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Research Article

A Comparative Study of RFID System Performance in Large-Scale Network Planning Facility

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ABSTRACT

Big data in manufacturing fields present several challenges leads to reduce profitability and missed opportunity for innovation. One of the used strategies is the use of radio frequency identification system. considered a business strategy to increase productivity, speed up decision-making, and enhance production monitoring and control while preserving the structure and integrity of current manufacturing systems. The present research compares five artificial inelegant algorithms based on RFID system in facility layout design to investigate the fitness of each algorithm in manufacturing big data processing. The objective functions have been used are the minimum number of required readers, minimum readers overlap, and maximum tags coverage. The contribution in this work is the workability of each algorithm in different facility design condition based on design alternatives. the results present that cuckoo search (CS) has the optimum fitness reach to 74.68% in big data and large area condition while particle swarm optimization (PSO) observed optimum fitness 74.46% in small data and large area. The simulation results illustrate the applicability and robustness of the proposed method, with the characteristics maintaining exceptional approximation capabilities even in high-dimensional spaces.

1. INTRODUCTION

RFID systems are transformative elements. It can simultaneously scan many tags, possesses substantial data storage capacity, and retains the unique serial number of each tag for worldwide item identification. RFID denotes radio frequency identification and detection, representing a communication route that does not rely on light. A radio frequency identification (RFID) tag is an electronic device utilized in noncontact automated identification systems. RFID tags utilize radio frequency (RF) signals for communication and energy provision to engage with monitored objects [1]. An RFID system has three primary components: middleware, reader, and tag. An object requiring identification often possesses a connected transponder. This item identification comprises an antenna and a chip, each possessing a unique code. The tag receives radio signals transmitted by the interrogator or reader. A reader typically comprises a control unit, an antenna, a radio frequency module for signal transmission and reception, and a transmitter. Readers possess additional interfaces (RS 485, RS 232, etc.) to facilitate data transfer across systems, including personal computers and robotic control systems. The final element is the middleware, which connects databases and RFID scanners [2].

RFID tags are categorized into two types: active and passive. An active tag circuit incurs a higher cost because its battery needs. Its compact form belies its processing capability, making it ideal for managing substantial commodities such as port containers or parking lot vehicles. Conversely, a passive tag is compact, lightweight, economical, and perhaps powered by the reader's radio frequency. It is ideal for small goods, such as those in a retail warehouse, where they may be assigned an ID and embedded data, as it does not retain processing history. RFID network planning (RNP) is essential for the successful implementation of an RFID system that provides an adequate quality of service (QoS). The RNP aims to accomplish several objectives, including optimizing tag coverage, preventing reader interference, ensuring equitable load distribution among all readers, and maximizing economic efficiency.

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Consequently, enhancing the comprehensibility of tag coverage is the paramount objective among all RNP goals. RNP optimization may be achieved by determining the optimal placement and power level for each reader. Consequently, many algorithms have been utilized to identify the optimal positions for readers [3].

2. OPTIMIZATION TECHNIQUES

Artificial intelligence (AI) techniques have aided the birth of a fascinating new field of technology application. Identifying the maximum or minimum value of a function to achieve optimal performance within limits exemplifies an optimization strategy that enhances functional processes. Artificial intelligence (AI) techniques have facilitated the emergence of an intriguing new domain of technological application. Optimization techniques are a robust array of tools employed to identify optimal solutions for many types of issues. The optimization and search algorithms incorporated in the RFID system are essential for efficiently addressing challenges such as extensive search spaces, elevated complexity, and exploration in inadequately organized areas. Consequently, nature-inspired algorithms are employed in this field [4].

In 2008 and 2009, Karaboga introduced the artificial bee colony algorithm (ABC), an optimization approach derived from the intelligent foraging behaviors of honey bee swarms. Compared with alternative optimization techniques, the ABC algorithm has several advantages [5]. It accommodates stochastic aims, has considerable flexibility and robustness, requires minimal control parameters, converges rapidly, integrates seamlessly with other methodologies [6] and serves both exploratory and exploitative purposes [7]. The ABC algorithm is altered by including a novel approach termed the Gbestguided ABC (GABC) algorithm [8]. The ABC hybrid type can manifest in one of three configurations: sequential, parallel, or multistage. In the former, one algorithm functions as the global optimizer, while the other performs local searches; in the latter, the execution of each algorithm alternates until a convergence requirement is met. The results encompass high-quality solutions [9]. Multicolony bacteria foraging optimization (MC-BFO) serves as an alternative optimization technique for complex RFID network design challenges [10]. This approach leverages cell–to-cell communication within the bacterial community to link the chemotactic behavior of an individual bacterial cell to the interacting multicolony model, thereby enhancing the single-population bacterial foraging algorithm [11]. The process by which a bacterium acclimats to a less challenging environment after identifying a superior home in a favourable area. If a bacterium's fitness remains constant while its swimming distance increases, it enters exploratory mode [12]. In many cases another algorithm was developed to optimize the big data of manufacturing issues such as Support Vector Machin and K-Means methods. Nirmala et al., in 2022 used Support Vector Machin SVM in flash big data and improved the accompanying layers [13]. Also, zaib et al., in 2023 apply K-Means in big data to minimize the human remarks [14].

