A Survey on DV-Hop localization Techniques in Three-Dimensional Wireless Sensor Networks

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Abstract—Location information is prerequisite for wireless sensor networks (WSNs) monitoring and control applications, since there is no meaning without position information for collected data. Distance vector hop (DV-Hop) localization algorithm as the typical range-free algorithm that has been widely applied in various applications. Nowadays, the research on range-free localization for WSNs is mostly based on two-dimensional (2D) space. Hence, there are few surveys concentrated on range-free localization in three-dimensional (3D) WSNs. This motivated us to present an extensive overview of enhanced DV-Hop localization algorithms in 3D WSNs. This paper focused on critical challenge between 2D and 3D in localization model, representative range-free 3D localization technique surveys. Moreover, a comprehensive taxonomy of most essential enhanced methods applied in 3D DV-Hop is illustrated. A considerable comparison in term of localization error, computational complexity and node type is given. Future research directions dealing with localization under 3D DV-Hop is also discussed.

Keywords—Wireless sensor networks (WSNs), Range-free, Three-dimensional Localization algorithm, DV-Hop algorithm.

1 Introduction

Micro-Electro-Mechanism System (MEMS), advanced wireless communication and digital electronics technology have promoted the development of Wireless Sensor Networks (WSNs) [1]. WSNs are composed of a great huge number of nodes, which has significant research value and already successful applied in various fields, such as environmental monitoring, military applications, and target tracking etc. Location information is prerequisite for wireless sensor network monitoring and control application, since most monitoring or tracking information need to be accompanied with

corresponding location information, otherwise, these data will be lost collected meaning. Therefore, localization technology plays a fundamental role in WSNs, and it is also a hot spot in current research direction [1-2].

Location information also can be used for other purpose besides report where the incident occurred [3]. It can be utilized to establish geographic routing protocol for data transfer and query target information. It is critical for network management to build network topology based on location information for timely calculate network coverage and take necessary action to low node density area. In addition, users can transfer data to specific area at fixed time. In short, obtaining location information can make WSNs work more purposeful and efficient [4].

It is impossible if manually label location of each sensor node, since WSNs contain thousands of nodes that are randomly distributed in target or monitoring area. It is much easier that equipped each node with a Global Positioning System (GPS). However, considering the constraints of price, volume, power consumption and other factors, such as GPS has strict requirement of deploy environment, this solution is usually not adopted. Therefore, only a small amount number of nodes is attached GPS or marked exact location in advance. Over past two decades, many scholars have proposed multitude localization algorithms based on characteristics of WSNs. Those mainstream localization algorithms are commonly divided into range-based and range-free algorithms based on whether it needs additional ranging equipment or not. Comparing with range-based scheme, range-free has attracted much attention in WSNs since it only depended on network connection information without extra ranging equipment.

The distance vector hop (DV-Hop) localization algorithm as typical range-free algorithm that has been widely used for its simplicity and economy. However, it has a large error during location process, which results in suffering from low localization accuracy. Several methods have been suggested in literature to improve localization accuracy in DV-Hop localization algorithm. However, nowadays, research on range-free localization of WSNs is mostly based on two-dimensional (2D) space. Hence, there are few surveys concentrate on range-free localization in three-dimensional (3D) WSNs. For our best knowledge there is no review paper focus on DV-Hop localization algorithms for 3D WSNs. Kaur et al. [5]. proposed a thorough survey on DV-Hop localization techniques, but it is only involved ten plus paper under 2D WSNs. What's more, the latest literature is 2016. It motivated us to investigate a large body of enhanced localization algorithms in DV-Hop for 3D WSNs.

With this paper, readers can have a more thorough understanding of DV-Hop localization under 3D WSNs, as well as research trends and future research directions in this area. In this survey, we present key issues and inherent challenges faced by DV-Hop localization techniques in 3D WSNs.

