PRADA: Practical Access Point Deployment Algorithm for Cell-Free Industrial IoT Networks

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***Abstract*—We propose a novel practical access point (AP) deployment technique for 6G ultra-reliable industrial Internet-of-things (IIoT) networks. In particular, a cell-free massive multiple-input multiple-output (CF-mMIMO) architecture is adopted to improve reliability with macro-diversity, where a station (STA) is simultaneously associated with and served by multiple APs. We first mathematically formulate an integer linear programming (ILP)-based optimization problem that minimizes the number of required APs while satisfying a certain quality-of-service (QoS) of IIoT networks, such as the minimum number of concurrent communication links and the minimum required signal-to-noise ratio (SNR). However, the optimal technique requires significant computational complexity and time, unfortunately. Hence, we propose a low-complexity AP deployment algorithm based on parallel search methods, named PRADA. The proposed algorithm sufficiently reduces the number of required APs in a computationally efficient manner while satisfying the QoS constraints.**

***Index Terms*—Industrial Internet-of-things (IIoT), access point deployment, cell-free massive multiple-input multiple-output (CF-mMIMO), macro-diversity, minimum set cover problem.**

I. Introduction

INDUSTRIAL Internet-of-things (IIoT) networks are being considered the core infrastructure of the fourth industrial revolution (Industry 4.0), and demand ultra-reliable and low-latency communications (URLLC) capability to support mission-critical applications in general [1], [2]. Furthermore, next-generation (6G) IIoT networks are expected to require even massive machine-type communications (mMTC) services to realize intelligent industrial automation systems [3], [4]. Recently, cell-free massive multiple-input multiple-output (CF-mMIMO) has emerged as a promising network architecture to satisfy URLLC and mMTC requirements [5], [6]. Basically, a canonical CF-mMIMO system consists of a single central processing unit (CPU) and a number of distributed access points (APs) without cell boundaries. All APs are connected to the CPU via wired/wireless fronthaul links, and cooperatively serve all users/devices over the same radio resources. The CF-mMIMO technique significantly improves communication reliability with macro-diversity from multiple APs, which are distributed over a communication area, and it provides better energy efficiency, coverage, and uniform quality-of-service (QoS) provisioning than a centralized mMIMO technique. In particular, a user-centric approach, in which each user is served by its neighboring APs, not all APs, is considered a more feasible CF mMIMO architecture [6].

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On the other hand, although a large number of APs will be installed, the AP deployment for CF mMIMO systems has not yet been well-investigated to the best of our knowledge. Given the fronthaul capacity and scalability, the CF mMIMO system will also require sophisticated AP deployment schemes to maximize the advantages [5]–[7]. Specifically, the more installed APs, the higher the signaling overhead for exchanging information, data, and control signals between the CPU and APs, and the higher the capital and operational expenditures. It is worth noting that AP (or base station: BS) deployment has traditionally been studied as essential for communication systems [8], [9]. In particular, it is a reasonable strategy to minimize the number of deployed BSs while ensuring the QoS requirements of user equipment (UE). There are some studies on minimum-number AP (BS) deployment techniques considering macro-diversity [8]–[11]. However, the authors of [8] focused on ensuring line-of-sight (LoS) links through multiple BSs and did not contain the constraint that UE must be associated with multiple BSs. In [10], the authors considered the limited coverage, which is the moving path of the mobile station (STA), and distance-based coverage from the AP. In [11], macro-diversity was exploited for fault tolerance, so each STA is actually associated with only a single AP. In [9], the authors maximized the average number of accessible BSs rather than guaranteeing a specific macro-diversity order for each UE. Furthermore, these studies ignored practical link budgets [8]–[10].

This motivates us to investigate a novel AP deployment technique for CF mMIMO IIoT networks, especially for smart indoor factories. We exploit the CF mMIMO architecture with macro-diversity to support ultra-reliable service and consider mobile industrial robots as STAs. This means that each STA must be able to maintain simultaneous communication links with multiple APs that can provide QoS above a certain level. In addition, these conditions must be satisfied over the whole area to capture the time-varying nature of the positions of mobile STAs. With these constraints, we formulate an integer linear programming (ILP)-based AP deployment problem that minimizes the number of required APs, and design a low-complexity AP deployment algorithm based on parallel search.

