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Locating Targets in RFID System in a Sensing Covered Anchor-Free Network

Arpita Dey, Buddhadeb Sau

Abstract—In an RFID system, the RFID readers consume huge energy and are considerably expensive in practical applications. To minimize the total number of readers with guaranteed surveillance such that the position of each tag can be uniquely determined is a challenge. This paper considers a simple but practically useful model of anchor-free network of RFID readers where each tag falls within the sensing zone of at least two readers. To maintain the quality of service in the real applications, a practical condition, the communication range is at least twice its sensing range, is considered. Under this condition, a characterization of a network is proved. An efficient algorithm for recognizing such a network is then developed without any initial position information of the readers. Using these readers as the references, an algorithm is designed for finding the exact positions of the tags in distributed manner. Unlike the existing techniques, it requires no external references for tag tracking. The proposed technique finds at most two possible positions (in some cases, unique position), out of which one is correct, for each tag.

Index Terms—Targets tracking, exact positions of RFID readers, 2-sensing covered network, locating targets with no anchors, locating RFID tags with RFID readers.

I. INTRODUCTION

In diverse applications over the world like tracking animals in a dense forest, finding a book among a large number of books in a library system, localizing luggages in a railway or airport system, or finding a displaced object in a shopping mall is a challenging work. The method of detecting such objects i.e. finding the positions of those objects in the field of interest is known as *target tracking*.

Technologies are developing on continuous basis to cope up with the challenge of tracking of targets or objects in the field where human intervention is almost impossible. In real-life situations, there may be a huge possibility of existence of obstacles (both static and dynamic) in the field of interest. General sensing technology in a Wireless sensor network (WSN) works on the basis of line-of-sight of the sensors. So, obstacles can create a barrier in the line-of-sight of the sensors. That is why, Radio frequency identification system i.e. RFID system (consists of RFID readers and RFID tags) is significantly being used in these cases to take care of an event.

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***** Correspondence Author
Arpita Dey*, Department of Mathematics, Jadavpur University, Kolkata, India. Email: arpitadey.maths@gmail.com
Buddhadeb Sau, Department of Mathematics, Jadavpur Industry, Kolkata, India. Email: buddhadeb.sau@jadavpuruniversity.in

Important methods have been discussed for keeping an eye on RFID tags in [23] [24] [5] [9] [4] [22] [15]. These methodologies (based on available inputs for computation) explain the usefulness of the working principles RFID technology.

Using RFID system, tag-to-tag or reader-to-reader or tag-to-reader distances can be measured efficiently though the technique of *Angle of arrival (AOA)*, *Time of arrival (TOA)*,*Received signal strength(RSS)* etc. In the *Proximity* based RFID localization, when a tag is sensed by more than one transmitter, position of the tag is computed based on the position of the transmitter (whose position is known) whose signal strength is the strongest. In the literature, the target tracking techniques involve mostly the mobile objects. To localize static objects is a major issue in reality. Such an example is using RFID tags in place of barcodes.

A. Using RFID tags in stead of barcodes

Barcode is a well known technology (based on image processing) which works on the basis of line-of-sight for tracking products. Suppose, there is a shopping outlet where barcode is present on the front side of each item displayed on different racks. Barcode readers are used to read these barcode printed on different items. When multiple number of customers randomly choose the items, the items are displaced from their original position. At the same time, the barcodes may be easily distorted. As a result, when the barcode reader is used to track any item from a rack, it may not detect the required item while the line-of-sight is blocked. Further, the standard infrared barcode scanner need to be placed quite close (approximately 1 feet) to read the barcodes to access the direct line-of-sight which may not be possible in most cases. Therefore, finding an item uniquely is a challenge using the existing barcode technology. RFID is a huge improvement to this system where RFID tags do not need to be positioned in a direct line-of-sight with the RFID reader. Data on the tags can be read from a distance upto 300 ft. To compare with barcode, one RFID tag can preserve huge data (like detail of product manufacturization, expiry date,shipment history etc.) and will last longer in adverse situations too (with exposure to rain, sunlight etc). The increasing use of RFID tags also reduces manpower as the readers can read multiple tags at a time. Due to the robustness and efficiency of RFID tags, we are highly motivated to form a network of RFID readers and tags in a static environment to identify and track the objects.

B. Issues and difficulties using RFID

RFID is an emerging technology and it effectively grabs people's attention in detecting objects in various interesting fields. Some of them are mentioned here for example and easy understanding of its usefulness likedigital passport checking in railway stations and airport, for security management in museum and amusement parks,
tracking time of sport events, in hospital managements (inventory tracking, tracking of staffs, patients, surgical equipments etc.), in asset managements, in warehouse management systems, etc. [21] [8]. An RFID reader emits signals through its antenna in the form of radio-frequency. Readers have some communication capability with which it can access data in the RFID tags within its sensing region. In real life applications using RFID system, some inherent problems are found which are discussed below.

1) Holes in the field of interest:

RFID readers aredeployed to cover the field of interest to locate RFID tags. In reality, there may be regions (e.g., Fig. 1) whose points are covered by sensing zone of no reader. Such a region is called a *hole* in the network.

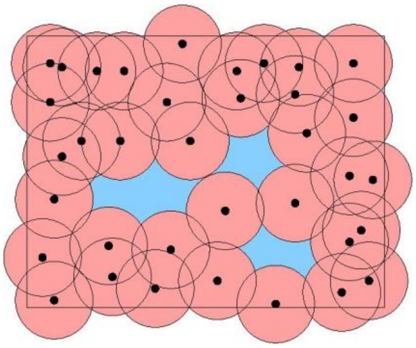

Fig. 1. Holes in the field of interest.

Definition 1: A *hole* is a connected region consisting of points covered by no sensor.

In the example of a library system, if there exist holes then any book with an RFID tag falling in such a hole, can be located by none of the readers in the system. To overcome such problems, sensing covered networks may be used [1].

2) Using passive tags and low range readers:

In the real-life applications, active tags and passive tags are the two varieties of RFID tags which are popularly used [13]. Active tags mainly vary from passive tags due to their long read range as well as active tags are owned with self power resources. In case of a RFID system formed with passive tags, the tags become active after receiving signal from nearby readers. So, it is clearly understood that using passive RFID tags for indoor and outdoor localization is the cost-effective way.

RFID readers with ultra high frequency (UHF) have a longer read range of 1500 feet in average where as the read range of passive RFID readers is about 10 feet. The readers using high frequency radio waves consumes more energy and useful in wild life tracking, battle-field surveillance, detecting fire in dense forest etc. The cost of these high range readers are multiple of thousands where as the cost of low range readers are within Rs. 500 in average. In fact, covering a region with greater number of passive readers is cost-effective than covering it with the three long range readers. In this case, more connectivity information are available and the chances of formation of holes due to failure of an reader is much lower. In addition to this, Passive tags are so smaller (even smaller than smart cards) so that it can be attached to tiny objects too purposely, if needed. In the practical field of interest, where long read range is not required, suppose for tracing a text book in the library, we can use passive tags efficiently and cost-effectively. That is why, in this paper, we have chosen only the read-only passive tags.

3) Advantages of Sensing Covered Network:

In real life, there are several examples of tracking static objects. Such an example is to find the position of any particular book among multiple of thousands of books even within a room of a library system. One effective way out to track the static objects is to use RFID technology. The required book may be at an arbitrary position in the library. For tracking the book, it must lie within the sensing zone of at least one RFID reader, i.e. every point of the library must fall within the sensing zone of some readers. Such an environment is usually known as *sensing covered field* (Fig. 2). In accordance with the advantage of sensing coveredness, Sau and Mukhopadhyaya [17] had explored sensing covered (1-sensing covered) network in detail. They had also considered the specific restriction $r \geq 2s$(where r is the communication range and s is the sensing range) and proved the uniqueness of localization for a sensing covered network. Some important results from their work are mentioned below.

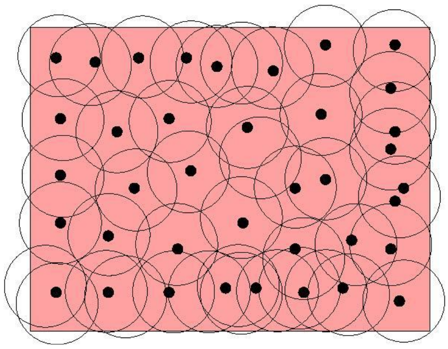

Fig. 2. Sensing covered network.

Result 1: The 1-sensing covered network preserving the restriction $r \geq 2s$ is uniquely localizable excluding some border nodes. For $r < 2s$, the network may not be uniquely localizable even if it is 1-sensing covered.

4) Drawbacks of 1-sensing covered network:

If a region is 1-sensing covered, then using the above result it is understood that the network is uniquely localizable whereas tracking the tags (an event) with unique position in a 1-sensing covered environment is not always guaranteed in the field of interest. If the tag T is identified by only thereader R_1 (Fig. 3), then the position of the tag T may be any pointlocated on the perimeter of the circle with radius TR_1.

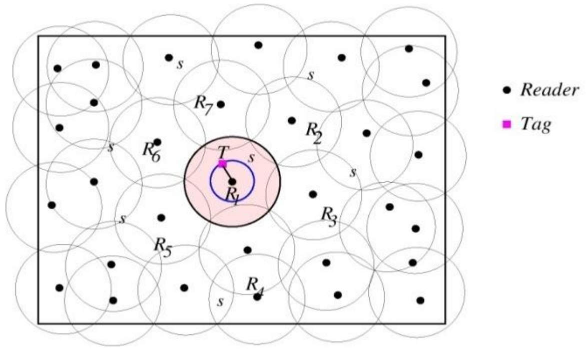

Fig. 3. Drawback of 1-sensing coverage.

In a practical situation, TR_1 may be some 10 to 20 metres. Within this circular region, to find the position of a particular tag among a multiple of hundred of tags is difficult for a human being. To remove this inefficiency of the 1-sensing coverage, 2-sensing covered network has been considered for tracking tags. In 3-sensing covered network, uniqueness of localization is guaranteed, but it requires deployment of larger number of nodes (tag readers) than 2-sensing covered network. Therefore, it is a costly way to make an area of interest 3-sensing covered. Whereas if a library system is under 2-sensing coverage, two possible positions for a particular book is obtained from which the exact position may be chosen by a simple human intervention.

In this paper, we are interested in localization of WSN of readers (sensors) as well as target tracking with noiseless distance measurements.

5) *Drawbacks of using anchors:* In most of the real applications, exact distance measurements may not be possible or costly due to hardware constraints. Sometimes, network localization depends on anchors (nodes whose positions are given). For sparse network, connectivity information is not sufficient for related computations. In this case, using anchors may be helpful but the total number of anchors depends on the total number of nodes in the network. In practical applications, total number of anchors used in a large network is high. In case of random deployment of nodes, assigning positions of anchors is itself an important issue. To recover this difficulty, an anchor-free network has been considered which is more realistic in applications of large scale networks.

6)*Related Works:* In the literature, there exists different methods for tracking objects using RFID technology.

Kalman filtering method is well known due to its robustness and simplicity for identifying and tracking the tags attached with objects[2] [16] [14]. In case of indoor localization, Bekkali et al. [2] adopted an RFID environment which is formed with two mobile RFID readers and expensive land-marks (whose positions are known) for tracking accurately. In this work, the standard Kalman Filtering and a probabilistic RFID map matching method is used to reduce the noise in the position estimation. Their proposed algorithm is based on RSS (Received signal strength) technique due to which it is not energy-efficient.

Zhang et al. [5] used both RFID readers and reference tags (tags deployed at the known locations) to increase the accuracy of the technique of tracking. In their work [5], localization of a target tag is based on varying power levels of readers as well as using some tags whose positions are known to the server. These reference tags creates a “feedback system” which affects tag readability and the accuracy of positions of targets and includes “round off” error too. The interpolation localization technique used in this field also introduces location errors due to the positions of reference tags. Moreover, continuously varying of power of the readers requires a sophisticated hardware. This process is not robust. Zhang et al. [24] experimented the simple DOA (Direction of arrival) method for localizing the passive RFID tags (both stationery and moving tags). Simulation showed that this method is quite helpful for only dense network (closely deployed tags) and is not error-free.

William et al. [10] also used phase difference method for improvement of the accuracy in computation. This technique can be directly adapted with RSS based scene analysis method. Still, the computing technique is not error-free. They used active RFID tags which are expensive and are not energy-efficient too.

C. Our contribution

In real-life applications, if holes exist in the field of interest then none of the reader can sense any target in the holes. That is why, sensing covered region is considered for finding the locations of the targets. The concept of 1-sensing covered network [17] [18] was introduced by Sau and Mukhopadhyaya. According to their work, there may have infinitely many possible locations for a tag. To address this problem we have introduced the 2-sensing covered network of RFID readers. Neither the concept of anchor readers nor the concept of external reference tags is used for computing the positions of target tags because manual computation of the positions of anchor readers or reference tags in the large scale network is difficult. In this paper, characterizations of the 2-sensing covered network are given. Using it, an efficient algorithm is proposed to recognize 2-sensing covered networks accurately. This algorithm is also applicable for the distributed environment.

However, the proposed technique computes the unique positions of the RFID readers. These readers are used as references to compute the co-ordinates of targets. No external reference is used. Our technique is able to compute unique positions for some targets. For each target tag, the algorithm, in the worst case, computes two possible positions out of which one is correct. In addition to, the proposed technique consumes less energy with respect to other existing methods described above.In this work, a heterogeneous model of network is considered with RFID readers and RFID tags. Passive RFID tags are considered for energy efficiency and cost-effectiveness. The proposed technique is also applicable for other environments where active tags are used. A preliminary part of these concept was introduced to a Conference [6]. In this paper, our work is thoroughly expanded with detail analysis and is improved by positioning uniquely the targets even when they lie on borders of the field of interest.

D. Organization of the paper

In the Section II, the basic model of the RFID network and the mathematical representation of localization problem are formally defined. The idea of the 2-sensing coverage of the network and its characterization are elaborately described in Section III. Section IV proposes an algorithm in order to identify the 2-sensing covered networks of readers and then finding the positions of readers including the correctness proof of the algorithm. Section V includes the techniques of target tracking within the 2-sensing coverage of a network. Lastly, a thorough discussion depending on our conclusion is included in the Section VI.

II. BASIC MODEL AND PROBLEM STATEMENT

When an event (suppose any natural disaster) takes place in a region where human intervention is practically difficult or next to impossible, it is a challenge to take care of that event as early as possible. WSN plays a great role in such cases. Sometimes, sensors are randomly deployed in that field of interest from an aircraft or sometimes sensors are placed maintaining a previously defined topology. Our main focus is to localize these sensors using an efficient and error-free technique to take care of that particular event (as the event must be detected by some sensors). In our work, we have considered a wireless network formed of both RFID readers and RFID tags. In this regard, we are going to define formally the localization of readers and tag-tracking below.

A. Model of RFID system as a WSN

In our proposed RFID system, each of the RFID reader has the same transmitting power which is *r*. It means that each reader can contact to another reader by transmitting signals if and only if their distance is not greater than *r*. Moreover, one RFID reader can sense a RFID tag by emitting signals if the tag-to-reader distance is not greater thans. Therefore, if we assume one reader as the centre of any circle, then the tag must be within the circle or on the perimeter of that circle. In this work, it is assumed that the geometric co-ordinates of both the tags and readers are not known after deploying them in a region$\mathbb{R}^2$. The RSSI (Received Signal Strength Indicator) technique is used to measure the actual distance (i.e. error-free) between reader-to-reader and reader-to-tag. Hence, the graphical representation of our proposed model is narrated in the following:

- R represents the set of *m* readers R_1, R_2,…,R_m and T is the set consisting of *n* RFID tags T_1, T_2,….,T_n .
- Consider an undirected and egde-weighted graph *G = (V, E, d)* where V = R ∪ T and *d : E*→ $\mathbb{R}^+$. Note that $\mathbb{R}^+$is considered i.e. distance is positive , because no to readers are deployed in the same position.
- For i ≠ j , $\{R_i, R_j\}$∈ E if and only if the distance between two readers R_i and R_j i.e. *d* (R_i, R_j) = r_{ij}≤*r* and 1 ≤ i ≤ m, 1 ≤ j ≤ n, $\{R_i, R_j\}$∈ E if and only if *d* (R_i, T_j) = t_{ij}≤ *s*.
- Let ρ be the radius of curvature at any point on the boundary of the region of interest.The distance between the centers of any two reader is at least $\frac{s^2}{\rho}$.

Moreover, no two reader can fall at the same position if a constant distance between them is maintained throughout the model.

B.Problem Statement

Let x_i = (x_{1i}, x_{2i}) be the position of the tag T_i for 1 ≤ i ≤ *n*. Let y_j = (y_{1j}, y_{2j}) be the position of the reader $R_j$for 1 ≤ j ≤*m*. Consider X = $[x_1 \ , x_2 \ , \dots , x_n \ ]^T$ be a 2 ×*n* matrix. To find X is the requirement for the model described above. The task of tracking tags is described in the following :

Find X ∈ $\mathbb{R}^{2\times n}$ such that

$$\| y_i - x_j \|^2 = {t_{ij}}^2 \text{ for } \{R_i, T_j\} \in E ,$$
$$\| y_i - x_j \|^2 > s^2 \text{ for } \{R_i, T_j\} \notin E ,$$
$$\| y_i - y_j \|^2 = {r_{ij}}^2 \text{ for } \{R_i, R_j\} \in E ,$$
$$\| y_i - y_j \|^2 > r^2 \text{ for } \{R_i, R_j\} \notin E .$$

The above defined problem is categorically a non-convex optimization problem to solve. To find the exact solution of this kind of problem is practically NP-Hard. The existing methods showed that an approximate local minima can be found for the standard non-convex problem in linear time. In order to reduce these difficulties, one convincing way to solve this type of optimization is to remove the non-convex constraints and thus transforming the original problem into a convex optimization problem. A similar technique has been proposed by Doherty et al [7] for their defined centralized localization problem. With the help of the proximity inputs, they used the semi-definite programming based approach to give the better solution of the convex problem. In [3] Biswas et al. also applied a relaxation technique to solve their SDP for finding the noisy localization problem in a distributed environment. The disadvantages of these techniques are the formulated optimization problem differs from the original problem. Different techniques are discussed in [19] [11] [12] to show whether a sensor localization is uniquely realizable or not. In a general network, Saxe explained that the task of unique realization of a graph model of network is NP-hard even when the distances between the sensors are without error. In case of convex problems, if the input graph is uniquely localizable, it confirms that an unique realization of that graph can be given through SDP optimization in polynomial time [20]. This is not applicable for our model as it is not convex and non-linear too.

Taking into account the difficulties of the general network localization problem, we have designed *2-sensing covered network* for object tracking where each tag is covered by two or more readers. In our work, we are not concerned about the connectivity information and angular measurements which require extra hardware. The problem of tracking RFID tags with this provided model is solved in the following steps.

- In the first step, the positions of the readers are uniquely computed without anchors.
- In the next step, the tag positions are obtained under the model with the readers as references.

In case of *2-sensing covered network*, the readers are uniquely localizable except a few readers which are on the boundary or close to it.

Existing researches on WSN include the detecting mechanism for border sensors. Some of them computed the positions of border nodes with the help of anchors or using landmarks. Accordingly, the total number of anchors or landmarks depends on the size of the network. In stead of using anchors or landmarks, the technique discussedin this paper deduced some geometric restrictions which are able to provide the unique positions of border readers. In practical applications, it is effective for surveillance of border areas of the WSN.

III. 2-SENSING COVERED NETWORK

From the discussion in section II, it is clear that when we need to localize any RFID tag, there is a possibility of getting infinitely many positions (Fig. 3) for the tag. Therefore, these positions may not provide solutions in the real field of interest. That is why, in our proposed model of network, some simple but realistic restrictions are applied as follows.

- The communication range r of a reader is greater or equal to twice of its sensing range s, i.e., $r \geq 2s$.
- Each point in the proposed network of readers is covered by at least two readers.
- Readers and tags maintain generic position which implies that three tags and readers do not fall on the same straight line. .

The condition $r \geq 2s$is considered in order to maintain the quality of service, uniqueness of localization and security of the network. With this restriction, some important properties for the 2-sensing covered network are derived. Unique location of the readers and the tags can be computed with the help of these characteristics. If $r < 2s$, it is shown that the positions of the readers may not be unique i.e. the underlying graph of the readers is not globally rigid in view of the following observation.

Observation 1: If $r < 2s$, then the graph *G = (V, E, d)* defined in section II may not be rigid even if each point of the network is covered by at least two sensors.

Proof 1: We have proved the result by a counter example. $\mathcal{F}$ refers to the field of interest consisting of RFID readers with the restriction $r \geq 2s$, if not mentioned otherwise. One of the goal of our work is to make $\mathcal{F}$, 2-sensing covered. Sau and Mukhopadhyaya had already shown that in case of a 1-sensing covered network preserving the restriction$r \geq 2s$, all of the interior nodes are uniquely localizable along with some of the border nodes. In our model of WSN, some conditions are applied on the shape of the WSN to make it uniquely localizable including all the interior nodes (interior readers) as well as border nodes (border readers). In later part of this section, it is discussed in detail.

Definition 2: A field of interest is said to be under *k*-sensing coverage when at least *k* readers covers each point in that field for k = 1,2,….,n.

A network is 2-sensing covered automatically implies that it is 1-sensing covered too by formation. This basic concept of *k*-sensing coverage is explored in [18] in detail. To ensure clear understanding, necessary results from [18] are mentioned in this paper. For proof of these results, interested person can go through [18]. Throughout this work, $\overline{S(R_i)}$ and $S(R_i)$ symbolizes for the sensing zone and the boundary of the sensing zone of any reader R_i respectively.

Result 2 ([18]): A field $\mathcal{F}$ of readers with $r \geq 2s$ is 1-sensing covered if and only if for each reader R, each point of $\overline{S(R)} \cap \mathcal{F}$is covered by at least one other reader.

With the above mentioned assumptions 2-sensing covered network is explored here and some useful results are discussed in the following.

Theorem 1 (Characterization): The region $\mathcal{F}$ maintaining $r \geq 2s$is 2-sensing covered if and only if, according to each readerR_i, all the points of $\overline{S(R_i)} \cap \mathcal{F}$ lie within the sensing coverage of at least two other readers.

Proof 2: Only if:

Let, the region $\mathcal{F}$ be under 2-sensing coverage of readers. Assume that R_1 is a reader randomly chosen from $\mathcal{F}$. We need to prove that $\overline{S(R_1)}$ is covered by another two readers in $\mathcal{F}$. Take an arbitrary point T from $S(R_1)$ as depicted in(Fig. 4). As $\mathcal{F}$ is 2-sensing covered, the point T must lie within the sensing zone of another one reader R_2.

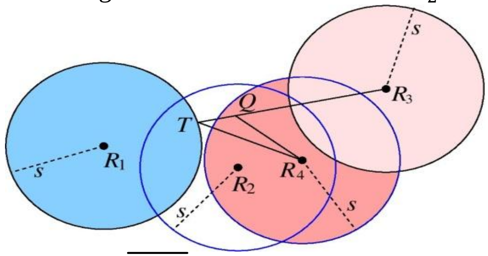

Fig.4. Coverage of $\overline{S(R_i)}$

Suppose, T is closest to a reader $R_3 \notin \{R_1, R_2\}$. If possible , let $TR_3 > s$ and $\delta = (TR_3 - s)/2$. Chose a point Q on TR_3 such that $TQ < \delta$ and QT falls in $S(R_2)$. Hence, $QR_3 > s$. Since none of R_1 and R_3 covers Q, there must exist a reader $R_4 \notin \{R_1, R_2, R_3\}$ covering Q. Thus $TR_3 = 2\delta + s > \delta + QR_4 > TR_4$.This contradicts that T is closet to R_3. Therefore, $TR_3 \leq s$.

If: Take any point from $\overline{S(R_i)} \cap \mathcal{F}$. Suppose, this point is covered by at least two other readers except R_i. Also, take an arbitrary point P in $\mathcal{F}$. Therefore, P must be covered by the range of at least one reader say R_1 (Fig. 5). If possible, suppose that no other reader covers P. Let P be closest to a reader R_2among the readers which cannot sense the point P. Hence, $R_2 \neq R_1$and $PR_2 > s$. Let PR_2 intersects $\overline{S(R_2)}$ at T . As T is covered by one more reader, select$R_3 \notin \{R_1, R_2\}$ such that R_3cannot sense P, otherwise, the result follows. Select a point Q on PR_2 such that Q do not lie in the sensing

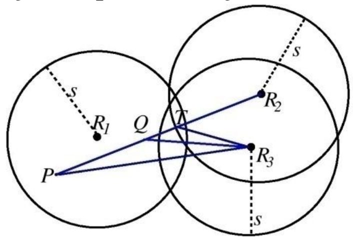

Fig. 5. Each point is covered by two readers.

range of both the readers R_2 andR_3. $PR_2 = PQ + QT + s \geq PQ + QT + TR_3$. From$Q T \Delta_3$,$PR_2 \geq PQ + QR_3 > PQ + s \geq PR_3$. Therefore, $PR_3 < PR_2$. It is contradictory to that $R_2$is closest to P. It implies, $PR_2 \leq s$. Hence the result follows.

Corollary 1: For the prescribed network model (2-sensing covered) of readers which lies in $\mathcal{F}$ with$r \geq 2s$, any intersecting point on the perimeters of any two readers falls within the sensing coverage of at least two other readers.

Proof 3: Proof is done using properties of triangle from geometry.

Finding the positions of the targets is the goal of this work. In stead of using anchors or reference tags, the proposed technique uses RFID readers with self-computing powers. These readers are capable of computing their positions uniquely. The following result is significant in this respect.

Result 3 ([18]): If $r \geq 2s$, a 1-sensing covered network of sensors is uniquely localizable except a few nodes close to the boundary.

Result 4: The interior of the WSN in $\mathcal{F}$ along with some border nodes form a wheel extension.

Lemma 1: Let V' be a set of globally rigid readers from $\mathcal{F}$. Let $\mathcal{F}'$ be the region where the readers in V' collectively 2-sensing covers a region $\mathcal{F}' \subseteq \mathcal{F}$. If $\mathcal{F} \setminus \mathcal{F}' \neq \phi$, there exists a set of readers $X \subseteq V \setminus V'$ such that $V' \cup X$ is globally rigid.

Proof 4: $\mathcal{F}$ is a 2-sensing covered region with $r \geq 2s$. So, all the interior readers are globally rigid. This implies $V' \neq \phi$. The construction of $\mathcal{F}'$ implies that all the readers from V' may not be in the region $\mathcal{F}'$. The readers in V' are denoted by R_i' for $i = 1, 2, 3, \ldots$ (and marked as black bullets in the Fig. 6). The readers from $V \setminus V'$ are denoted by R_j for $j = 1, 2, 3, \ldots$ (and marked as red bullets). The boundary of $\mathcal{F}'$ is denoted by $\overline{\mathcal{F}'}$.

There must exist some points on $\overline{\mathcal{F}'} \setminus \overline{\mathcal{F}}$ for anyone of which a small neighbourhood is obtained in which some points are still in F but 1-sensing covered by the nodes of V' (otherwise it leads to the fact that $\mathcal{F} = \mathcal{F}'$). Suppose, R_1 is the reader from $V \setminus V'$ which covers these points (which are still 1-sensing covered) and do not intersect $\overline{\mathcal{F}'} \setminus \overline{\mathcal{F}}$. Then, there must exist a gap between $\overline{\mathcal{F}'} \setminus \overline{\mathcal{F}}$ and $\overline{S(R_1)}$. It guarantees that there must exist some points in this gap which are still 1-sensing covered. Hence, there exist a reader R_1 from $V \setminus V'$ for which $\overline{S(R_1)}$ intercepts some part on $\overline{\mathcal{F}'}$. In Fig. 6, $\overline{S(R_1)}$ intersects some part on $\overline{S(R_2')}$ at the points P and Q. Therefore, R_1 is adjacent to two readers R_1' and R_2' from V' (as $\mathcal{F}'$ is itself 2-sensing covered). Consider a small deleted neighbourhood $N'(P, \delta)$ at P which contains at least one point which is not still 2-sensing covered. Now, there are two possible cases.

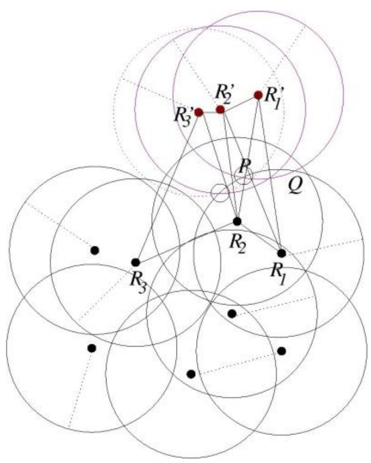

Fig. 6. Localization of border nodes.

1) If this point of $N'(P, \delta)$ is covered by one other reader from V', then R_1 is adjacent to three globally rigid readers $R_1', R_2', R_3' \in V'$. Thus, the position of the reader R_1 is fixed uniquely.
2) If this point of $N'(P, \delta)$ is not covered by one other reader from V', then it must be covered by one reader R_2 from $V \setminus V'$. If R_2 is adjacent to one other reader R_3' from V', a triangle cycle is obtained which is connected with three globally rigid readers and the proof is done. Otherwise $\overline{S(R_2)}$ will intersect at least one point at P_1 on $\overline{S(R_3')}$. At that point, there exist a small neighborhood $N'(P_1, \delta_1)$ with some points which are still 1-sensing covered. Continuing this process, a triangle cycle will be obtained extending this triangle chain. Otherwise, it leads to the existence of a gap between $\mathcal{F}'$ and $\mathcal{F} \setminus \mathcal{F}'$ which remains still 1-sensing covered. It contradicts the 2-sensing coverage of the region of interest F.

Theorem 2: If a network consisting of RFID readers with $r \geq 2s$ is 2-sensing covered by a set of readers V, there exists a set $V' \subseteq V$ such that V' is uniquely localizable.

Proof 5: A 1-sensing covered network of readers with $r \geq 2s$ can be uniquely realizable [18] excluding a few readers which are either nearest to the boundary or fall on the boundary of the field of interest $\mathcal{F}$. In Lemma 1, it is guaranteed that a set of readers $V' \subseteq V$ can be obtained with which $\mathcal{F}' \subseteq \mathcal{F}$ is 2-sensing covered and the readers of V' are uniquely localizable. Then, using Lemma 1, $\mathcal{F}'$ is expanded by including readers in V' from $V \setminus V'$ which will 2-sensing covers $\mathcal{F}$.

IV. IDENTIFICATION OF 2-SENSING COVERED NETWORK

In the previous sections, it is clearly understood from our detail discussion that how much practically useful is the network of RFID readers which is 2-sensing covered.When readers are deployed at a random, a region may not be 2-sensing covered. When this case happens, more readers need to be deployed to achieve the 2-sensing coverage of the region. In this part of our work, we are going tocompute the local coverage for every reader.

Finally, our aim is to integrate them in order to achieve the global coverage. Thus, the procedure of identifying the 2-sensing coverage is done in the distributed way as follows.

- The base station randomly chooses any reader *R* from the field of interest.
- The base station sends a query to *R* to know the coverage of its perimeter.
- *R* fixes its local co-ordinate system taking itself as the origin and computes the position of its neighbouring reader.
- *R* checks its arc for computing its coverage.
- After checking the coverage of *S(R)*, a reader R_1 is selected from the neighbours of *R* and the same procedure is followed by that reader.

- When the coverage of all the neighbour readers of R is completed, this technique continues with the neighbours of R_1 and so on.
- Finally, all the data is sent to the base station to take decision on the coverage of the field of interest$\mathcal{F}$.
- While $\mathcal{F}$ is not 2-sensing covered, the server deploy more readers to fulfill the two-sensing coverage.

There is a geometrical description for Fig. 7. Suppose R_1,R_2 are two readers from the field of interest and they intersect each other. Then, some part of $S(R_1)$ is being intercepted by $S(R_2)$ and this part is the arc MN.

Therefore, $\angle MR_1N = \alpha_2 - \alpha_1$at R_1. As, $\frac{arc\,MN}{s} = \angle MR_1N$, the angular interval $[\alpha_1, \alpha_2]$ represent the arcMN. According to the Theorem 1, for any readerR_i, all the points on $S(R_i)$ must be sensed by at least another two readers. The total arc of $S(R_i)$is represented by the interval $[0, 2\pi]$ of angle (incurredby $S(R_i)$at R_i) in order to compute the coverage of $S(R_i)$.

A. Computation technique for 2-sensing coverage

If we choose readers from $\mathcal{F}$ one by one and it reports that all the points on its boundaryfalls within the sensing range of at least two neighboring readers, then it will be ensured that $\mathcal{F}$ is successfully 2-sensing covered. With our proposed Algorithm 1, every reader $R_1 \in \mathcal{F}$are able to compute such coverage properly.

