

PSO-Optimized DV-Hop Localization Algorithm for Wireless Sensor Networks

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Abstract— This paper enhances the DV-Hop algorithm in WSNs by using Particle Swarm Optimization (PSO) to address accuracy limitations. The proposed scheme optimizes three critical parameters: connectivity range, beacon node ratio, and beacon node placement. Comparative MATLAB simulations demonstrate that the PSO-based approach significantly reduces localization error. Results show a substantial improvement in RMSE over the traditional DV-Hop algorithm. Ultimately, this optimization confirms that tuning network parameters effectively boosts overall localization reliability and precision.

Keywords— wireless sensor networks, DV-Hop, Particle Swarm Optimization, Localization

I. INTRODUCTION

Localization is a fundamental function in WSNs, as most network operations depend on knowing sensor node positions. Accurate localization improves network performance and data interpretation, yet remains challenging due to energy limitations, low-cost hardware, and environmental uncertainty. Consequently, localization continues to be a major and evolving research topic in WSNs, especially with the integration of intelligent computing and optimization techniques [1], [2].

Localization methods in WSNs are generally classified into range-based and range-free approaches. Range-based methods estimate node positions using physical measurements relying on distance or angle estimation. In contrast, range-free methods use only connectivity information between nodes, without precise measurements [3]. Among them, DV-Hop is widely used due to its simplicity and low hardware cost, but it suffers from limited accuracy caused by hop-size estimation errors and sensitivity to network topology and anchor placement [4], [5].

Recent studies have focused on enhancing DV-Hop localization by integrating PSO to mitigate its inherent limitations. Hadir et al. [6] proposed a PSO-based DV-Hop approach that reduces average hop-size estimation errors and refines sensor node positions in IoT and WSN scenarios. Chen et al. [7] presented an improved DV-Hop method using weighted iteration and optimal beacon selection, where per-hop errors are minimized via an iterative weighted MMSE scheme. Additionally, a PSO-based DV-Hop algorithm in [8] addresses the sensitivity of conventional least-squares estimation, achieving faster convergence and significantly improved localization accuracy.

This paper focuses on improving the DV-Hop algorithm by proposing a PSO-based DV-Hop scheme that optimizes key parameters, including connectivity range, beacon node coordinates, and beacon node ratio, to enhance localization accuracy. The remainder of the paper is organized as follows: Section II reviews the theoretical background and related work on DV-Hop localization, Section III describes the proposed PSO-based DV-Hop method, Section IV presents the simulation setup and results, and Section V concludes the paper.

II. LOCALIZATION IN WSNs

A. WSN ARCHITECTURE

A wireless sensor network (WSN) consists of spatially distributed sensor nodes that cooperatively monitor physical or environmental parameters and transmit collected data wirelessly to a sink or base station [1], [2]. Each node typically integrates a sensing unit, processing unit, transceiver, and power supply, while operating under strict energy, memory, and computational constraints [2]. Despite these limitations, nodes self-organize and communicate through multi-hop links [1]. In standard deployments, some nodes act as beacon nodes with known positions, whereas the locations of other nodes are estimated using localization algorithms. A hierarchical architecture is commonly adopted, where sensor nodes relay data through intermediate cluster-head nodes to reach the sink. Figure 1 depicts the general WSN architecture, including the Network Management and Application Layer, which encompasses the gateway, computer network, application requirements, and network management functions [9].

B. DV-Hop Localization Algorithm

Localization refers to the estimation of sensor node positions in a network and is a fundamental task in WSNs. Knowledge of node locations improves network coverage, data accuracy, and overall performance by enabling efficient data collection, routing, and network management through the integration of topology and spatial information [1]. Moreover, localization supports adaptive power control, allowing nodes to adjust transmission power based on relative distances, thereby improving energy efficiency and reducing unnecessary power consumption [2].

Since its initial introduction by Dragos Niculescu and Badri Nath in [10], the DV-Hop method [4]–[6] has garnered substantial research interest among range-free localization algorithms. The DV-Hop algorithm's primary benefits include low hardware requirements, ease of use, high efficiency, and low energy consumption [11]. As a result, it can be widely used in real-world situations. The concept is that each unknown node uses the first information it receives from a beacon node to estimate its average hop distance. The average hop distance is then multiplied by the minimum hop count between beacon nodes to determine the physical distance between them. The unknown node uses trilateration or maximum likelihood estimation techniques to find its coordinates after the locations of three or more beacon nodes are known [11]. The execution of the standard DV-Hop algorithm can be divided into three principal steps, as outlined below [4],[7],[11]-[12]:

Step 1: Minimum Hop Count Estimation: In the first phase, each beacon node floods the network with a message containing its position and an initial hop count (set to zero). Upon reception, nodes record the minimum hop count to each beacon, increment the hop value by one, and rebroadcast the message only if it provides a smaller hop count than previously stored. Through this iterative flooding process, all nodes obtain the minimum hop count to every beacon node.