II. System Model

We consider a two-dimensional $W[\text{m}]\times H[\text{m}]$ millimeter wave (mmWave) CF mMIMO-based indoor factory network, as shown in Fig. 1. The area is divided into $\Delta_{\mathsf{AP}}[\text{m}]$ squares, and grid points marked with '●' represent the candidate (*placeable*) locations for deploying an AP. Let $\mathbf{p}_i = [x_i, y_i]$ ($i \in \mathcal{L}_{\mathsf{AP}}$) be the Cartesian coordinates of the grid point i with $x_i = \Delta_{\mathsf{AP}}((i-1)\text{mod}(W/\Delta_{\mathsf{AP}}+1))$ and $y_i =$

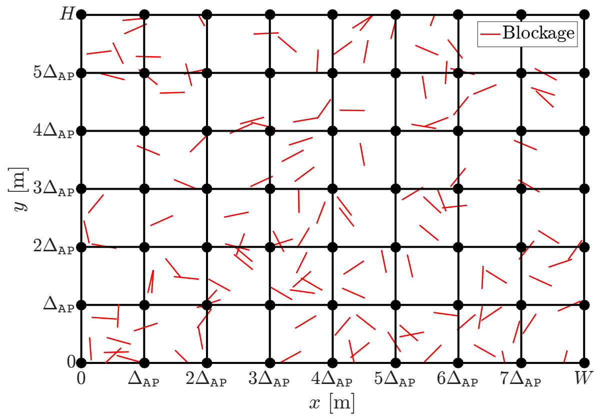

Fig. 1. An example of the indoor factory system model for deploying APs with randomly distributed blockages (red lines).

$\Delta_{\mathsf{AP}}\lfloor(i-1)/(W/\Delta_{\mathsf{AP}}+1)\rfloor$, where $\mathcal{L}_{\mathsf{AP}}$ $(=\{1,2,\ldots,L_{\mathsf{AP}}\})$ denotes the index set of the AP-placeable points and $L_{\mathsf{AP}} = \lfloor W/\Delta_{\mathsf{AP}}+1\rfloor \times \lfloor H/\Delta_{\mathsf{AP}}+1\rfloor$.

A. Blocking Model

There are various blockages in the indoor factory network, such as pillars, machines, equipment, etc. Because mmWave signals suffer severe penetration loss, an accurate blockage model is required. In this paper, we employ a stochastic model well known as the germ-grain model to implement and experiment with various blocking environments [12]. Specifically, as illustrated in the red lines in Fig. 1, the blockages are modeled as a sequence of line segments $\Phi_{\mathsf{B}} = \{\mathbf{p_B}, l_\mathbf{B}, \theta_\mathbf{B}\}$ where $\mathbf{p}_{\mathsf{B}}$, l_{B}, and θ_{B} denote the location of midpoint, length, and orientation of each segment, respectively. The sequence of midpoints ($\mathbf{p}_{\mathsf{B}}$) is distributed according to a Poisson point process with density λ_{B} in the area, and the sequence of orientations (θ_{B}) is modeled to follow independent and identically distributed (i.i.d.) uniform random variables in $[0, 2\pi)$.

B. Propagation Model

We exploit *downlink received signal strength (RSS)* readings as constraints on the AP deployment problem. Let $r_{j,i}$ be the average RSS that the point $\mathbf{p}_j$ $(=[x_j, y_j],\ j \in \mathcal{L}_{\mathsf{STA}})$ receives from the point $\mathbf{p}_i$, where $\mathcal{L}_{\mathsf{STA}}$ $(=\{1,2,\ldots,L_{\mathsf{STA}}\})$ denotes the index set of STA-placeable points and $L_{\mathsf{STA}} = \lfloor W/\Delta_{\mathsf{STA}}+1\rfloor \times \lfloor H/\Delta_{\mathsf{STA}}+1\rfloor$ accordingly. The STA-placeable locations can also be regarded as service demand points with equal weights, and our goal is to cover these points.

The average RSS for all j and i can be calculated as follows:

$$r_{j,i} = P_{\mathsf{Tx}} G_{\mathsf{Tx}} G_{\mathsf{Rx}} L_{(1m)} L_{j,i}(\|\mathbf{p}_j - \mathbf{p}_i\|), \tag{1}$$

