hence, we can define the user coverage area ***UCA*** as,

$$\boldsymbol{UCA} = \sum_{i=1}^{N_u} OR\left[l_{eu}(i,j), \cdots, l_{eu}(i,N_e)\right] \tag{8}$$

Therefore, the coverage percentage ***C*** for each plan will be:

$$\boldsymbol{C}(\%) = \frac{UCA}{N_u} \times 100 \tag{9}$$

To examine the impact of each node on the users, we determine the station effectiveness $\boldsymbol{EFF_e}$ for each *eRN* as follows:

$$\boldsymbol{EFF_e} = \sum\nolimits_{i=1}^{N_u} l_{eu}(i,k); \quad k = 1, \cdots, N_e \tag{10}$$

B. THROUGHPUT ANALYSIS

To evaluate the significance of the proposed plan of the relay nodes deployment effect, we calculate the throughput for each covered link $\boldsymbol{TP_l}$ and the total cell-edge throughput $\boldsymbol{TP_{tot}}$ as follows:

$$\boldsymbol{TP_{eu}} = B.B_{eff}.log_2(1 + \frac{SINR}{SINR_{eff}}) \tag{11}$$

where $\boldsymbol{TP_{eu}}$ is a matrix $\boldsymbol{TP_{eu}} = \begin{bmatrix} TP(1,1) & \cdots & TP(1,N_u) \\ \vdots & \ddots & \vdots \\ TP(N_e,1) & \cdots & TP(N_e,N_u) \end{bmatrix}$ contains the throughput for each user link from each edge relay node depending on (11) that derived from the well-known Shannon capacity as in [13], B is the system operation bandwidth, B_{eff} is the bandwidth efficiency, $SINR_{eff}$ is the signal to interference plus noise ratio efficiency.

If the user received a signal from the relay node less than the *uSNRth* and an interfered signals from the other relay nodes less than *uSINRth*, we would consider the $\boldsymbol{TP_{eu}}$ for this link equal zero. Since the covered user can receive links from more than edge relay node; we can calculate the throughput link $\boldsymbol{TP_l}$ as

$$\boldsymbol{TP_l} = \frac{\sum_{i=1}^{N_e} TP_{eu_i}}{\sum no.\ of\ accepted\ links} \tag{12}$$

Consequently,

$$\boldsymbol{TP_{tot}} = \sum_{i=1}^{N_u} TP_{l_i} \tag{13}$$

C. COST ANALYSIS

The main objective in our work is to obtain the optimum plan for the cell, which is a trade-off between enhancing the coverage area at the cell edge and saving cost. The cost calculation is based on three suggested concepts. The first concept is the fixed cost represented by the construction cost of the site, licenses, rent, and equipment. The second concept is the variable cost represented by the transmitting power of each RN, which we indicate by a power factor $\boldsymbol{x}$ that is the ratio between the power of the relay node to the power of the eNB. Lastly, the third concept involves the impact of the channel resources into the cost analysis, so we called channel cost-efficiency ***CCE***, modified from the equation (2) in [28], and can be calculated as follows:

$$\boldsymbol{CCE} = \frac{TP_l}{B.(1 + \sum V_n.(a + b\,[eRN_x]))} \tag{14}$$

where a represents the initial fixed cost when constructing the relay node regardless of its power, b represents the variable cost due to the power of the relay node (an increase in the power leads to an increase in the relay node cost), V_n refers to the resultant valuable relay nodes chosen at each plan, and eRN_x represents the edge relay node power factor.

Thus, we suggest the cost equation $\boldsymbol{C_t}$ as follows:

$$\boldsymbol{C_t} = \frac{CCE + \sum V_n.(a + b\,[eRN_x])}{\sum(a + bc\forall\,[eRN_x])} \tag{15}$$

where, c represents the maximum power value of the power factor.

The cost equation is a normalization between the cost of each plan due to both their number and transmit power value and the maximum possible cost when all relay nodes are used and each one has the maximum relay node transmit power.

From (9) and (15), we call our objective function the coverage to cost index ***CCI***, where the maximum value of this index represents the optimum plan.

$$\boldsymbol{CCI} = \frac{\boldsymbol{C}}{\boldsymbol{C_t}} \tag{16}$$

III. A SUGGESTED OPTIMIZATION APPROACH FOR THE SUBMITTED CELL PLANNING

As shown in Figure 1, we consider a square area represents a macro cell with a 2 km × 2 km cell size and the eNB position at the center of the cell with an omnidirectional antenna.

