

# Localization of WSN using Distributed Particle Swarm Optimization algorithm with precise references

Ravichander Janapati<sup>1</sup>, Ch.Balaswamy<sup>2</sup>, K.Soundararajan<sup>3</sup>

<sup>1</sup>Department of ECE, SR Engineering College, Warangal, India.  
ravi\_chander\_j@srecwarangal.ac.in

<sup>2</sup>Department of ECE, QIS Engineering College Ongole, India.  
ch.balaswamy7@gmail.com.

<sup>3</sup>Department of ECE, TKR Engineerig College, Hyderabad, India  
soundararajan\_jntuacea@yahoo.com

**Abstract**—Localization is the key research area in Wireless Sensor Networks. Finding the exact position of the node is known as localization. Different algorithms have been proposed. Here we consider a cooperative localization algorithm with censoring schemes using Crammer Rao Bound (CRB). This censoring scheme can improve the positioning accuracy and reduces computation complexity, traffic and latency. Particle swarm optimization (PSO) is a population based search algorithm based on the swarm intelligence like social behavior of birds, bees or a school of fishes. To improve the algorithm efficiency and localization precision, this paper presents an objective function based on the normal distribution of ranging error and a method of obtaining the search space of particles. In this paper Distributed localization algorithm PSO with CRB is proposed. Proposed method shows better results in terms of position accuracy, latency and complexity.

**Keywords**—censoring schemes, cooperative Wireless sensor networks, Crammer Rao Bound (CRB), Distributed localization, Particle swarm optimization (PSO), swarm intelligence.

## I. INTRODUCTION

Location awareness is rapidly becoming an essential feature for many commercial, public service, and military applications in WSN [1], [2]. Information collected or communicated by wireless node is often meaningful only in conjunction with knowledge of the nodes location. Network nodes cannot be manually positioned or located by a central system administrator hence nodes must have the capability to self-localize in a practical environment [3], [4]. To perform localization the position estimation can be based on received measurements. Two popular measurement techniques are range and angle estimation. Range estimation is used to measure the distance between two nodes. These range measurements can be used to indicate possible positions in the form of circles in two

dimensional cases. The common intersection of these circles can be used as a position estimate of the mobile node. For angle estimation nodes need to determine arrival of direction of the incoming signals. These measured angles of arrival can be used to present a line on which the transmitting node must be located. Intersection of the lines gives an estimation of the position of the mobile node and it is referred as triangulation. Radio signal exchanges between nodes assists them to estimate the distance to each other, by taking out some physical quantities such as the Received Signal Strength (RSS), Time of Flight (TOF), Time Difference Of Arrival (TDOA), Angle of Arrival (AOA) from the signals travelling between them. In indoor environments Wireless signals are affected by noise because of non-line-of-sight, multipath and multiple access interference [5]. Localization algorithms can be classified into different types:

### 1.1. Centralized Versus Distributed

In centralized localization central processor calculates the locations of all agent nodes. Central processor collects measurements from anchors as well as agents and computes the positions of all the agents. Centralized algorithms are generally not scalable so unfeasible for large networks. In distributed localization there is no central controller and each agent node determines its own location based on the neighborhood collected information. Distributed algorithms are scalable to fit for large networks [6].

### 1.2. Non-cooperative Versus Cooperative

In a non-cooperative method there is no communication among agent nodes. Communications exist only between agents and anchors. Every agent node is required to communicate with many anchors, requiring either a large concentration of anchors or long-range anchor broadcasts. In cooperative localization, communication among agent nodes eradicates the necessity for all agents to be within communication range of multiple anchors thus large anchor density or long-range anchor transmissions are no longer

essential, since agents can get information from both anchors and other agents in the interior communication range [6].

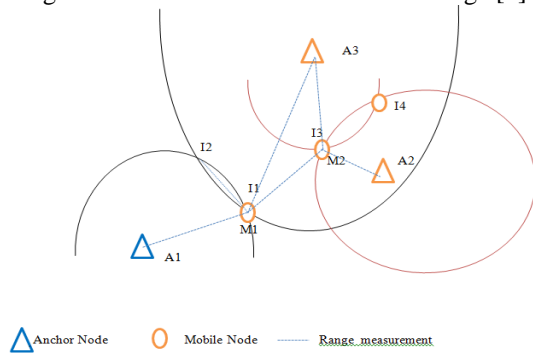


Fig. 1. Cooperative network.