The particle swarm optimization (PSO) algorithm is a population-centric optimization method. This method was derived from the collective migratory patterns of fish and birds. In addressing diverse optimization difficulties, the advantages of PSO include its rapid operational speed, straightforward installation, and lower need for parameter adjustments. [15]. MCPSO is a particle swarm optimizer that accommodates multiple swarms. An analysis of the performance of the proposed algorithms against classic PSO and its variations indicates that MCPSO is superior. [16]. Swarm intelligence (SI) and evolutionary algorithms (EAs) are two potent optimization techniques employed to develop a mathematical model. The RFID network, which uses reader location and is based on particle swarm optimization (PSO), achieves the optimal result [17]. Particle swarm optimization can optimize complicated RFID scanners in extensive systems. The quantitative results demonstrate the method's effectiveness [18]. The implementation of an innovative particle swarm optimization (PSO) technique that incorporates a tentative reader elimination (TRE) operator to identify and exclude readers during the PSO search phase, followed by their subsequent recovery, improves the overall efficacy of the RFID network. The quantity of readers may be modified accordingly. The experimental findings indicate that the suggested technique may include a larger area with fewer readers than existing algorithms do. Han presented an innovative optimization technique in [19], referred to as multicommunity GA-PSO. This facilitated the challenging endeavor of designing an RFID network for a large-scale system. The suggested method uses genetic algorithms (GAs) with PSO to improve the efficiency of the PSO algorithm and provide viable solutions for the coverage problem. The researchers employed multiobjective evolutionary algorithms and swarm intelligence techniques to address the RNP problem and identify all Pareto optimum solutions and optimal planning strategies [20]. Multiobjective particle swarm optimization (MOPSO) uses particle swarms to concurrently attain many objectives [21]. Simulation experiments indicate that the multiobjective artificial bee colony technique (MOABC) outperforms NSGA-II and MOPSO in terms of computational robustness and optimization accuracy for RFID network design [22]. The adaptive small-world topology demonstrated that the ASWPSO had significant resilience and efficiency in evaluations over thirteen benchmark functions [23]. Elewe et al. (2017) employed the firefly method with the density-based clustering technique (DBSCAN) to enhance the topology effect in multiobjective RFID network design [24]. A suboptimal algorithm was employed to improve cost efficiency. Researchers have reported that using the approach in extensive, intricate environments with varying geometries of internal workspaces poses significant obstacles for RFID network planning [25].

3. MULTIOBJECTIVE FUNCTION MODEL

The next section describes the present system methodology. Finding the optimal solution that considers all of the objective functions independently is the aim of the multiobjective function approach. Minimizing or maximizing a vector of goal functions may be defined mathematically as locating a set of design variables that lie inside the feasible zone. While goals can coexist, achieving one can inevitably necessitate sacrificing another. There is no optimal solution that takes into account all objective functions simultaneously. You may always find a "compromise solution" to any issue, but no such thing as a flawless solution. For this reason, the expression of the best solution of multiobjective optimization problem can be in terms of vector a, where vector a reduces one objective function and increases another.

RFID applications in the fields of stock management and logistics. It reduces the amount of time spent handling cases and pallets and improves inventory counts in warehouses and distribution locations. It also assists in the orderly loading of delivery vans and vehicles, reducing loading errors and guaranteeing proper distribution, by monitoring shipment contents and loading sequences. goods processes are streamlined by reading multiple RFID tags at once, which lowers the operator workload and prevents goods from going out of style. Furthermore, it enables real-time stock level data, which support dynamic inventory management and help prevent stock outs and overstocking. This technology could have a significant effect on sectors such as retail and food distribution, where inventory control is essential. RFID technology is essential for supply chain optimization. Raw materials may be swiftly identified and tracked during the production process by being tagged with RFID labels, which expedites the selection process. This functionality considered very helpful to industries that need to be able to trace specific manufactured goods by lot number. By tracking work-in-progress (WIP) across the manufacturing floor and providing visibility to product progress at every stage, RFID technology also helps optimize the production process. Efficiency and accuracy are significantly increased by substituting labor-intensive and prone-to-error manual methods with an automated conversion process made possible by RFID tagging of tools and raw materials. Furthermore, radio frequency identification (RFID) makes it possible to trace finished items from production to the consumer, providing information about their location and supporting pricing strategies, stock management, and efficiency. To improve patient safety, the healthcare sector uses radio frequency identification (RFID) to monitor patients, medical devices, drugs, and medical data. As a result, patients receive better care overall, and medical errors are less likely to occur. The automotive industry can monitor parts in assembly plants, ensure that parts arrive on time, and better manage component inventories via radio frequency identification (RFID). Consequently, this enhances production procedures and ensures the quality of the final product. Aerospace businesses can easily identify the locations of tools used in assembly and maintenance lines via radio frequency identification (RFID), which lowers costs and issues related to tool loss (also known as foreign object damage, or FOD [26].