During this procedure COMPUTECOVERAGE(R_1), three lists of intervals are maintained which are U, I and C respectively. U = List of intervals corresponding to the arcs on $S(R_1)$sensed by none of the neighbor readers of R_1. I = List comprising intervals corresponding to the arcs on $S(R_1)$sensed by exactly one of among its neighboring readers.

C= List of intervals corresponding to the arcs on $S(R_1)$covered by at least two of its neighboring readers. At the beginning of the process, $U = [0, 2\pi]$,$I = \phi$ and $C = \phi$. The technique for computing such coverage is thoroughly described in Algorithm 1 as follows.

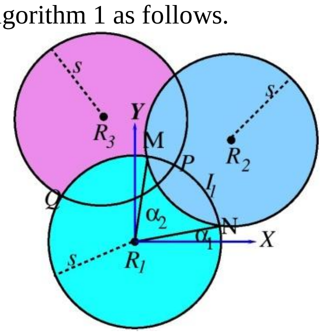

Fig. 7. Technique for computing 2-sensing covered network.

Algorithm 1*2-sensing coverage of a reader*

1: **procedure** COMPUTECOVERAGE(R_1)
2: Initialization: $U = [0, 2\pi]$, $I = \phi$, $C = \phi$.
3: Fix a local coordinate system with origin at R_1,
4: Consider $R_2 \in N(R_1)$,R_2 is a neighbor of R_1.
5: $Q \leftarrow N(R_1)$
6: **while**$Q \neq \phi$**do**
7: $Q \leftarrow Q - \{R_2\}$
8: **Fix**R_2 based on available distances from its neighbors with positions already computed.
9: **Find** interval I_1 of angle created at R_1 corresponding to arc of $S(R_1)$ within $S(R_2)$.
10: **Update**U; I, C accordingly from I_1.
11: **Search**$R_3 \in Q$ such that R_3 is a neighbor of some reader in $N(R_1)$ with position already computed.
12: **if** (searching of R_3 fails) **then**
13: **break to exit the while loop**.
14: **end if**
15: **Set**$R_2 \leftarrow R_3$
16: **endwhile**
17: **if**$C = [0, 2\pi]$ **then**
18: **return** success
19: **endif**
20: **return** failure
21: **endprocedure**

B. Correctness proof of Algorithm 1

The above mentioned algorithm recognizes the 2-sensing covered network distributedly by checking the coverage of $S(R_1)$. The respective procedure running in R_1 is based only on the local messages, no processed data from another reader. That is why, synchronization among the processes which are running in several readers is not an issue. Observation 2 proves the finite termination, progress and correctness of the algorithm.

Observation 2: For any RFID reader R_1who executes the procedure COMPUTECOVERAGE(R_1) always computes the coverage of $S(R_1)$ within finite time.

Proof 6: Let, R_1 be any reader. Choose a reader $R_2 \in N(R_1)$ from the **while**-loop. The process computes MN on $S(R_1)$ intercepted by $S(R_2)$ (Fig. 7). $I_1 = [\alpha_1, \alpha_2]$ is the interval which indicates that the arc MN is incorporated in U, I and C accordingly.

Q consists of all the neighboring readers of R_1 which need to be considered yet in the **while**-loop in order to compute their positions and contributions to the coverage of $S(R_1)$. Select another reader R_3 from Q such that $R_3 \neq R_2$. R_3 is also a neighbor of some reader in $N(R_1)$ whose position is already fixed. Since $\mathcal{F}$ is 2-sensing covered, there always exists suchreader R_3 as follows:

- The arc PQ on $S(R_1)$ intercepted by $S(R_3)$ includes some part of $S(R_1)$ which is already covered by some other reader in $N(R_1)$ and
- Some part of $S(R_1)$yet to be covered by the readers in $N(R_1)$ while $S(R_1)$ is not covered completely.

If not, either $S(R_1)$ is totally covered that means $I = [0, 2\pi]$or $\mathcal{F}$ is not 2-sensing covered. Thus, the progress of the algorithm is ensured. The **while**-loop may transform into an infinite loop whether $\mathcal{F}$ is not 2-sensing covered. Then, the following **if** statement in the line: 14 of Algorithm 1 breaks to exit the **while**-loop. Therefore, it is ensured that the algorithm terminates in finite time. As the no.

of members of $N(R_1)$ is a finite number and all of the RFID readers in $N(R_1)$ considered to be processed in **while**-loop, then according to the Theorem 1, at the termination of the **while**-loop $C = [0, 2\pi]$. It concludes the correctness of the proposed algorithm.

C. Performance analysis

Message communication among the readers dominates other operations for running time as well as energy consumption. We have assumed the challenge in the distributed system of RFID reader is reliable. To maintain the synchronization among the readers, standard techniques are used. A successful execution of Algorithm 1 in a reader ensures the 2-sensing coverage of its locality. 2-sensing coverage of all the individual readers guarantee that the whole network of RFID readers is also 2-sensing covered.

Therefore the complexity analysis of the Algorithm 1 over the complete run of this target tracking task is discussed as follows.

a) ***Time complexity:*** All the readers may run simultaneously to execute Algorithm 1 individually. Therefore, the execution time of Algorithm 1 in the whole run of the target tracking task is equal to the maximum time to run it in the readers individually. So the worst case run time of Algorithm 1 to complete the task is *O*(largest number of neighbors of the individual readers).

b) ***Energy complexity:*** In general, the energy dissipation due to other operations is dominated by the energy dissipation due to message communication over the whole network. Message communication is done in either of the two ways. One of them is each reader communicates with the server and the other is each reader communicates with its neighbors. At the time of communicating with the server directly, the energy complexity will be equal to $O(N)$ in the worst case where N is the total number of readers. For the requirement of locating tags, the readers communicate with its neighbors. The energy consumption for such communication will be proportional to the order of the links or edges in the network.