Step 2: Average Hop Size (AHS) Estimation: Using the hop counts and known locations of other beacons acquired in Step 1, each beacon node calculates its Average Hop Size (AHS) in the second stage. The average physical distance between beacons per hop is known as the AHS, and it is computed as follows:

$$AHS_i = \frac{\sum_{j \neq i} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\sum_{j \neq i} h_{ij}} \quad (1)$$

where (x_i, y_i) and (x_j, y_j) are the coordinates of beacons i and j , and h_{ij} is the minimum hop count between them.

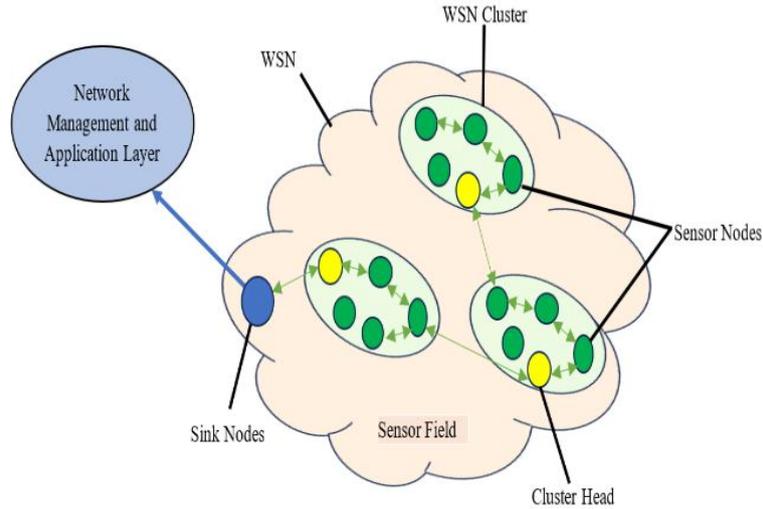


Fig. 1. General WSN architecture

After that, each beacon uses controlled flooding to broadcast its calculated AHS. If the first received AHS matches the nearest beacon, unknown nodes log it and send it on to their neighbors. Each unknown node calculates its distance to beacon i using the hop counts and stored AHS from Step 1 as follows:

$$d_{ui} = AHS_i \times h_{ui} \quad (2)$$

where d_{ui} denotes the estimated Euclidean distance between the unknown node u and beacon node i .

This step allows every unknown node to approximate its physical distance to multiple beacons, preparing for position estimation in Step 3.

Step 3: Position Estimation: In the final phase, each unknown node estimates its position using the distances to at least three beacon nodes obtained from Step 2. The method is typically based on trilateration or the maximum likelihood estimation (MLE) approach.

III. SIMULATION RESULTS

To evaluate localization performance, both the standard DV-Hop and the PSO-optimized DV-Hop algorithms were simulated in MATLAB and compared under identical network conditions using RMSE as the performance metric. In the PSO-based approach, key parameters—including the connectivity range R , the number of beacon nodes, and their coordinates—were optimized using PSO. The simulation considered 100 sensor nodes randomly deployed in a $100 \text{ m} \times 100 \text{ m}$ area, each with a connectivity range of 50 m. Eight nodes were designated as beacon nodes with predefined coordinates (x_i, y_i) , $i = 1, \dots, 8$, serving as reference points for localization. Figure 2 illustrates the network topology and the spatial distribution of sensor and beacon nodes.

For each parameter, the standard DV-Hop localization process is executed, and the RMSE between the true and estimated coordinates of all unknown nodes is computed as the fitness function:

$$f = \sqrt{\frac{1}{N_u} \sum_{i=1}^{N_u} [(x_i - \hat{x}_i)^2 + (y_i - \hat{y}_i)^2]} \quad (3)$$

where (x_i, y_i) and (\hat{x}_i, \hat{y}_i) denote the actual and estimated positions of the i^{th} unknown node, respectively.

A. Optimization of the Connectivity Range R

In this simulation, all network parameters were fixed as previously defined, and the PSO-optimized DV-Hop algorithm was applied to determine the optimal connectivity range R by minimizing the objective function, yielding $R_{\text{opt}} = 26.8917 \text{ m}$. Figure 3 presents the RMSE variation with respect to the number of deployed nodes, showing a noticeable reduction in localization error after optimizing R using PSO. The conventional DV-Hop algorithm produces RMSE values ranging from 30.43 m to 33.32 m, whereas the PSO-optimized DV-Hop reduces the RMSE to 25.13 m–29.24 m. These results confirm that the optimized DV-Hop achieves higher localization accuracy than

the standard approach. The improvement is attributed to PSO-based fine-tuning of the connectivity range, which enables a more accurate estimation of hop distance and, consequently, inter-node distances.