3. The System Methodology

The next section describes the present system methodology.

Step 1: Topology Planning

The facility's topology must be premeditated in this approach. Previous research conducted by Mirosław Matusek [27] was employed to develop the facility layout design at this stage. A firm manufacturing medium-voltage driver is assigned 1700 square meters. The factory must have an inspection room, a materials warehouse, a power cable assembly area, sections for components, doors, and fans, a labelling and engraving centre, a final assembly zone, testing facilities, packaging areas, shipping zones, and a witness testing area. The project team consisted of a logistics specialist, layout engineer, quality assurance officer, production manager, process engineer, independent expert, and safety at work professional, founded on these essential components.

Step 2: Developing tag coverage

The density and configuration of tag distributions offer an effective method. What factors influence the read range of an RFID system? The characteristics of RFID technology predominantly dictate [28]. The extent of communication between the reader and the tag, as well as the signal transmitted from the tag to the reader, are essential elements of the tag coverage function. It is recommended to employ the following objective function to decrease tag coverage: [29].

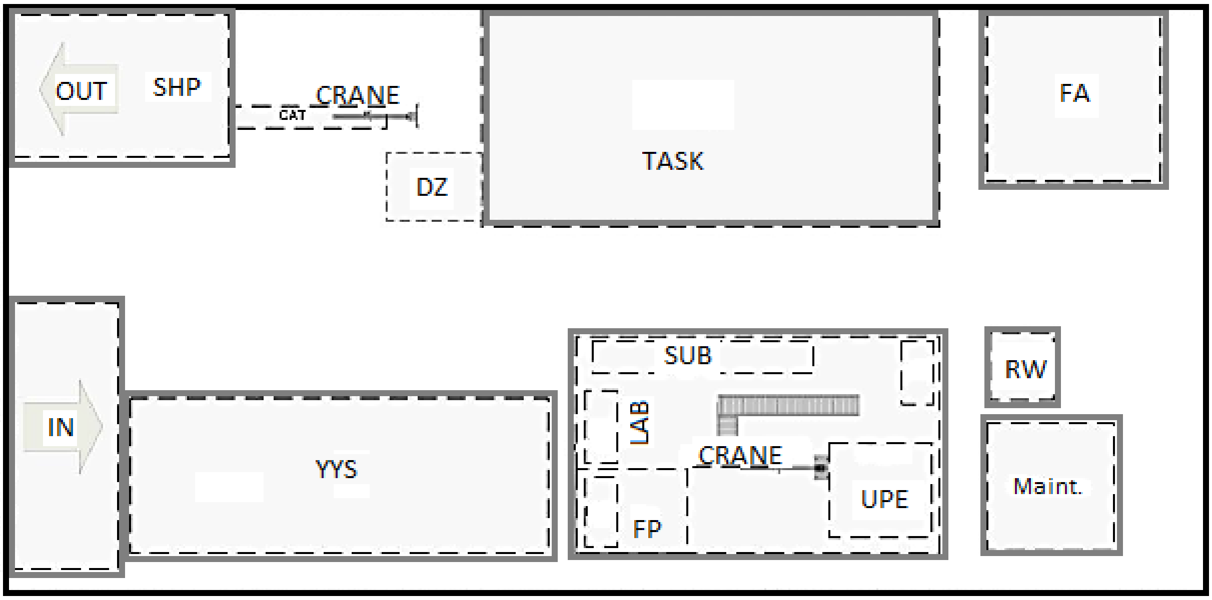

Fig. 1: Facility layout design [30]

$$C_{\min} = \sum_{i=1}^{Np} (P_i^r - P_d) \tag{1}$$

$$P_r = (P_r . G_t . P_r) / (4\pi \frac{d}{\lambda})^2 \tag{2}$$

Step 3: Developing the RFID system

Concerning RFID network planning, two principal concerns exist. The initial phase involves delineating the reader's parameters. In the RFID network planning (RNP) problem, each optimization strategy possesses a distinct array of parameters that have been fine-tuned to enhance the results. The parameter values [30] are identified in Table I.