To solve the problem of the difficulties of a low number of reliable anchor nodes it might be helpful to get the mobile nodes cooperate for localization. Fig. 1 shows the manner in which two mobile nodes get advantage from cooperation. Mobile node M1 is connected with anchor node A1 and A3 and mobile node M2 is connected with anchor nodes A2 and A3. Generally in range based localization both mobile node M1 and M2 cannot openly fix their locations. Mobile node M1 might be positioned in either intersection of I1 or I2 whereas mobile node M2 might be in I3 or I4. However, if the two mobile nodes cooperate and measure the distance between them this distance might be used to determine that the only possible placement is that M1 is in I1 and M2 in I3. Cooperative localization needs communication between the mobile nodes to assist them to aid each other. In the example of Fig. 1 that could be mobile node M1 sending its possible position coordinates of I1 and I2 to the mobile node M2 that would then be able to determine its position unambiguously using the interdistance of the two mobile nodes. The position of M2 should then be returned to M1 assisting it to as well determine its position. Cooperative localization can compromise augmented accuracy and coverage.

The performance of positioning accuracy can be extremely enhanced by also replacing positional information between agents. Cooperative localization method improves positioning accuracy [7], increases the computational complexity, as well as the network traffic and positioning latency. Some of the positional information may also be destructive as some devices have poor estimates [8]. Hence, a big challenge is how to select and reject information. In the [9] proposed to use the links which are the closest from the agent in consideration. However, the closest neighbors may not correspond to the best links as positioning also depends on the geometric configuration of the agent and its neighbors. So selecting the anchor nodes to determine position of a node is a big task. The Cramer Rao bound (CRB) has been proposed as a criterion to censor vain links [8], [10], rather than depend on proximity as a criterion, [10] proposed to use a preset number of links that give lowest CRB. In [16] the authors proposed to use the CRB to select those anchors that would give the best positioning

accuracy. The mentioned methods are appropriate for non-cooperative networks to select the best anchors. In cooperative localization, the number of links available may be in the order of 10-30 in a large network. The above methods can degrade the positioning accuracy only when a small number of preset links were used for updates. This initiative was applied to cooperative networks in [18], where adaptively links are detached without affecting the positioning quality. All of the methods discussed above can only remove the bad links after receiving information from neighbors. So the number of packet exchanges is not attractively reduced.

In this paper, we extend previous algorithms with a combination of transmit and receive censoring. In our proposed method Distributed PSO, we adopt a distributed criterion to censor information without decreasing the positioning quality. CRB is used as the censoring parameter in received censoring to remove non-informative links after receiving information from neighbors and is used in transmitting censoring to block the broadcast of unreliable nodes. This paper is organized as follows. In Section 2 discuss about censoring criterion, proposed method is discussed in section 3, simulation results & analysis are given in section 4, Section 5 gives Conclusion.

## II. CENSORING SCHEMES

In a dense network, agents can receive information from many neighbors. Not all of those links are important and by censoring the bad links, we can achieve reduced complexity and latency with little or no performance loss. In Figure 2 Transmit and receive censoring schemes are shown, the three agents are connected between them with fixed anchors. Agent 3 is connected to only one anchor. Hence, it has limited knowledge initially about its position. So this agent node cannot assist other nodes to be localized and should not broadcast its positional information which is known as transmit censoring. Agent 1 will get information from three anchors and also from Agent 2. If the information from agent 2 is not taken into consideration, its positioning accuracy may not be affected. We define this as receive censoring. Based on censoring criterion agents decide whether to censor or not. In this research work the Cramer-Rao bound (CRB) is used because of its rigorous foundation, and its wide applicability to cooperative positioning algorithms.

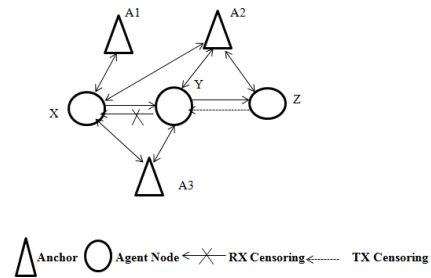


Fig. 2. Censoring schemes in cooperative WSN.

