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# A Distributed Area Based Method for WSN Localization

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## Abstract

A good wireless sensor network localization method tries to raise accuracy and reduce complexity cost, simultaneously. In this regard, a low cost fully distributed method that relies on adjacency constraints is presented in this paper. In this regard, an extended communication range is introduced which guarantees to encompass the communication range of target node with unknown location. Utilizing this extended bound makes cooperative localization possible. Each node finds the most probable square area, by iteratively solving two constrained convex optimization problems using extended bound for target nodes and communication range for anchor nodes. As well as, it is proven that the algorithm converges after finite number of iterations. Also, low communication complexity of the algorithm makes it suitable for many applications. In addition, experimental results of many simulations will show that the proposed algorithm outperforms seven other well-known range-free methods in homogenous and heterogeneous networks, also has acceptable run time than its counterparts.

**Keywords:** Wireless Sensor Network, Localization, Range Free, Cooperation, Convex Optimization, Distributed Computing.

## 1. Introduction

A wireless sensor network (WSN) is a network of wireless nodes which monitor environmental conditions using different types of sensors. The acquired information from each node is useless as long as its location is unknown. Localization algorithms try to find the estimated location of target nodes (with unknown locations) using the location of anchor nodes (nodes have been equipped with GPS or have been located in pre-known locations) and connectivity information of nodes.

Localization algorithms could be classified into different categories, as we discuss below.

Processing the information (e.g. measurements) of nodes for estimating the locations of target nodes could be carried out in two distinctive fashions: centralized or distributed. In centralized methods, information from all nodes of the network is collected by a fusion center. While in distributed methods, central unit does not exist and nodes act with their neighbors reciprocally to estimate their locations. it scalable easily [1] and attractive for large-scale networks.

In traditional localization algorithms, a number of anchor nodes connect to one or more target nodes. Thus, preciseness of the algorithm is proportional to the number of anchor nodes. In cooperative algorithms, both anchor-target connections and target-target connection are considered to improve the accuracy of location estimation. Therefore, in situations where there is lack of anchor nodes or the method should be cost effective, cooperative algorithms are more desirable.

On the other hand, localization algorithms could be range based or range free. In range based algorithms, different measurements techniques are used by sensor nodes. AOA[1] method finds each sensor's location by evaluating the angle of the input signal it receives [2-4]. Also, in TDOA[2] method, distance between the transmitter and the receiver is computed using the relationship between the speed of light in vacuum and carrier signal frequency [5, 6].

As well as, in RSS method, measuring RSS is used to estimate distances between sensor nodes applying precise model of RSS-distance dependency [7, 8]. As well as, Wu et al. [9] utilized RSS-based localization method to localize infrastructure nodes in two steps: first, coarse-grained localization with RSS-based method, then a fine-grained localization is done using iterative offline inference.

In range free localization algorithms, sensors do not perform any measurement. Actually, the estimation of unknown locations is computed using only connectivity information [10]. Range-free algorithms have applications in coarse grain scenarios which does not need precise location estimation for sensors.

DV-hop approach is a well-known range free method. In this algorithm, first the number of steps between two anchors is counted, then the distance between two nodes divided by the number of steps and approximate distance is obtained for each step. Given the number of steps that it is far from an anchor node and approximate distance for each step, the estimated location for that target node could be obtained [11-15]. LAEP method is an extended DV-hop method which utilizes WSN parameter to derive the expected hop process for computing the distance between any pair of nodes precisely. This method has better accuracy than DV-hop with less communication complexity [16].

Approximate Point in Triangle (APIT) is the proposed method by Tian He et al. [17]. Which anchor nodes are equipped with high powered transmitter. The algorithm divides the field to triangulars between anchor nodes. Being in the inner side or outer side of traingulars makes narrower the possible places where a target node locates.

APIT algorithm consists of four steps: (1) beacon exchange, (2) Point-in-Triangulation (PIT) test, (3) position calculation. Next, we describe each step.

Jilong Liu et al. introduced novel virtual nodes-based range-free localization scheme to improve the APIT scheme [18].

Also, L. Yi et al. proposed an enhanced hybrid localization algorithm with combining the advantages of APIT algorithm and DV-Hop algorithm. The proposed hybrid algorithm can improve the localization accuracy but it has high computational complexity [19].

Another range free method developed by Shang et al. [20, 21] and improved in [22]. The method uses MDS[3] to construct a geometric picture from distance-like data.