where P_{Tx} denotes the AP transmit power; and G_{Tx} and G_{Rx} are the antenna gains of the transmitter (AP) and the receiver (STA), respectively. Since mmWave signals experience high propagation and penetration losses, APs will be equipped with large-scale antenna arrays with directional beamforming. In this paper, we assume that the AP can aim this beam direction to any STA-placeable point, i.e., the antenna gain of the AP is the same as the main lobe gain in any direction. On the other hand, it is assumed that the STA generates an omnidirectioanl beam; $L_{(1m)}$ represents the reference path loss at a unit meter distance defined as $L_{(1m)} = (\frac{c}{4\pi f_c})^2$ where c and f_c denote the light speed ([m/s]) and carrier frequency ([Hz]), respectively; $L_{j,i}(\delta)$ denotes the path loss, which is a function of the Euclidean distance between $\mathbf{p}_j$ and $\mathbf{p}_i$, defined as $L_{j,i}(\delta) = \delta^{-\alpha_{\mathsf{L}}}$, if link is LoS, i.e., $\#(\Phi_{\mathsf{B}} \cap \overline{\mathbf{p}_j, \mathbf{p}_i}) = 0$, $L_{j,i}(\delta) = \delta^{-\alpha_{\mathsf{N}}}$, if link is non-LoS (NLoS), i.e., $\#(\Phi_{\mathsf{B}} \cap \overline{\mathbf{p}_j, \mathbf{p}_i}) > 0$, where α_{L} and α_{N} are path loss exponents depending on whether the link state is LoS or NLoS, respectively; $\#(\Phi_{\mathsf{B}} \cap \overline{\mathbf{p}_j, \mathbf{p}_i})$ represents the number of line segments from Φ_{B} that intersect the link between $\mathbf{p}_j$ and $\mathbf{p}_i$, denoted as $\overline{\mathbf{p}_j, \mathbf{p}_i}$.

C. Association Policy

To obtain macro-diversity, the STA must be able to access multiple APs simultaneously and maintain links associated with them. In this paper, the association policy from the STA to the AP is based on the maximum reference signal received power (RSRP) rule. Specifically, each STA is associated with M APs that provide the strongest RSS to itself, where M is defined as the macro-diversity order. Meanwhile, recall that the CF mMIMO architecture has been adopted to achieve ultra-reliability in indoor factory networks. In the same vein, we also assume that all associated links use channels orthogonal to each other. This allows the service demand points to take a threshold signal-to-noise ratio (SNR) as a criterion for QoS requirements since it is sufficient not to consider inter-AP interference. It is worth noting that the threshold SNR can be drawn from the required data rate or error rate.

III. AP Deployment for CF mMIMO Networks

We formulate an ILP-based AP deployment problem exploiting macro-diversity and present a practical low-complexity algorithm. Our main objective is to deploy the minimum number of APs while satisfying the number of accessible APs that meet the SNR condition across the whole service area. Specifically, each STA-placeable location must be associated with at least M APs that provide SNR above a certain threshold, denoted by γ. Before formulating the problem, we introduce the notations for optimization variables as follows: $z_i = 1$, if an AP is installed at the candidate point i, $z_i = 0$, otherwise; and if point j is associated with point i, $c_{j,i} = 1$, otherwise $c_{j,i} = 0$, where indices i $(\in \mathcal{L}_{\mathsf{AP}})$ and j $(\in \mathcal{L}_{\mathsf{STA}})$ represent AP- and STA-placeable points, respectively. There are binary variables.

A. Problem Formulation

To alleviate the computational complexity, we define an SNR indicator matrix $\mathbf{A}$ $(\in \{0,1\}^{L_{\mathsf{STA}} \times L_{\mathsf{AP}}})$ with each element of $a_{j,i} = \mathbf{1}_{\{r_{j,i}/N_{BW} \geq \gamma\}}, \forall j, i$, where $\mathbf{1}_{\{\cdot\}}$ is an indicator function and N_{BW} $(= N_0 \cdot BW)$ denotes the noise power considering the power spectral density of white Gaussian noise N_0 and the channel bandwidth BW. Each $a_{j,i}$ indicates that if the SNR from i to j is greater than or equal to the threshold, a link can be associated between the STA-placeable point j and the candidate AP i. An ILP-based AP deployment problem considering macro-diversity can then be formulated as follows:

$$\min_{z_i} \sum_{i \in \mathcal{L}_{\mathsf{AP}}} z_i \tag{2a}$$

$$\text{s.t. } z_i \geq \frac{1}{|\mathcal{L}_{\mathsf{STA}}|} \sum_{j \in \mathcal{L}_{\mathsf{STA}}} c_{j,i}, \qquad \forall i \in \mathcal{L}_{\mathsf{AP}}, \tag{2b}$$

$$\sum_{i \in \mathcal{L}_{\mathsf{AP}}} a_{j,i} c_{j,i} \geq M, \qquad \forall j \in \mathcal{L}_{\mathsf{STA}}. \tag{2c}$$