### 2.1. Cramer-Rao-Bound

The Cramer-Rao bound (CRB) is a lower bound on the performance of any unbiased estimator. It is calculated by taking inverse of the Fisher Information matrix (FIM) [11], [12]. Considering the location  $x_i$  of agent node  $i$ , then the FIM is given by equation 1.

$$F(X_i) = -E \left( \frac{\partial^2 \Delta(X_i)}{x_i^2} \right) \quad (1)$$

It can give that the FIM of  $x_i$  will be in the form of [19]

$$F(X_i) = \sum_{j \in S \rightarrow i} q_{ij} q_{ij}^T \frac{1}{\sigma_{jei}^2} \quad (2)$$

CRB can be computed using the formula

$$CRB(x_i) = \text{trace}([F(x_i)]^{-1}) \quad (3)$$

### 2.2. Censor transmitting

In transmit censoring an agent will make a decision whether to broadcast or censor its positional information based on its computed CRB because the true location of the either agent node nor of its neighbor node is known. The CRB will be calculated by using the expected positions given by equation 4, 5.

Hence, an agent will transmit-censor when

$$CRB(\hat{x}_i) = \text{trace}([\tilde{F}(\hat{x}_i)]^{-1}) > \gamma_{TX} \quad (4)$$

$$\tilde{F}(\hat{X}_i) = \sum_{j \in S \rightarrow i} \tilde{q}_{ij} \tilde{q}_{ij}^T \quad (5)$$

$$\text{Where } \tilde{q}_{ij} = \frac{\tilde{x}_i - \tilde{x}_j}{\|\tilde{x}_i - \tilde{x}_j\|}$$

### 2.3. Receive censoring

In receive censoring an agent node will receive location information from its neighbors and calculate its present Cramer Rao bound  $CRB(\hat{x}_i)$ . The agent will then remove links, as long as  $CRB(\hat{x}_i) < RX$ . Here the threshold  $RX$  again depends on the model and the preferred performance. In particular, the agent node can discard the bad links according to following algorithm:

$$1) CRB_k(\hat{x}_i) = \text{trace}([\tilde{F}_k(\hat{x}_i)]^{-1}) \quad (6)$$

$$\text{Where } \tilde{F}(\hat{X}_i) = \sum_{j \in S^k \rightarrow i} \tilde{q}_{ij} \tilde{q}_{ij}^T \quad (7)$$

2) Select the bad link

$$\hat{k} = \text{argmin}_k CRB_k(\hat{x}_i) \quad (8)$$

3) If  $CRB_{\hat{k}}(\hat{x}_i) < \gamma_{RX}$  set  $S_{\rightarrow i}$  to  $S_{\rightarrow i}^{\hat{k}}$  and go to step1 otherwise stop.

Fig. 3 shows flowchart for implementation of transmit-receive censoring.

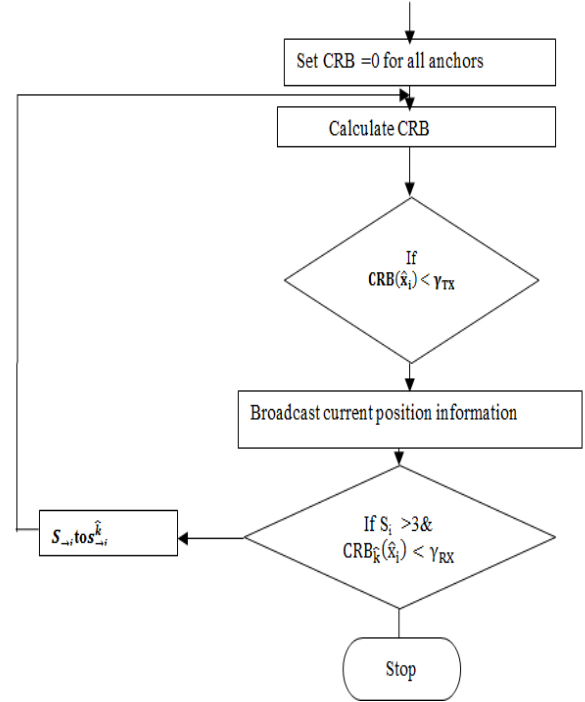


Fig. 3. Flowchart for transmit-receive censoring schemes in cooperative WSN.