The structure of rest paper is as follows. Recently advanced literatures review on range-free localization techniques in both 2D and 3D WSNs are illustrated in section 2. In Section 3, basic DV-Hop is introduced. Deeply analysis of localization error in DV-Hop is presented in Section 4. In Section 5, enhanced 3D DV-hop localization algorithms are comprehensively elaborated. Eventually, conclusion and future work are formulated in Section 6.

2   Related Surveys on DV-Hop Localization

In recent years, it have been several surveys and tutorials on localization for WSNs, which focus on different concern points, such as [5-8] highlights localization algorithms, [9] spotlights mobile localization algorithms, [10-13] concentrates on location protocols, location-services applications and IoT infrastructure, location security, location techniques etc., [14-17] are in terms of 3D localization algorithms, all of them are illustrated in Fig 1.
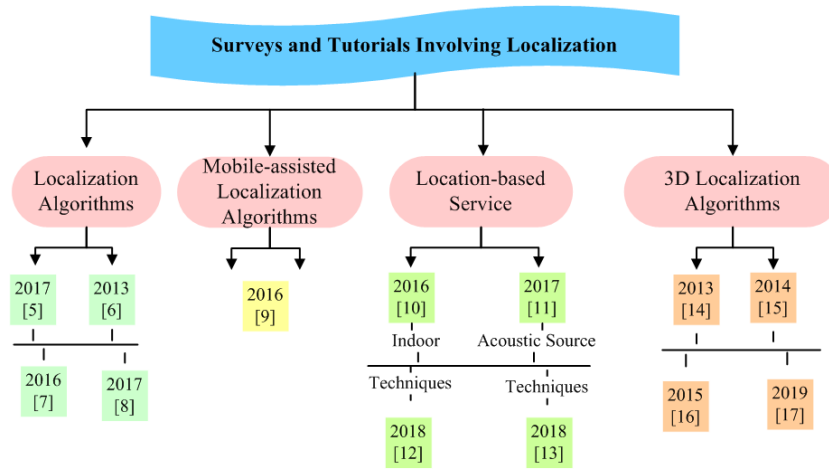

Fig. 1. Recent representative surveys and tutorials involving localization

The comparative analysis of above published survey work since 2013, are briefly outlined in Table 1, which allows readers to capture the main contributions of each existing surveys. Furthermore, we also have compared the previous survey papers with our work, and highlight a variety of open research challenges and identify possible future trends for DV-Hop localization in 3D WSNs, according to the latest developments of WSNs.

Table 1. Comparison of existing surveys relating localization in WSNs.

Ref.	Year	Focus Topics	Static Coverage	Mobility Coverage	Localization Coordinates
[5]	2017	DV-Hop	Limited	Limited	2D
[6]	2013	Localization algorithms	Extensive	Limited	2D Limited 3D
[7]	2016	Localization algorithms	Yes	Yes	2D Limited 3D
[8]	2017	Localization algorithms	Yes	Yes	2D Limited 3D
[9]	2016	Mobile localization algorithms	Limited	Extensive	2D Limited 3D
[10]	2016	Indoor localization approaches	Yes	Yes	2D 3D
[11]	2017	Acoustic source localization methods	Yes	Limited	2D Limited 3D
[12]	2018	Localization techniques in IoT	Yes	Yes	2D Limited 3D
[13]	2018	Localization enabling technologies	Yes	Limited	2D Limited 3D
[14]	2013	3D localization algorithms	Yes	No	3D
[15]	2014	3D localization algorithms	Yes	Yes	3D
[16]	2015	Localization algorithms between 2D and 3D	Yes	Limited	2D 3D
[17]	2019	3D localization algorithms	Yes	Yes	Limited 2D 3D
*	Our work	3D DV-HOP localization algorithms	Extensive	Extensive	Extensive 3D

3   Basic DV-Hop Algorithm

DV-Hop localization scheme was first came up with Dragons Niculescu and his team [18] for 2D WSNs. It is already successful applied under 3D WSNs. The localization process of DV-Hop is consisting of 3 basic steps. Here, we take 2D as an illustration.