In MDS algorithm, first, the shortest paths (i.e., the number of hops) between all pairs of nodes are computed. Then, using shortest paths values, a distance matrix is constructed. Then multi dimensional scaling is applied to the distance matrix and an estimated value of the relative coordinates of each node is computed. Finally, absolute coordinates are obtained from the relative coordinates by substituting the absolute coordinates of anchors for the estimated relative coordinates. MDS algorithm often has good performance when nodes are positioned uniformly in space, but it is currently a costly solution.

R. Nagpal et al. [23] presented a WSN localization method with forming a Coordinate system using local communication by distributed computations. The algorithm works well, except when the number of neighbors of a target node is less than 15.

In centroid [24] algorithm target nodes estimate their location as the centroid of the location of anchor nodes in their communication range. This method is not precise and at least one anchor neighbor node is needed for location estimation of each target node.

In another range-free method proposed by J. Sheu et al. [25] each target node collects the required information via two-hop flooding. Also, each target node uses a simple method to calculate the estimated rectangular area. Improved grid-scan algorithm is used to find the initial location estimations for target nodes and a vector-based refinement method is utilized to correct the initial estimated locations.

Also, CPE method proposed by L. Dohetry et al. [26], considering WSN localization problem as a linear or semidefinite program. The authors of CPE algorithm first provide an optimization concept, and then the locations of target nodes in a WSN are found as a result of a joint optimization problem. Also, an abstract optimization model is used to explain how they find the smallest rectangle for each target node. Nevertheless, the method in [26] is fully cooperative; therefore, it can be considered as a benchmark algorithm that one compares other range-free algorithms against it. However, CPE is centralized and it is not amenable to distributed implementation.

Also, Xiang et al. [20] proposed an iterative distributed algorithm to perform cooperative localization. The method uses non-connectivity constraints which hinders distributed implementation because it requires communication with non-neighbors. In addition, it is not specified how set intersections are carried out in practice.

It is worth considering that approximated energy which is needed to execute three million instructions is equivalent to the energy which is needed to broadcast 1 bit of information over 100 meters [27].

Given that, measuring distance between sensors in range-based methods raises energy consumptions in sensors and requires extra hardware, we proposed a new distributed range-free method which is fully cooperative. The proposed method uses convex optimization techniques to find the bounding boxes that guarantee to contain the locations of target nodes.

Besides good location estimation, the proposed method is fully distributed, which allows having small nodes with small amount of memory and energy to do small amount of computation separately. In addition, being a distributed algorithm, makes it scalable easily [1] and attractive for large-scale networks.

The rest of the paper is organized as follows. Section 2 has described the system model; section 3 defines a distributed area based method for WSN localization. In section 4, the convergence proof of the proposed algorithm is pointed out. Section 5 presents comparison of the algorithm and with other methods. Section 6 discusses about the pros and cons of the proposed algorithm and finally, the paper is concluded in Section 7.

## 2. System Model

Location of M target nodes are unknown ($x_i \in \mathbb{R}^m$; i=1,…, M) and positions of N anchor nodes are priorly known ($a_j \in \mathbb{R}^m$; j=M+1,…, M+N).

Also, Neighborhood of target node i is defined as:

$$N_i = \left\{ k \middle| \begin{matrix} k \neq i, \text{node } k \text{ is in the communication range of} \\ \text{node } i \end{matrix} \right\} \quad (1)$$

where $N_i$ shows the set of nodes which are in the communication range of node i.

Also, R is equal to the maximum communication range in different angles, which is a very common assumption in many methods [20, 26, 28, 29], so, a ball-shaped outer bound is used in this paper.

Communication range could be affected by many parameters. However, upon inspection of the proposed algorithm it becomes clear that it does not need to rely on the exact communication range and a simple outer bound for the communication range is sufficient. For this reason, a ball-shaped outer bound is used in the proposed method which is very simple. It should be noted that we are not the first to consider such an outer bound.

In general, we could approximate the outer bound on communication pattern more accurately by using ellipsoids instead of balls. However, we avoid this because it increases the communication cost by transmitting the m by m matrix which characterizes an ellipsoid. This demands communicating $O(m^2K)$ scalars which increases the communication overhead significantly as complexity becomes quadratic in m.

Figure 1 shows a small WSN with two target nodes and two anchor nodes. Target node $x_1$ could find its estimated location using location information of anchor nodes $a_1$ and $a_2$; while target node $x_2$ find its estimated location using location estimation of target node $x_1$, only with cooperation.

The system parameter in this paper has been shown in table 1.

