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An effective approach in robustness optimization for solving the RFID network planning problem with uncertainty

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RFID technology enables remote storage and retrieval of data on RFID tags, making it a versatile and efficient tool with widespread applications in various industries. This paper presents a solution to the challenge of deploying RFID readers, which has been a persistent problem in the RFID technology practical and theoretical communities. To address the deployment problem, the paper proposes a robust multi-objective approach that optimizes many requested objectives as: coverage, the number of deployed readers, and interference while taking into account uncontrollable parameters in the system. The simulation results demonstrate the robustness of the approach in solving the deployment problem and optimizing the RFID system under varying and unpredictable conditions. The proposed approach has the potential to contribute to the RFID technology industry and enable more efficient and effective RFID systems across different sectors.

Keywords: *RFID; robustness; optimization; multi-objective approach; deployment problem.*

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1. Introduction

RFID is an acronym for "radio–frequency identification", which refers to a technology that uses radio waves for communication between a reader device and a small tag containing a microchip and antenna which is stored and attached on items or objects that need to be tracking. This technology is commonly used to identify and track objects and can be applied in a variety of industries, such as inventory management, access control, and supply chain management. The process aim to attach an RFID tag to an object, which can be easily tracked and monitored.

The RFID network planning problem (RNP) known as an NP-HARD problem with the aim of finding the optimal placement and configuration of RFID readers and antennas to achieve complete coverage of all tags in a given work area while minimizing interference inside the system. This involves considering various factors such as the number and placement of readers and antennas, the power levels of the readers, and the layout of the RFID tags. The objective of RFID network planning is to ensure reliable and efficient reading of all tags in the area while minimizing the cost and complexity of the system. Achieving an optimal RFID network planning solution is essential for enabling efficient tracking and management of objects in various applications.

The problem is often solved by using mathematical optimization techniques such as linear programming, integer programming, heuristics, and meta-heuristics algorithms, for more details about such algorithms, please refer to [1–6] described various proposed methods for solving the RFID network planning problem. The use of RFID systems was first reported by Guan et al. in [7]. Several studies have been presented, including many algorithms and methods to solve the problem of deploying RFID readers. Among the existing well-known studies, H. Chen et al. propose the approach of the weighted sum method to convert multiple objectives into a single objective optimization problem to optimize label coverage, interference, load balance, and economic efficiency in [8]. The optimization problem uses various algorithms such as genetic algorithm (GA) and particle swarm optimization

(PSO) in [9], bacterial multi-colony foraging optimization in [10], multi-group optimizer and bacterial foraging adaptive optimization in [11, 12], simulation results comparing all these algorithms and showing which one is more efficient for RNP. In addition, H. Chen et al. A multi-objective approach to the RNP problem based on two algorithms: the multi-objective evolutionary and swarm intelligence approach in [8] and the hierarchical artificial bee colony algorithm in [13], by optimizing the same proposal objectives. Except for these works, there is some approach such as O. Botero et al. A heuristic technique (GA) was implemented in [14] to solve the RNP problem, and a software tool was developed for RFID network planning in [15], Gong et al. propose PSO algorithm based on a preliminary reader elimination operator, which deletes and restores provided readers during the search process to achieve optimal delivery. In addition to all these approaches, there are other studies such as M. Tuba et al. who formulate the problem by considering four objectives: coverage, interference, number of readers, and transmission power. In [16], they introduce the implementation of the Firefly algorithm using a single-objective approach and show that it is more efficient than the cooperative multi-objective artificial bee colony (CMOABC) algorithm, multi-objective artificial bee colony (MOABC), and non-dominated Genetic Sorting Algorithm II (NSGA-II) in [17] Tuba et al. solved RNP problems using hierarchical and multi-objective approaches. Also in [18] the authors use the Fireworks algorithm to solve the problem and find that it is more efficient than GPSO and VNPSO. In [19] they propose an artificial bee colony (ABC) algorithm combined with a heuristic algorithm to determine the approximate number and location of (RFID) readers. Despite all this work, few studies consider uncontrollable parameters and uncertainties in RFID network planning, such as [4, 5, 20] Raghib et al. in [21] Zhao et al. find a robust optimal solution to the RID network planning problem that is insensitive to the uncertainty of the optimization parameters. Tuba et al. [22] propose a probabilistic coverage model to address the use of RFID readers. These methods are usually able to find optimal solutions with high performance. However, to our knowledge, there are a few studies taken into consideration uncertainty on uncontrollable variables and parameters in the system.

In this paper, we propose a robust optimization approach to solve the RFID network planning problem under uncertainties in the system. Our proposed solutions deal for the first time of researches with the formulation of the RNP problem as a multi-objective optimization problem under uncertainties, and we propose the roust optimization approach to deal with the (RNP) under uncertainties with many attractive features: identifying the minimal number of readers and their best locations to ensure that all tags in the network are covered and minimizing tags and readers interference. Moreover, the results of applying our approach in famous benchmarks known in the community are optimal and unaffected by uncertainty in the interrogation zone of readers.

This paper is organized as follows: section 2 presents in detail the RFID network planning, mathematical modeling, and the robust optimization approach to deal with RNP under uncertainty. In section 3 we present the implementation of the proposed approach and we provide the numerical results. Finally, section 4 provides the conclusions of this work and give some perspectives.