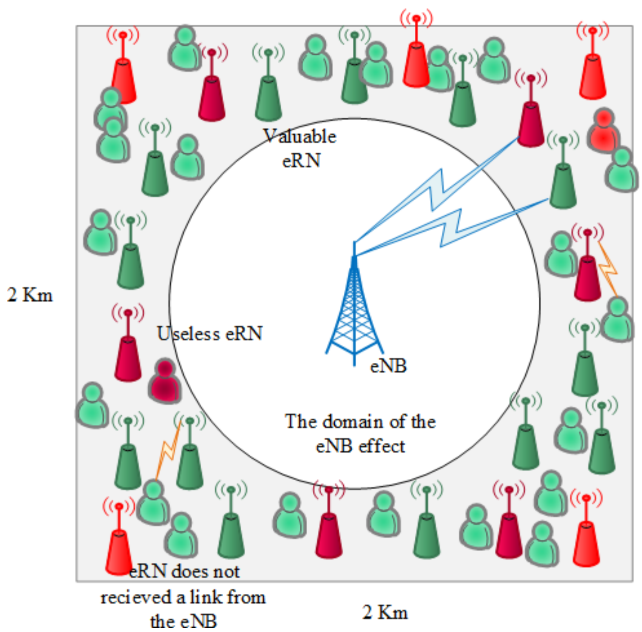

FIGURE 1. Proposed scenario with each of the PSOGSA, PSO, and FSABA algorithms.

Therefore, the domain of the eNB effect for the users is shown as a white circle, and we define the distance from the circle to the square border as a cell edge. As one of the main pillars of the upcoming trends is a dense network with the help of a multi-tier heterogeneous cellular network [32], we initially deploy **52** eRNs as a result to form a uniform grid around the cell edge to cover **5000** users. For users, the threshold power of the eRN link *uSNRth* is **20** dB and the threshold power of the interfered links from the other eRNs *uSINRth* is **−7** dB to distinguish the accepted links, also **20** dB is the threshold power *uSNRth* for the relay nodes from the eNB.

To optimize the suggested cell plan means to achieve a trade-off between enhancing the coverage area at the cell edge and at the same time, decrease the cost of the proposed cell plan as possible. Consequently, we will regard here on reducing the number of eRNs as it leads to a lessening in the cost of construction, power, and channel resources without affecting coverage in the cell edge.

As a result of the optimum cell plan, we can define three varieties of the deployed eRNs at the cell edge as follows:

- Valuable eRN $\boldsymbol{V_n}$ indicated in dark green colour represents the chosen eRN in the final cell plan.
- Useless eRN in dark red colour represents the eRN that serves an insufficient number of users where its presence becomes more expensive than its usefulness.
- The eRN in red colour that basically, does not receive a link from the eNB.

Accordingly, the problem optimization will take three successive steps:

[1]

A relationship is established between the eRNs and the number of users by checking the links received at each user from all the eRNs in (7). Thus, we introduce a user station matrix ***USM*** where each row represents the user number and each column represents the eRN number. This one-zero matrix clarifies the relationship between each user and each eRN in the grid.

$$\boldsymbol{USM} = \begin{array}{c} \xRightarrow{\hspace{4em}} \\ \text{users} \\ \vdots \\ \xrightarrow[(ex{:}row_{27}=userno.27)]{\hspace{4em}} \end{array} \begin{bmatrix} one, \\ zero \\ matrix \end{bmatrix}_{N_u \times N_e}$$
$$\Uparrow eRNs \cdots \uparrow$$
$$(ex:\ column\ 10 = eRNno.10) \tag{17}$$

Thus, we designate an array called station vector ***SV*** where the number of elements equals the number of eRNs $\boldsymbol{N_e}$. This array demonstrates the impact of each relay node where each element ***a*** represents the number of users served solely by each correlated relay node.

$$\boldsymbol{SV} = [a_1 a_2 \ldots\ldots\ldots\ldots a_i]_{1\times N_e};\quad N_e = 1,\ldots,i \tag{18}$$

The element values in the ***SV*** array generated from the two conditions at the ***USM*** are explained with the following procedures:

- Detect the relationship between each relay node and all the users.
- If there is a link from the eRN to the user, then the element value = 1 (first condition verification).
- To guarantee that this user covered only by the correlated eRN, check if the sum of this row represents the user =1. (second condition verification).
- Apply these two conditions for all users to know exactly how many users are covered only from this eRN.
- Apply these procedures to each eRN.

[2]

Remove any useless relay nodes from the grid. Based on the suggested user threshold number ***USRth***, we define *USRth* as the minimum number of users that the eRN should serve to be valuable.

$$\boldsymbol{USRth} = Th \times \left(\frac{N_u}{No.\ of\ eRNs}\right) \tag{19}$$

where *Th* is a relative coefficient that helps to indicate ***USRth*** from the minimum number of users that each eRN should cover in the ideal case.

Compare each element in the ***SV*** array with *USRth*, if the element has a value larger than or equal to *USRth*, then we will keep this valuable eRN; otherwise, eliminate this useless eRN.