Step 1: Estimate minimum hop counts between nodes

All anchor nodes broadcast information packet with position and hop count to neighbor nodes. The communicable neighbor node after received collected data, it will compare with precious hop count, if it is smaller, data hop count plus 1. Then, transfer to next neighbor nodes, until the whole network gets minimum hop counts between each node.

Here, Fig. 2 is one case of DV-Hop algorithm, A1, A2 and A3 are anchor nodes, and the rest nodes are unknown nodes. It is assumed unknown node Ti is the one that needs to be located. The minimum hop A_1 to A_2, A_2 to A_3 and A_1 to A_3 is 2, 5 and 7, respectively, based on first phase. The minimum hop of U_i to A_1, A_2 and A_3 is 4, 2 and 3, respectively.
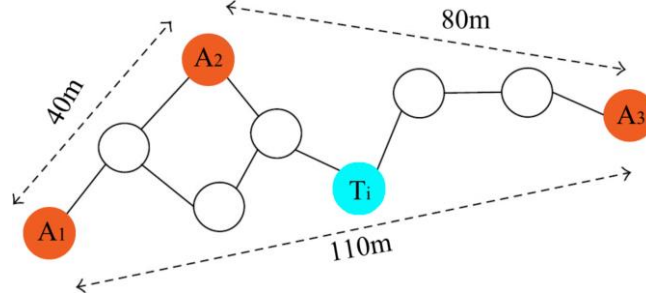
Fig. 2. An instance of DV-Hop

Step2: Estimate average hop size (AHS)

All anchor nodes obtained minimum hop counts and node position information after Step 1. It employed Equation (1) to calculate AHS.

$$AvgHopSize_i = \frac{\Sigma_{i \neq j}^{m} \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}}{\Sigma_{i \neq j}^{m} H_{ij}} \qquad (1)$$

Where (x_i, y_i) and (x_j, y_j) are the coordinate of anchor node i and j, respectively. H_{ij} is the hop count between anchor node i and j. $AvgHopSize_i$ represents the AHS of anchor node i.

The AHS of A_1, A_2 and A_3 can be calculated as following.

$AvgHopSize\_A_1 = (40 + 110) / (2+7) = 16.67$

$AvgHopSize\_A_2 = (40 + 80) / (2+5) = 17.14$

$AvgHopSize\_A_3 = (110 + 80) / (7+5) = 15.83$

Equation (2) is employed to calculate estimate distance d_{ij} between anchor node i and unknown node U.

$$d_{iu} = AvgHopSize_i \times H_{iu} \qquad (2)$$

Here, we still employed Fig. 2 as an instance. Since the minimum hop of U_i to A_1, A_2 and A_3 are 4, 2 and 3, respectively, so it chose $AvgHopSize\_A_2$ to estimate the distance of U_i to A_1, A_2 and A_3, it can be obtained by Equation (2).

d$\_A_1\_T_i = 17.14 \times 4 = 68.56$

d$\_A_2\_T_i = 17.14 \times 2 = 32.48$

d$\_A_3\_T_i = 17.14 \times 3 = 51.42$

Step 3: Estimate unknown node coordinate.

When unknown node received at least three estimated distance form anchor nodes, maximum likelihood method or multilateral measurement method can be utilized to estimate the coordinate of unknown node.

Let (x_u, y_u) is coordinates of unknown node u, and d_{iu} is the distance between unknown node u and anchor node A_i, $\in \{1, 2, 3...n\}$, d_{iu} can be obtained based on Equation (2).

$$(x_u - x_1)^2 + (y_u - y_1)^2 = d_{1u}^2$$
$$(x_u - x_2)^2 + (y_u - y_2)^2 = d_{2u}^2 \tag{3}$$
$$(x_u - x_n)^2 + (y_u - y_n)^2 = d_{nu}^2$$

Equation (3) can formulated into AX=B, see as follow.

$$A = -2 \times \begin{bmatrix} x_1 - x_n & y_1 - y_n \\ x_2 - x_n & y_2 - y_n \\ x_{n-1} - x_n & y_{n-1} - y_n \end{bmatrix} \tag{4}$$

$$X = \begin{bmatrix} x_u \\ y_u \end{bmatrix} \tag{5}$$

$$B = \begin{bmatrix} d_1^2 - d_n^2 - x_1^2 + x_n^2 - y_1^2 + y_n^2 \\ d_2^2 - d_n^2 - x_2^2 + x_n^2 - y_2^2 + y_n^2 \\ d_{n-1}^2 - d_n^2 - x_{n-1}^2 + x_n^2 - y_{n-1}^2 + y_n^2 \end{bmatrix} \tag{6}$$

The coordinate (x_u, y_u) of unknown node can be estimated by Equation (7).

$$X = (A^T A)^{-1} A^T B \tag{7}$$

4   Error Analysis of DV-Hop in 3D WSNs

DV-Hop utilized hop multiple hop size to instead straight-line distance. There is inevitable error in estimate coordinate of unknown node. In addition, there are some distinguishes between 2D and 3D localization algorithm, the later one has more challenges. Fig.3 demonstrated difference between 2D and 3D localization model in WSNs. Where, U and A denote unknown node and anchor nodes, respectively. It takes at least three anchor nodes in 2D space, but it must employ four in 3D environment, that means more anchor nodes are needed under 3D environment, which brings not only higher requirement to anchor density, but also higher algorithm complexity.
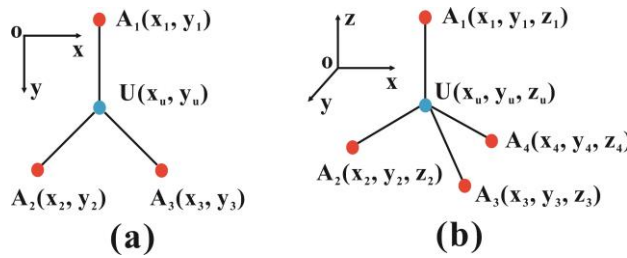

Fig. 3. Localization model in (a)2D and (b)3D

It exists more coplanar issue that if four anchor nodes are coplanarity and it leads to failing locate unknown nodes. As illustrated in Fig.4, four anchor nodes are in the same plane, the location of unknown node U is not unique. Besides, signal is influ-

enced by terrain obstacle, especially, in harsh environment. DV-Hop localization algorithm will perform badly without considering these issues.
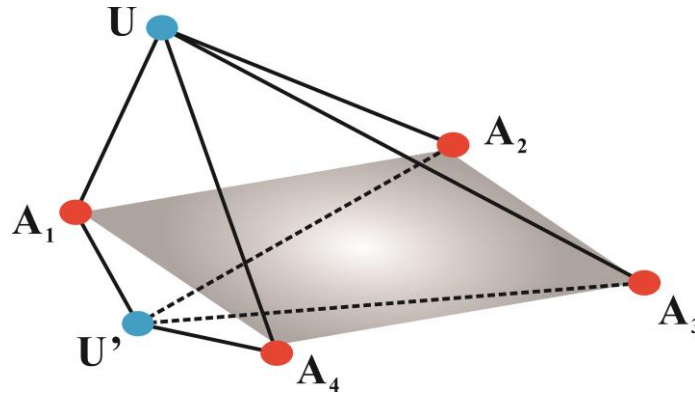

Fig. 4. Localization coplanarity issue in 3D model

5 Enhanced DV-Hop localization in 3D WSNs

In recent years, researchers in various countries have proposed numerous enhanced DV-Hop localization algorithms for 3D WSNs. We classified recent improved DV-Hop localization algorithms under 3D into four categories according to the character of localization process, based on nature-inspired optimization algorithm, weighted optimization algorithm, geometry optimization algorithm and hybrid localization algorithm. The classification is illustrated in Fig.5 and comprehensive summary and comparison of enhanced DV-Hop localization algorithm is discussed in next following sections.
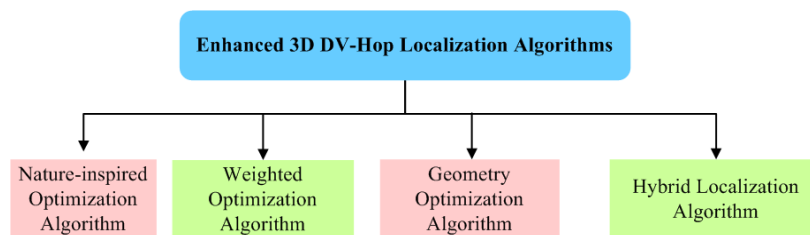