Table 1. Setting of the system model

| **The parameter** | **Setting** |
|---|---|
| WSN dimension | m |
| #target nodes | M |
| #anchor nodes | N |
| Communication range of node i | $R_i$ |
| Field shape | Square (S×S)($m^2$) [30] |

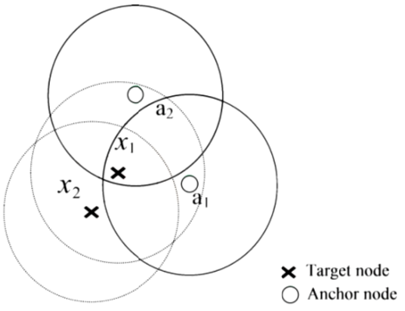

Figure 1. Cooperative localization in a small WSN

## 3. A Distributed Area Based Method for WSN Localization

Every adjacency constraint for a target node makes a feasible set which restricts the location of that target node. Needless to say, increasing the number of adjacency constraints shrinks the feasible set.

Let's define adjacency constraint for two nodes as:

$$\left\|x_i - z_j\right\|_2 \le R_j;\ j \subseteq N_i \tag{2}$$

$$z_j = \begin{cases} \hat{x}_j, & \text{for target node jth} \\ a_j, & \text{for anchor node jth} \end{cases} \tag{3}$$

where $\hat{x}_j$ is estimated location for target node j. Simply, relation (2) could be rewritten as:

$$x_i \in B_j \tag{4}$$

$B_j$: ball shaped outer bound for node j with radious $R_j$

Relation (4) could be generalized for situation that target node's location is constrained by several adjacency constraints through:

$$x_i \in F_i = \cap_{j \in N_i} B_j \tag{5}$$

In other words, $x_i$ is located in the convex intersection area of its neighbors' ball-shaped outer bounds. Relation (5) includes two types of adjacency constraints: anchor-target and target-target constraints.

Computing such convex hull is difficult. Hence, the convex hull is approximated by an outer bounding box as follow [30]:

$$\begin{aligned} &\text{maximize} \|h - g\|_\infty \\ &\text{subject to } x, y \ \in F_i \end{aligned} \tag{6}$$

where, h and h are two points in the convex hull. Rewriting non-convex optimization problem in (6) to a convex problem results in [30]:

$$\begin{aligned} &\text{maximize}_{x;y} \max(|h_1 - g_1|, \dots, |h_m - g_m|) \\ &\qquad \text{subject to } h, g \in F_i \end{aligned} \tag{7}$$

With a straightforward manipulation (δ is a dummy variable):

$$\begin{aligned} &\max\{f_1, \dots, f_n\} \ge \delta \Leftrightarrow f_1 \ge \delta \text{ or } f_2 \ge \delta \ \dots \text{or } f_m \ge \delta; \\ &f_i = |h_i - g_i|, i = 1, \dots, m \end{aligned} \tag{8}$$

Thereupon, two second order cone programs could be achieved in each dimension (d=1, …, m) as follows:

$$\underset{\substack{\delta \in \mathbb{R}, x \in \mathbb{R}^m \\ \text{subject to } \|x - z_i\| \le R, i=1,\dots,N+M \\ x_d \ge \delta}}{\text{maximize}} \quad \delta \tag{9}$$

$$\underset{\substack{\delta \in \mathbb{R}, x \in \mathbb{R}^m \\ \text{subject to } \|x - z_i\| \le R, i=1,\dots,N+M \\ x_d \le \delta}}{\text{minimize}} \quad \delta \tag{10}$$

The bounding box's four sides could be obtained through (9-10).

Now, let $BB_j$ denotes the bounding box which contains target node j with diagonal=2l and center=cb. As well, assume $B_j$ represents the ball-shaped outer bound for target node j with radius R and center c.

Let suppose that target node k is one of neighbors of target node j. Knowing coordinates of $BB_j$ could makes the obtained feasible set for node k tighter.

In this regard, extended ball-shaped outer bound for target node j could be figured simply. This extended bound always guarantees that contains neighbors target nodes.

In worst case the exact location of target node j could be on the edges of $BB_j$. Dashed balls in figure 2 could show an example for the areas which could be considered as probable communication range of target node j (in worst cases).