[3]

Furthermore, adding two constraints, *Min**C*** and *Max*$\boldsymbol{C_t}$, to the objective function in (16) to represent a condition that assists in obtaining the optimum plan with the maximum coverage and minimum cost. Therefore, the objective function will be as follows:

$$\begin{gathered} if \\ \boldsymbol{C} \geq Min\boldsymbol{C}\ \boldsymbol{and}\ \boldsymbol{C_t} \leq Max\boldsymbol{C_t} \\ \therefore\ \boldsymbol{CCI} = \frac{\boldsymbol{C}}{\boldsymbol{C_t}} \\ else \\ \boldsymbol{CCI} = 0 \end{gathered} \tag{20}$$

IV. OPTIMIZATION PHASE

The idea of the optimization is to find a search procedure that obtains the optimal solution through the search space. Stochastic optimization algorithms that depend on random variables initially deployed in the search space have attracted the attention of researchers in recent years [33]–[35]. We have proposed three optimization algorithms to obtain the optimum solution, which we refer to as our optimum cell plan. Two advanced algorithms, the PSOGSA and FSABA, are proposed in addition to the PSO algorithm.

A. PSO

The PSO algorithm was proposed by Kennedy and Eberhart 1995 [36]. It is inspired by natural behavior, such as the flocking of birds and insects. Candidate solutions represented by a number of particles are initially deployed randomly in the search space to look for the best solution. Each particle is expressed by both its velocity and position.

The PSO equations for a particle ***a*** are:

$$\mathbf{V_a}\left(\mathbf{t}+\mathbf{1}\right) = wv_a\left(t\right) + c_1 \times rand \times \left(X_{abest} - X_a(t)\right) + c_2 \times rand \times \left(g_{best} - X_a(t)\right) \quad (21)$$

$$\boldsymbol{X_a}\left(\boldsymbol{t}+\mathbf{1}\right) = X_a\left(t\right) + V_a\left(t+1\right) \quad (22)$$

where $\mathbf{V_a}\left(\mathbf{t}\right)$ is the velocity of particle a in iteration t; w is the inertia weight; c_1 and c_2 represent the recognition parameter and social parameter, respectively; *rand* is a random number in between [0, 1]; $\mathbf{V_a}\left(\mathbf{t}+\mathbf{1}\right)$ is the new velocity of particle a in iteration *t+1*; and $\boldsymbol{X_a}\left(\boldsymbol{t}+\mathbf{1}\right)$ is the new position of particle a in iteration *t+1*.

The new velocity and position of each particle are updated in each iteration depending on the previous velocity of the particle, the self-experience of the particle and the mutual cooperative experience between the particles.

B. PSOGSA

The PSOGSA was proposed by Mirjalili and Hashim in 2010 [37]; it is a hybridization of two different meta-heuristic algorithms [38], where it called a heterogeneous algorithm, the PSO algorithm [36] and the GSA [39], that cooperate and run in parallel to attain the optimal solution.

The main goal of the PSOGSA is to combine and integrate the exploitation feature of PSO and the exploration feature of GSA to achieve better search performance with a global optimum solution [37]. In other words, the PSOGSA gathers between the (g_{best}), as a result to a cooperative experience between the agents from the PSO and the cleverness of the agents that locally explores the search space by attracting the other agents according to the heavier masses from the GSA.

Accordingly, the PSOGSA procedure is as follows:

- Initially, distribute a random number of agents in the search space as a candidate solution.
  During the iterations:
- For all agents, sequentially, g_{best} should be obtained and updated. It acts as a memory that stores the best solution yet to help all agents approaching the solution to reach the global optima [40]. And the following GSA equations are calculated.

$$\boldsymbol{G}\left(\boldsymbol{t}\right) = G_{\circ} \times \exp\left(-\alpha \times \frac{iter}{maxiter}\right) \quad (23)$$

where $\boldsymbol{G}\left(\boldsymbol{t}\right)$ is the gravitational constant in iteration t; $G_{\circ}$ represents the initial gravitational constant value; α is the descending coefficient; *iter* is the current iteration; and *maxiter* is the maximum number of iterations.

$$\boldsymbol{F_{ab}}\left(\boldsymbol{t}\right) = G\left(t\right)\frac{M_{wa}\left(t\right) \times M_{db}\left(t\right)}{R_{ab}\left(t\right) + \varepsilon}\left(X_b\left(t\right) - X_a\left(t\right)\right) \quad (24)$$

where $\boldsymbol{F_{ab}}\left(\boldsymbol{t}\right)$ is the gravitational force from agent b on agent a; $M_{wa}\left(t\right)$ is the gravitational mass of the withdrawn agent a; $M_{db}\left(t\right)$ is the gravitational mass of the drawer agent b; $R_{ab}\left(t\right)$ is the Euclidian distance between the two agents a and b in iteration t; ε is a small constant; $X_b\left(t\right)$ is the position of agent b in iteration t; and $X_a\left(t\right)$ is the position of agent a in iteration t.

