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Binary Particle Swarm Optimization (BPSO) Algorithm for Distributed Node Localization

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Abstract. In this paper, we propose a binary particle swarm optimization (BPSO) algorithm for distributed node localization in wireless sensor networks (WSNs). Each unknown node performs localization under the distance measurement from three or more neighboring anchors. The node that gets localized will be used as a reference for remaining nodes. A comparison of the performances of PSO and BPSO in terms of localization error and computation time is presented using simulations in Matlab.

Introduction

Localization is a process to find out the locations of sensor nodes which are deployed randomly in the sensing area [1]. Generally, localization processes equip each node with the global positioning system (GPS), which is not effective due to size, cost and power consumption constraints. Therefore, many localization algorithms in wireless sensor network (WSN) use special nodes called anchors to estimate the location of unknown nodes by using a priori knowledge of the anchors nodes' coordinates. In other words, they need anchors being aware of their position and the unknown nodes measure the distances or angles from anchors nodes to estimate their positions [2].

Related Work

PSO is a population-based stochastic optimization technique developed by Kennedy and Eberhart in 1995 [3]. A summary of applications of PSO in WSN can be found in [4]. In [5], the authors proposed a localization method for WSN with unknown nodes based on a priori information of locations of anchors using PSO algorithm. The proposed scheme used PSO to minimize the localization error. This approach is a centralized architecture for the WSN, which requires a lot of communication that may lead to congestions, delays, and also energy exhaustion.

In contrast, Kulkarni et al. proposed distributed iterative node localization in WSN using PSO algorithm [6]. An unknown node which has three or more anchors in its communication range runs PSO to minimize the localization error which used same function as [5]. This method does not require that each node transmit its range measurement to a central node. In addition, it can localize all nodes that have three localized nodes or anchors in their communication range. However, the localization based on PSO requires complex computations that cause relatively large computation power and longer computation time.

Proposed Algorithm

Binary Particle Swarm Optimization (BPSO). Unlike PSO, the BPSO algorithm was used in binary discrete search spaces. Kennedy and Eberhart have implemented the BPSO to search in binary discrete search spaces, by applying a sigmoid transformation to the velocity component to force the velocities into the value between 0 and 1, and the position of the particles to be either 0 or 1. Basically, PSO and BPSO are the same in the sense of the logical flow of the algorithm, which in finding *pbest* and *gbest*, update velocity and position [7]. The only difference between PSO and BPSO is the equations used to define the updates of velocity and position of each particle. Equation (1) is used to update the velocity while (2) and (3) are used to update the position of each particle.

$$v_{id}^{k+1} = wv_{id}^{k} + c_1 r_1 (p_{best_{id}} - x_{id}) + c_2 r_2 (g_{best_d} - x_{id}), \tag{1}$$

$$\text{sigmoid}(v_{id}^{k}) = \frac{1}{1+e^{-v_{id}^{k}}}, \tag{2}$$

$$x_{id}^{k} = \begin{cases} 1, \text{if} \quad rand < \text{sigmoid}(v_{id}^{k}) \\ \quad 0, \text{otherwise.} \end{cases} \tag{3}$$

Distributed Localization with BPSO Algorithm. In this paper, the goal of nodes localization is to estimate the location of sensor nodes in distributed environment. The coordinate of unknown nodes, N, is estimated using stationary anchors, M. In this case, anchors are assumed to know their own locations and both unknown nodes and anchors are deployed randomly in 2-D area. Anchor nodes frequently transmit their coordinates and have a transmission range of R. At the end of iteration, the nodes that get localized will be used as references for other nodes. Each node is referred as localizable node if it is within communication range from three or more neighboring anchors or any localized nodes, $M \geq 3$. Each localizable node estimates its distance from each of its neighboring anchors. The actual distance, d_i in (4) is the Euclidean distance between two nodes. According to (4), (x, y) is the location of unknown nodes while (x_i, y_i) is the location of i^{th} anchors. Both PSO and BPSO will find the (x, y) coordinates that minimize the cost function, $f(x, y)$ which represents the localization error in WSN. Equation (5) is used in the calculation to execute the error which defined as the difference between estimated distance and actual distance of the nodes.

$$d_i = \sqrt{(x-x_i)^2 + (y-y_i)^2}, \tag{4}$$

$$f(x,y) = \frac{1}{M}\sum_{i=1}^{M}(\sqrt{(x-x_i)^2 + (y-y_i)^2} - \hat{d}_i)^2. \tag{5}$$

Communication Model. In this paper, the distance from the anchor to unknown node is calculated by using the received signal strength indication (RSSI) as in (6). The RSSI model provides a feasible way to estimate the distance between sensor nodes. The neighboring nodes of the anchor estimate their distance from the anchor by measuring the received signal strength (RSS) of the broadcast signal. A node estimates distances from each of the anchors if it receives broadcast signal from at least three anchors. From (6), P is the received power at reference distance, D_0, n is the path loss index, D is the nodes distance and X_σ is the noise parameter with a zero mean Gaussian random variable.

$$\text{RSSI} = P - 10n \times (\frac{\log D}{D_0}) + X_\sigma. \tag{6}$$

Simulation Results and Discussion

To evaluate the performance of the proposed algorithms, we used Matlab for simulation. The parameters used for localization are listed in Table 1 and the parameters for PSO and BPSO algorithms are listed in Table 2. In this paper, localization error and computation time are used as the performance metrics.

Table 1: Simulation parameters for localization.