2. Problem modeling and methods

2.1. RFID system

The RFID systems work by using radio waves to communicate between an RFID reader and an RFID tag. The RFID tag contains a small microchip and an antenna, which allows it to respond to the signals sent by the reader. When an RFID reader emits radio frequency waves, it creates an electromagnetic field in its interrogation range. If a passive RFID tag is within the interrogation range of the reader, it will receive the signals and use the energy from the wave to power up its microchip. The tag's microchip will then send back a signal to the reader, which contains the tag's unique identification number and any other data that has been programmed into the tag. The RFID reader then receives the signal from the tag and sends the data to a computer or other device, which processes the data and provides information about the tagged item. This can include the item's location, status, and other important details.

Figure 1 shows the basic components of the RFID system.

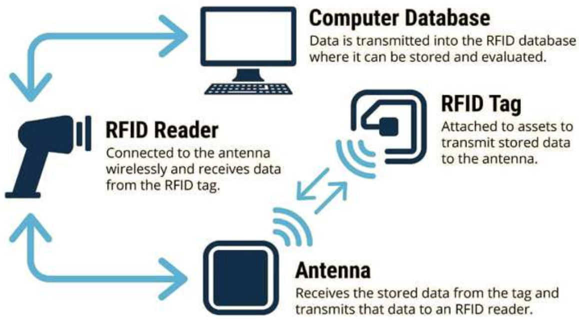


Fig. 1. Basic components of the RFID system.

A typical RFID system consists of three main components: RFID tags, RFID readers, and the middleware.

— **RFID Tags** are tiny devices that consist of a microchip and an antenna. They can be affixed to an object to enable its identification and tracking. These tags are commonly used in various industries for inventory management, supply chain management, and asset tracking. They rely on radio frequency identification (RFID) technology, which allows for quick and easy scanning of tags without the need for line-of-sight, making them very convenient for use in large-scale operations. Overall, tags have revolutionized the way we manage and track objects, offering a reliable and efficient means of identification and tracking.
  There are three types of RFID tags:
  1. Passive RFID tags: do not have a built-in power source, and rely on the radio waves emitted by the RFID reader to power them up and transmit data. Passive RFID tags are typically smaller and less expensive than other types of RFID tags, but they have a shorter read range.
  2. Active RFID tags: have a built-in power source, such as a battery, and can transmit data over longer distances than passive tags. They can also have additional features, such as sensors for temperature or motion, but they are typically larger and more expensive than passive tags.
  3. Semi-passive RFID tags: Also known as battery-assisted passive (BAP) tags, these tags have a small battery that powers the tag's internal circuitry, but rely on the reader's radio waves to communicate with the tag. They have a longer read range than passive tags, but are smaller and less expensive than active tags.

— **RFID readers**: RFID readers are electronic devices that are designed to emit radio waves and receive signals from RFID tags. These devices can either be handheld or fixed in place, and their primary function is to read and retrieve the information that is stored on the RFID tags. They work by sending out a radio signal that activates the RFID tag, causing it to send back its unique identification code to the reader. The reader then processes this information and sends it to a computer or other system for further analysis or tracking.
  There are several types of RFID readers available in the market, including:
  1. Fixed RFID readers: These readers are stationary and are typically installed in a fixed location, such as a doorway or a loading dock. They can read tags within a specific range and are commonly used in applications such as inventory management and access control.
  2. Handheld RFID readers: These readers are portable and can be carried by the user. They are ideal for applications that require mobility, such as asset tracking and field service.
  3. Mobile RFID readers: These readers are designed to be mounted on vehicles, such as forklifts or trucks. They can be used for tracking inventory in a warehouse or tracking assets in a supply chain.

— **Middleware**: Middleware is an software component that acts as an intermediary between RFID readers and the information system that manages and analyzes the data collected by the readers. It plays a crucial role in RFID systems by filtering and processing the data received from the reader and forwarding it to the appropriate information system. The middleware enables the system to manage large amounts of data generated by RFID tags and provides useful information to the user. It is designed to handle different types of data, such as raw data, filtered data, and processed data, and can perform various functions such as data aggregation, data filtering, and data enrichment. The middleware can also help to integrate RFID systems with other enterprise systems, such as warehouse management systems and inventory management systems, to provide a comprehensive view of the entire supply chain.

2.2. RFID network planning problem

The RFID network planning problem involves designing an efficient and effective RFID system that can respond to the needs of a particular application. The main problem in RFID network planning is determining the optimal placement of RFID readers and antennas to ensure that all the tags attached to objects are covered by at least one reader, and then can be easily tracked accurately and efficiently.

The following are some of the common challenges that must be addressed in RFID network planning:

— Reader coverage: RFID readers have a limited range, and it can be challenging to ensure that all tagged items are within range of at least one reader. To address this challenge, multiple readers may be required, and the placement of the readers must be carefully considered to ensure adequate coverage.
— Interference: The presence of metal, liquids, and other materials can interfere with the radio waves used in RFID systems, leading to reduced performance. The network planner must consider these factors and design the system to minimize interference.
— Reader synchronization: in some applications, it is important to ensure that multiple readers are synchronized to prevent data collisions and improve accuracy. This requires careful planning of the reader placement and timing.
— Data management: RFID systems can generate a large amount of data, which must be managed and analyzed to provide useful information. The network planner must consider how the data will be collected, processed, and analyzed to ensure that the system is effective.

To address these challenges, network planners can use modeling and simulation tools to analyze different scenarios and optimize the placement of RFID readers and antennas. They can also perform field testing to validate the performance of the system and make adjustments as needed. Ultimately, the goal of RFID network planning is to design a system that can accurately and efficiently track tagged items, improve operational efficiency, and reduce costs.

