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A novel algorithm LWFO for redundant reader elimination in RFID networks

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Abstract

Today, the Radio frequency identification system is widely used in various applications on a large scale. The readers must be densely deployed in order to cover their entire work area. If the number of readers is not optimal, some readers will be redundant, which will reduce the efficiency of the whole system. In more detail, redundant readers increase system overhead, unnecessary tag-reader communication, tag collision, and reader collision, and also, decrease the lifetime of RFID networks. The redundant reader elimination problem is a process that finds the least number of readers to cover all system tags. It is proved that the redundant reader elimination problem is NP_ hard. One of the useful tasks in eliminating redundant readers is improving the performance of existing approximation algorithms. In this paper, we propose a distributed algorithm, the LWFO algorithm, which combines the count base algorithm (CBA) and a weighting algorithm. The simulation results show that the proposed algorithm reduces reader redundancy compared to existing algorithms also processing time is reasonable.

Keywords: RFID, Optimal tag coverage, Redundant reader elimination, NP_hard problems
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1 Introduction

Radiofrequency identification (RFID) is a wireless technology with a unique identifier that makes use of the radio frequency for data communication; it is transferred from the device to the reader via radio frequency waves [1, 2]. It is a proven technology that has been in commercial use since the 1970s [19].

The ability of RFID to identify, trace, track information, cost-effectiveness, and use easily deployable tags have been widely used in supply chain management [13], military, industrial [26], agricultural, transportation [21], environmental monitoring [17], and medical [29]/healthcare [5], etc.

Three main components of an RFID system are tags, readers, and application software system [12, 20]. (Fig. 1.)

RFID tags can be classified into three major categories: active, passive, and battery-assisted-passive (BAP). An active and BAP tag contains both a radio transceiver and a battery that is used to power the transceiver [9, 11]. The

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Figure 1: An RFID system [19]

passive tag does not use any battery to boost the energy of the reflected signal. A simplified view of data transfer in low-frequency passive RFID tags is as follows [23, 25]:

- RFID reader broadcasts an electromagnetic signal to the tag.
- Antenna in the tag receives the signal from the reader and stores the charge in a capacitor.
- When the capacitor has built up enough energy, it releases an encoded radio wave containing the information in the tag.
- The reader receives the responding signal from the tag and decodes the information.

An electromagnetic signal is issued to the tag attached to the object by a reader. After the tag received the reader's signal, transfers its embedded code to the reader. Through this communication, the presence and location of things can be tracked by the RFID system as they move through the supply chain [8, 15, 22]. The RFID readers have a limited interrogation range. On the other hand, large-scale RFID networks usually require readers and tags deployed in higher density in order to cover an acceptable number of tags. As a result, in such systems, tags and readers which share the same working area, are the reason for the collision problem [14, 16, 30]. Some key features of the collision problem are highlighted as follows:

- Let an RFID system is represented by $s = \{P, R, T\}$ where P, R, T are "the coverage space", "the set of readers", and "the set of tags", respectively [14].
- The interrogation zone: The interrogation zone is the area around the reader where tags can detect and reply to the reader's signal. Furthermore, the reader can detect correctly the tags' responses [18].
- Tag collision problem: Tag collision is a problem that occurs when a number of tags reply to a reader at the same time and the reader cannot decode signals accurately. (fig. 2(a)) [18, 24].
- Reader collision problem: Reader collision is a problem that occurs when RFID tags are placed in the common area of two or more reader interrogation zones and receives queries from the readers simultaneously. These queries will interfere and cause the RFID tags cannot be detected by any reader. (Fig. 2(b)).

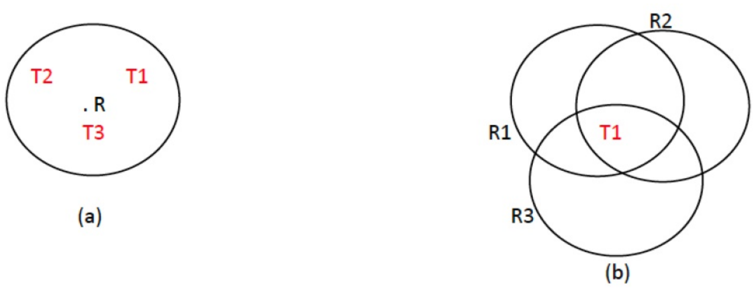

Figure 2: (a) Tag collision problem. (b) Reader collision problem

- Cover (R, T): The cover (R, T) denotes T' that is a subset of all the tag set $T(T' \subseteq T)$ and is covered by the reader set R [14].
- Redundant reader set: A redundant set R' is a subset of the original reader set R, where $R' \subseteq R$ and cover $(R, T) = cover(R - R', T)$ [15].

- Redundant reader elimination problem (RREP): The RREP is an NP-hard problem that finds a redundant reader set $r \subseteq R$, for any other redundant reader set $r' \subseteq R$, which relation of $|r| \geq |r'|$ is true [15].
- Neighboring reader: Assume $R_i, R_j \in R$. R_i and R_j are neighbor readers if they concurrently cover the same tag.
- Neighboring coverage density: Let $\{R_{i1}, R_{i2}, R_{i3}, ..., R_{im}\}$ is the Neighbor reader set of R_i. The Neighbor coverage density of R_i is $d_i = \sum_{j=1}^{m} cover(Rij)$ [15].

In [6], it was clarified that RREP is an NP-hand. Therefore, there is no polynomial-time algorithm for RREP, unless $P = NP$ [27]. All previous approaches used approximate algorithms such as heuristic and approximation algorithms to work out RREP. In this paper, we proposed a novel algorithm, the LWFO algorithm. This algorithm optimizes the CBA algorithm by adding a weighting algorithm. As a result, the proposed algorithm detects more redundant readers. In addition, the running time complexity of the LWFO algorithm is reasonable. Therefore, the proposed algorithms decrease the energy consumption of the RFID network and increase the network lifetime in comparison with LEO, RRE, and CBA algorithms. This paper is organized as follows:

Section 2 provides an overview of related work. The proposed algorithm is explained in section 3. Section 4 evaluates the performance of the algorithm and simulation results are presented. Finally, section 5 concludes the paper.

2 Related work

There are kinds of literature on the redundant reader elimination problem. In this section, A summary of a number of selected algorithms that are related to our research is presented. The aim of the problem is to detect the least number of readers to cover all tags in the RFID system. We consider three types of solutions: A. Centralized algorithms, B. Distributed algorithms, and C. Hybrid algorithms [14].

A. Centralized algorithm. In these algorithms, a central controller is used for holding all the readers' information in the RFID networks. For example, in the Greedy algorithm, a central controller is used to select a reader with maximum tag coverage [7], after deactivating it, this process continues until no tag remained or all readers are deactivated in the system. The Greedy algorithm figures out redundant readers based on central information therefore the Greedy algorithm's performance is better than decentralized algorithms. However, the centralized algorithms require global information about the RFID system thus they often cannot implement practically. Another centralized algorithm, NTE [3], is a heuristic greedy algorithm. The steps of the NTE algorithm are as follows:

1. Weight of each active reader R_i is calculated as follows.

$$W_{R_i} = \frac{cover(R_i)}{NEB(R_i)} (NEB(R_i) \text{is the number of neighbors of} R_i.)$$

2. The reader with the highest weight and all tags in its interrogation zone is deactivated
3. Steps of 1,2 continue until all tags are deactivated.

The NTE algorithm is usually impractical for implementation because it needs special hardware and a central controller (such as other centralized algorithms).

B. Distributed algorithm. Distributed algorithms use from greedy heuristic approximation approach to overcome the RREP problem. They don't need a central controller, therefore having the benefit of easy implementation and low complexity. Redundant reader elimination (RRE) is the first distributed topology[6]. It contains two steps. Firstly, each reader (R_i) writes the cover (R_i) in all tags in its interrogation zone. Each tag selects a reader with the maximum value as a holder. Secondly, the reader reads the holder of tags in the interrogation zone. The reader that hasn't been selected by any tags can be turned off and it is a redundant reader.

Another distributed algorithm is layered Elimination optimization (LEO) [10]. The main principle of LEO is "first read first own". All readers send queries to the tags in their interrogation zone to get the holder of the tag. If the tag's holder ID is null, the reader becomes the tag's holder, otherwise, the holder ID cannot be changed.

The Density-based Redundant Reader Elimination (DRRE) [28] is another distributed algorithm that evaluates the priority of a reader using the concept of neighboring reader density.

The NCD proposed a new weighting algorithm base on neighboring coverage density. Let $\{R_{i1}, R_{i2}, R_{i3}, ..., R_{im}\}$ be the neighboring reader set of R_i. The weight of reader R_i is: $W_{R_i} = \frac{cover(R_i)}{d_i}$

NCD topology advantages the concept that a reader with a high neighboring coverage density has a more probability of being a redundant reader.

Count Based Algorithm (CBA) [18] used a decentralized strategy to solve the RREP problem. In this strategy, all tags calculate how many readers cover it which saves it as COUNT in its storage. If a reader has at least a tag in its interrogation zone that count = 1, that reader holds all the tags and isn't a redundant reader. Our proposed algorithm develops the CBA algorithm that will be explained in section 4.

Meng ma et al. [14], to address redundant iteration overhead in the central algorithms such as the GREEDY algorithm and some of the distributed algorithm proposed Threshold Selection Algorithm (TSA). The TSA algorithm was presented with the motive that in centralized algorithms if the number of holder selections is limited to a certain number, such as n, their performance can be improved by reducing the repetition overhead. In the TSA algorithm, a holder is selected based on its expected coverage rate and a selection threshold sequence was defined as follows. $ST = \left(\tau\left(\frac{|T|}{|R|}\right), \tau\left(\frac{n-1}{n}\right)\left(\frac{|T|}{|R|}\right), ..., \left(\frac{1}{n}\right)\tau\left(\frac{|T|}{|R|}\right), 0\right)$. In this sequence, n is the number of algorithm iterations and τ is a linear multiplier.

C. Hybrid Algorithm. The hybrid algorithm is composed of centralized and distributed algorithms. For instance, LE [4] is a hybrid algorithm that combines LEO and a weighting algorithm (Efficient algorithm). The LE algorithm consists of two steps. In the first step, using the LEO algorithm, a number of redundant readers are removed from the "first read, first own" method. In the second step, the Efficient algorithm, which is a weighting algorithm, is executed on the rest of the readers.

Table 1 presents a summary of the mentioned approaches. In Table 1 'T' and 'R' are the number of tags and the number of readers respectively.

Table 1: A summary of related approaches

Algorithm	Category	Information store in tags	Algorithm complexity
GREEDY	Centralized	None	O (T R log R)
NTE	Centralized	None	O (T R log R)
RRE	Distributed	Tag holder, holder count	O (T log R)
LEO	Distributed	Tag holder	O (T)
DRRE	Distributed	Tag holder, Holder weight	O (T log R)
CBA	Distributed	Count (number of reader)	O(T R)
NCD	Distributed	Tag holder	O (T log R)
LE	Hybrid	Tag holder	O (T R log R)
TSA	Distributed	None	O (nT)

3 Proposed algorithm

The proposed algorithm that is named Low Weight First Out (LWFO) algorithm, improves the performance of the CBA algorithm [23] and is a combination of CBA and NCD algorithms. The steps of the LWFO algorithm are as follows:

1. Each Reader is assigned a weight based on Formula (3.1).

$$W(R_i) = a_1 * Fcov(R_i) + a_2 * Fnei(R_i) \tag{3.1}$$

in this formula, the two functions $Fnei$ and $Fcov$ are obtained from the following relations:

$$Fcov(R_i) = \text{coverage}(R_i)/\text{Maxcoverage}$$

$$Fnei(R_i) = \text{Maxneighbor}/\text{neighbor}(R_i)$$

a_1, a_2 are arbitrary coefficients and apply to the relationship $a_1 + a_2 = 1$. Here, $a_1 = 0.9$ and $a_2 = 0.1$.

2. Readers are sorted in ascending order by weight.
3. The number of Readers that cover each tag is calculated and stored in a variable called Reader-num in the tag memory (in other words, how many readers could communicate with a tag as Reader-Num).
4. A Reader is extracted from the beginning of the queue (reader with the lowest weight). If all the tags in the reader's interrogation zone have Reader-Num > 1 then it is deleted as a redundant reader. In addition, all tags decrease their Reader-Num by 1 (Reader-Num − −).
5. The reader that has a tag in its interrogation zone whose Reader-num = 1 is not redundant and holds all the tags in its interrogation zone.
6. Steps 4 and 5 continue until all readers are checked or no tags remain.

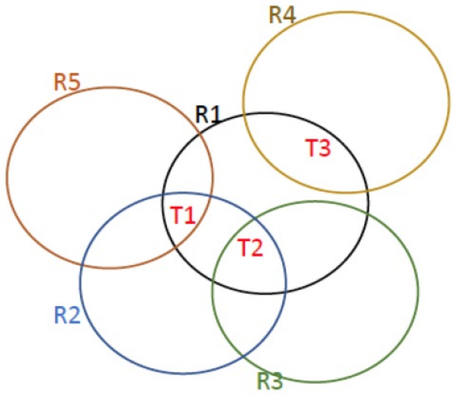

Figure 3: A simple RFID system

Figure 3 shows a simple RFID system. This system has five readers ($R_1, R_2, ..., R_5$) and three tags (t_1, t_2, t_3). The performance of the CBA algorithm for figure 3 is illustrated in detail in table 2.

Table 2: The performance of the CBA algorithm

	T1	**T2**	**T3**
Value of count before deleting any reader	3	3	2
Value of count after deleting R1	2	2	1
Value of count after deleting R2	1	1	1
Value of count after selecting R3	1	–	1
Value of count after selecting R4	1	–	–
Value of count after selecting R5	–	–	–

After execution of the CBA algorithm, R_1 and R_2 is regarded as redundant reader and deleted. The R_3, R_4, and R_5 hold all tags in its interrogation zone. Figure. 4. (a) illustrate the new RFID system after the performance of CBA.

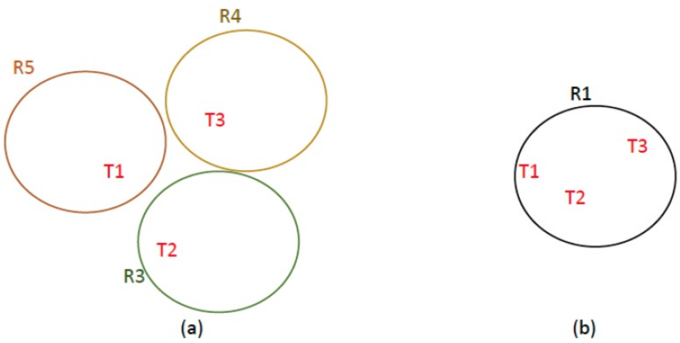

Figure 4: (a) The RFID system after performance CBA. (b) The RFID system after performance LWFO

However, the optimal answer is the R1 reader. For improved performance of the CBA algorithm, we proposed the LWFO algorithm. In the LWFO algorithm at first, we calculate weight for readers, the weights of (R1, R2, R3, R4, R5) are calculated by the formula (3.1) as follows:

$$W_{R1} = 1 \qquad W_{R2} = 0.74 \qquad W_{R3} = 0.5 \qquad W_{R4} = 0.7 \qquad W_{R5} = 0.5$$

After that, the lowest weight reader is selected and steps 4, and 5 of the LWFO algorithm are executed. The performance of the LWFO algorithm for fig. 3. has been shown in table 3. As can be seen, after the performance of the LWFO algorithm R1, R2, R3, and R4 are deleted and R1 remains. (fig. 4(b))

Table 3: The performance of the LWFO algorithm

	T1	**T2**	**T3**
Value of Reader-num before deleting any reader	3	3	2
Value of Reader-num after deleting R3	3	2	3
Value of Reader-num after deleting R5	3	2	1
Value of Reader-num after deleting R4	2	2	1
Value of Reader-num after deleting R2	1	1	1
Value of Reader-num after selecting R1	–	–	–

The pseudocode of the LWFO algorithm is explained in algorithm 1.

Algorithm 1 LWFO

```
LWFO-Algorithm(S)
a1 = 0.9;  a2 = 0.1;
Maxcoverage = 0; Maxneighbor = 0;

FOR    i =1 to  R      {For each reader ∈R}
        Coverage (Ri) = the number of tags belong to interrogation zone of Ri.
        Write (IDRi , coverage (Ri)) to all tags of its interrogation zone.
        neighbor (Ri) = the number of reader that are neighbor of Ri.
        if Coverage (Ri) >   Maxcoverag  then Maxcoverag = Coverage (Ri)
        if neighbor (Ri) >   Maxneighbor  then Maxneighbor = neighbor (Ri)
END

For  i=1  to  R
        Fcov(Ri) = coverage (Ri)  /    Maxcoverage
        Fnei(Ri) = Maxneighbor  /    neighbor (Ri)
        W(Ri) = a1 * Fcov(Ri)  + a2 * Fnei(Ri)
END

Q← Readers are sorted ascending order by W(Ri).

For I=1 to T      {for  each tags ∈ T}
        Reader –num (ti) = number of ID was written in ti.
END

For j=1 to R
LWR ← Q(j)          {LWR  is the Lowes Wight reader}
For    i=1    to   T
        IF (Reader – num(i) =1 )   88    (LWR ∈  tag-coverage (i) )
        Tag holder (i) = LWR;
END
For i=1    to   T
        IF (Reader –num (i) > 1 && (LWR ∈  tag-coverage (i) )
                Reader-num(i)--;
                Redundant Reader += LWR;
        END
END
END
```

The complexity of LWFO: The Nested FOR at the end of the algorithm gets the most time. therefore, the algorithm complexity of the LWFO is O (RT). R is the number of readers and T is the number of tags.

4 Simulation results and discussion

In this section, simulation is used to analyze the performance of the proposed algorithm. This simulation was implemented and performed under C language and an Intel Core i5 processor with a 1.4 GHz CPU and 8GB RAM running on Windows 10. Two RFID network simulation environments were designed. In the first experiment, the number of tags changes. The detailed simulation Environment is given in Table 4. Figure 5 compares LWFO with CBA, LEO, and RRE. In addition, The GREEDY algorithm was considered a benchmark which means the GREEDY algorithm was used as a basis for comparing the performance of other algorithms because it has a better performance than other algorithms.

As can be seen, for all compared algorithms when the number of tags is low, the detected redundant readers' number is high. When the number of tags increases, all algorithms detected fewer redundant readers, because as the growing number of tags, the readers must cover more tags. However, LWFO can eliminate the greatest number of readers all the time (almost equal to the benchmark algorithm).

Table 4: Simulation environment for different number of tags. (a) dense (b) sparse

(a)

PARAMETERS	VALUES
The testing domain	200×200 m^2
The number of readers	3000
The member of tags	4000 - 28000
The interrogation radius	5m

(b)

PARAMETERS	VALUES
The testing domain	200×200 m^2
The number of readers	600
The member of tags	1000 - 7000
The interrogation radius	5m

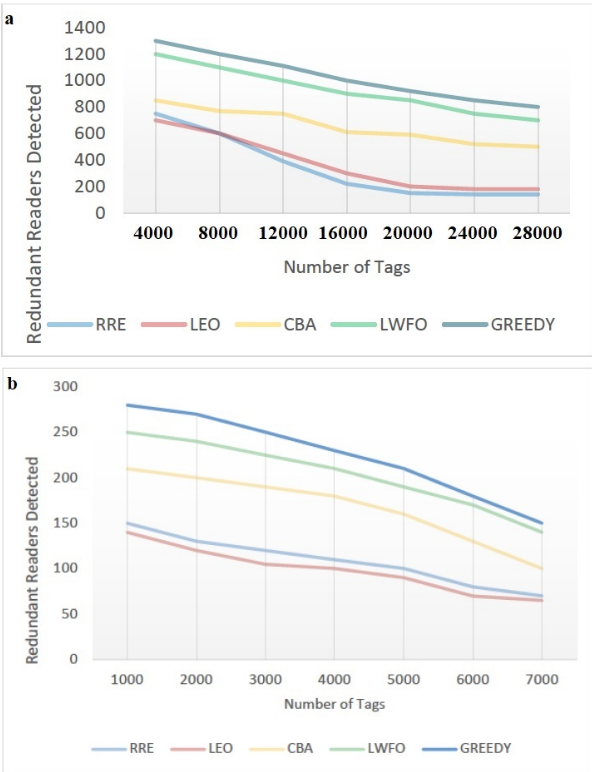

Figure 5: (a): Redundant readers for different number of tags in dense environment. (b): Redundant readers for different number of tags in sparse environment.

These algorithms can compare with two methods:

1) Detection redundant rate (DR) and 2) Relative Detection redundant rate (RDR) that is defined as follows: Let "Alg1" and "Alg2" are two algorithms for detecting redundant readers.

1. $DR_{Alg1} = \frac{DAlg1}{DAct}$
2. $RDR_{(Alg1\ to\ Alg2)} = \frac{DAlg1}{DAlg2}$

where "D_{Alg1}" is the number of detected redundant readers by algorithm Alg1 and "D_{Act}" is the number of actually existing redundant readers.

Figure 6 Shows RDR of four algorithms (RRE, LEO, CBAM, LWFO) to Greedy algorithm in dense environment. According to this graph, the RDR of the LWFO algorithm is higher than other algorithms.

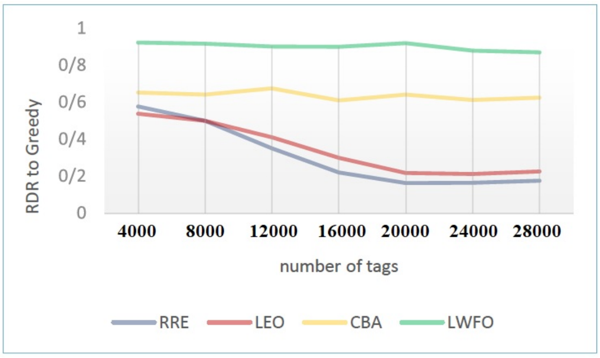

Figure 6: RDR to Greedy for different number of tags in dense environment.

In the second experiment, the number of readers changes. The detailed simulation environment is given in Table 5. Figure 7 shows changes in redundant reader detection when the number of readers increases. According to this graph, LWFO can eliminate the greatest number of redundant readers all the time.

Table 5: Simulation environment for different number of readers. (a) dense (b) sparse.

(a)

PARAMETERS	VALUES
The testing domain	200×200 m²
The number of readers	1000 to 5000
The member of tags	15000
The interrogation radius	5m

(b)

PARAMETERS	VALUES
The testing domain	200×200 m²
The number of readers	200 to 600
The member of tags	3000
The interrogation radius	5m

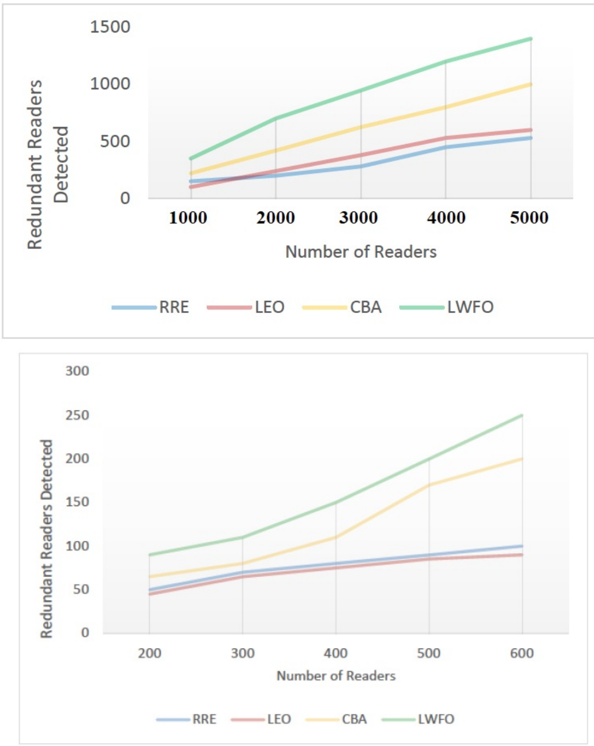

Figure 7: (a): Redundant readers for different number of readers in dense environment. (b): Redundant readers for different number of readers in sparse environment.

5 Conclusion

In this study, the redundant reader elimination problem (RREP) was examined in RFID networks. It was also stated that the redundant reader elimination problem is NP_hard. Therefore, there is no polynomial time algorithm for RREP. An important issue in RREP is the improved performance of existing algorithms. In this paper, a number of algorithms were investigated related to our research. Then the LWFO algorithm was introduced to remove redundant readers, which is a combination of CBA and NCD algorithms. This algorithm assigns weight to each Reader and first examines the readers with the lowest weight and removes it as redundant Reader if all the tags they cover have Reader_num greater than 1. The LWFO algorithm was evaluated with four algorithms. The greedy algorithm as "Benchmark" and RRE, LEO, and CBA algorithms for comparison. The study was also performed in two environments: a) when the numbers of tags are variable and the number of readers is fixed b) when the number of tags is fixed and the number of readers is variable. The simulation showed that the LWFO algorithm detects more redundant readers in both environments than the "RRE, LEO, and CBA" algorithms and has a performance close to that of Greedy.

Although this algorithm improves the performance of the CBA, but as a future work, after selecting each reader, it is possible that reassign weight to the remainder of the readers then the algorithm is repeated.

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