TABLE I: RFID PARAMETERS[30]

Parameters	**Values in C1G2 Standard**
RFID Reader System Operating Frequency	UHF band: 902-928 MHz, Center Frequency: 915 MHz
RFID Reader Transmitting Power	2 Watt [20:33]Dbm
RFID Reader Antenna Gain (Gr)	6.7 dBm
RFID Tag Antenna Gain (Gt)	3.7 dBm
RFID Reader Minimum Power (RFID Reader Sensitivity)	-70 dBm
RFID Tag Minimum Power (RFID Tag Sensitivity)	-14 dBm
Wave Length (λ)	0.328 m

The second issue with the mathematical model of RFID network design is the delineation of the objective functions for RNP issues. Three formulae provide a succinct overview of the objective functions. The ideal tag coverage, C, is addressed in the first equation. A notable aspect is its capacity to encompass all tag IDs distributed across the region [31]. The calculation involves calculating the disparity between the actual power received by each tag and the requisite power, expressed as:

$$C_{\min} = \sum_{i=1}^{N_T} (P_{tagi} - P_{req}) \tag{3}$$

Where:
Ptagi= Actual received power at each tag
Preq= Required threshold power
NT=Number of tags in the working area

For each tag, the Friis transmission equation power is applied to find the power input at the receiving antenna, as shown below[32]:

$$P_r = (P_t . G_t . G_r) / \left(4\pi \frac{d}{\lambda}\right)^2 \tag{4}$$

where λ is the wavelength (m), Pr is the power input at the receiving antenna, Pt is the power output at the transmitting antenna, d is the distance between the tag and the reader, Gr is the receiving antenna gain, and Gt is the transmitting antenna gain[33]. The collisions that can occur by readers' interference can be solved by specifying the reader's interrogation ranges and controlling the radiated power of readers. Interference is formulated as[34]:

$$\text{int.} = \sum_{i=1}^{N-1} \sum_{(j=i+1)}^{N_{\max}} [d_t(R_i, R_j) - (r_i + r_j)] \tag{5}$$

where $Nmax$ represents the total number of readers, "dt" represents the distance between readers, Ri represents the position of the ith reader, Rj represents the position of the jth reader, rj represents the interrogation range of the jth reader and ri represents the interrogation range of the ith reader[35]. The presented interference formula takes place when the sum of the interrogation domains of two readers (ri + rj) is greater than the distance from the center to the center of the same readers [(ri + rj) > d]. In addition, to determine the extra readers that were deployed at the initial stage, the following formula was used[36]:

$$Nreq = Nmax - Nextra \tag{6}$$

The present solution observes a number of effective readers and the best position of each reader. The present objective functions are applied in both the firefly algorithm and MC-GPSO to find the optimum level of network planning

Step 4: Applying the Algorithm

Kennedy and Eberhart asserted that the particle swarm optimization (PSO) algorithm is an adaptable method grounded in social psychology analogies. It operates by permitting a population of individuals, or "particles," to randomly revisit locations where they have previously achieved success. The particle swarm method involves two fundamental operators: velocity modification and position adjustment. In each generation, every particle is propelled towards both the global optimum and its previous optimum. In each iteration, a new velocity value is computed for each particle on the basis of the current velocity, the distance to the previous optimal location of the particle, and the distance to the global optimal position. The updated velocity value is employed to determine the particle's subsequent position in the search space. The method is thereafter replayed until the minimum number of errors is achieved or until a certain number of iterations has occurred. The PSO algorithm depends on its implementation in the following two relations:
The velocity of particle *i* is updated via the following equation:

$$v_{id}(t+1) = wv_{id}(t) + c_1 r_1(t)(p_{id}(t) - x_{id}(t)) + c_2 r_2(t)(p_{gd}(t) - x_{id}(t)) \tag{7}$$

$$v_{id} \in (-V_{\max}, +V_{\max}) \tag{8}$$

The positions of particles i and xi are then updated via the following equation:

$$x_{id}(t+1) = x_{id}(t) + v_{id}(t+1) \tag{9}$$

The second step involves applying the PSCO algorithm developed by Mahdavi-Meymand et al. in 2023: then apply FFA, which was developed by Elewe et al. in 2018, followed by CS and ABC.