## III. DISTRIBUTED LOCALIZATION USING PSO

### 3.1. Particle Swarm Optimization

PSO is a population based search algorithm depends on the intelligence of the swarm. It is developed based on social behavior of bees, birds and a school of fishes [13, 14]. It gives a set of solutions called as particles which are used to investigate the search place to get the global solution. The current position occupied by the  $i_{th}$  particle is denoted as position  $X_i$  and velocity  $V_i$  in  $D$ -dimension space. Each particle assesses its fitness through an objective function and it keeps track of its personal best fitness  $P_{best}$  and global best fitness  $g_{best}$  solution. Position  $X_i$  and velocity  $V_i$  using equation (9) and (10) is updated until either a satisfactory  $g_{best}$  is achieved or a preset number of iterations is reached. Primarily objective function and search space are defined to use PSO in localization. Particle swarm optimization (PSO) algorithm increases the localization accuracy by minimizing estimation errors, reduce energy consumption and complexity with less number of iterations in Comparison with general localization algorithms. This paper proposes a distributed PSO method based on the probabilistic distribution of ranging error. The updated particle's position can be mathematically modelled according the following equation:

$$V_i^{k+1} = w V_i^k + c_1 r_1 (p_{best} - x_i^k) + c_2 r_2 (g_{best} - x_i^k) \quad (9)$$

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (10)$$

Where  $v_i^k, X_i^k$  are velocity and current position of node  $i$  at iteration  $k$ ,  $C_1$  and  $C_2$  are acceleration constants,  $r_1$  and  $r_2$  are random numbers uniformly distributed in  $[0, 1]$ , and  $w$  is the inertia weight to control the scope of the search. Usually  $w$  is set to linearly decrease with the progression,  $p_{best}$ ,  $g_{best}$  are personal best and global best of the particles.

Particle swarm optimization (PSO) is easily implemented using moderate computing resources with speed of convergence [20, 21] which is viable for localization of sensor network. For improvement in the efficiency and accuracy of PSO-based localization methods are used, this paper proposes a distributed PSO algorithm based on the probabilistic distribution of ranging error. New objective function is proposed to evaluate the fitness of particles. It attempts to localize more unknown nodes in a high accurate search space [15]. The main objective is to improve the localization precision and to speed up the convergence.

Let  $(x, y)$  be the coordinates of an unknown node  $U$  and  $(x_i, y_i)$  be the position of its  $i_{th}$  ( $i=1, 2, \dots, M$ ) neighboring anchor node  $A_i$  of  $U$  and  $d_i$  be the measured distance between  $U$  and  $A_i$  given by equation 11

$$f(x,y) = \frac{1}{M} \sum_{i=1}^M \sqrt{(x - x_i)^2 + (y - y_i)^2 - \hat{d}_i} \quad (11)$$

The localization functions  $f$  is defined as all the range-based localization methods with PSO use the objective function as which does not consider the probabilistic distribution of ranging error. If the actual distance  $d_i$  between  $U$  and  $A_i$  is a normal distribution as

$$d_i \sim \mathcal{N}[\hat{d}_i, (\hat{d}_i \delta)^2] \quad (12)$$

where  $\delta > 0$

The distributions of ranging errors between different nodes are independent, we get

$$\sum_{i=1}^M d_i \sim \prod_{i=1}^M \mathcal{N}[\hat{d}_i, (\hat{d}_i \delta)^2] \quad (13)$$

The following function is maximized, to minimize the localization error Hence the objective function is given in equation (14):

$$f(x,y) = \frac{1}{M} \sum_{i=1}^M \frac{\left( \sqrt{(x - x_i)^2 + (y - y_i)^2} - \hat{d}_i \right)^2}{(\hat{d}_i \delta)^2} \quad (14)$$

## IV. SIMULATION & RESULTS ANALYSIS

### 4.1. Simulation setup

In our simulation, we consider a wireless sensor network with 100 randomly placed agents with 20 m communication limit, and 13 anchors placed in an organized way in a 500m X500 m map (see Fig. 4). The standard deviation of range

measurement noise is 1% of measured distance. The cooperative networks are used in which agents can also participate in localization process. Different range measurement techniques like RSS, AOA, TOA can be implemented. Here, The combination of RSS and TOA is considered. For simulation of sensor distributed localization algorithms a multi featured MATLAB-based code and GUI tool for the calculation of the CRB and localization are used [17], as shown in the Fig. 4. This tool can find bounds for measurements when any combination of RSS, TOA, and AOA measurements is used. For each sensor, the GUI displays the CRB by giving the lower bound on the  $2\text{-}\sigma$  ellipse. In Cooperative Networks all the agents which are involved in the localization process, may not give correct position information. CRB is used to censor the information from fault agents to improve positional accuracy and reduce complexity. For that, threshold parameters  $R_{Tx}$  is set for the stop limit. The parameters used are  $R_{Tx} = 0.08$  (conservative approach) and the  $R_{Tx} = 0.05$  (aggressive approach). To test our proposed method, the cooperative Distributed PSO algorithm is used [1], [15]. The Distributed PSO algorithm with censoring techniques minimize the localization error, complexity with respect to other measurements.