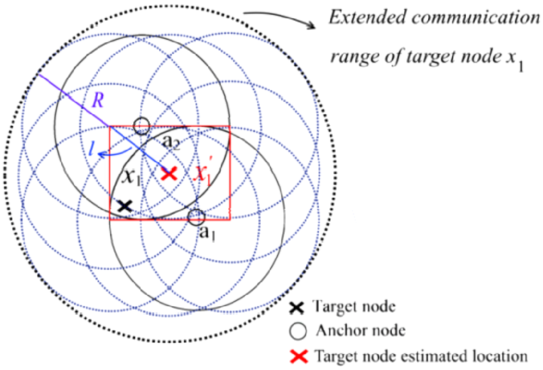

Figure 2. Outer bound of target node $x_1$ location estimation (black dotted line ball)

Using probable communication range of target node j, extended communication range of target node j could be approximated with an outer bound. This outer bound for target node j is formed as extended ball $EB_j$ with radius R+l and center cb. So, in relation (9-10) $R_j$=R+l for target node j. Figure 2 depicts this outer bound (black dotted line ball) in an for target node 1.

In light of previous statements Algorithm I demonstrates the proposed algorithm. The algorithm finds the most probable area which includes the target node's location.

**Algorithm 1. Distributed and cooperative area based WSN localization method**

```
Begin
  — Set the estimated location of all nodes as the center of the field
    and their bounding box as the whole field (=$BB_{j,0}$; j=1,…, M ).
  for k=1 to K (predefined number of iterations) do
    for j=1 to M (the number of target nodes) do
      — Find $BB_{j,k}$ (updated bounding box outer approximation of
        target node j in k'th iteration) solving following problems in
        each dimensions:
          maximize $_{\delta\in\mathbb{R},x\in\mathbb{R}^m}$ $\delta$
            subject to $\|x_j - z_{i,k}\| \le R_i, i=1,\dots,N+M$
            $x_d \ge \delta$
          minimize $_{\delta\in\mathbb{R},x\in\mathbb{R}^m}$ $\delta$
            subject to $\|x_j - z_{i,k}\| \le R_i, i=1,\dots,N+M$
            $x_d \le \delta$
        where $R_i=R+l_{j,k}$ is the radius of the extended ball of target
        node j in iteration k'th ($l_{j,k}$ is half of diagonal of $BB_{j,k}$) and
        $R_i=R$ for anchor nodes.
      — Update $EB_{j,k}$ for target node j.
      — Set $\hat{x}_{j,k} (= z_{j,k})$ as the center of $BB_{j,k}$.
      if $\hat{x}_{j,k}$ was outside the field
        — Change $\hat{x}_{j,k}$ to the nearest point of field
          coordinates.
      end
    end
  end
```

## 4. Convergence Proof

**Lemma 1:** We provide an outer bound on nodes locations by specifying a bounding box that guarantees to contain the target node's location.

**Proof:**

For ease of manipulation let's define $EB_{j,k}$ as extended ball-shaped outer bound for target node j (in iteration k'th). Also, $B_{j,k}$ is defined as follow (ball-shaped outer bound for node j):

$$B_{j,k} = \begin{cases} EB_{j,k}; \text{for target node j} \\ B_j; \text{for anchor node j} \end{cases} \tag{11}$$

It is clear that for any target node j, $x_j \in BB_{j,0}$; j=1,…, M. Assuming that for any target node j, $x_j \in BB_{j,k}$ for some k≥1. For each node $p \in N_j$:

$$\|x_j - z_p\|_2 \le R_p \tag{12}$$

Also, similar to the assumption for node j, $z_p \in BB_{p,k}$ and the area which could be considered as its extended communication range is:

$$EC_{p,k} = BB_{p,k} + \{B_p(c) | c \in BB_{j,k}\} \subseteq EB_{p,k} \tag{13}$$

where c is the center of the ball.

Also, relation (12) results in:

$$x_j \in \cap_{p \in N_j} EB_{p,k} \tag{14}$$

So, $BB_{j,k+1}$ will be obtained, by solving:

$$\begin{aligned} &\text{maximize} \quad {}_{\delta\in\mathbb{R},x\in\mathbb{R}^m} \quad \delta \\ &\quad \text{subject to } \|x_j - z_{p,k}\| \le R_p, p=1,\dots,N+M \\ &\quad x_d \ge \delta \end{aligned} \tag{15}$$

and

$$\begin{aligned} &\text{minimize} \quad {}_{\delta\in\mathbb{R},x\in\mathbb{R}^m} \quad \delta \\ &\quad \text{subject to } \|x_j - z_{p,k}\| \le R_p, p=1,\dots,N+M \\ &\quad x_d \le \delta \end{aligned} \tag{16}$$

Therefore:

$$x_j \in \cap_{p \in N_j} = EB_{p,k} \subseteq BB_{j,k+1} \tag{17}$$

Relation (17) means that the obtained bounding box in iteration k+1, guarantees to contain node j.