Fig. 5. Classification of enhanced 3D DV-Hop

5.1 Based on nature-inspired optimization algorithm

Nature-inspired algorithm is inspired by the laws of nature, which provides new ideas for solutions to complex problems. It has characters of intelligence, parallelism, learning ability and global search ability, and widely used in many fields such as industry, management, and computer science. Nature-inspired algorithms such as Non-

dominated genetic algorithm (NSGA Ⅱ), Particle Swarm Optimization (PSO), Cuckoo Search (CS), Genetic Algorithm (GA) etc. are successful exploited in DV-Hop localization scheme with transformed locate node problem into optimal solution. The most popularity converted function is as below.

$$f(x, y, z) = Min \ \frac{1}{m} \sum_{i=1,2,\ldots m}^{m} \left| \sqrt{(x - x_i)^2 + (y - y_i)^2 + (z - z_i)^2} - d_i \right| \qquad (8)$$

Where, f (x, y, z) is the value of particle position (x, y, z). And (x_i, y_i, z_i) is coordinate of anchor node i. And d_i is estimated distance between unknown u and anchor node i.

Qu [19] proposed adaptive fruit fly optimization algorithm (AFOA) to enhance the drawbacks of FOA in 2D DV-Hop by adopted a weight coefficient, named as 3D-AFOA. It boosted search ability through learn from merits of PSO and FOA. However, even it obtained better result, but did not conduct same experiment with DV-Hop. Similarly, Zhang et al. [20] introduced adaptive cuckoo search (ACS) algorithm to conquer slow convergence issue of original CS. The ACS mainly concentrated on search step, abandoned nest strategy, and introduced convergence function which greatly boost stability and efficiency. Besides, the author also considered multicollinearity problem by adopted tetrahedron mesh. To reduce the complexity of nature-inspired optimization algorithm, Chen et al. [21] introduced basic PSO in 3D DV-Hop, its initial population is generated around unknown nodes. But the 3D DV-Hop PSO increased one phase comparing with traditional DV-Hop algorithm that need much time to locate unknown nodes. Grey wolf optimization (GWO) is employed to optimize optimal AHS in DV-Hop algorithm, named as GWO-DV-Hop [22]. The author also introduced weighted GWO to further enhance estimate distance between unknow node and anchor nodes. Both GWO-DV-Hop and WGWO-DV-Hop conducted under 2D and 3D network environment, results shown both boost localization accuracy to some extent, but computational complexity is increased.

A 3D AC-PSO [23] is applied in DV-Hop that combined ant colony (AC) and PSO. Since PSO has advantages of strong search ability to obtain optimal value, hence, it is applied in AC algorithm to enhance information and expectation heuristic factor. Furthermore, improved AC algorithm is adopted to DV-Hop to iterate coordinate of unknown node. Compared with DV-Hop, 3D AC-PSO effectively heighten localization accuracy, but its complexity is increased since hybrid two optimization algorithms. Sharma et al [24]. adopted GA to DV-Hop, stated as 3D-GAIDV-Hop. In 3D-GAIDV-Hop, AHS is corrected based on actual distance between anchor nodes and then upgraded by line search algorithm. Coplanar issue is also studied by degree of coplanarity (DCP) that is selected from maintained lookup table. Furthermore, the position of unknown nodes is optimized by GA algorithm. It is worth emphasized that already located node will be assisted as anchor nodes in next round, that greatly enhanced localization accuracy. Still, computational time is higher than basic DV-Hop. All above nature-inspired algorithms are transformed DV-Hop localization scheme into single-objective position model, that has larger error for AHS in converted equation. Hence, Gai et al. [25] introduced NSGA Ⅱ into DV-Hop that converted localization issue to multi-objective position model, named as N2-3DDV-Hop. The N2-

3DDV-Hop demonstrated strong stability and higher localization accuracy under diversions complex topologies.