As we have $\boldsymbol{N}$ agents in a search space, the total force that affects agent a by the other agents in iteration t is:

$$\boldsymbol{F_a}\left(\boldsymbol{t}\right) = \sum_{b=1,b\neq a}^{N} rand_b F_{ab}\left(t\right) \quad (25)$$

where $rand_b$ is a random number between [0, 1]. From here, we can calculate the acceleration of agent a according to the law of motion, taking into consideration the inertial mass $M_{ia}\left(t\right)$ of agent a in iteration t.

$$\therefore\ \boldsymbol{acc_a}\left(\boldsymbol{t}\right) = \frac{F_a(t)}{M_{ia}(t)} \quad (26)$$

The PSOGSA combines the local search from the GSA by the acceleration of the agents and the global search from the PSO new position equation [41]. Thus, the velocities and therefore the positions of all agents can be calculated by:

$$\boldsymbol{V_a}\left(\boldsymbol{t}+\mathbf{1}\right) = wv_a\left(t\right) + c_1' \times rand \times acc_a\left(t\right) + c_2' \times rand \times \left(g_{best} - X_a(t)\right) \quad (27)$$

$$\boldsymbol{X_a}\left(\boldsymbol{t}+\mathbf{1}\right) = X_a\left(t\right) + V_a\left(t+1\right) \quad (28)$$

where $\boldsymbol{V_a}\left(\boldsymbol{t}\right)$ is the velocity of agent a in iteration t; w is the inertia weight; c_1' is the exploration parameter; c_2' is the exploitation parameter; *rand* is a random number in between [0, 1]; $acc_a\left(t\right)$ is the acceleration of agent a in iteration t; and g_{best} is the best solution obtained by all agents.

Both c_1', c_2' should be adjusted to the values that balance between the recognition component and the social component and encourage the agents to converge to the global best solution [42].

- The updating will stop when the end criterion, the maximum number of iterations, is met.

C. FSABA

In 2010, Xin-She Yang introduced a new natural inspired algorithm called the Bat Algorithm (BA) [43] that depends on the echolocation phenomenon of bats. A simplified adaptive bat algorithm based on frequency (FSABA) is an algorithm proposed by Zhen Chen in 2013 [44] to overcome the shortcomings of the BA, such as the premature convergence due to a lack of exploration, and then can obtain the local optimum [45]. The FSABA algorithm adopts several amendments [43]:

- The algorithm modifies the search equations as the reliance on the velocity equation is eliminated, and then the search is dominated by updating the position equation.

$$\boldsymbol{X_a}\left(\boldsymbol{t}+\mathbf{1}\right) = wX_a\left(t\right) + f_1\left(t\right) \times \left(p_{rnd} - X_a\left(t\right)\right) + f_2\left(t\right) \times \left(p_{go} - X_a\left(t\right)\right) \quad (29)$$

$$\boldsymbol{p_{rnd}} = X_a\left(t\right) \times 2 \times rand \quad (30)$$

where $X_a(t)$ is the location of bat a in iteration t; w is the inertia weight; $f_1(t)$ and $f_2(t)$ are the frequencies; p_{rnd} is the random position of the bat in the present iteration; p_{go} is the global optimum position in the present iteration; and *rand* is a normal distribution of random numbers.

- The algorithm adjusts the inertia weight as random values to enhance the global search.

$$w = \mu_{min} + (\mu_{max} - \mu_{min}) \times rand + \sigma \times \left(\frac{1}{2} \times rand + \frac{1}{2} \times poissrand\right) \quad (31)$$

where μ_{min} and μ_{max} are the minimum and maximum values of the random weight average; σ is the variance of the random weight; and *poissrand* is a Poisson distribution of random numbers.

- The algorithm alters between the separate frequencies values in the period search, with f_2 values over f_1 values tending to diversify and vice versa in the latest period search to obtain the optimum solution.

$$f_1(t) = 1 - e^{(-|F_{avg}(t) - F_{gbest}(t)|)} \quad (32)$$

$$f_2(t) = 1 - f_1(t) \quad (33)$$

$$F_{avg}(t) = \frac{1}{N\sum_{t=1}^{N}(f(X_a(t)))} \quad (34)$$

where $F_{avg}(t)$ and $F_{gbest}(t)$ correspond to the adaptation value of the average and the optimal locations for the bat colony in iteration t, respectively, and N is the number of iterations.

- The algorithm updates the declining loudness and the increasing pulse emission rate of the bats according to the following equations:

$$A = A_{\circ} \times \left(e^{(-0.1\times t)}\right) \quad (35)$$

$$r = r_{\circ} \times \left(1 - \frac{A}{A_{\circ}}\right) \quad (36)$$

where A and $A_{\circ}$ are the loudness and its initial value, and r and $r_{\circ}$ are the pulse emission rate and its initial value, respectively.

D. PSOGSA APPROACH FOR THE PROPOSED SCENARIO

The path of the deployment scenario for each of the PSOGSA, the FSABA, and the PSO algorithms procedures are shown in Figure 2. where initially we determined the number of iterations also generated the agents of each algorithm. Then the agents start to search on the optimal solution according to the suggested fitness function. Hence; each algorithm differentiates in the processing path. For the PSO algorithm; the velocity and positions for all agents have updated, then the end criterion for the iteration will be examined. As for the FSABA algorithm, the bat position, the inertia weight, and the frequencies values have updated. Next, the loudness has updated and the pulse emission rate has increased. Concerning the PSOGSA procedure; the total force and acceleration for all agents are calculated then the velocity and position for agents have updated, later the end criterion for the iteration will be checked.