**Lemma 2:** it is guaranteed that the set $BB_{j,k}$ shrinks in each iteration and thus converges to a final minimal set. This happens due to the following relationship:

$$BB_{j,k+1} \subseteq BB_{j,k};\ j = 1, \dots, M \text{ and } k = 0, \dots, K \tag{18}$$

**Proof**:

1. k=0: $BB_{j,0}$ is equal to whole field .
2. k=1: without loss of generality: assuming that target node j has at least one anchor node in its neighborhood, solving (15-16) provides:

$$BB_{j,1} \subseteq BB_{j,0} \tag{19}$$

3. k=2: for $p \in N_j$, from the assumption in previous step:

$$BB_{p,1} \subseteq BB_{p,0} \tag{20}$$

thus: $EB_{p,1} \subseteq EB_{p,0}$ consequently, by solving (15-16):

$$BB_{j,2} = \bigcap_{p \in N_j} EB_{p,1} \subseteq BB_{j,1} = \bigcap_{p \in N_j} EB_{p,0} \tag{21}$$

4. Repeating steps 2 and 3 for k=3, …, K, provides:

$$BB_{j,k} = \bigcap_{p \in N_j} EB_{p,k-1} \subseteq BB_{j,k-1} = \bigcap_{p \in N_j} EB_{p,k-2} \tag{22}$$

or simply:

$$BB_{j,k+1} \subseteq BB_{j,k} \tag{23}$$

# 5. Results

In this section, first the effect of increasing the number of iterations on the mean error of location estimation in homogeneous and heterogeneous WSNs are discussed, and then the effect of increasing ratio of anchor nodes on the size of bounding box (Bbox) is shown due to the experimental results of the proposed algorithm.

In the next subsection, performance of the proposed algorithm would be compared with some other famous range free algorithms. In the third subsection, communicational complexity of the proposed method is compared with other considered range free algorithms.

Finally, in the fourth subsection, run time of the proposed method is compared with other methods through simulations.

## 5.1. Reduction Ratio of Bounding Box's Size

Every experiment has been done 50 times in different random topologies and the average results have been presented. The proposed method was simulated on a network with N+M=200, K=3, S=500 (m) and N=40, 60, 80 [31] with different number of iterations. Considering a homogeneous network, communication ranges (R) for all nodes are equal and in this section R=50 (m).

As it was explained in previous section, the size of bounding box for each target node is reduced in each iteration.

As it is clear in the figure 3, after iteration 3 the slope is reduced. Hence, from now on, the appropriate number of iterations is set equal to 3.

Also, the size of bounding box is proportional to the ration of anchor nodes. Figure 4 shows how the reduction of average size is happening for bounding boxes with increasing the number of anchor nodes.

All of the simulations have been implemented in MATLAB 8.3 (R2014a) and the average RMSE has been reported over 50 different random topologies of fully connected networks. Simulations are carried out with considering K=3, S=500 (m) and N=20 [31] with different number of target nodes.

Communication ranges (R) for all nodes are equal and R=50 (m). The number of target nodes (M) varies between 20 and 180. APIT [17], Centroid [24], Amorphous [23], DV-hop [11] LAEP [16], Vector refinement [25] and CPE [26] algorithms have been simulated for comparison.

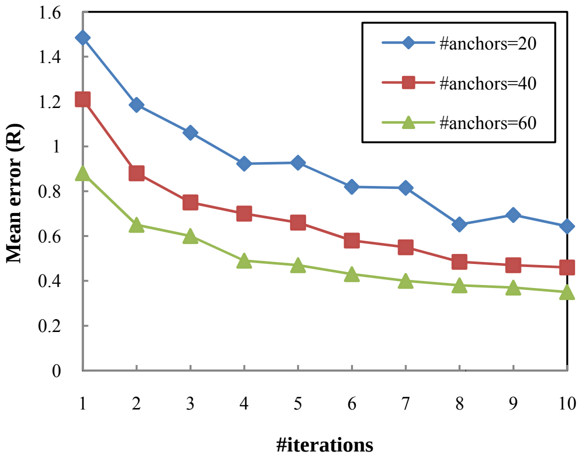

Figure 3. Effect of increasing the number of iterations on the mean error of estimation (as a coefficient of R (m))