All before-mentioned optimization algorithms are improved localization accuracy of 3D DV-Hop at some degree, that mainly take advantage of each nature-inspired algorithm characteristic. Besides, converted function or fitness function will largely affect located results. The summary of Table 2, which briefly describe representative nature-inspired optimization algorithm of DV-Hop algorithms in 3D WSNs with their key characteristics.

It can be summarised from Table 2 that nature-inspired based algorithms can highly reduce localization error, but computational complexity is increased. Most above-mentioned algorithm transformed localization issue into single optimization problem, average localization error is largely reduced based on multi-objective optimization. We can conduct below outcomes, see as following:

- Those enhanced localization methods based on nature-inspired optimization algorithms for DV-Hop to are most concentrated in the third step instead of lease squares to obtain more accuracy coordinate of unknown nodes [19-20, 23, 25]. It did not add any communication cost, but add algorithm complexity to a certain degree.
- In addition, it applied to optimize AHS in step two by take advantage of its great search ability, since AHS is the main reason that lead to greater location error [22, 24]. It also did not increase communication overhead.
- Besides, nature-inspired optimization algorithm is adopted to narrow coordinate error of unknown node that calculated by basic DV-Hop [21]. It added one step that not only increase computational complexity but also consume more energy.

Table 2. Comparing of enhanced 3D DV-Hop based on nature-inspired optimization algorithm

Ref.	Algorithm Name	Localization Error(m)	Contributions	Limitations	Computational Complexity	Communication Overhead	Consider Coplanar issue?
[19]	3D-AFOA-DV-Hop	0.01-0.1	(1) Improved FOA (2) Adopted AFOA in Step 3	Increase algorithm complexity	Middle	Middle	No
[20]	3D-ACS-DV-Hop	0.15-0.5	(1) Improved ACS (2) Applied ACS in Step 3	Increase algorithm complexity	Middle	--	Yes
[21]	3D DV-Hop PSO	0.2-0.5	(1) Introduced basic PSO to optimize obtained coordinated of unknow nodes	Add one step and increase location time	Middle	--	No
[22]	3D GWO-DV-Hop 3D WGWO-DV-Hop	0.4-0.7 0.35-0.65	(1) Improved GWO (2) Applied GWO in Step 2 to optimize	Increase location time, not considered communication cost	Middle	--	No

			AHS (3) Adopted WGWO in Step 3				
[23]	3DAC-PSO-DV-Hop	0.3-0.45	(1) Combined AC and PSO (2) applied AC+PSO in Step 3	Increase algorithm complexity	High	--	No
[24]	3D-GAIDV-Hop	0.15-0.65	(1) Corrected AHS by distance (2) Applied GA in Step 3	Increase communication overhead	High	--	Yes
[25]	N2-3DDV-Hop	0.25-0.55	(1) Consider two constrained factors (2) Applied NSGAⅡ in Step 3	Increase algorithm complexity	High	High	No

5.2 Based on weighted optimization algorithm

The main drawbacks of DV-hop are inaccurate AHS that lead to more hop counts more errors. Accordingly, some academics brought forward weighted factors to balance priority of less hop counts in whole networks. Zhang et al. [26] introduced distance deviation correction and total least squares (TLS) in DV-Hop, named as NTLDV-HOP. AHS is corrected by distance deviation correction that depend on actual distance between anchor nodes. Besides, TLS is instead of least square to solve non-linear equation. The NTLDV-HOP illustrated good performance under low anchor node density. Correspondingly, AHS is redressed by weighted value that based on multiple communication radius in paper [27]. However, employed more communication radius will greatly increase energy consumption. A. Hadir et al. [28] adopted weighted average method to optimize AHS and employed hyperbolic location scheme in third stage. He [29] also adopted mobile beacon nodes to further improve localization coverage, but it extremely increased hardware cost. The new concept of DCP in 3D is proposed in paper [30]. The authors introduced DCP3D to heighten localization accuracy of DV-Hop by narrow hop counts and DCP value. The idea of DCP is also applied in paper [31] to address coplanar issue, called 3D-IDC. Every four communicable anchor nodes are divided into one group, best anchor group is selected based on DCP value. Furthermore, quasi-newton method is utilized to address unconstrained optimization equation. It is highlight that located node as auxiliary anchor nodes to participate in location process under next round. Table 3 is outlined typical DV-Hop localization schemes in 3D WSNs based on weighted optimization algorithms. It is observed from Table 3, strengthen algorithm localization accuracy based on mobile nodes is hugely enhanced.