2.3. Uncertainty in an RFID system

The uncertainty in an RFID system can refer to a variety of factors that can affect the accuracy and reliability of the system. Some examples include:

— **Tag-to-reader distance:** the distance between an RFID tag and a reader is an important factor that affects the accuracy and reliability of the system [23]. The readability of a tag depends on the distance between the tag and the reader, and the signal strength of the reader. The tag-to-reader distance is influenced by various factors such as the power of the reader, the sensitivity of the tag, and the environment in which the system operates. Uncertainty in this distance can lead to errors in the location or identification of a tag.
— **Reader orientation and placement:** reader orientation and placement play a crucial role in the effectiveness of an RFID system. Proper positioning and alignment of readers can ensure maximum coverage and minimize the occurrence of missed or inaccurate reads. In some cases, the placement of readers may be limited due to physical constraints or other factors. However, even small variations in the position or alignment of readers can impact the performance of the system. Uncertainty in the position or alignment of the reader can lead to missed or inaccurate reads.
— **Tag orientation and placement:** the placement and orientation of RFID tags are important factors that affect the efficiency and accuracy of the RFID system. The readability of the tags

largely depends on the position of the tags and their alignment with the reader antenna. For instance, if the tag is placed in such a way that the antenna faces away from the reader, it will not be read properly. Similarly, if the tag is placed in a cluttered environment, it may be obstructed by other objects, which can lead to a weak or lost signal. Uncertainty in the position or alignment of the tag can lead to missed or inaccurate reads.

— **Interference:** it is a major factor that can affect the performance and accuracy of RFID systems. Interference can be caused by other electronic devices or radio signals operating in the same frequency band as the RFID system [24]. This interference can cause the reader to receive false or corrupted signals from the tags, leading to errors in the identification and tracking of objects. In addition, interference can also be caused by the physical environment in which the RFID system is deployed. For example, metal objects or reflective surfaces can cause signal reflections or attenuation, which can lead to interference and affect the performance of the system.
— **Environmental factors:** environmental factors play a crucial role in the performance of an RFID system. Temperature, for instance, can have a significant impact on the readability of RFID tags. Extreme temperatures, whether too hot or too cold, can damage the tags or reduce their sensitivity, leading to poor performance. Humidity is another environmental factor that can impact the performance of RFID systems [25]. High humidity levels can cause moisture to accumulate on the tags and interfere with the signal strength, resulting in poor tag reads. On the other hand, low humidity levels can cause static electricity to build up and damage the tags. The presence of metal in the environment can also affect RFID performance. Metal can reflect or absorb radio signals, leading to reduced readability of tags. Similarly, water can also absorb radio signals, reducing the effective range of RFID readers and making it difficult to read tags accurately. Other environmental factors that can impact RFID performance include electromagnetic interference (EMI) and radio frequency interference (RFI) from other electronic devices, as well as physical obstructions like walls and other objects that can block or reflect RFID signals. It is important to consider these environmental factors when designing and implementing RFID systems to ensure optimal performance and accuracy.

Managing and mitigating sources of uncertainty is crucial to the success of an RFID system. While RFID technology has the potential to revolutionize supply chain management and improve efficiency, there are several factors that can lead to errors and inaccuracies in the system. One of the most significant sources of uncertainty is tag-to-reader distance. The distance between a tag and a reader can affect the readability of the tag and lead to errors in the location or identification of the tag. It is essential to ensure that tags are placed within the optimal range of the reader for reliable readings. In this work we will focus on this source of uncertainty on interrogation zone of the readers.

2.4. Multi-objective optimization

A multi-objective optimization problem (MOOP) is a type of problem that involves optimizing multiple objectives simultaneously while also satisfying numerous constraints [26–28]. These objectives are typically expressed as a set of mathematical functions, and the objective is to identify a set of solutions that are optimal with respect to all of the objectives. This can be a challenging task since there may not be a single solution that is optimal for all objectives, and trade-offs may need to be made between different objectives.

In general, a MOOP can be defined as follows:

$$\begin{cases} \text{Min/Max}_{x\in\mathcal{X}} F(x) = (f_1(x),\dots,f_M(x)) \quad x=(x_1,\dots,x_n), \quad M \geqslant 2, \\ \text{such that:} \\ g_j(x) \leqslant 0 \quad j=1,\dots,J, \\ h_k(x) = 0 \quad k=1,\dots,K, \\ x_i^{(L)} \leqslant x_i \leqslant x_i^{(U)} \quad i=1,\dots,n. \end{cases}$$

Where F is the objective function and $\mathcal{X} \subset R^d$ is a search space, the function $(g_j)_{j=1}^J$ is the equality constraint, $(h_k)_{k=1}^K$ is the inequality constraint x is n a vector of decision variables, each decision variable, x_i is between the lower bound $x_i^{(L)}$ and the upper bound $x_i^{(U)}$, and p is the G component design range.

We say that a vector $\boldsymbol{F}(\boldsymbol{x})$ Pareto dominates $\boldsymbol{F}(\boldsymbol{x}')$, denoted by $\boldsymbol{F}(\boldsymbol{x}) \succ \boldsymbol{F}(\boldsymbol{x}')$, if $\boldsymbol{F}(\boldsymbol{x}) \geqslant \boldsymbol{F}(\boldsymbol{x}')$ and $\exists j \in \{1, \ldots, M\}$ such that $f_j(\boldsymbol{x}) > f_j(\boldsymbol{x}')$. And the Pareto frontier over a set of objective vectors $\mathcal{F} = \{\boldsymbol{F}(\boldsymbol{x}) | \boldsymbol{x} \in X \subseteq \mathcal{X}\}$ is $\text{Pareto}(\mathcal{F}) = \{\boldsymbol{F}(\boldsymbol{x}) \in \mathcal{F} \colon \nexists \boldsymbol{x}' \in X \text{ s.t. } \boldsymbol{F}(\boldsymbol{x}') \succ \boldsymbol{F}(\boldsymbol{x})\}$.