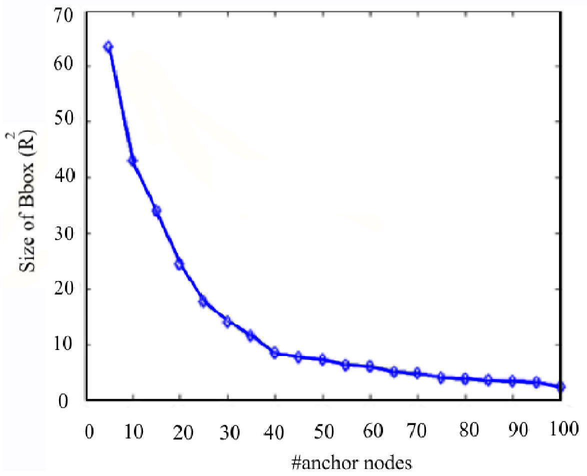

Figure 4. The effect of increasing ratio of anchor nodes on the size of bounding box (Bbox)

Figure 5 depicts that Centroid method has the poorest performance among rest because has higher values of RMSE.

Vector refinement method has better accuracy than Centroid. Also, amorphous method has slightly better performance than Centroid method in term of RMSE. The third place in error of estimation belongs to Apit method as it is clear in the figure 5. Dv-hop method has better location estimation performance than Apit (Figure 5). Also, LAEP method shows better efficiency that Dv-hop. CPE method as the bench mark method in range free algorithms has a gentle slope for changing the number of targets between 10 and 180.

The performance of the algorithm is better than the others (Figure 5). The low slope of RMSE for the proposed method shows that how much the algorithm's cooperation method optimally works and it suppresses the effect of could conquer the effect of increasing the number of target nodes with fixed number of anchor nodes. It is worth noticing that CPE method is a centralized method and the proposed method is fully distributed, regarding this, the performance of the proposed method is acceptable.

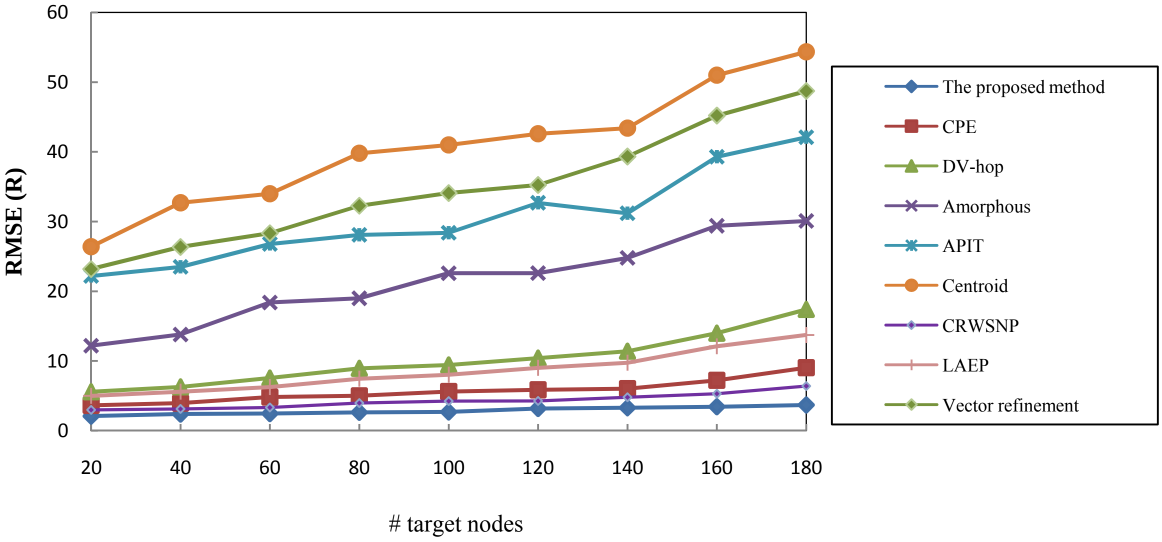

Figure 5. Comparison of the proposed method with 7 other range-free algorithms in in hemogeneous WSNs

RMSE for the proposed algorithm is always between 2.11× R and 3.7×R, which is between 3.44×R and 6.9×R for CPE method and too high for the others.

As a consequence, figure 5 illustrates that in different topology of the network, the proposed method has more efficiency in terms of RMSE to find the target nodes location than other range free methods in homogeneous WSNs.

In this article it is assumed that each sensor has the homogeneous communication range, while in practice, communication range is not homogeneous. Environmental effects such as fading, shadowing and presence of obstacles cause irregularity in communication range, so different nodes might have different outer bounds.