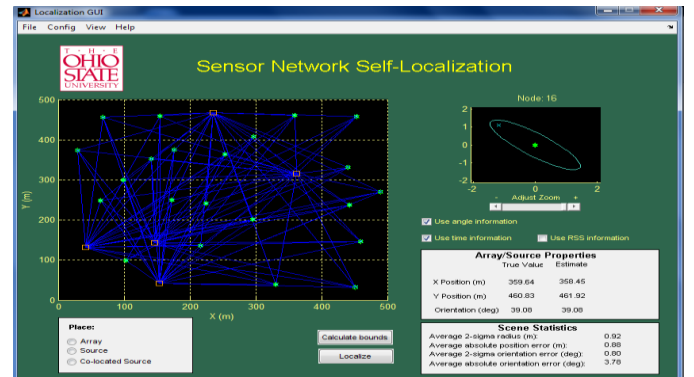


Fig. 4. Simulation setup of cooperative WSN using Matlab based GUI Tool.

### 4.2. Results analysis

Simulation tests have been carried out to evaluate the performance of the proposed approach. The algorithm is executed for 40 iterations. Cumulative Distribution function for Position estimation errors for different values of Threshold stop limits  $R_{Tx}=0.08$  (Conservative) approach and  $R_{Tx}=0.05$  (Aggressive) are plotted. Fig. 5 shows a CDF of position estimate errors for  $R_{Tx}=0.08$  and Fig. 6. Shows a CDF for the position estimate errors with  $R_{Tx}=0.05$ . Figures 6&7 compare CDF for Different Approaches like to receive censoring, transmit-receive censoring, cooperative distributed PSO (without censoring), Non cooperative distributed PSO (without censoring). It is observed from Fig. 5 that Transmit censoring performs better in conservative approach. Results in Fig. 6 show that transmit-receive censoring performs better in aggressive approach compared to other methods.

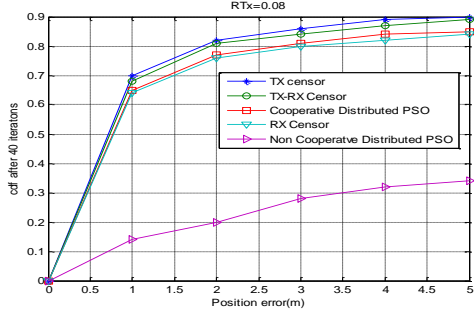


Fig. 5. Performance comparison of different censoring schemes in conservative approach.

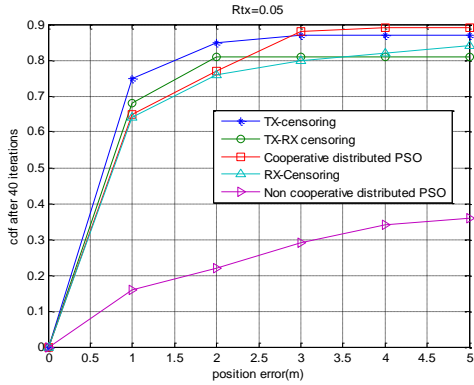


Fig. 6. Performance comparison of different censoring schemes in Aggressive approach.

In addition to the positioning accuracy, reduced complexity like reduced average no. of transmissions per agent of cooperative Distributed PSO-CRB Censoring is compared with other algorithms like cooperative and non-cooperative LS algorithms. Fig. 7 shows the average number of packets transmitted per node per iteration, as a function of the iteration index. Only agent nodes that can communicate with at least three anchors estimate position initially. Hence, only that node will broadcast their position estimates and the number of packets per agent is very low. As iterations progress, most of the agents obtain estimates through cooperation and will initiate broadcasting. When transmitting censoring is made active, 15% and 45% reduction in total data traffic are achieved with the conservative and aggressive approaches respectively. These values depend on the transmit censoring threshold.