In general, multi-objective optimization problems have multiple non dominated solutions [26] within the feasible range. It considers the trade-off between objective functions, the set of all non dominated solutions builds the Pareto–front [26].

Figure 2 shows an example of the Pareto–front of a multi-objective optimization problem.

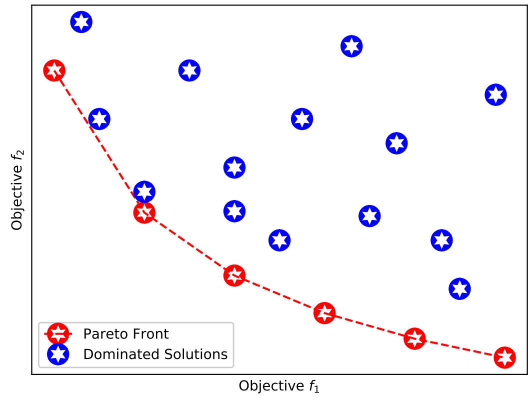


Fig. 2. Example of the Pareto–front.

2.5. RNP problem modeling formulation

In this section, we describe the various objectives, parameters and variables considered to solve the RFID network planning problem. Our goal is to find simultaneously the optimal number of readers and their coordinates to deploy in the network, covering all tags in the entire space and minimizing interference.

The RFID Network Planning (RNP) process focuses on three main objectives: the first, we need to minimize the total number of readers and find their optimal location to reduce the cost of the RFID system. The second, the principal goal of deploying RFID readers is to cover all tags throughout the area. We then need to ensure that each tag must be within the interrogation zone of at least one reader deployed in the network to achieve full coverage. Finally, minimizing interference can increase the efficiency of RFID systems.

In this paper we will use the following notations:

— N_r: The total number of readers available in a network;
— N_t: The total number of the tags;
— d_{ij}: The distance between the j^{th} reader and i^{th} tag.

The total number of deployed readers. The first objective function in the RFID network planning problem represents the number of deployed RFID readers, which is important to evaluate the performance of the deployment. To reduce the cost of deployment of the RFID readers we need to minimize the total number total of readers. This objective function can be defined as

$$f_1 = \sum_{j=1}^{N_r} r_j,$$

where

$$r_j = \begin{cases} 1 & \text{if the } j^{\text{th}} \text{ reader is deployed,} \\ 0 & \text{otherwise} \end{cases}$$

In addition, our proposed approach finds the robust optimal position of each deployed and ensures that we can only place each reader in a certain space. For a rectangular zone with height H, width W, and depth D, this constraint is satisfied:

$$0 \leqslant x_j \leqslant H, \; 0 \leqslant y_j \leqslant W \quad \text{and} \quad 0 \leqslant z_j \leqslant D \quad \forall j = 1, \ldots, N_r.$$

Coverage of tags. The principal objective function for RFID network planning is to cover all the tags in the whole space. If the radio signal received at a tag is greater than a certain threshold P_d, the communication between reader and tag can be established, that is means the tag is covered.

Therefore, for maximizing the coverage of tags we suggest minimizing the non-coverage of tags to achieve an optimal deployment of RFID readers, it can be formulated as follows:

$$f_2 = N_t - \sum_{i=1}^{N_t} y_{ji},$$

where

$$y_{ji} = \begin{cases} 1 & \text{if } \exists! j = 1, \dots, N_r \text{ such that } Pr_i \geqslant P_d \text{ and } r_j = 1, \\ 0 & \text{otherwise.} \end{cases}$$

Tags Interference. The tags interference occurs if many readers interrogate tags in the same space at the same time. It decreases the efficiency of the RFID system.

The figure 4 shows an example the interference of six tags covered by three RFID readers. The tags interference must be reduced by the following expression:

$$f_3 = \sum_{k=1}^{N_r-1} \sum_{j=k+1}^{N_r} \big(d_{kj} - (IR_j + IR_k)\big).$$

The RFID system is affected by uncontrollable parameters and environmental noise. In this paper, we considered the uncontrollable variations in the reader's interrogation range parameter. Therefore we can formulate the third objective by:

$$f_3 = \sum_{k=1}^{N_r-1} \sum_{j=k+1}^{N_r} \big(d_{kj} - (IR_j + IR_k - \delta_k - \delta_j)\big).$$

In general we consider that our RFID system has the same readers that means $IR_j = IR_k$ and $\delta_k = \delta_j = \delta$, then

$$f_3 = \sum_{k=1}^{N_r-1} \sum_{j=k+1}^{N_r} \big(d_{kj} - 2(IR - \delta)\big).$$

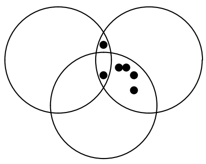


Fig. 3. Example of the interference of six tags covered by three RFID readers.