V. RESULTS AND DISCUSSION

A. SIMULATION MODEL

We used Matlab R2015a to implement a simulation of our deployment scenario with the optimization algorithms by a computer with a 2.20 GHz core i7 processor and 6 GB of RAM.

We tended to decrease the number of variables that the optimization algorithm searches for the optimal solution in our scenario, and we determined to deploy the edge relay nodes in a uniform grid at the cell edge.

For the simulation, we employ **50** iterations to ensure that **10** agents that act as candidate solutions for the search space will fully converge to the optimum solutions for **2** variables in the optimization algorithms:

- eRN_x is introduced to detect the optimum power factor for all the edge relay nodes that grant the best coverage area.
- ***Th*** is introduced to detect the optimum value that represents the minimum number of covered users that makes the edge relay node useful.

Table 1 and Table 2 include our simulated parameters [13], [46].

TABLE 1. Simulation parameters.

Parameter	Value
N_e	52
N_u	5000
nSNRth	20 dB
uSNRth	20 dB
uSINRth	-7 dB
$SINR_{eff}$	1.25
a	0.60
b	0.40
c	0.65
B	10 MHz
B_{eff}	0.88
P_{eNB}	46 dBm
P_{RN}	30 dBm
P_n	-104 dBm
eNB antenna Pattern	Omnidirectional.
RN antenna pattern	Omnidirectional.
$P_{l_{NLos(eNB\rightarrow RN)}}(R)$	125.2+36.3 log10 (R)
$P_{l_{NLos(RN\rightarrow UE)}}(R)$	145.4+37.5 log10 (R)
$P_{l_{NLos(eNB\rightarrow UE)}}(R)$	131.1+42.8 log10 (R)
Min**C**	0.75
Max$\mathbf{C}_t$	0.80

Since each iteration in the PSOGSA is based on the previous iteration result, we logically chose a wide domain range for the search space for our two constraints to support the