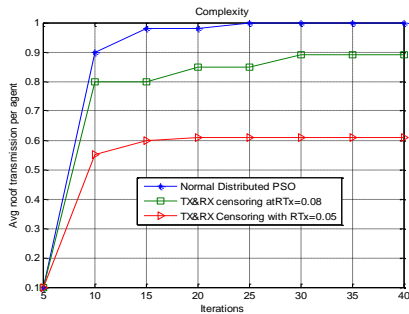


Fig. 7. Comparison of different algorithms for average number of transmissions with respect to no. of iterations.

The average number of links per node is 13 in normal cooperative PSO Method and 4 for the transmit and receiving censoring. Table I shows the comparison of number of links for different approaches.

TABLE I: AVG. NUMBER OF LINKS USED FOR DIFFERENT CENSORING SCHEMES IN COOPERATIVE WSN

	Normal cooperative PSO	Tx Censoring	Rx Censoring	Tx-Rx Censoring
Conservative approach	13	11	6	5
Aggressive approach	13	9	5	4

In Table I, the average number of used links is compared per node during the update of location. Here it is observed that less than half of the links are used for receiving censoring compared to normal cooperative PSO. Compared to other approaches, transmit-receive censoring uses the less number of links. Hence the overall decrease in used links makes little impact on the computational complexity for PSO positioning, but it will be significant when more complicated algorithms are considered.

The positions of the nodes are represented by randomly generated in (x, y) coordinates within the boundary of 500mX500m area. Different localization algorithms like cooperative LS, Cooperative Distributed algorithms with and without censoring schemes have been implemented for the performance comparison using the same assumptions. At each experiment, the simulation is run for 40 iterations with duration of 58 sec. However, to simulate noise, each measured distance was disturbed by a normal random variant with the following settings: a mean of 0.1% of the measured distance and a standard deviation of 1% of the measured distance. The implemented algorithms are evaluated in terms of the location error. The localization error of an unknown node is defined as the distance between its estimated and real position, and the localization error of each algorithm is defined as the average of localization errors of all localized unknown nodes. Localization error is the most important performance evaluation of localization algorithm. Figure 8 shows that the localization errors in terms of mean square error [8]. Here the definition of Root Mean Square Error for localization is introduced to compare performance of each algorithm.

$$RMSE = \frac{1}{M} \sqrt{\sum_{k=1}^m (x_k - \hat{x}_k)^2 + (y_k - \hat{y}_k)^2} \quad (16)$$

When compared with other algorithms, the localization error of the cooperative Distributed PSO algorithm is the least as shown in Fig. 8. The estimated location accuracy by cooperative Distributed PSO is better than other approaches on the path.

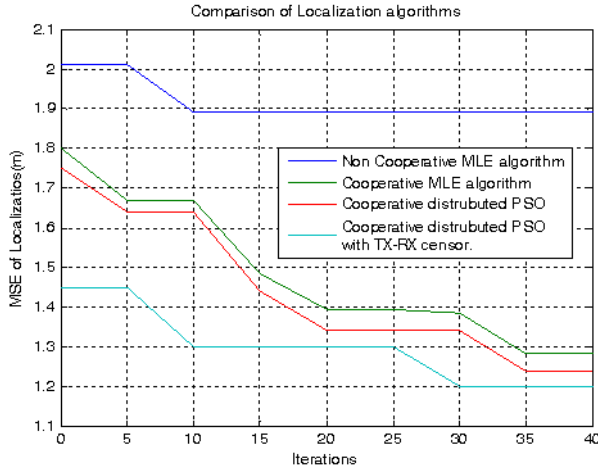


Fig. 8 Comparison of different algorithms for Mean square error of localization with respect to no. of iterations.

## V. CONCLUSIONS

In this paper, different censoring schemes and algorithms are used for cooperative localization in wireless sensor networks and are compared in terms of reduce complexity, no. of links and location precision. CRB is used as censoring criterion and censoring results are disseminated to all nodes. Transmit, Receiving, Transmit-Receiving censoring schemes are applied to a cooperative distributed PSO algorithm. Transmit censoring performs better in conservative approach and Transmit-receiving censoring performs better in an aggressive approach in terms of cumulative distribution function error. Complexity also reduced using TX-RX censoring scheme compared to other schemes. Cooperative distributed PSO with TX-RX censoring performs better in localization with least mean square error compared to other schemes.

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