Therefore, the problem can be formulated mathematically as follows:

$$\begin{cases} \text{Min}\, F(x,y,r) = [f_1(x,y,r), f_2(x,y,r), f_3(x,y,r)] \\ \text{s.t.} \\ 0 \leqslant x_j \leqslant H \quad \text{and} \quad 0 \leqslant y_j \leqslant W \quad \forall\, j = 1, \dots, N_R, \\ (x,y,r) \in \big(\mathbb{R}_+^N, \mathbb{R}_+^N, \{0,1\}^N\big). \end{cases}$$

2.6. The proposed approach

The goal of the robust optimization is to achieve a set of solutions that is Pareto optimum when the uncontrollable parameters exist, the robust solutions are insensitive to the variations of uncontrollable parameters. We suggest to apply a robust approach [29] to deal with uncertainty and obtain an optimal deployment of readers in the network. Let a multi-objective optimization problem:

$$\begin{cases} \text{Min}\, F(X) = \big[f_1(X), f_2(X), \dots, f_m(X)\big] \quad X = (x_1, x_2, \dots, x_n) \\ \text{s.t. } X \in \Omega. \end{cases}$$

A solution x^* is called a multi-objective robust solution of type I, if it is the global feasible Pareto-optimal solution to the following multi-objective minimization problem (defined with respect to a δ-neighborhood $B_\delta(x)$ of a solution x).

$$\begin{cases} \text{Min}\, \big[f_1^{eff}(X), f_2^{eff}(X), \dots, f_m^{eff}(X)\big] \quad X = (x_1, x_2, \dots, x_n) \\ \text{s.t. } X \in \Omega, \end{cases}$$

where

$$f_j^{eff}(X) = \frac{1}{|B_\delta(x)|} \int_{y \in B_\delta(x)} f_j(y)\, dy.$$

For the deployment of RFID readers we apply the proposed approach to achieve the optimal solutions, we let $\delta \in [-1, 1]$,

$$\begin{cases} \text{Min}\left[f_1^{eff}(x,y,\delta), f_2^{eff}(x,y,\delta), f_2^{eff}(x,y,\delta)\right] \\ \quad f_1^{eff}(x,y,\delta) = f_1(x,y,\delta), \\ \quad f_2^{eff}(x,y,\delta) = f_2(x,y,\delta), \\ \quad f_3^{eff}(x,y,\delta) = \dfrac{1}{2}\displaystyle\int_{-1}^{1} \sum_{k=1}^{N_r-1} \sum_{j=k+1}^{N_r} \big(d_{kj} - 2(IR - \delta)\big) d\delta. \end{cases}$$

2.7. The NSGA-III algorithm

NSGA-III, or Non-dominated Sorting Genetic Algorithm III, is an evolutionary multi-objective optimization algorithm. It is an extension of the NSGA-II algorithm, proposed by Kalyanmoy Deb, Himanshu Jain, and Samir Agrawal in 2014 [30].

The main objective of NSGA-III is to find a set of solutions that are not dominated by any other solution in the search space. This set of solutions represents the Pareto-optimal front, which represents the trade-off between conflicting objectives. NSGA-III employs a combination of genetic operators, such as selection, crossover, and mutation, to evolve a population of candidate solutions over generations. Figure 4 shows a flowchart of the non-dominated sorting genetic algorithm III (NSGA-III)

The key features and steps of NSGA-III algorithm are as follows:

1. Initialization: NSGA-III begins by randomly initializing a population of candidate solutions.
2. Non-dominated sorting: the population is sorted into different non-dominated fronts based on the dominance relationships among individuals. Individuals in the first front are non-dominated by any other individual, those in the second front are dominated only by individuals in the first front, and so on.
3. Crowding distance calculation: the crowding distance is computed for each individual in each front, which measures the density of solutions surrounding that individual in the objective space. This helps to maintain diversity in the population.
4. Environmental selection: NSGA-III employs a reference point-based selection strategy. Reference points are evenly distributed throughout the objective space and guide the search towards the Pareto-optimal front. Individuals are selected based on their dominance ranks and crowding distances, favoring non-dominated solutions closer to the reference points.
5. Reproduction: selected individuals are used to create the next generation through genetic operators such as crossover and mutation. The offspring population is combined with the parent population to form the new population.
6. Termination: the algorithm continues to iterate through the steps until a termination condition is met, such as reaching a maximum number of generations or a predefined convergence criteria.

NSGA-III has been widely applied in various domains, including engineering, finance, and decision-making. It offers an effective approach to solving multi-objective optimization problems by providing a diverse set of high-quality solutions on the Pareto front, allowing decision-makers to explore different trade-offs between conflicting objectives.

3. Results and discussion

In this section, we test and evaluate the performance of the proposed approach through six Radio Frequency Identification (RFID) Network Planning (RNP) scenarios, namely C30, R30, C50, R50, C100, and R100. These scenarios involve 30, 50, and 100 tags, respectively, deployed in a working space. The RFID readers and tags are placed within a $50\,\text{m}\times 50\,\text{m}$ work area. The optimization task in this research uses the NSGA-III (Non-dominated Sorting Genetic Algorithm III) due to its numerous advantages. The specifics of the NSGA-III algorithm are outlined in detail in the reference [30].