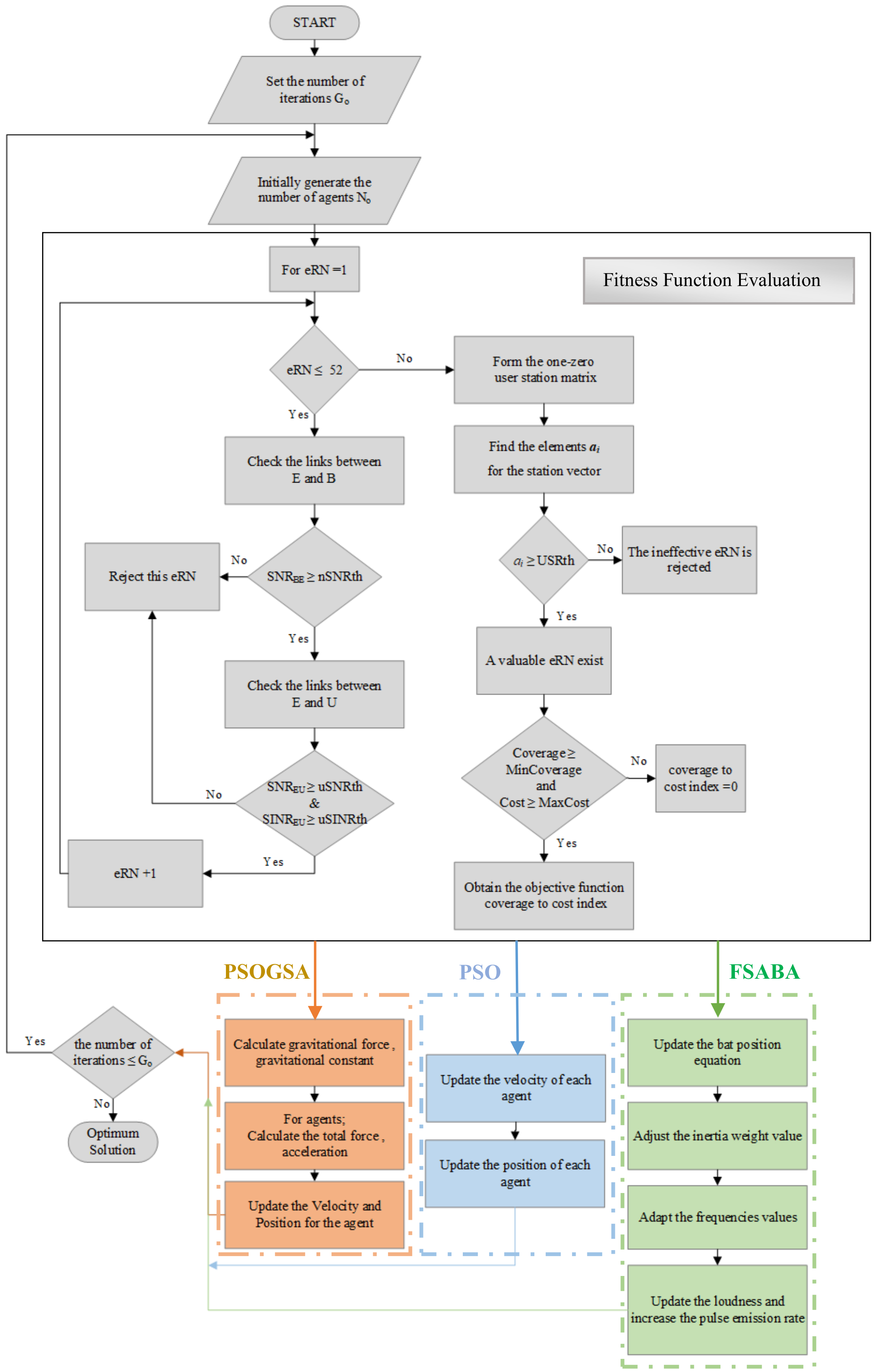

FIGURE 2. The cell plan of the proposed scenario.

agents in converging to the optimum solution. *MinC* acts as the lower bound for the search space that refers to the coverage value, and we aspire to reach 0.75 and regulate $MaxC_t$ to be 0.80. As a result of many runs, the power factor of the edge relay node permanently approaching to the upper bound value, which refers to the maximum transmitting power; thus, we have considered its search space from 0.50 to 0.65. The *Th* bounds from 0.40 to 0.70 indicate to the number of the

TABLE 2. Simulation parameters of the optimization algorithms for the proposed scenario.

Parameter	Definition	Value
Variables	Represent the problems that we search to find the best solutions.	2
eRN_x	The power factor of the eRN.	The search space lower bound is 0.50. The search space upper bound is 0.65.
Th	Represents the minimum number of users that should be covered by the eRN to keep on this eRN.	The search space lower bound is 0.40. The search space upper bound is 0.70.

TABLE 3. Itemized results for the optimum plan of each algorithm.

		PSOGSA	FSABA	PSO
Coverage of the optimum solution		79.54%	80.40%	80.86%
Cost of the optimum solution		52.24%	54.14%	54.41%
Number of endorsed eRNs in the optimum plan		27	28	28
Number of endorsed eRNs for different runs		27-31	28-31	28-33
Variables Values	eRN_x	0.6500	0.6479	0.6500
	Th	0.6000	0.5995	0.6000

chosen edge relay nodes to maintain the balance between both coverage and cost.

B. RESULTS OF THE COMPARATIVE STUDY

Our attractive results highlight the ability of the proposed objective function to achieve our main idea and the virtues of each optimization algorithm. Clearly, the PSOGSA exhibited greater performance than the PSO algorithm and even the FSABA. For this reason, we exhibit the optimum cell plan obtained from the PSOGSA, and then the distinctive results of the three algorithms will be assessed in details.

The important correlation between the coverage and cost of the resulting plan is illustrated in the coverage to cost index value, where a higher index value corresponds to a better cell edge plan.

As depicted in Figure 3a, which exhibits an emulation of the optimum cell plan in reality, we can see that the massive green area represents the covered users throughout the cell edge without considering the impact of the eNB, which stresses the importance of the relay nodes existence and the awareness of their optimal distribution, whereas the tiny red area corresponds to the uncovered users. The selected eRNs in the optimum plan are expressed in the black triangle Δ, while the blue relay nodes represent the rejected eRNs either from the farthest ones at the cell edge that do not receive a link from the eNB [$\boldsymbol{eRN_1}$, $\boldsymbol{eRN_{11}}$, $\boldsymbol{eRN_{42}}$, $\boldsymbol{eRN_{52}}$] or it becomes a useless relay node as we define [$\boldsymbol{eRN_2}$, $\boldsymbol{eRN_3}$, $\boldsymbol{eRN_5}$: $\boldsymbol{eRN_7}$, $\boldsymbol{eRN_9}$, $\boldsymbol{eRN_{18}}$, $\boldsymbol{eRN_{21}}$, $\boldsymbol{eRN_{24}}$: $\boldsymbol{eRN_{29}}$, $\boldsymbol{eRN_{32}}$, $\boldsymbol{eRN_{35}}$, $\boldsymbol{eRN_{44}}$, $\boldsymbol{eRN_{46}}$: $\boldsymbol{eRN_{48}}$, $\boldsymbol{eRN_{50}}$].

The valuable eRNs adopted in the optimum plan are [$\boldsymbol{eRN_4}$, $\boldsymbol{eRN_8}$, $\boldsymbol{eRN_{10}}$, $\boldsymbol{eRN_{12}}$: $\boldsymbol{eRN_{17}}$, $\boldsymbol{eRN_{19}}$, $\boldsymbol{eRN_{20}}$, $\boldsymbol{eRN_{22}}$, $\boldsymbol{eRN_{23}}$, $\boldsymbol{eRN_{30}}$, $\boldsymbol{eRN_{31}}$, $\boldsymbol{eRN_{33}}$, $\boldsymbol{eRN_{34}}$, $\boldsymbol{eRN_{36}}$: $\boldsymbol{eRN_{40}}$, $\boldsymbol{eRN_{41}}$, $\boldsymbol{eRN_{43}}$, $\boldsymbol{eRN_{45}}$, $\boldsymbol{eRN_{49}}$, $\boldsymbol{eRN_{51}}$].