4. RESULTS AND DISCUSSION

The simulations were executed, and the results were acquired via four methodologies (PSO, PSCO, FFA, CS, and ABC), as illustrated in Figs. 2–9. The initial set illustrates the expansive 1700 m2 facility, accompanied by a rather modest quantity of tags (50 tags). This sample exemplifies the normal operating procedures of this establishment. In the second instance, 130 tags represent the entire heavy load production. All findings produced from the RFID Network

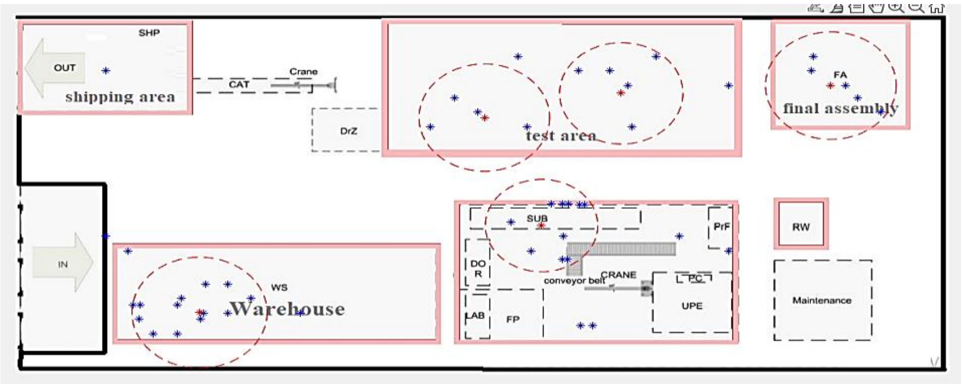

Fig. 2: FFA results for small tag data in a large area

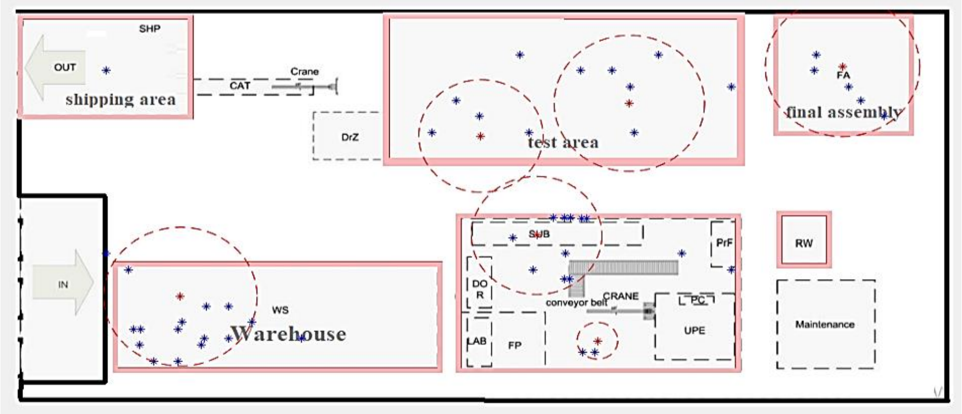

Fig. 3: PSO results for small tag data in a large area

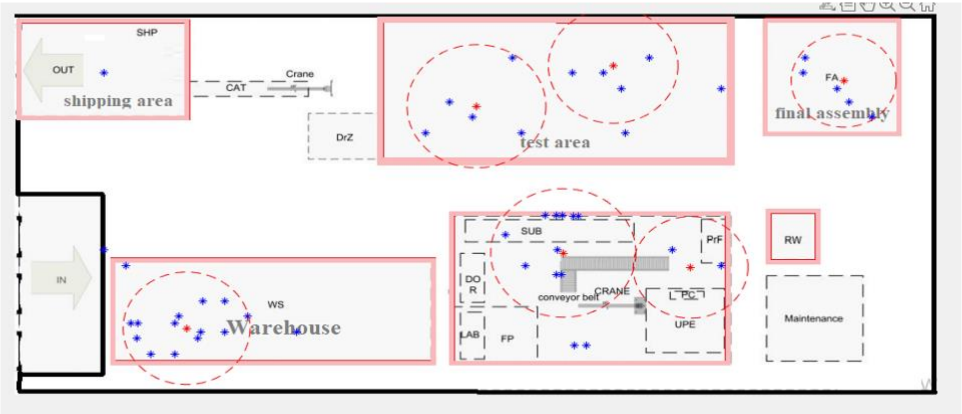

Fig. 4: CS results of small tag data in a large area

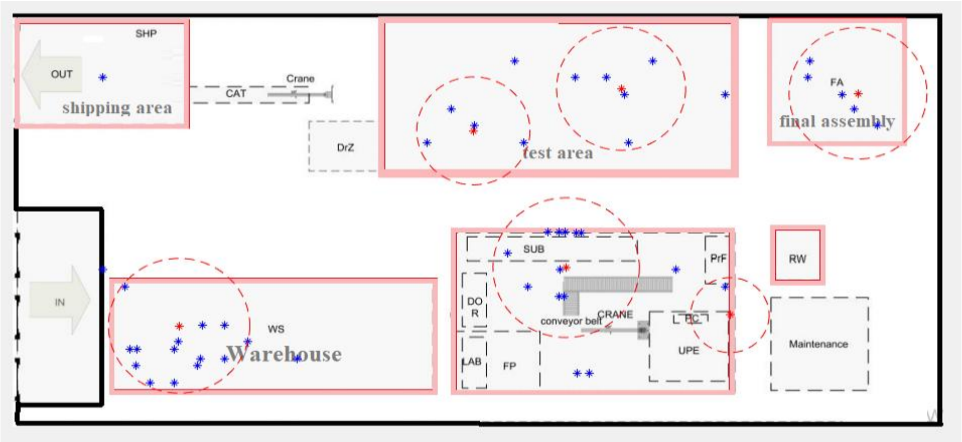

Fig. 5: ABC results for small tag data in a large area

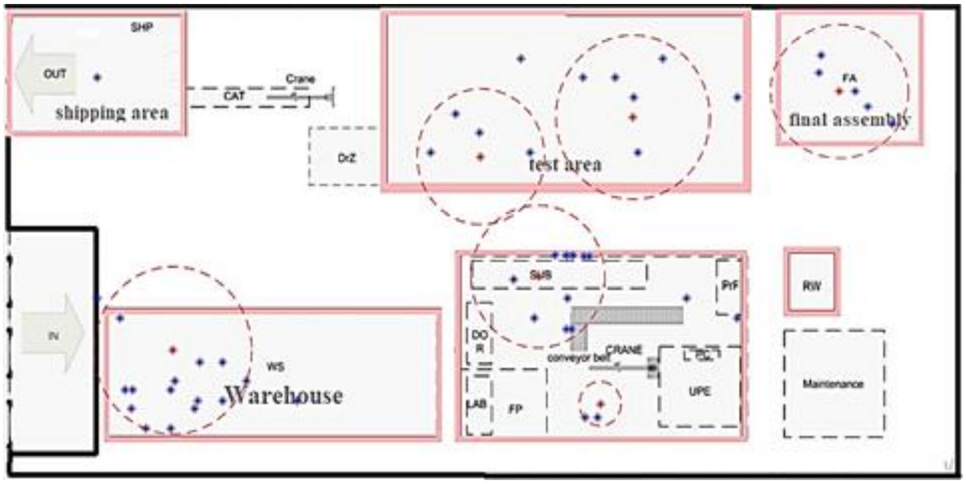

Fig. 6: PSCO results for small tag data in a large area

The planning objective function was based on the parameters presented in the preceding sections. This study examines two categories of network architecture instances: random (R50) and clustered (C130). This represents the result of 10,000 iterations over 50 separate runs on MATLAB 2021. The readers are represented by the red star in the center of the map, while the tags are signified by the blue plus sign. The red dashed line is used to delineate the scope of inquiries. The data analysis indicated that the RFID readers were allocated into two zones, each exhibiting a distinct likelihood of detecting and encompassing the tags. The outcomes are presented in "Table II" below:

TABLE II: SIMULATION NUMERICAL RESULTS OF THE FIRST GROUP

algorithm	**Tags Number**	**active readers**	**tags coverage**	**overlapped tags**	**fitness**
PSO	50	6	43	0	0.7446
PSCO	50	6	43	0	0.7443
FFA	50	5	40	0	0.7371
CS	50	6	42	0	0.7326
ABC	50	6	42	0	0.7326

The results revealed that the highest level of algorithm performance was for the PSO algorithm, which achieved a performance level of 74.46%, and it also covered 43 tags of 50 despite the distance of the facility and its random distribution. These results are initially considered satisfactory. In the second group test, the tag number was increased to 130 tags, which represents a difficult condition for testing the system performance. The results are shown in the figures below:

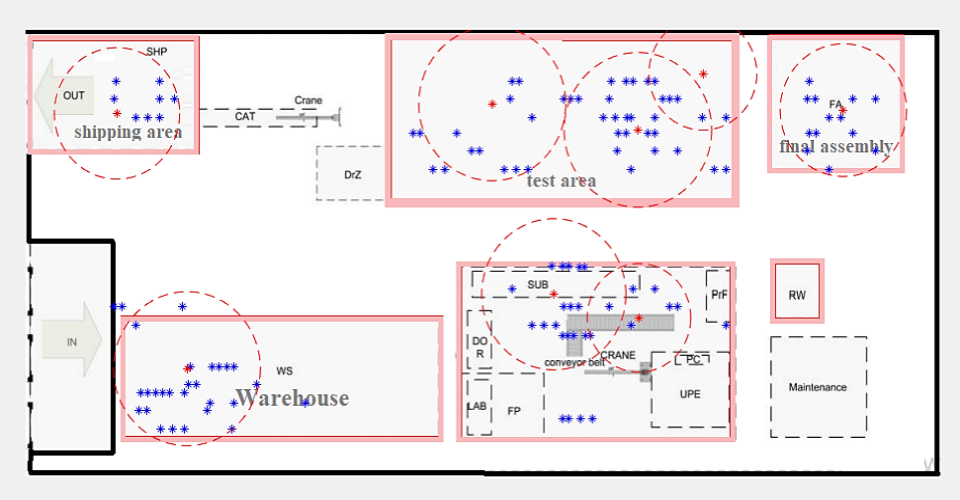

Fig. 7: CS results of large tag data in a large area

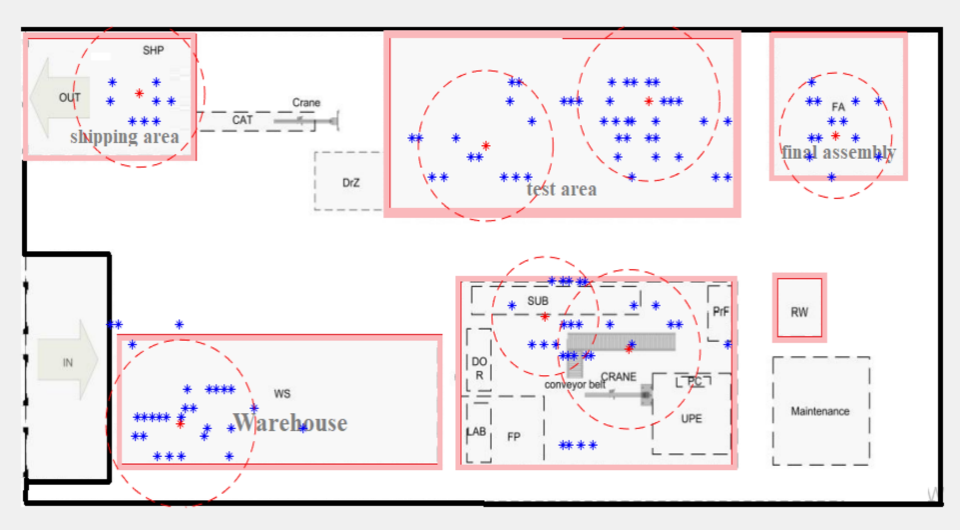

Fig. 8: PSO results for large tag data in a large area

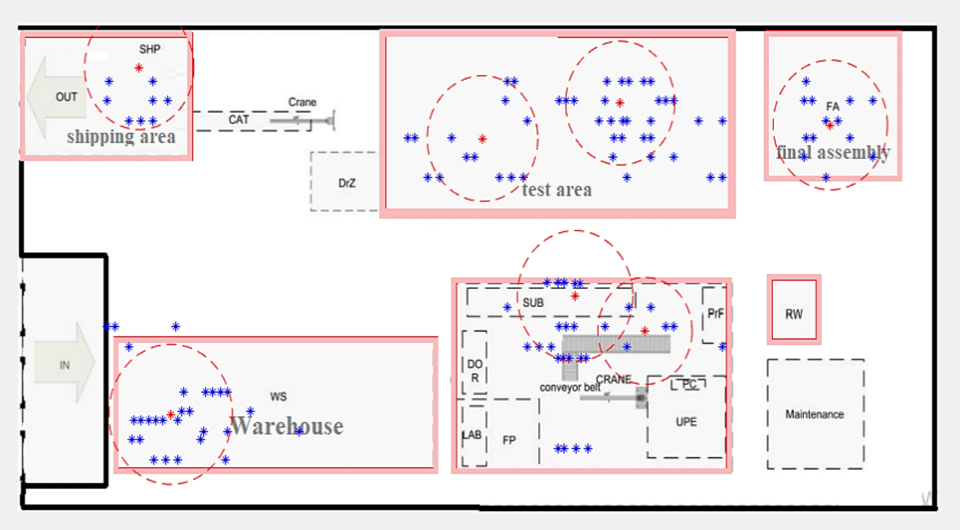

Fig. 9: ABC results of large tag data in a large area

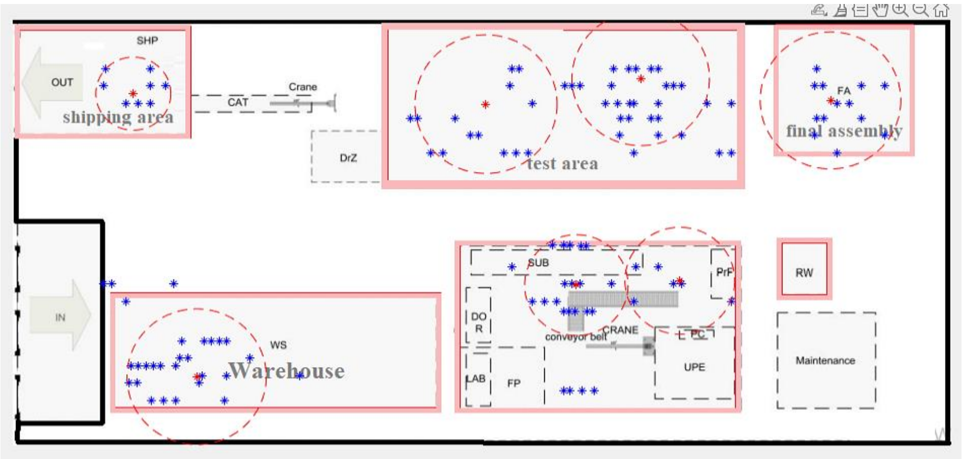

Fig. 10: FFA results for large-scale tag data in a large area

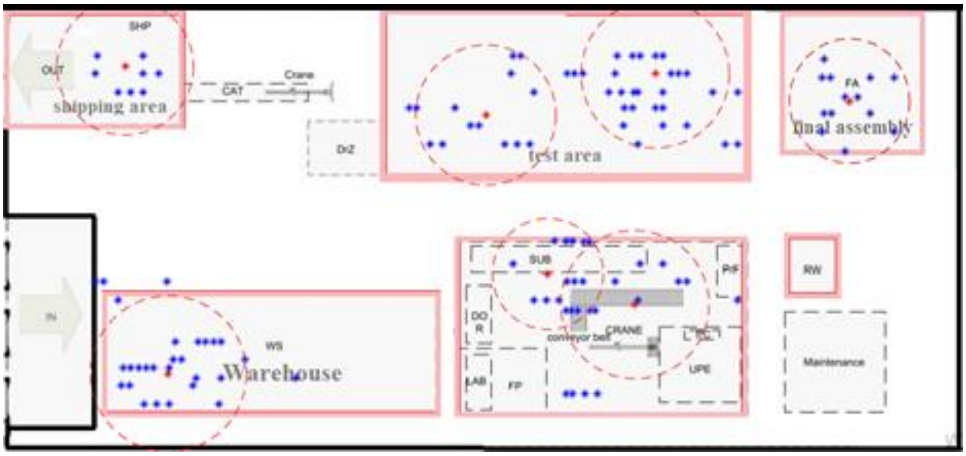

Fig. 11: PSCO results for large-scale tag data in a large area

The identical situations were conducted on a larger region with an increased number of tags to examine the associations between them. The chosen algorithms were PSO, CS, FFA, and ABC. The numerical findings are shown in Table III.

TABLE III: SIMULATION NUMERICAL RESULTS OF THE SECOND GROUP

algorithm	Tags Number	active readers	tags coverage	overlapped tags	fitness
CS	130	8	117	7	0.7468
FFA	130	7	114	6	0.7419
PSO	130	7	102	2	0.6677
PSCO	130	8	117	7	0.7448
ABC	130	7	108	0	0.6985

The data indicate that CS had superior performance. The extent of tag coverage decreases with increasing number of tags. It is also important to consider the influence of tag distribution. The algorithm's ability to recognize tags and allocate readers to tag sets is undermined. This is mostly attributable to the fact that greater distances between tags result in a reduced propagation range. Numerous obstacles impede the discovery of a global solution due to the extensive array of options. The timing of each run was documented.

5. CONCLUSION

Examining the optimal method for large-scale applications Meticulous network planning is essential for the implementation of RNPs in actual applications, such as the regulation of industrial processes utilizing an RFID system. Manufacturing data is derived from diverse sources (sensors, machines, systems, etc.) that possess varying formats and structures. Integrating this data into a cohesive format can be intricate and expensive, necessitating substantial technological enhancements and possibly the replacement of outdated systems. Data silos, characterized by scattered information across many departments or systems, impede effective analysis and decision-making. for that. the present work investigates different artificial inelegant algorithms to specify their responses. This was achieved by initially analyzing the algorithm's reaction to an increase in tags, followed by comprehensive testing and comparison of cutting-edge methodologies. This study aims to assess the vulnerability of the search algorithm when it is implemented in an exceptionally vast area. The most effective method for identifying a limited quantity of tags was determined to be PSO. Ultimately, CS emerged as the most effective algorithm for identifying a substantial quantity of tags. Benchmark testing indicates that PSO outperforms its competitors in terms of the convergence rate, processing duration, and cost efficiency. The findings demonstrate that the algorithm's performance is inadequate owing to the significant disparity between the tag positions. A maximum number of swarms can exist. The restriction is due to transfer limits.

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