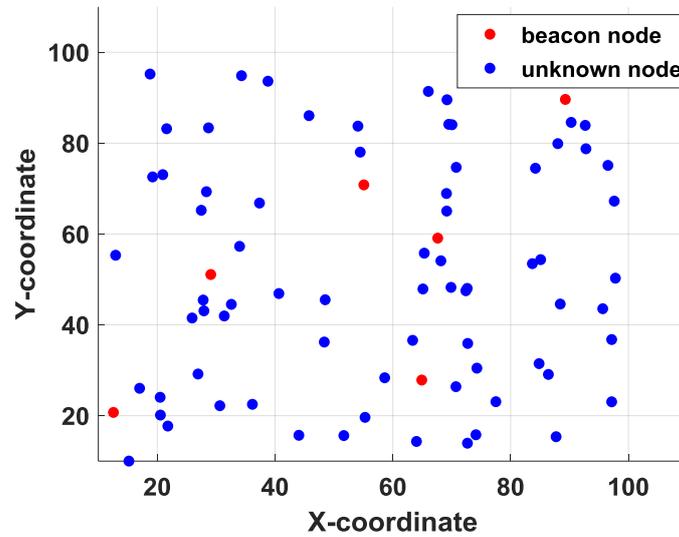


Fig. 2. Layout of the studied WSN

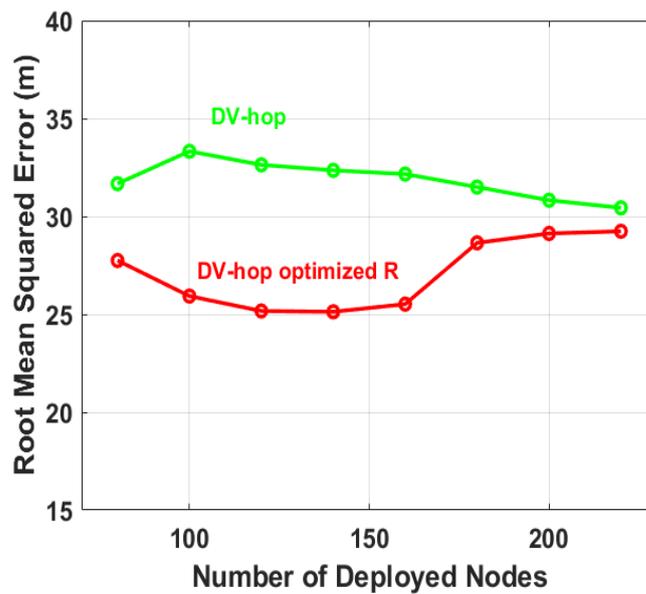


Fig. 3. RMSE comparison between DV-Hop and DV-Hop with optimized connectivity range R.

B. Optimization of the Beacon Node Rate (BNR)

In this part, the PSO-optimized DV-Hop algorithm was employed to determine the optimal anchor node ratio (ANR), yielding an optimal value of $ANR_{opt} = 10.61\%$. For a network of 100 nodes, this corresponds to approximately 11 beacon nodes. Figure 4 shows the RMSE variation with respect to the number of deployed nodes for both algorithms. In the conventional DV-Hop method, where the beacon node ratio is fixed at $BNR = 0.08$ (eight beacon nodes), the RMSE ranges from 30.43 m to 33.32 m. By contrast, the PSO-optimized DV-Hop achieves lower RMSE values between 28.78 m and 29.46 m. This improvement indicates that optimizing the beacon node ratio allows the DV-Hop algorithm to better adapt to network characteristics, leading to more accurate inter-node distance estimation.

C. Optimization of Beacon Node Positions

In this simulation, the PSO-optimized DV-Hop algorithm was used to determine the optimal coordinates of the eight beacon nodes. Figure 5 shows the RMSE variation with the number of deployed nodes for both the standard

and PSO-optimized DV-Hop algorithms. Optimizing the beacon node coordinates reduces the RMSE to 21.50–22.61 m, compared to higher values for the conventional DV-Hop. This result demonstrates that PSO-based coordinate optimization improves the algorithm's adaptability to the network, yielding more accurate distance estimation and enhanced overall localization performance.