Parameter	Value
Sensor Field Size	100 x 100 [m^2]
Anchor Nodes, M	10
Unknown Nodes, N	50
Transmission Range, R	25 [m]

Table 2: Simulation parameters for algorithms.

Parameter	Value
Maximum Iteration, k_{max}	150
Inertia weight, w	0.7
Acceleration constant, c_1, c_2	50
Random numbers, r_1, r_2	0 to 1
Particle positions	$x_{min} = 0$, $x_{max} = 100$

The actual location of nodes and anchors, and the coordinates of the nodes estimated by PSO and BPSO are shown in Fig. 1 and Fig. 2, respectively. The deployment of anchor nodes for both algorithms is identical for comparison purposes. Simulation results of both PSO and BPSO algorithms show that all 50 unknown nodes can be localized inside the sensor field. Fig. 3 shows the comparison of both algorithms in terms of localization error for each unknown node. From Fig. 3, the accuracy is better in PSO but the error difference between PSO and BPSO is less than 34.31% on average. The average localization error is defined as the total error between nodes location and estimated location by using the algorithms divided by total number of unknown nodes, N. The details of performance are summarized in Table 3.

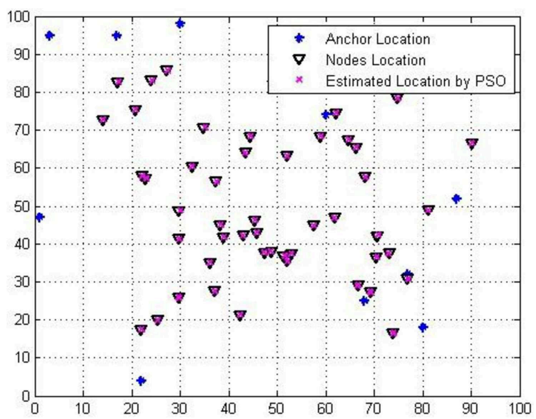

Fig. 1: Estimated locations by PSO.

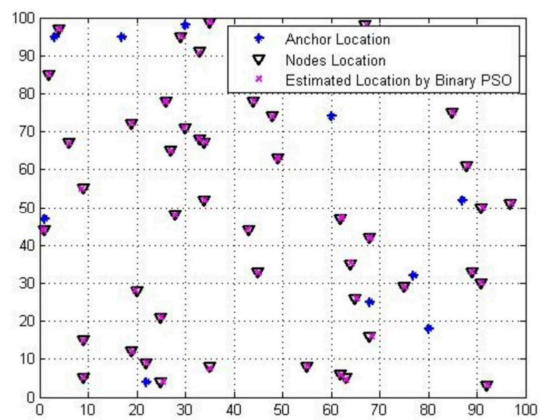

Fig. 2: Estimated locations by BPSO

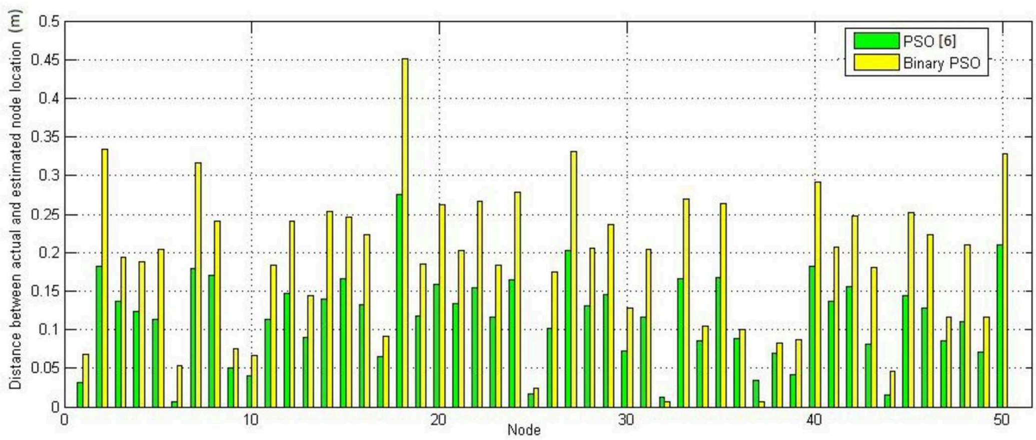

Fig. 3: Distance between actual and estimated node location by PSO and BPSO.

Table 3: Comparison of the algorithms.

Algorithm	Average Localization Error [m]	Computation Time [s]
PSO	**0.0809**	361.6185
BPSO	0.1144	**201.1747**

From Table 3, it can be seen that, BPSO algorithm has higher average localization error but less computation time compared to PSO algorithm. In BPSO, the next value for the bit is independent of the current value of that bit and it is updated using the velocity vector only. That is why BPSO algorithm produces lower localization accuracy compared to PSO. But, the computation time become less since BPSO was used in binary discrete search space. In detail, simulation results show that the proposed algorithm reduced the computation time required for the localization by 57.02% while increasing the localization error by 34.31%. By reducing computation time for the localization, the energy can be saved and the lifetime of WSN can be extended.

Conclusion

In this paper, we proposed a binary particle swarm optimization algorithm for distributed node localization in wireless sensor networks. Each unknown node performs localization under the distance measurement from three or more neighboring anchors. The localized node will then be used as a reference for remaining nodes. The distance from the anchor to unknown node is calculated by using the received signal strength indication. As measures of performance, localization error and computation time are used during simulations in Matlab. Simulation results show that PSO determines the node coordinates more accurately, but BPSO does so more quickly.

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