V. LOCATING THE RFID TAGS IN THE 2-SENSING COVERED NETWORK

When readers are dropped into a field randomly, it is not guaranteed that the field is under the 2-sensing coverage of readers. Due to this, the cases may happen as follows.

1) Suppose, the RFID tag falls in a hole, server cannot be able to find its position.
2) If the tag falls within the 1-sensing covered network, it may not have unique position. It's position may be any point on the perimeter of the circle with radius R_1T with centre at R_1 (Fig.8).
3) When tags falls within a 2-sensing covered network of readers, we can provide upto two possible positions (Fig.9) of tags and in some cases unique position.
4) It is obvious that if a tag is covered by three readers or more, then it gives unique position of the tag. Such an coverage of the field where every point is covered by more than two readers is very costly and it consumes huge energy due to which it is not easily affordable.

In this work, our goal is to track the objects uniquely within a 2-sensing covered network of readers. RFID tags are attached with these objects in the field of interest. So, tracking an object implies tracking the corresponding RFID tag successfully. Section IV designs an algorithm to recognize the 2-sensing covered networks. With the help of Theorem 1, the 2-sensing covered network of the readers is uniquely realizable by forming a wheel extension [18]. In Result 4, we have proved that our proposed network of readers along with some border readers are uniquely localizable. Therefore, we obtain unique position for most of the RFID tags who fall within the 2-sensing covered network of readers. This property enhances the practical usability of our model. When all the unique positions of the readers are computed, the locations of tags is easy to find using the already measured tag-to-reader distance.

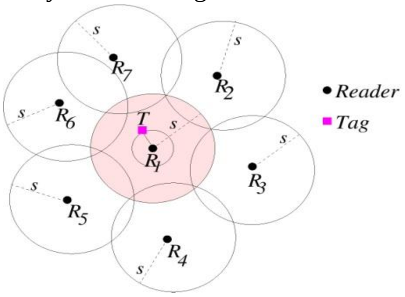

Fig. 8. Locating tags in a 1-sensing covered network.

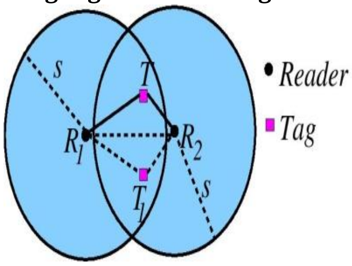

Fig. 9. Locating tags in a 2-sensing covered network.

VI. CONCLUSION

The main key of all the working strategies in a Wireless Sensor Network is the communication among the nodes. The goal of the localization problem stands upon how better the sensors communicate with each other using less energy resources. Therefore, if holes are present in a network, the network automatically becomes weak and it may not be able to work successfully when an event occurs. In fact, if the event falls in the hole region, it cannot be sensed by any of the nodes and thus to take necessary actions for that event is just impossible. That is why, existence of hole in a sensor network leads to a great problem. Generally, the nodes are deployed randomly in a region which not necessarily guarantees the sensing coverage of the region. To overcome these shortcomings, we have proposed a 2-sensing covered network of RFID readers which ensures the sensing coverage of the field of interest. The condition $r \geq 2s$ is strictly maintained at the time of positioning these readers either manually or dropping them from an aircraft. According to the Theorem 1 it is guaranteed that the unique geometric positions of these readers exist and it can be computed easily with our provided strategy.

In this paper, we have also provided an efficient technique to identify whether our proposed model of network is 2-sensing covered or not in a distributed environment. In practical applications, if a wireless network of readers is not totally 2-sensing covered, it can be transformed into 2-sensing coverage efficiently. Due to the defined sensing coverage, our method for tracking tags uniquely is an improvement to the existing techniques and works in a better way in the real environment. Furthermore, using read-only passive tags we have made our method more robust and cost-effective which will motivate other research works in this field.

VII. FUTURE SCOPE OF THE WORK

We have planned to develop localization technique for RFID system including both the readers and the tags forming heterogeneous network without the imposed restrictions like 2-sensing coverage. In this paper, we have worked with an environment where all the distance measurements are assumed to be free from errors. We have also thought of make of an experiment with our technique in a noisy environment. Then, we will do simulations for both the cases to compare the usefulness of the techniques.

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AUTHORS PROFILE

Arpita Dey is currently continuing her research works towards her Ph. D. degree from Jadavpur University. She has completed her B.Sc. in Mathematics & M. Sc. in Mathematics from Jadavpur University in the year 2011 and 2013 respectively. She is now a research scholar under the supervision of Prof. Buddhadeb Sau in the Department of Mathematics, Jadavpur University. Her research interest includes localization in Wireless Sensor Networks, RFID System and its several applications, sensing coverage of sensor networks, object tracking both for static and mobile objects in an environment, path following techniques with the help of mobile robots etc. Her two papers are published in Conferences.

Buddhadeb Sau is currently a Professor in the Department of Mathematics, Jadavpur University. He has completed his B.Sc. degree in Mathematics from University of Calcutta in 1993 and M.Sc. in Mathematics from Jadavpur University in 1995. He has done his M.Tech from Indian Statistical Institute, Kolkata in 2000. He has also completed his Ph. D. degree from ISI, Kolkata in the year 2012. His research area includes Computer Science, Wireless Sensor Network(WSN), Localization of WSN and Adhoc Networks, Graph drawing, Visibility graph, Rigidity of graphs, non-convex optimization problem etc.. His multiple research papers are published in both international conferences and journals.