The objective function (2a) minimizes the total number of installed APs. Constraint (2b) states that if point j is associated with point i, then the AP should be deployed at i. Constraint (2c) denotes that each point j must be associated with at least M APs that provide SNR above the threshold. Since we consider the mobile STAs, this constraint must be satisfied in all areas ($\mathcal{L}_{\mathsf{STA}}$). Combining constraints (2b) and (2c), the ILP-based minimum AP deployment problem taking into account macro-diversity can be formulated as follows:

$$\min_{z_i} \sum_{i \in \mathcal{L}_{\mathsf{AP}}} z_i \tag{3a}$$

$$\text{s.t. } \mathbf{Az} \geq M\mathbf{e}, \tag{3b}$$

where $\mathbf{z} = [z_1, z_2, \ldots, z_{L_{\mathsf{AP}}}]^{\mathrm{T}}$, and $\mathbf{e}$ $(= \{1\}^{L_{\mathsf{STA}} \times 1})$ is an all-ones vector, respectively. This problem contains as a special case (with $M = 1$) the minimum set cover (MSC) problem which is known to be NP-hard [13].

B. Practical AP Deployment Algorithm: PRADA

Since APs are generally installed semi-permanently, the polynomial-time algorithm for AP deployment may be insignificant as the problem can be solved offline. Thus, one may consider solving the ILP using a standard solver such as CPLEX. However, it often fails to find a solution in a reasonable time, especially for large problems. In our case, we found that CPLEX exhibits poor scalability and even runs out of memory when the area (W, H) is large or the step size (Δ_{AP}, Δ_{STA}) is small. Therefore, we further design a low-complexity AP deployment algorithm based on the heuristic method with the same objective and constraints.

Before elaborating on the proposed algorithm, we define some new notations. First, U denotes the number of sets for parallel search, from which U greedy algorithms are performed. We also define the initial step size as $\Delta_{\mathsf{Init}} = n\Delta_{\mathsf{AP}}$ to generate various initial AP locations, where n is chosen such that $n \in \mathbb{R}^+$ and $n \gg 1$. This is because if Δ_{Init} is assigned a small value, then U sets will consist of similar location indices. This will reduce the diversity of parallel searches.

Algorithm 1 represents the pseudo-code of the proposed PRADA (*PRactical Access point Deployment Algorithm*), where $\mathbf{R}$ $(\in \mathbb{R}_+^{L_{\mathsf{STA}} \times L_{\mathsf{AP}}})$ and $\mathbf{A}$ denote the RSS matrix consisting of (1) and SNR indicator matrix, respectively.

*1) **Step I. Initial AP Location**:* First of all, U AP candidate locations that can cover a large area, i.e., have many STA-placeable points that satisfy the SNR constraint, are extracted. Equivalently, they consist of columns with many ones in the matrix $\mathbf{A}_{\mathsf{Init}}$. At this time, if the same number of STA-placeable points are covered, a candidate location with the highest RSS sum at those points is selected.

*2) **Step II. Parallel Search**:* Now, starting from each of the sets $\Lambda_u^{(0)}$, we deploy APs in parallel until at least one set that satisfies constraint (2c) occurs. Let $\mathbf{b}$ $(= [b_1, b_2, \ldots, b_U])$ be a flag vector indicating whether all STA-placeable points satisfy the number of accessible APs conditions. It is initialized as an all-zero vector $\mathbf{0}^{U \times 1}$. During iteration, if the set $\Lambda_u^{(\tau)}$ satisfies the constraint (2c), b_u becomes one, otherwise, it remains zero. Also, if there are duplicate sets during iteration, deduplication is performed by merging them.

Considering $u = 1$ without loss of generality, the process of *Step II* is as follows. First, a set $\mathcal{L}_{\mathsf{unsat}}$, consisting of STA-placeable points where the number of accessible APs constraint is not satisfied when APs are deployed at locations of the set $\Lambda_1^{(\tau)}$, is defined. If there are points that do not meet the constraints, an additional AP is deployed at the candidate location that can reduce those points the most. As before, if multiple locations are selected, a location with the highest RSS sum at the measurement points where the SNR constraint is not yet satisfied is determined. This process is repeated until all STA-placeable locations satisfy the constraint, which is the number of accessible APs, and terminates if any of the U sets meet the constraint.

*3) **Step III. Choose a Combination**:* Some sets $\Lambda_{\tilde{u}}^{(\tau)}$ that satisfy the number of accessible APs constraints in the whole area were obtained from the previous step. Note that all these sets are essentially combinations of AP locations that achieve our underlying goal of installing the minimum number of APs,

Algorithm 1 Practical AP Deployment (PRADA)

Input: $\mathbf{R}$, $\mathbf{A}$, M, U, Δ_{Init}.
Output: Λ_{u^*}.
Initialization:
  $\mathcal{L}_{\mathsf{Init}} = \{i \,|\, (x_i)\mathrm{mod}(\Delta_{\mathsf{Init}}) = 0 \wedge (y_i)\mathrm{mod}(\Delta_{\mathsf{Init}}) = 0\}$,
  $\mathbf{A}_{\mathsf{Init}} = [\mathbf{a}_1, \ldots, \mathbf{a}_k, \ldots, \mathbf{a}_{|\mathcal{L}_{\mathsf{Init}}|}]$, $k \in \mathcal{L}_{\mathsf{Init}}$,
  $\Lambda_0^{(0)} = \varnothing$, $\tau = 1$, $\mathcal{L}_{\mathsf{unsat}} = \varnothing$, $\mathcal{U} = \{1, 2, \ldots, U\}$.

▷ ***Step I. Initial AP Location***
for all $u \in \mathcal{U}$ **do**
  $\mathcal{K} = \underset{k \in \mathcal{L}_{\mathsf{Init}} \setminus \Lambda_0^{(u-1)}}{\arg\max} \left(\sum_{j \in \mathcal{L}_{\mathsf{STA}}} a_{j,k}\right)$
  $k^* = \underset{k \in \mathcal{K}}{\arg\max} \left(\sum_{j \in \mathcal{L}_{\mathsf{STA}}} r_{j,k}\right)$
  Update $\Lambda_0^{(u)} \leftarrow \Lambda_0^{(u-1)} \cup \{k^*\}$
end for
Let $\Lambda_0^{(U)} = \{k_1, \ldots, k_U\}$, and define $\Lambda_u^{(0)} = \{k_u\}$, $\forall u \in \mathcal{U}$

▷ ***Step II. Parallel Search***
Define a *flag* vector, $\mathbf{b} = \mathbf{0}^{U \times 1} \in \{0, 1\}^{U \times 1}$
while $\mathbf{b} = \mathbf{0}$ **do**
  for all $u \in \mathcal{U}$ **do**
    $\mathcal{L}_{\mathsf{unsat}} = \{j \mid \sum_{i \in \Lambda_u^{(\tau-1)}} a_{j,i} < M\}$
    if $\mathcal{L}_{\mathsf{unsat}} \neq \varnothing$ **then**
      $\mathcal{K} = \underset{k \in \mathcal{L}_{\mathsf{AP}} \setminus \Lambda_u^{(\tau-1)}}{\arg\max} \left(\sum_{j \in \mathcal{L}_{\mathsf{unsat}}} a_{j,k}\right)$
      $k^* = \underset{k \in \mathcal{K}}{\arg\max} \left(\sum_{j \in \mathcal{L}_{\mathsf{unsat}}} r_{j,k}\right)$
      Update $\Lambda_u^{(\tau)} \leftarrow \Lambda_u^{(\tau-1)} \cup \{k^*\}$
    else
      Update $b_u \leftarrow 1$
    end if
  end for
  Define a temporary set $\mathcal{U}' = \mathcal{U}$ for *deduplication*
  for all $u' \in \mathcal{U}'$ **do**
    if $\{u | \Lambda_u^{(\tau)} = \Lambda_{u'}^{(\tau)}, u < u', u \in \mathcal{U}'\} \neq \varnothing$ **then**
      Update $\mathcal{U} \leftarrow \mathcal{U} \setminus u'$
    end if
  end for
  $\tau \leftarrow \tau + 1$
end while

▷ ***Step III. Choose a Combination***
Choose a set Λ_{u^*} from $\Lambda_{\tilde{u}}^{(\tau)}$ where $\tilde{u} \in \{u | b_u = 1, u \in \mathcal{U}\}$

TABLE I
KEY SYSTEM PARAMETERS OF SIMULATIONS.