For modeling such impacts in communication ranges of nodes, quasi unit disk graph (Q-UDG) model is used [32-34], which is closer to reality because considers probable existence of obstacles. In this model, irregularities of the communication ranges are adjusted by parameter ε. In Q-UDG model, communication range of each node could be any value of r, $r = (1 - \varepsilon) \times R_i$ , where $0 \leq \varepsilon \leq 1$ and $R_i$ is the maximum communication range in each direction, Figure 6.

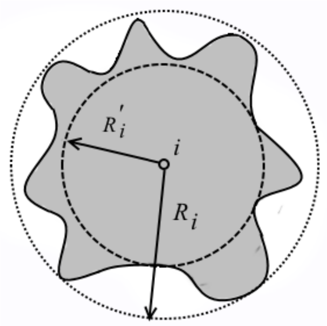

Figure 6. Communication range of node i, $R'_i \leq r \leq R_i$ ($R_i$ and $R'_i$ are minimum communication range and maximum communication range, respectively)

D stands for the Euclidean distance between two nodes. So, if $D \leq r$, the two nodes are connected. Otherwise, if $D > R_i$, two nodes aren't connected. Also, if $r < D < R_i$, there is probable mutual connection between two nodes with uniform distribution. The proposed method is simulated with irregular communication ranges of nodes. Here, 50 random networks with different number of target nodes and fixed number of anchor nodes (N=20) are of concern.

Figure 7 depicts the RMSE comparison for the proposed method and other range free localization algorithms when ε = 0.4. In this figure, R is equal to the 50 and it's the average value of r for all nodes. Figure 7 shows that the performance of the algorithm is better than the others in irregular communication ranges. In general, an increase in communication irregularity decreases the possibility of hearing beacon packets from neighboring nodes, and results in increasing the RMSE.

## 5.2. Communication Complexity

In wireless sensor networks (WSNs), two types of complexities are of concern: communication complexity and computational complexity. It is considerably more costly to transmit a scalar than to compute a sum or product.

Therefore, the main figure of merit is communication complexity [27].

The simplicity is the key factor of the proposed method which makes it superior in low communication complexity among other range-free algorithms. This argument is discussed below in details:

The only information that is transmitted in the proposed algorithm is the (estimated) location of sensor and anchor nodes. That is, each sensor/anchor broadcasts its position at the end of every algorithm's iteration. Therefore, assuming K iterations, the communication cost per node is O(Km) which is linear in problem dimension. In the same manner, the total communication cost for all sensors becomes O(KMm), which is the total communication cost in WSN. It is both linear in number of sensors and problem dimension.

Also, APIT method communication complexity is O(MmL), where L is the number of APIT [17] tests. Centroid algorithm [24] communication overhead is O(Mm) which is the lowest among all approaches considered, although its accuracy is low and it is not cooperative.

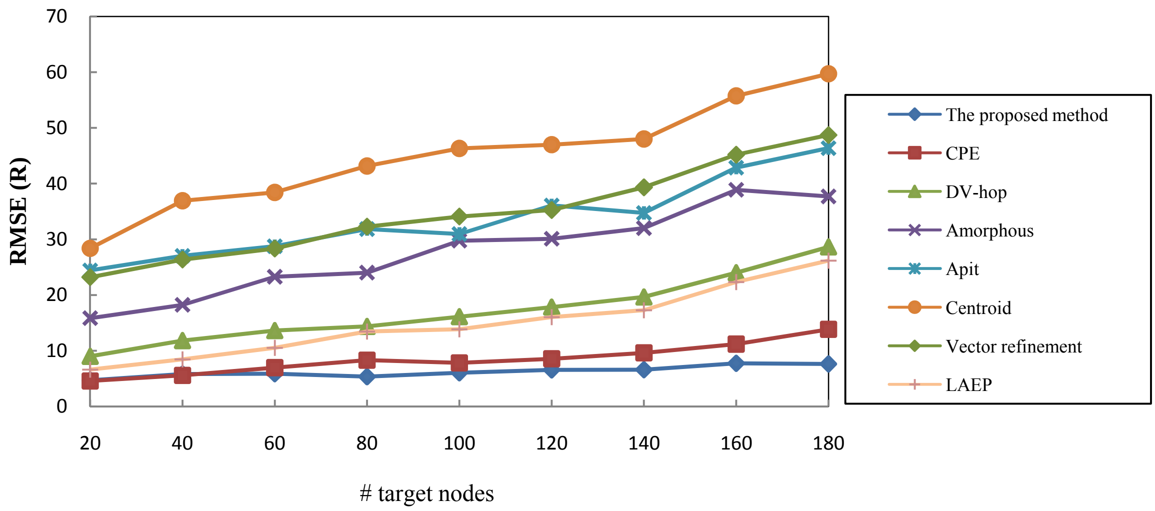

Figure 7. Comparison of the proposed method with 7 other range-free algorithms in heterogeneous WSNs

As well as, communication complexity of Amorphous method is $O(Mm\max_s h(s)$ (h: the numbers of hops in the algorithm).