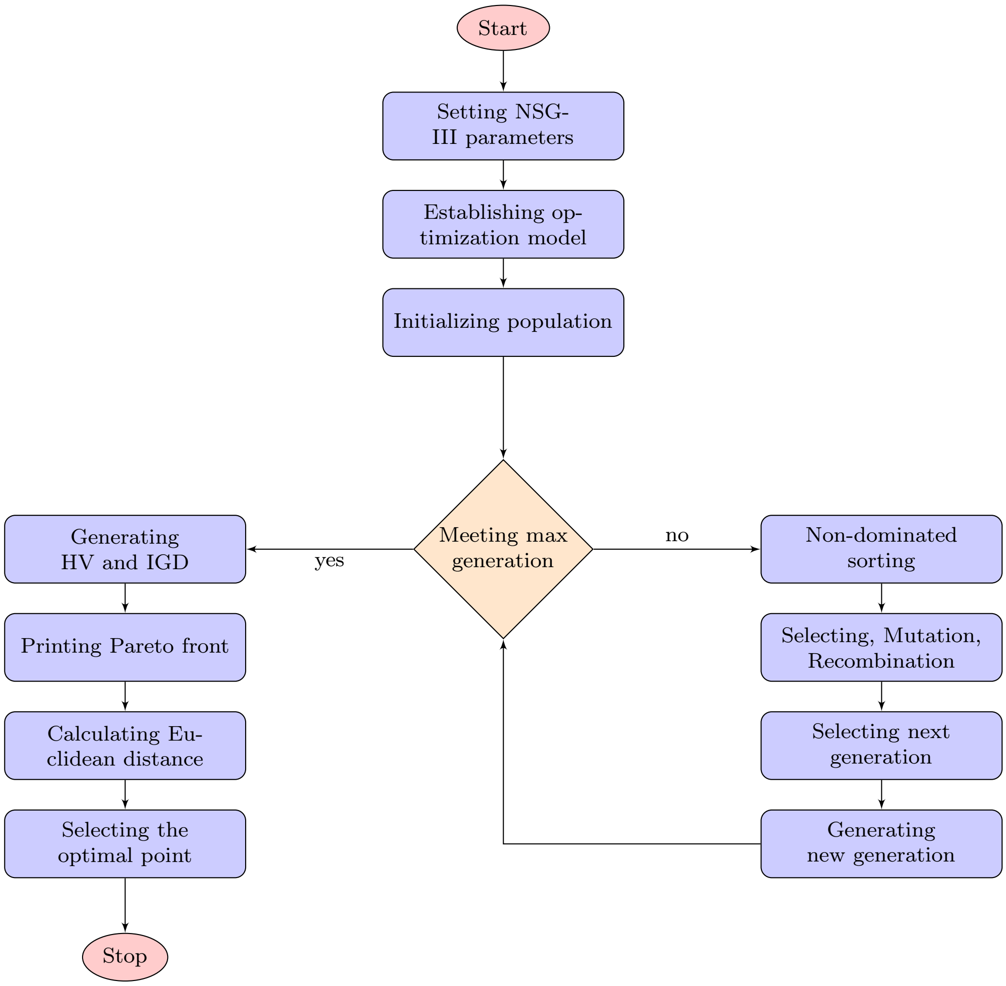


Fig. 4. NSGA-III flowchart.

Table 1 lists the parameters and their corresponding values used in both deterministic and robust multi-objective optimization strategies for deploying RFID readers with the help of NSGA-III.

Table 1. The parameters of RFID network.

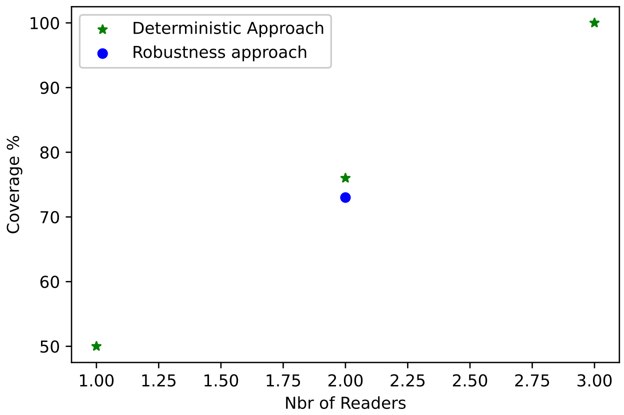
Parameters	Value
Space height H	50.0 m
Space weight W	50.0 m
Number of available readers N_r	12
Maximum iterations	25 000
Population size	20
Length of chromosome	10

Table 2. Results obtained by NSGA-III algorithm for C30, R30, C50, R50, C100, and R100.

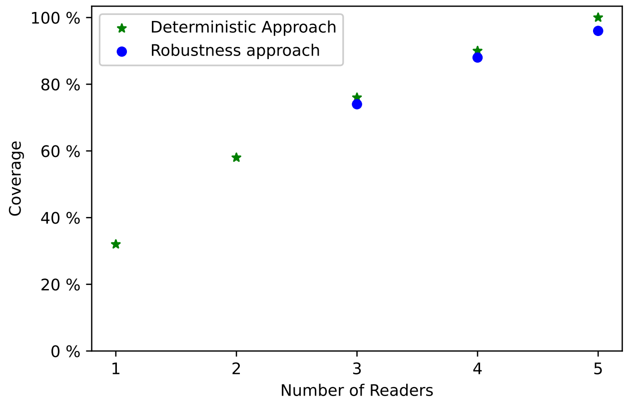
Benchmarks	Coverage	Number of readers
C30	100%	3
R30	100%	6
C50	100%	5
R50	100%	7
C100	100%	5
R100	100%	8

Figure 5 exhibits the optimal placement of RFID readers for six benchmark problems. The Pareto figures demonstrate that our approach consistently achieves optimal solutions while ensuring robustness. This aids decision-making by offering a comprehensive perspective across various scenarios, accounting for variations in the readers' interrogation range parameter. However, it is worth noting that the obtained robust Pareto falls short of the optimal solutions. Consequently, some performance trade-offs are necessary to attain a higher level of robustness.