The trajectory of either the agents, bats, or particles for the related PSOGSA, FSABA and PSO algorithm in the search space until reaching the maximum coverage to cost index value in accordance with the objective function is shown in Figure 3b. Further runs due to the random distribution of users are performed; thus, an average of 20 runs selected as samples for each algorithm are also displayed.

Figure 3c explains the proportion of the participation of each valuable relay node chosen at the optimum plan for the cell edge coverage based on the selected values for both eRN_x and *Th*.

Of particular interest in Figure 3b, we can observe that the average of the PSOGSA that achieves 96.8% from the maximum coverage to cost index surpasses its counterpart, the average of the FSABA and the average of the PSO algorithm, by 3.4% and 2.61%, respectively.

In a related manner, the optimum solution of the PSOGSA represented by the blue curve performs the best but still precedes the optimum solution of the FSABA coloured in green by 3% and the PSO curve coloured in red by 2%. It is also clear that the imminent optimum solution of PSOGSA outperforms the average PSOGSA by 3.2%.

With insight into Figure 3b, it shows that the average of both the PSOGSA and the PSO converges to the best solution at a preceding iteration earlier than the FSABA by 34%. The optimum plan of both the PSOGSA and the PSO converges at a transcend iteration previous the optimum plan of the FSABA by 17%. In addition, the optimum plan and the average of the PSOGSA achieve the best solution without a change in performance at the third iteration.

When tracking the processing time that each run is supposed to consume to obtain and confirm the optimum plan, we considered the average of the processing time for 20 runs for each of the three optimization algorithms. The average of the PSOGSA takes 33.68 sec, which is faster than the average of both the PSO and the FSABA algorithms by more than half a minute.

From the data presented in Table 3, it can be found that the proposed scenario has been able to achieve a distinctive coverage percentage of more than 79.5% of the cell edge. Although the coverage percentage from the FSABA and the PSO is slightly more than the coverage of the PSOGSA plan, the outputted cost from the PSOGSA is significantly lower than the FSABA and the PSO. Thereupon, the importance