Also, communication complexity of DV-hop [11] method is bounded by $2O(NM)$. Also, Communication complexity of CPE algorithm [26] as the benchmark for range –free and cooperative algorithms is $O(K(M + N)m)$. As it is obvious in previous statements, communication complexity of the proposed method is acceptable along with good accuracy among other mentioned methods.

## 5.3. Run Time Comparison

To demonstrate the efficiency of the proposed method, average run time of the proposed algorithm has been compared with its counterparts, in table 2 along with their RMSE for N=20 and M=40.

Note that this run time is the metric that shows average amount of runtime when the localization method is simulated in Matlab environment and it does not show runtime on real test bed, where each node has its own processor.

In this regard, average runtime of each algorithm over 50 simulations with random topologies are considered. All algorithms are simulated on same computer with 1.6 GHz CPU and 2 GB RAM and the network has same characteristic as section 5.1.

Second column of table 2 shows the runtime of simulation for different range-free algorithms. Centroid algorithm has the lowest runtime but also has the lowest accuracy among all the algorithms. The proposed method has the lower run time than other methods but slightly more than Centroid method. Also, run time of APIT method is more than all of other methods. Table 2 shows that the proposed method has acceptable runtime in comparison with the other range-free methods and LAEP method's runtime is a little lower than APIT.

According to above discussions the proposed method promises to have acceptable accuracy with almost low run time. It provides better accuracy than CPE method (which is the benchmark range free method) because of its distributed nature.

Also, runtime of the proposed method is slightly more than Centroid algorithm (which has the lowest run time in range free algorithms).

Vector refinement has more runtime than the proposed method.

As well as, distributed nature of the proposed algorithm make it capable to scale up for large networks easily.

Also, it is worth nothing that because of simple nature of the algorithm, it does not need very sophisticated and time-consuming settings.

Table 2. Comparison of the proposed method with its counterparts along with their RMSEs for N=20 and M=40

| The Localization Algorithm | Average Runtime(s) | RMSE (R) |
|---|---|---|
| APIT [17] | 24.54 | 23.5 |
| Centroid [24] | 6.11 | 32.7 |
| Amorphous [23] | 22.38 | 13.8 |
| DV-hop [11] | 18.76 | 6.3 |
| CPE [26] | 21.43 | 3.56 |
| Vector refinement [25] | 14.9 | 26.37 |
| LAEP [16] | 23.45 | 8.46 |
| The proposed algorithm | 10.69 | 2.4 |

## 6. Discussion

As the previous section demonstrates, the proposed method has acceptable accuracy in comparison with considered range-free methods, although it is still low compared with range-based methods. Communication overhead of the algorithm is acceptable among other methods. Also, the proposed method does not need any extra initialization and the number of iteration is set to be 3 in all experiments. But, it is possible for some different scenarios to have more or even less number of iteration to perform more optimal.

Also the extended bound radius is the worst case and it has to determine more effectively through more researches.

The computation complexity of the proposed method is directly dependent on the optimization problem which is solved to find the bounding box area and it could be reduces through finding new methods with lower complexities. As well as, communication complexity of the proposed method is low and this helps energy saving.

# 7. Conclusion

WSN localization is a key factor in many applications, like routing and etc. Because range based methods require additional hardware and have higher energy consumption, particularly, a new range free algorithm has been presented in this paper, which trade-off accuracy for simplicity as it only measures proximity of nodes. However, it does not rely on any external hardware to do so.

Being cooperative allows having good location estimation even with low number of anchors. Distributed nature of the algorithm makes it easily applicable in large scale networks. The main idea behind the proposed method is to find the smallest rectangular area which contains each target node through solving two constrained convex optimization problems. Also, a new kind of cooperation has been presented with extended communication range for target nodes. The bounding box area iteratively shrinks because cooperation makes estimation more precise after each iteration.

Also, in comparison with seven other well known localization algorithm, the proposed method is of better efficiency in homogeneous and heterogeneous WSNs. Runtime comparison and communication complexity analysis show the acceptable performance of the proposed method.

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[1] Angle of Arrival
[2] Time Differences of Arrival
[3] Multi-Dimensional Scaling