Following conclusions can be draw, see as below.

Most weighted optimization algorithm are introduced to optimize AHS in Step 2 by distance deviation correction [26], hyperbolic location method [28], assistant mo-

bile beacon node [29]. Besides, it is adopted to correct hop count by multiple communication range [27], selected high quality beacon node [30-31], which will increase communication cost at some degree.

Table 3. Comparing of enhanced 3D DV-Hop based on weighted optimization algorithm

Ref.	Algorithm Name	Locali-zation Error	Solve Equation Method	Computa-tional Complexity	Contributions	Limitations	Node Type	Consider Coplanar issue?
[26]	NTLDV-Hop	0.2-0.45	Total least squares	Middle	(1) TLS is introduced instead of LS in step 3 (2) Correct AHS in Step 2	Increase Location time	Static	No
[27]	WCR-DV-Hop	0.15-0.4	Least squares	Middle	(1) Adopted multiple communication range to rectify AHS	Largely increased communication cost	Static	No
[28]	WH-DV-Hop	0.2-0.5	Hyperbolic method	Middle	(1) Employed weighted factor to optimize AHS in Step 2 (2) Applied hyperbolic location scheme in Step 3	Increase Location time and computational complexity	Static	No
[29]	3DDV-Hop+RWP 3eDVHop+RWP	0.07-0.1 0.06-0.07	Hyperbolic method	Middle	(1) Mobile beacon node is assistant to optimize AHS and located node in Step 2 and 3.	Largely add hardware cost	Mobile	No
[30]	DCP3D	0.25-0.45	Least squares	Low	(1) Introduced DCP to narrow hop counts in Step 1	Decreased location coverage	Static	Yes
[31]	3D-IDC	0.1-0.3	Quasi-newton method	High	(1) Adopted DCP to select beacon node in Step 2. Newton Method is employed in Step 3	Largely increased communication cost	Static	Yes

5.3   Based on geometry optimization algorithm

It is a new direction that based on geometry optimization algorithms to enhance localization accuracy of DV-Hop under 3D WSNs. Yang et al. [32] introduced cube radius intersection scale method to settle the issue that communicable anchor nodes less than four. In addition, a constrained large-scale position model is constructed to deceased one-hop distance. Feng et al. [33] adopted bounding cube to restricted feasible region of unknown nodes that will narrow search area. Besides, projected Levenberg-Marquardt is applied in third phase to solve non-linear formulation. Another bounding cube is combined with DV-Hop by Yang et al. [34] that utilized centroid

method to estimate the coordinate of unknown nodes. DV-Hop is integrated with layered structure by Dai et al. [35] to address the monitoring building issue that needs more anchor nodes. The AHS is optimized by projection-based distance measuring method. Virtual force theory is employed to enhance localization accuracy in paper [36], but its computational complexity is high. similarly, DV-Hop is also collaborated with coal mine roadway localization scheme by Wang et al. [37]. It is based on computational geometry that by comprehensively analyzed Voronoi diagram model to boost position accuracy. However, it is only favorable in underground roadways. In summary, most geometry optimization algorithms are taken advantages spatial structure characteristics or based on specific application area. The advanced 3D DV-Hop approaches based on geometry were depicted in Table 4.

