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Localization algorithms of Wireless Sensor Networks: a survey

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Abstract In Wireless Sensor Networks (WSNs), localization is one of the most important technologies since it plays a critical role in many applications, e.g., target tracking. If the users cannot obtain the accurate location information, the related applications cannot be accomplished. The main idea in most localization methods is that some deployed nodes (landmarks) with known coordinates (e.g., GPS-equipped nodes) transmit beacons with their coordinates in order to help other nodes localize themselves. In general, the main localization algorithms are classified into two categories: range-based and range-free. In this paper, we reclassify the localization algorithms with a new perspective based on the mobility state of landmarks and unknown nodes, and present a detailed analysis of the representative localization algorithms. Moreover, we compare the existing localization algorithms and analyze the future research directions for the localization algorithms in WSNs.

beacon 信标
perspective 观点

以往定位算法分类：范围有限，范围无限
现在定位算法分类：信标移动，未知节点

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智能尘埃项目意味着可以将一个完整的传感器/通信网络系统集成到一立方毫米的封装中，该项目被认为可以同时在商业上及军事上具有“颠覆性”的项目

Keywords Wireless Sensor Networks · Localization algorithms · Mobility · