International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.8 (2016), pp.153-162
http://dx.doi.org/10.14257/ijmue.2016.11.8.17

The Method for RFID Reader Location Based on Self-Adaption Coverage Density

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Abstract

In order to solve the problem of the RFID reader allocation, the data is generated by the particle filtering technology to use. Factors of the number of locations covered and the probabilistic distribution of object are considered, and the new method for the RFID reader allocation is proposed based on self-adaptively coverage density. The public data is used to test and verify algorithms from the Lahar project of the Washington University. Simulation experiments have been carried out on collected data, and the relevant results are compared with and the traditional algorithm, it shows that the algorithm of Self-Adaptively Coverage Density has better effectiveness.

***Keywords**: Self-Adaptively; Coverage Density; Clustering; RFID Reader Location*

1. Introduction

In applications of radio frequency identification (RFID) technology, RFID readers should be installed at the high frequency targets activity regions in the supervisory work space, but the covering scope of signals which is transmitted by RFID antenna is limited for target tags and factors which include cost of RFID readers, energy consumption and efficiency [1]. This is the fundamental problem of RFID Network facilities allocation in large scope supervisory work space [2]. In research of RFID readers Network Planning, there are two major Planning methods [3,7], Nandakumar Mysore [3] and Ahmed Wasif Reza [7] which are proposed as the method that RFID antenna signals and RFID readers can completely cover the irregular regions. The other one is proposed by Church and ReVelle [8]. In conditions of the given RFID reader's numbers, the RFID antenna signals and RFID readers can make a maximum coverage for the irregular regions.

The deficiencies of these methods are as follows. Firstly, numbers of RFID reader are needed to define artificially, not through scientific computing. Secondly, the selection of the RFID reader's allocation is random and cannot be installed based on practical position distribution. Thirdly, if RFID signals cover completely the irregular regions, numbers of RFID reader will be so many to improve the cost. Fourthly, if numbers of RFID reader are given artificially, the number will be probably estimated insufficiently.

The rest of this study is organized as follows. Section 2 discusses related research elementary definitions about RFID. Section 3 characterizes the research methodology for RFID reader allocation based on self-adoptively coverage density. Section 4 describes and analyzes experimental results. According to this method, numbers of the RFID reader and position distribution can be computed through targets' distributions which are acquired through particle filtering algorithm [9] in the work space and this approach revises deficiencies of the existing RFID reader's network methods.

ISSN: 1975-0080 IJMUE
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Conclusions are given in Section 5, along with directions for future research.

2. Related Research Foundation

2.1. Foundation Definition

The basic event which happens in the application of RFID means action that the RFID reader fetches the object's tag [10] and every basic event happens at a time point. A RFID basic event e is expressed by the tuple $e=(Tag, R_v(s_A), Timestamp)$. Tag represents the object's tag. $R_v(s_A)$ means plane region which the RFID sensors are sited in. The plane region is divided by Voronoi graph [11] and every region which is divided is represented by the point s_A, denoted by $R_v(s_A)$. $Timestamp$ represents timestamp of the event.

The object may be several different locations at a timestamp and every location corresponds to its probability. Before the definition of probabilistic timestamp events is used, we must introduce the definition of probabilistic event, as below:

Definition 1 (probabilistic event): a probabilistic event $e^{(t)}$ is composed by tuple $(Tag, R_v(s^{(t)}), t, P)$, Tag represents the object's tag, $R_v(s^{(t)})$ represents the plane region which the object stay in. The t is timestamp and P is probability which one object entrances the region $R_v(s^{(t)})$ at timestamp t.

Definition 2 (probabilistic timestamp event): a probabilistic timestamp event $\overline{e}^{(t)}$ is composed by tuple $(Tag, t, \bigcup_{i=1}^{N}(R_v(s_i), P_i)$, where $\sum_{i=1}^{N} P_i = 1$, N is the possible number of locations which the object appears. $R_v(s_i)$ represents the plane region which the object stays in. The t is the timestamp, P_i is the probability which one object entrances the region $R_v(s_i)$.

Definition 3 (probabilistic centroid): Let a probabilistic timestamp event $\overline{e}^{(t)}$ contains N regions $R_v(s_i)$, $i=1...N$, the related point's coordination is (x_i, y_i), probabilistic centroid is c_t, and $c_t = (\sum_{i=1}^{N} x_i P_i, \sum_{i=1}^{N} y_i P_i)$.

Definition 4 (probabilistic timestamp events sequence): Let $\left[t_i, t_j\right]$ be the discrete timestamp interval, $t_i \le t_j$. So the sequence $(e^{(t_i)}, \ldots, e^{(t_j)})$ is probabilistic timestamp events sequence for an object corresponding to discrete timestamp interval $\left[t_i, t_j\right]$. According to definition 3, the sequence $e = \left(e^{(t_i)}, \ldots, e^{(t_j)}\right)$ of probabilistic timestamp events corresponds the sequence $c = \left\{c_{t_i}, \ldots, c_{t_j}\right\}$ of probabilistic timestamp centroid.

2.2. RFID Reader's Coverage Density and RFID Reader's Effect Function

The pattern of communication between sensor and receiver includes Line of Sight (LOS) and Non Line of Sight (NLOS) [12].Traditional approaches for location are generally based on LOS. RFID technology has features of untouchable and NLOS [13], so these factors are considered to decide the covering scope. The signal covering radius of RFID reader can be determined through parameters of the device. Because existing of all kinds of noise in real environment, the radius can be calculated by experiment data.

Let $A = \left\{\bigcup_{i=1}^{N}(R_v(s_i))\right\}$ be set of regions which RFID sensor α covers, the covering radius of RFID sensor α is $r(\alpha)$, $r(\alpha) = \max\{\| \alpha - s_i \|\}$. Let $\Re$ be set of all sensors in one RFID network, and $r(\Re) = \max\left\{r(\alpha_i), a_i \in \Re\right\}$.

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Definition 5 (coverage density): Let M be the number of readers in set $\Re$ in one RFID network, the covering radius of α_i is $r(\Re)$. Let $\bigcup e^{(t)}$ be the probabilistic timestamp events in the region whose central is α_i and radius is $r(\Re)$. Let N_i be possible number of locations and $\sum_{i=1}^{N} P_i$ be the sum of corresponding location probability. The coverage density of sensor α_i is denoted by $DC(\alpha_i)$, and $DC(\alpha_i) = \xi(N_i) + (1-\xi)\sum_{i=1}^{N} P_i$, where $0 < \xi < 1$.

In definition 5, the parameter ξ is the weight which involves the location and corresponding probability when the coverage density is calculated. The parameter can be adjusted by the purpose of designing. When $\xi = 0$, $DC(\alpha_i)$ illustrates the probability of objects which occur in the domain that the reader α_i can covers; When $\xi = 1$, $DC(\alpha_i)$ illustrates the number of the places which objects occur in the domain that the reader α_i can covers. On the base of definition 5, we make the definition of RFID reader's effect function to evaluate the effect of the network of RFID readers with coverage density.

Definition 6 (RFID reader's effect function): Let α be a reader in RFID network, A_i $(i = 1......n)$ is one attribute of reader α effects. The effect function of reader α is $TW_\alpha = \sum_{i}^{n} \eta_i A_i$, where, $\sum_{i=1}^{n} \eta_i = 1$, and η_i is the coefficient of attribute A_i for reader α.

The effects of the RFID reader is discussed by two aspects: the ratio of RFID readers coverage density indicated by f_D and the ratio of number of objects' occurring places indicated by f_N. The formulation are as follows:

$$f_D = \frac{DC(\alpha)}{\max(DC(\Re))} \tag{1}$$

$$f_N = \frac{Num(\alpha)}{Num(C_i)} \tag{2}$$

In formulation (1), $DC(\alpha)$ means coverage density, $\max(DC(\Re))$ means the maximum coverage density in RFID network. In formulation (2), $Num(\alpha)$ means the number of the number of objects' occurring places in covering domain of reader α, $Num(C_i)$ means the number of number of objects' occurring places in the cluster C_i. C_i will be explained in Section 3.

According to (1), (2) and definition 6, the effect function of reader α is:

$$TW_\alpha = \eta f_D + (1-\eta) f_N \tag{3}$$

Where, η and $(1-\eta)$ are coefficients for attribute f_D and f_N.

3. Clustering Algorithm Based on Self-Adaptively Coverage Density

The covering clustering algorithm in this research is one of partition clustering algorithm [14]. The feature of this algorithm is that the result of clustering is decided by attributes of samples based on similarity, without knowing numbers of clustering. The result of clustering is avoided by influencing with this feature due to parameters adjustment. The self-adoptive in this research means that initial clustering centre and the number of clusters are calculated based on attributes of samples, that are not randomly selected.

As is stated above, the distance between sensors is greater than the sum of radiuses in order to avoid largely overlapping of the covering signal. Let $r(\Re)$ be the radius for calculation of the covering density. The d is initial clustering cores' distance, and $2 \times r(\Re) < d$ is required. Every probabilistic centroid's covering density is calculated and

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is reordered by descending order. The probabilistic centroid of largest covering density is chosen as the first clustering core, then the next one is calculated by order. If the distance between this point and the former one is less than $2 \times r(\Re)$, the next point will be calculated. In so doing, other clustering cores are got.

The covering clustering algorithm [15] is equal to seek a group of domains in which samples are divided with less similarities and samples are clustered with more similarities. The procedure of clustering algorithm of RFID readers based on self-adoptively coverage density is as follows:

(1) dividing the plane region. According to the method of Voronoi graph division [16], the RFID workspace will be divided into many sub regions and every region is signed.

(2) collecting data and calculating the distribution. In order to reduce random of the site selecting method, the distribution of objects should be analyzed in the workspace. The method of object distribution estimation in this research is used by particle filter algorithm [9].

(3) collecting RFID data.

(4) calculating the estimation of RFID reader's position.

The clustering algorithm of RFID reader based on self-adoptively coverage density. The algorithm input, algorithm output and steps of algorithm are showed as follows:

Algorithm Input: raw RFID data collected; marginal distribution data generated by particle filter; upper bound of the initial cluster number M; parameters of coverage density ξ.

Algorithm Output: positions of the RFID reader; the effect function of RFID reader.

Step 1: calculating the covering radius $r(\Re)$. According to raw RFID data and unit type, the covering radius of RFID reader is calculated.

Step 2: calculating probabilistic timestamp centroid sequence C. According to the subsequence of timestamp, the probabilistic centroid of probabilistic timestamp event $e^{-(t)}$ is calculated.

Step 3: calculating the coverage density sequence. The coverage density of every probabilistic timestamp event is calculated by the centre which is the centroid, the covering radius $r(\Re)$ and coverage density parameter ξ. Generating the sequence $C-SEQ$ by descending order of the coverage density.

Steps 4: calculating the sequence of cluster canters. The first centroid of $C-SEQ$ is as the centre K_1 of the first class. According to the sequence of $C-SEQ$, we get the centroid sequence with the requirement that the distance between centroids should greater than $2 \times r(\Re)$. It means the ith centroid is K_i, $\|K_i - K_{i+1}\| > 2 \times r(\Re)$. All centroids generate the cluster centroid sequence $K-SEQ$.

The number of the cluster centroids from Step 4 is N. If $N < M$, all centroids of sequence $K-SEQ$ are cluster centroids; If $N > M$, the former M centroids of $K-SEQ$ is cluster centroids and the number of cluster centroids is M. These cluster centroids generate the initial cluster centroids set K.

Step 5: clustering for the marginal distribution data. The marginal distribution data is showed as the Table 3. Let E be the marginal distribution data set, the cluster corresponding to the ith cluster centroid K_i is C_i, where $K_i \in K$. For every probability event $e^{(t)} \in E$, we calculate $\min\left\{K \mid \left\|e^{(t)} - K_i\right\|\right\}$ and $e^{(t)} \in C_i$. The new probability center is calculated based on all objects belong to the cluster C_i. Let (x_j, y_j) be the coordinate of $e^{(t)}$, the coordinate of new probability center is $\left(\sum_{i=1}^{N} x_i P_i \Big/ \sum_{i=1}^{N} P_i, \sum_{i=1}^{N} y_i P_i \Big/ \sum_{i=1}^{N} P_i\right)$.

Step 6: If $f_D = 0$ or $f_N = 0$ in the covering domain KC_i whose the centre of a circle is K_i' and the radius is $r(\Re)$, the new probability center K_i' is the maximum probability

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location in cluster C_i .

Step 7: Repeating Step 5 and Step 6, calculating the new probability center K_i' of cluster C_i whose the centre of a circle is K_i' and the radius is $r(\Re)$ until the probability center K_i' of every cluster doesn't change. This process generates the final probability center set $K-Set$.

4. Experimental Results and Discussions

The public data is used to test and verify algorithm 1 and algorithm 2 from the Lahar project of the Washington University.

4.1. Experiment Data

The Lahar project of Washington University is carried out the RFID ecosystem which is a very big project. The researchers who participated in this project come from research groups of department of computer science and engineering. This RFID ecosystem includes 150 RFID sensors which distribute around six floors' building and new data for the research are collected.

Experiment data are used in this paper, it includes:

(1) The collection of original RFID data. The Table 1 only gives partial data to show the structure. The first row means a Markovian data stream's timestamp and sensor's ID. The blank space means that no objects had been supervised at this timestamp. This data set includes about 650 items.

(2) Real experiment data. The Table 2 gives partial data to show the structure. The first row means where the real position of an object is at every timestamp. This data set includes about 650 items.

(3) The particle marginal distribution generated by particle filtering. The Table 3 only gives partial data to show the structure. The first row means the marginal distribution for the object at a timestamp. This data set includes about 6000 items.

Table 1. Original RFID Data (Partial)

Timestamp	Reader ID
1226636100426	103
1226636101426	
1226636102426	104

Table 2. Real Experimental Data (Partial)

Timestamp	Region number
1226636100426	302461
1226636101426	394915
1226636102426	394915

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Table 3. The Particle Marginal Distribution Generated by Particle Filtering (Partial)

Object Tag	Timestamp	Location	Probability
2254716205721250000	1226636093426	375787	0.887259257084265
2254716205721250000	1226636093426	310450	0.083440545919008
2254716205721250000	1226636093426	394154	0.029298595297040

4.2. Discussions

(1) According to the data from the Lahar project of Washington University and the method of Voronoi graph, the experiment region is divided into sub regions, and every sub region $R_v(s^{(t)})$ is denoted by a point (Figure 3).

(2) The method for RFID Reader Allocation Based on Self-Adoptively Coverage Density is discussed. Firstly, the effectiveness of probability centers in algorithm 1 is discussed. The purpose of experiment emphasizes on that more number of locations that the object possibly appears can be covered. The $\xi = 0.9$ is got in calculation of coverage density. The upper bound of initial cluster number is $M = 15$. The results illustrate that algorithm 1 can efficiently cluster the object's possible locations in work space (Figure 3 and Figure 5). When $\xi = 0.9$, Figure 5 describes the initial cluster centroids and Figure 4 describes adjusted probability centers. It has gathered 14 probability centers. Most of points move slightly and two of them move by a large margin.

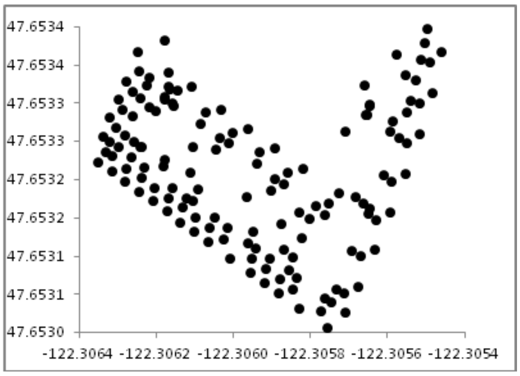

Figure 3. The Distribution of the Objects' Location

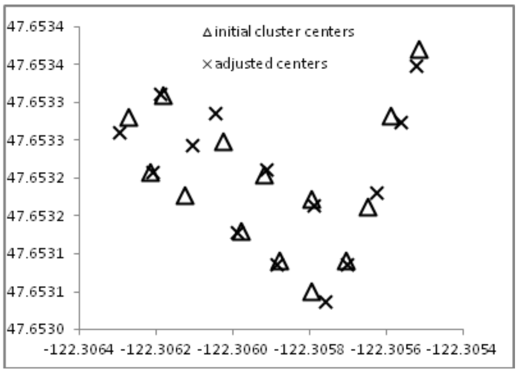

Figure 4. Initial Cluster Center and Adjusted Cluster Center when ξ =0.9

Secondly, the coverage effectiveness of the RFID readers' network is analyzed through the RFID readers' effect function. When $\xi = 0.9$, experiment results illustrate that there are 14 RFID readers, and there is no large extent of overlap (Figure 6). Figure 7 illustrates

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RFID readers' effect function values for every RFID reader. When $\xi = 0.9$ and $\eta = 0$, the distribution of f_N is not smooth and steady. The f_N of No.2 reader is the smallest one. When $\xi = 0.9$ and $\eta = 1$, The f_D of No.8 is the largest one, and other RFID readers' f_D are relatively steady. When $\xi = 0$ and $\eta = 1$, the distribution of covering locations probability is disperse and that of No.7 is the smallest. The results of comprehensive analysis are as follow: No.8 reader has the highest coverage density and this reader's f_N and f_D don't heavily fluctuate by compared with other readers. So, the cover effect of No.8 reader is preferable. No.2 reader's f_N is lower than other readers. It illustrates that the number of places covered by this reader is much less than other readers. In this case, it is necessary to supplement readers in insufficient covering cluster. Other readers' f_N are smooth and steady not to be adjusted.

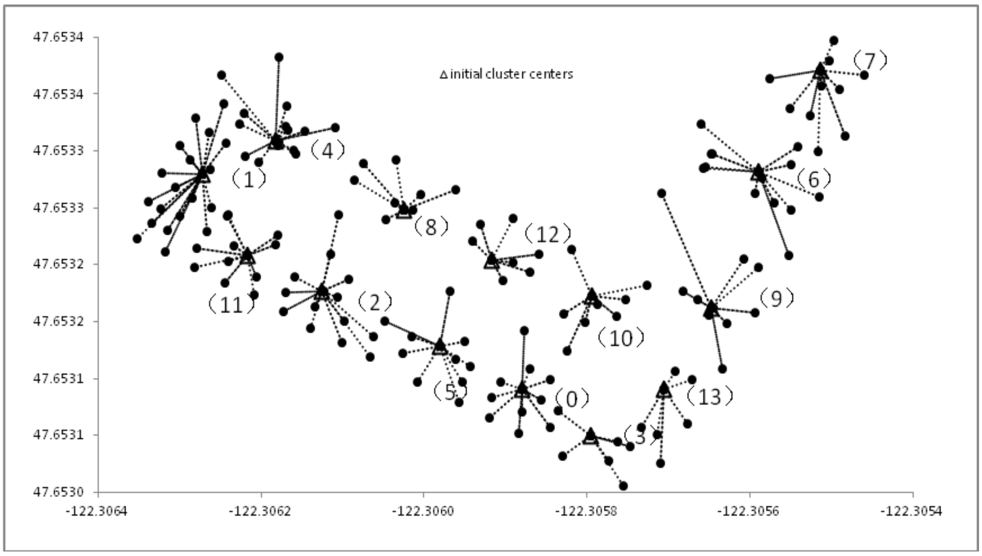

Figure 5. The Distribution of Clusters for Object when $\xi = 0.9$

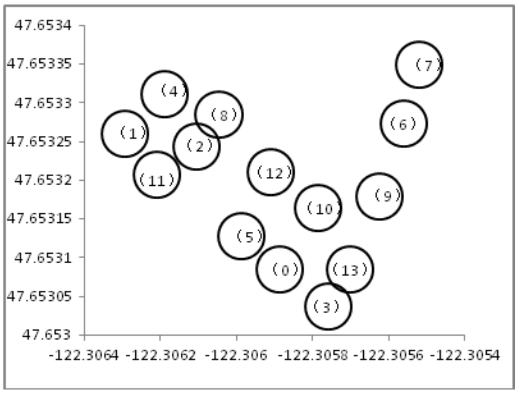

Figure 6. The RFID Network when $\xi = 0.9$

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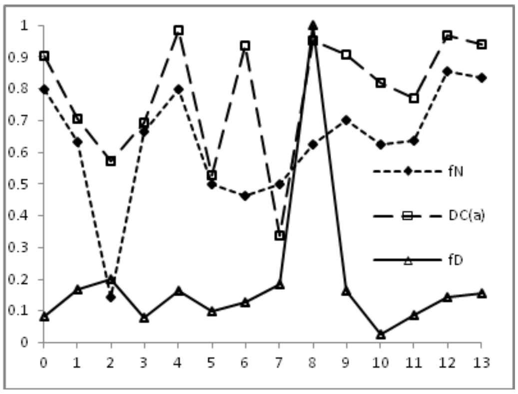

Figure 7. RFID Readers' Effect Function when $\xi = 0.9$

At last, the effectiveness of the RFID network added is analyzed through the strategy of supplement for insufficient covering cluster.

5. Conclusion

In order to solve the problem of RFID Network facilities allocation in large scope supervisory work space, the algorithm of RFID readers' clustering based on self-adoptively coverage density is proposed. It presents the strategy of adjustment for facilities and the strategy of supplement for the insufficient covering cluster. These methods consider factors of number of RFID readers' covering places and the probability of objects in these places. The distributed situation of the object's motion curve and location space to confirm number and location of RFID readers is considered. These methods lay the foundation for further research of RFID planning and can be applied for RFID facilities' site selection, optimization and evaluation of effectiveness. In future, the improved algorithm will applied to solve efficiently to RFID reader location and self-adaption coverage density is used with other algorithms for our research.

Acknowledgments

This work is partially supported by National Natural Science Foundation of PR China under Grant 71471006 and Social Science Planning Foundation of Liaoning Province in China under Grant L15AGL016. The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

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