Parameter	Notation	Value
Area size	$W \times H$	$40\ \mathrm{m} \times 30\ \mathrm{m}$ & $40\ \mathrm{m} \times 40\ \mathrm{m}$
Step size between adjacent AP-, STA-placeable points	$\Delta_{\mathsf{AP}}, \Delta_{\mathsf{STA}}$	$1\ \mathrm{m}$
Blockage parameters	$\lambda_{\mathsf{B}}, l_{\mathsf{B}}$	$0.1/\mathrm{m}^2,\ 2\ \mathrm{m}$
Carrier frequency	f_c	28 GHz
Channel bandwidth	BW	100 MHz
Path-loss exponents	$\alpha_{\mathsf{L}},\ \alpha_{\mathsf{N}}$	$2.0,\ 4.0$
Transmit power of AP	P_{Tx}	20 dBm (100 mW)
AP and STA antenna gains	$G_{\mathsf{Tx}}, G_{\mathsf{Rx}}$	18 dBi, 0 dBi
Noise power	N_{BW}	-174 dBm/Hz $+10\log_{10}BW$ Hz $+10$ dB (noise-figure)
SNR threshold	γ	20 dB

TABLE II
SIMULATION RESULTS ACCORDING TO M IN $40\ \mathrm{m} \times 30\ \mathrm{m}$ AREA.

M		ILP	PRADA	GA [14]
1	No. of required APs	5.82	6.91	8.21
	Exec. Time [s]	4.0073	1.4644	0.0214
2	No. of required APs	10.64	13.23	14.96
	Exec. Time [s]	19.9447	4.0381	0.0615
3	No. of required APs	15.43	19.63	21.56
	Exec. Time [s]	51.4899	6.7927	0.0164

TABLE III
SIMULATION RESULTS ACCORDING TO M IN $40\ \mathrm{m} \times 40\ \mathrm{m}$ AREA.

M		ILP	PRADA	GA [14]
1	No. of required APs	7.09	8.66	10.25
	Exec. Time [s]	14.4292	4.6152	0.0516
2	No. of required APs	13.44	16.58	18.51
	Exec. Time [s]	6271	11.7663	0.1408
3	No. of required APs	Not solved	24.27	26.52
	Exec. Time [s]	Not solved	21.2328	0.2709

and have the same number of elements. Hence, finally, a set is selected randomly from among them.

IV. SIMULATION RESULTS

Through computer simulations, we validate the proposed AP deployment techniques considering the macro-diversity of CF mMIMO networks in terms of the number of required APs. The simulation parameters are summarized in Table I, and the CPLEX optimizer tool is used for solving the optimization problem (3a)-(3b). Specifically, we consider a room of the mmWave CF mMIMO-based indoor factory and defined the step size of AP- and STA-placeable locations (Δ_{AP} and Δ_{STA}) as 1[m]. Although the smaller these values, the better the solution will be, it is extremely time-consuming and requires a huge amount of random access memory (RAM). The threshold SNR was set to 20[dB] at any STA-placeable location to enable ultra-reliable service. For the proposed PRADA, we define $\Delta_{\mathsf{Init}} = 5[\mathrm{m}]$ ($n = 5$) and $U = |\mathcal{L}_{\mathsf{Init}}|$, respectively.

Tables II and III present the comparison results of the PRADA with the optimal solution and a conventional technique. As discussed in [8], we also considered another AP deployment scheme [14] as a benchmark, where the constraint is replaced to remove points covered by M BSs to exploit macro-diversity, which can be regarded as a greedy algorithm (GA) for the MSC problem. Simulation results show that the constraint of the number of accessible APs is basically satisfied in the whole area. Unfortunately, the ILP-based optimal solution requires the smallest number of APs, but even if the area is only $40[\mathrm{m}] \times 40[\mathrm{m}]$, it could not be derived due to *out of memory* even with 256GB RAM. The proposed PRADA using the parallel search outperforms simple GA while achieving acceptable execution time.

V. CONCLUSION

CF mMIMO is considered a promising network architecture for next-generation wireless communication systems, and the AP (or BS) deployment is a traditional core problem for network planning and optimization. In this paper, we proposed AP deployment techniques for CF mMIMO networks. The objective is to minimize the number of installed APs while ensuring the minimum number of accessible APs to obtain macro-diversity across the whole area. We first formulated an ILP-based optimal AP deployment problem, but this is infeasible in large-area CF mMIMO networks due to its NP-hardness. Hence, we further proposed a practical low-complexity AP deployment algorithm based on parallel search methods named PRADA. Simulation results showed that the proposed PRADA achieves sufficiently good performance compared to the optimal solution and a conventional greedy algorithm in terms of the number of required APs and feasibility.

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