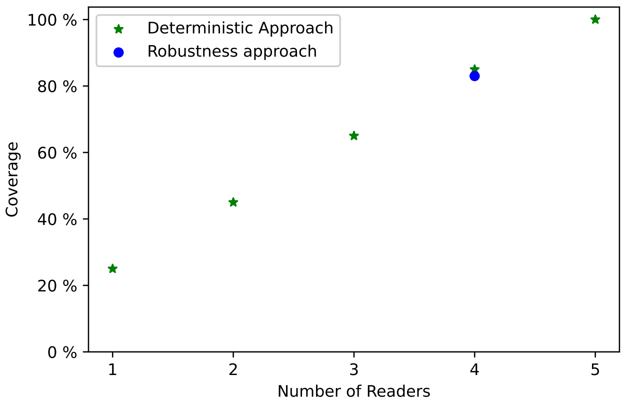
The results of the approach for solving six benchmarks are presented in Table 2. And Figure 6 demonstrates the optimal deployment of RFID readers for each of six benchmark problems. As shown in the figures Our approach always obtains the optimal solutions and robustness, which facilitate decision aiding by providing a global vision of all scenarios considering the interrogation range of readers parameter variation.



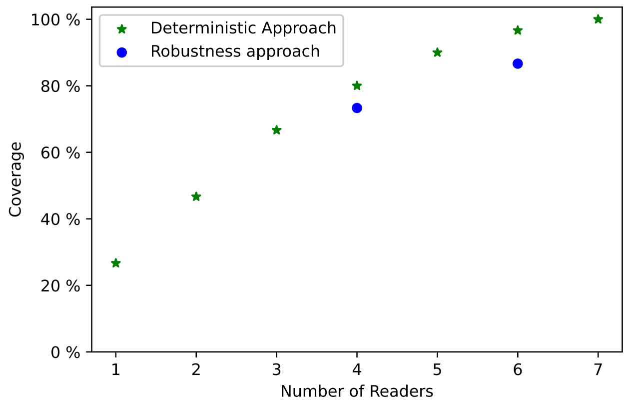
a Pareto-front obtained using the robust multi-Objective optimization approach for C30



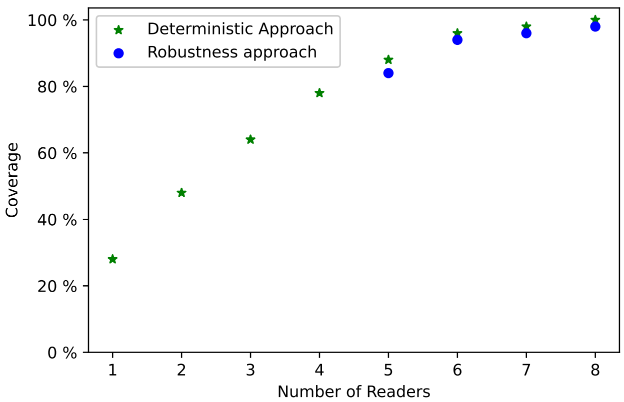
b Pareto-front obtained using the robust multi-Objective optimization approach for C50



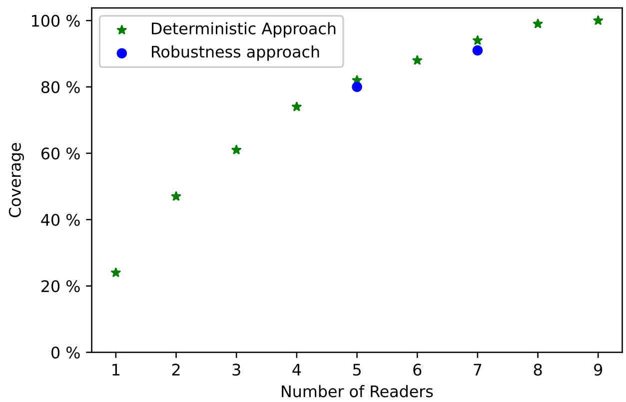
c Pareto-front obtained using the robust multi-Objective optimization approach for C100



d Pareto-front obtained using the robust multi-Objective optimization approach for R30

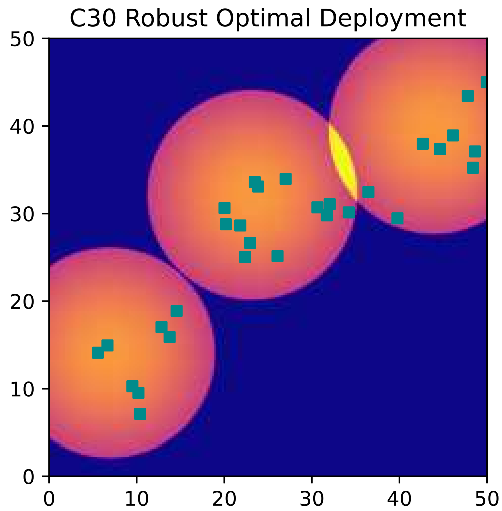


e Pareto-front obtained using the robust multi-Objective optimization approach for R50

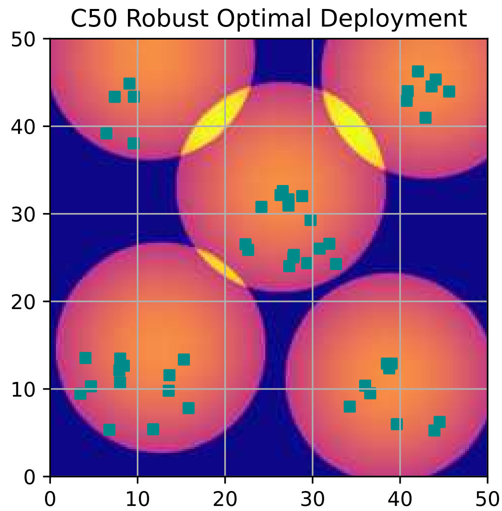


f Pareto-front obtained using the robust multi-Objective optimization approach for R100

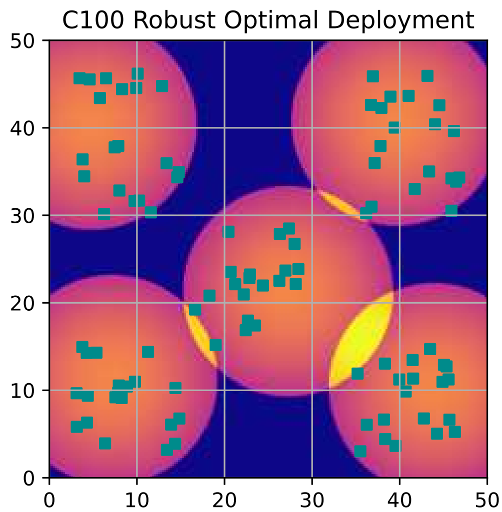
Fig. 5. The optimal deployment of RFID readers for each of the six benchmark problems.



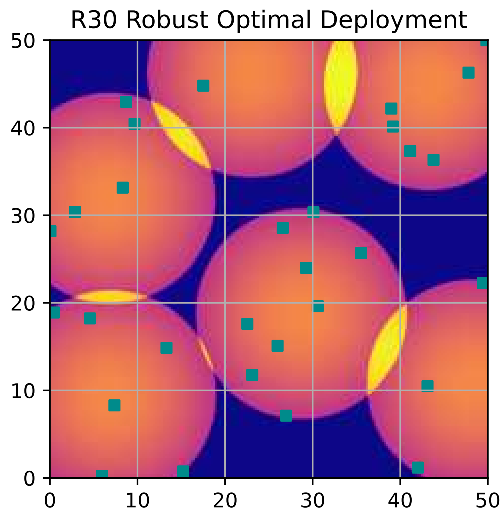
a C30 Robust Optimal Deployment



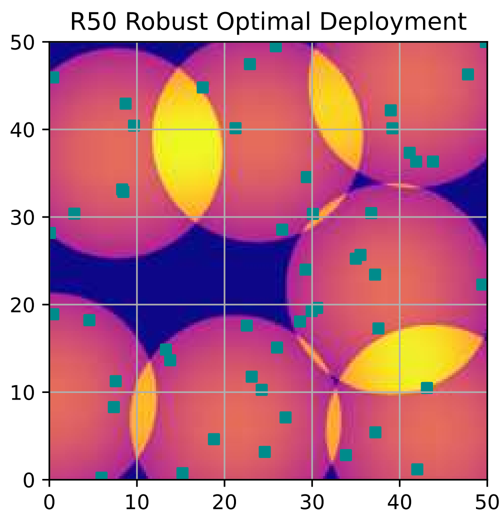
b C50 Robust Optimal Deployment



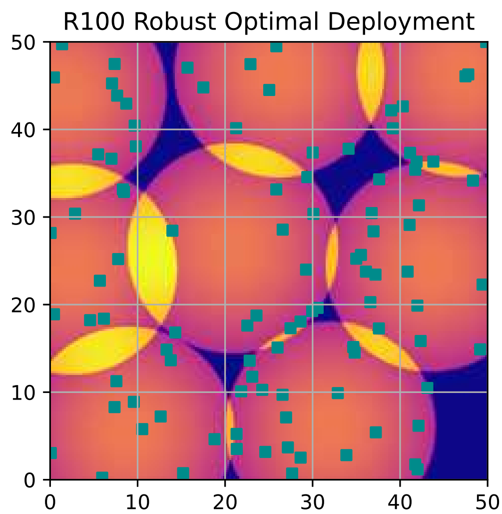
c C100 Robust Optimal Deployment



d R30 Robust Optimal Deployment



e R50 Robust Optimal Deployment



f R100 Robust Optimal Deployment

Fig. 6. The optimal deployment of RFID readers for each of the six benchmark problems.

4. Conclusions

This paper proposes a robust approach for solving the RFID network planning problem under uncertainty, and for obtaining an optimal solution for the deployment of readers in a multi-objective RFID network planning scenario. This aids decision-making by offering a comprehensive view of all scenarios while considering variations in the interrogation range of readers. The results obtained in this study demonstrate the efficiency and robustness of the proposed approach in achieving a minimal number of readers, as well as their optimal positions and locations while ensuring full coverage of all tags in the working space with minimal tag and reader interference. As a future perspective, we plan to improve the global Model by adding other objectives and constraints (Obstacles, etc). Additionally, we suggest applying the proposed approach to more complex benchmark scenarios and real-world applications.

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Ефективний підхід до оптимізації надійності для вирішення проблеми планування мережі RFID з невизначеністю

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Технологія RFID дозволяє дистанційно зберігати та отримувати дані з тегів RFID, що робить її універсальним та ефективним інструментом із широким застосуванням у різних галузях промисловості. У цій статті подано вирішення проблеми розгортання зчитувачів RFID, яка є постійною проблемою в практичних і теоретичних спільнотах, які займаються технологіями RFID. Щоб вирішити проблему розгортання, у статті пропонується надійний багатоцільовий підхід, який оптимізує багато запитуваних цілей, як-от покриття, кількість розгорнутих зчитувачів і перешкод, беручи до уваги неконтрольовані параметри в системі. Результати моделювання демонструють стійкість підходу до вирішення проблеми розгортання та оптимізації системи RFID за змінних і непередбачуваних умов. Запропонований підхід має потенціал для сприяння індустрії технології RFID і створення більш ефективних і результативних систем RFID у різних секторах.

Ключові слова: *RFID; міцність; оптимізація; багатоцільовий підхід; проблема розгортання.*