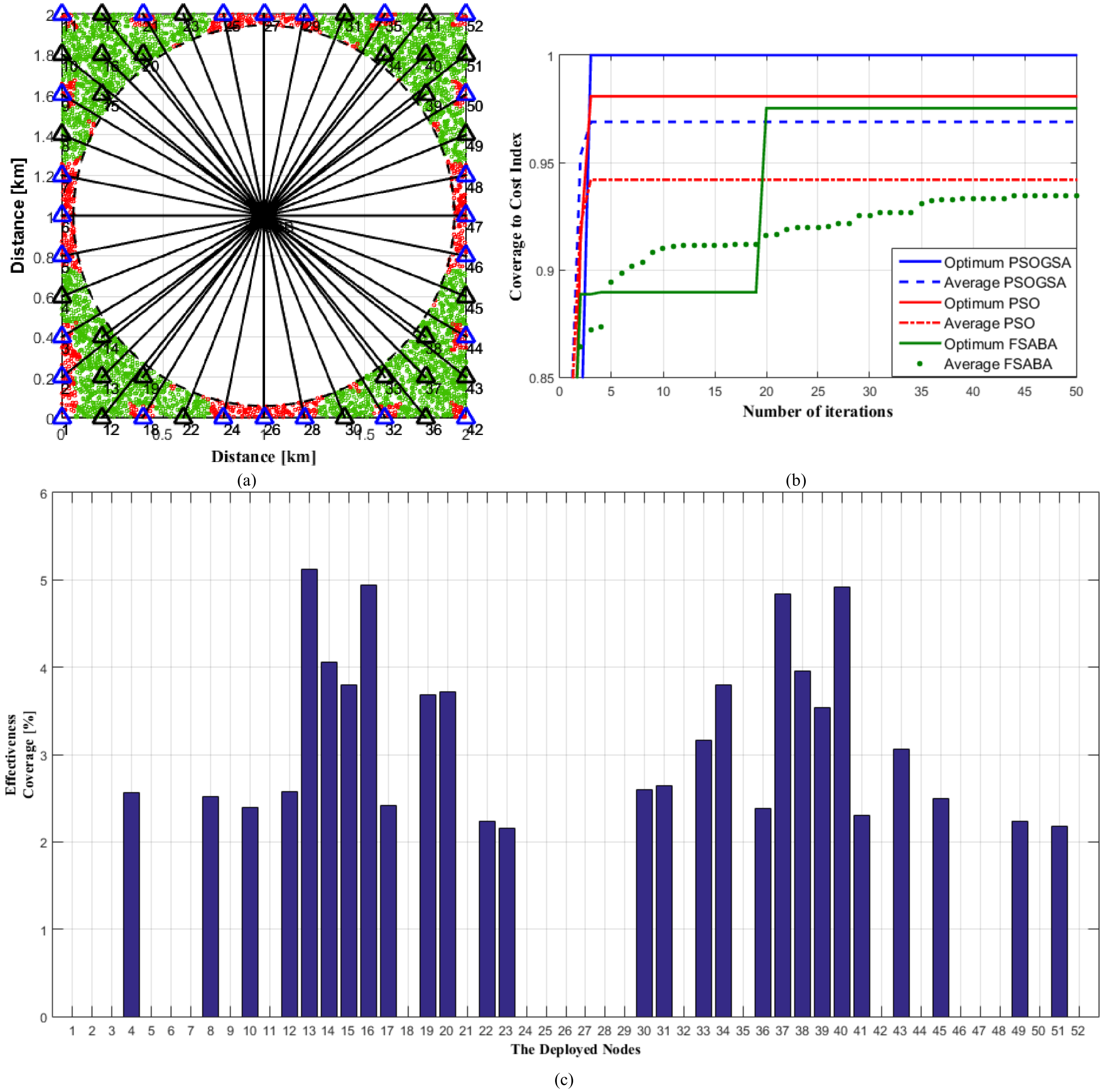

FIGURE 3. **The optimum plan of the proposed deployment scenario: (a) the PSOGSA cell plan with the deployment of the edge relay nodes; (b) the coverage to cost index of the optimum plans obtained from the three optimization algorithms and for an average of 20 runs; (c) the effectiveness of each edge relay node in the cell.**

of using the PSOGSA algorithm is evident in finding the optimum plan that achieves the trade-off between the coverage and the cost. The cost decreasing of the PSOGSA optimum plan attributed to that plan has the minimum number of the selected relay nodes, whereas the optimum plans of the FSABA and the PSO selected 28 edge relay nodes, as a consequence of the *Th* values.

On the other hand, the values of the power factors for the chosen relay nodes of each plan are convergent. Equally important, the total cell edge throughput for 3977 covered users randomly distributed is 134 Gbps, due to the optimum plan of the PSOGSA.

We find that the PSOGSA achieves a notable performance through our deployment scenario for the cell edge, superior to that of the parallel FSABA and the PSO algorithm in the objective function values. Also, the agents of the PSOGSA converge efficiently to the optimum.

Moreover; Figure 4 introduces an optimum cell plan study after endorsing in case the number of the distributed users changes up and down.

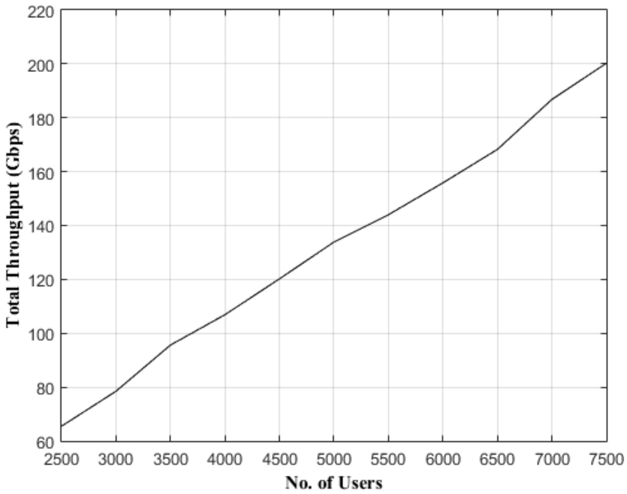

FIGURE 4. The optimum plan cell edge throughput.

In comparison to [19] where the authors proposed an energy-efficient and optimal RN placement (EEORNP) algorithm, we can notice from the results that this algorithm needs 57 relay nodes to cover 500 users whereas our optimum plan needs just 27 relay nodes to cover 3977 users. Furthermore, the algorithm in [19] requires 100 relay nodes to attain 88% coverage whereas our optimum cell plan with the PSOGSA algorithm demands 27 relay nodes to achieve 79.54% coverage means a fewer number of relay nodes by a third.

VI. CONCLUSION

In this paper, we aimed to achieve a trade-off between an optimal coverage area at the cell edge, which is considered to be problematic for the users, and a moderate cost. This problem can be settled by the advancement in the relay node track that plays a vital role through its merits. First, we designed the plan and explained our problem. Second, we proposed a deployment scenario for the relay nodes in the cell edge, considering the interference that emerges from these nodes to reach the optimal plan and realize our target. Then, a sophisticated PSOGSA optimization was employed to obtain the optimum plan and increase the leverage of the results. Therefore, we compared the results with another advanced algorithm, the FSABA, in addition to the PSO algorithm. From the essence of the results, the PSOGSA performs better than other algorithms, in which the plan of the cell edge has a coverage percentage is 79.54% from the impact of the relay nodes only, with the lowest cost. The cell edge throughput of the optimum plan is calculated. Consequently, the throughput is presented whether the number of users increase or decrease through the cell edge. The simulations patently prove the enhanced performance of the proposed plan using the optimization of the PSOGSA.

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