Table 4. Comparing of enhanced 3D DV-Hop based on geometry optimization algorithm

Ref.	Algorithm Name	Localization Error	Solve Equation Method	Computational Complexity	Communication Overhead	Consider Coplanar issue?
[31]	DV-Hop Cube	0.4-0.65	Least squares	High	--	Yes
[32]	Bias-incorporated-DV-Hop	0.25-0.5	projected Levenberg-Marquardt	Middle	--	No
[33]	DB	0.3-0.4	Centroid method	Low	Low	No
[34]	LS3D DV-Hop	0.2-0.5	Least squares	Middle	--	Yes
[35]	VF-DV-Hop	0.15-0.45	Least squares	High	--	No
[36]	CG-DV-Hop	2.2-3.0	Least squares	Low	--	No

5.4 Based on hybrid localization algorithm

Range-based scheme demonstrated superior performance in location accuracy, so, several scholars applied it in DV-Hop algorithm. Received signal strength indicator (RSSI) [38] is utilized to calculate weighted factor based on its first order partial derivative by Gou et al. [39]. AHS and estimate distance to unknown nodes are enhanced by above mentioned weighted factor. In addition, weighted least squares method is instead of least square to address equation in last phase. Zhang et al. [40] proposed 3D-RDH to reduce the dependency on more anchor nodes, which taken advantage of RSSI to correct estimate distance of unknown nodes in one hop count. Anchor node deployment configuration is optimized by maximal independent set. Besides RSSI, representative range-free scheme, approximate point in triangle test (APIT) [41] is combined with DV-Hop in 3D to address low location accuracy under dense anchor nodes condition in paper [42]. The hybrid localization integrated merit of both two algorithms that obtain better performance under low network coverage. Both hybrid range-based and range-free localization reduced localization error at some extent, however, it will increase algorithm complexity and extra cost, especially based on range-based schemes.

In summary, most combined range-based localization algorithm is utilized to optimize AHS in Step 2 by rectify hop count based on accuracy range information, which can obtain higher localization. However, it will largely increase hardware overhead,

since range-based location technique has high requirement of hardware. The hybrid range-free one is used in Step 3 to narrow position error of coordinate, it did not increase any hardware cost since it only depended on connectivity information. Since combined range-based or range-free will greatly increase algorithm complexity, especially, range-based add hardware cost. Hence, hybrid localization algorithm is the mainstream method that be adopted to enhance localization accuracy of DV-Hop.

5.5 Summary

It can be conducted that nature-inspired optimization algorithm and weighted optimization are recommended method to enhance localization accuracy of DV-Hop. The other two categories are constrained for high hardware cost or only suitable for specific scenarios or geographical environment. Most of them demonstrated superior performance of localization accuracy. The localization error of DV-Hop is largely reduced, nearly reduced by two times. It can satisfy the requirement of large-scale location-based applications. The DV-Hop localization algorithm is fit for large scale wireless sensor networks, for it only need connectivity information and wireless sensor networks consist of thousands of sensor nodes since monitoring areas are usually great large. Besides, its location accuracy is fundamental improved after adopted optimize method. So, it can be conducted that DV-Hop will be a hot research area, it is with great potential to fulfill requirement of high location-based applications.

6 Conclusion

Location information is prerequisite for wireless sensor network monitoring and control applications. In this paper, we have provided a tutorial and survey of enhanced DV-Hop localization algorithms under 3D WSNs since most previous works concentrated on 2D space. We summarized representative survey of range-free localization algorithms that concentrated both under 2D and 3D WSNs. Moreover, improved DV-Hop algorithms proposed in literature are investigated, with comparing in terms of localization error, computational complexity, energy consumption, node type and coplanar issue. We divided enhanced 3D DV-Hop localization into four types based on location processing characteristic. Each type of enhanced method is needed to balance location performance and algorithm cost, like nature-inspired based algorithm is greatly boosted localization accuracy, but computational complexity is high. Future probably hot topics of 3D DV-Hop localization are mobility network, irregular topology networks and multiple-objective optimization model-based localization schemes.

7 Acknowledgement

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