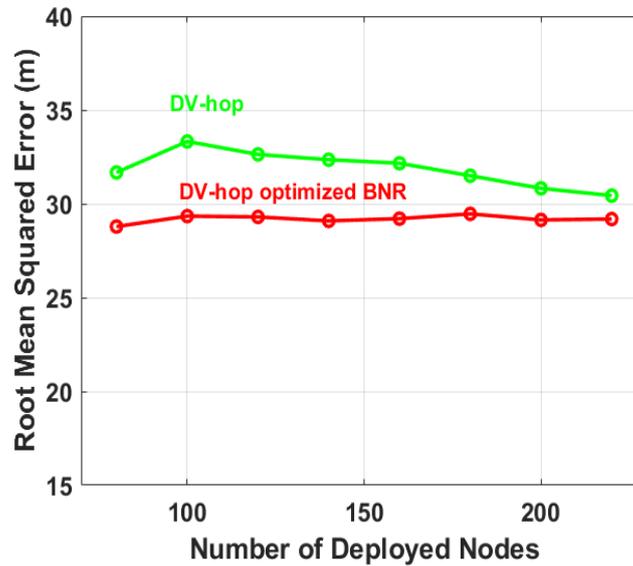


Fig. 4. RMSE comparison between DV-Hop and DV-Hop with optimized beacon node rate BNR

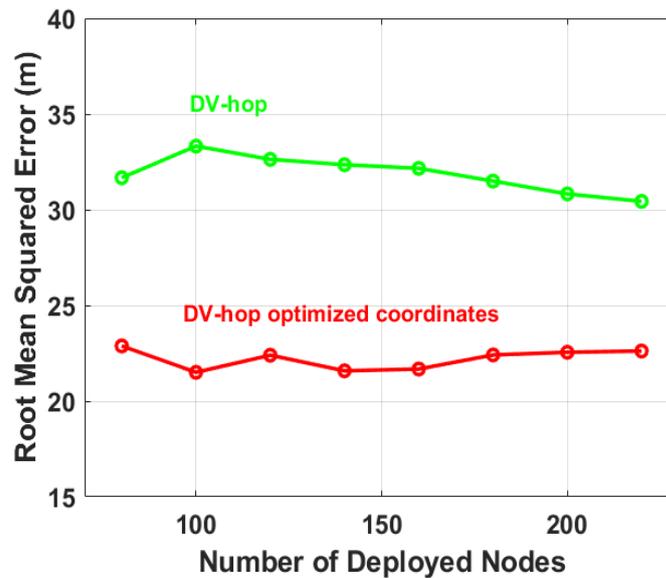


Fig. 5. RMSE comparison between DV-Hop and DV-Hop with optimized beacon node coordinate

C. Comparative Analysis of DV-Hop Optimization Results

Figure 6 compares the RMSE of the standard DV-Hop and PSO-optimized DV-Hop algorithms under three optimization approaches: beacon node ratio, connectivity range, and beacon node coordinates. The results show that optimizing beacon node coordinates achieves the greatest reduction in RMSE, yielding the highest localization accuracy. Connectivity range optimization provides the second-best improvement, significantly reducing RMSE though slightly less effective than coordinate optimization. Optimizing the beacon node ratio is the least effective, offering only minor enhancements compared to the other approaches.

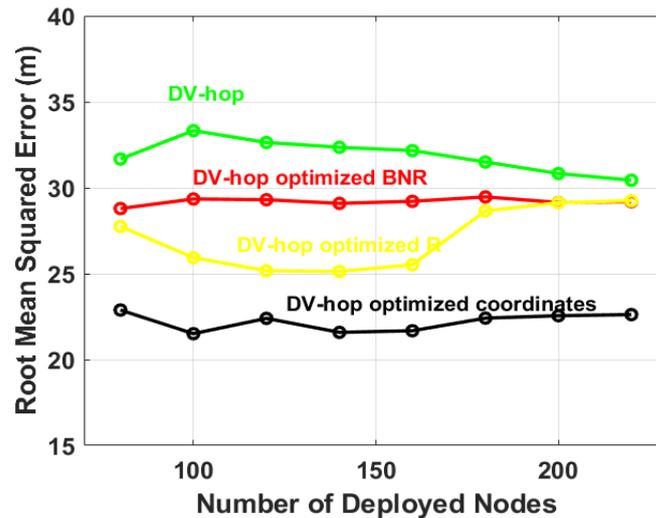


Fig. 6. RMSE comparison between standard DV-Hop and PSO-optimized DV-Hop approaches

IV. CONCLUSION

This simulation study confirms that the PSO-optimized DV-Hop algorithm significantly outperforms the traditional version by refining beacon node ratio, communication range, and spatial distribution. Results demonstrate that optimal parameter selection directly translates to higher positioning precision and improved RMSE. Beyond accuracy, these enhancements suggest broader benefits for WSNs, including better energy management and routing efficiency. While promising, future research should focus on real-world deployments to evaluate computational complexity and scalability in dynamic environments. Ultimately, a multi-objective framework balancing accuracy with energy and communication overhead remains the key path toward practical WSN integration.

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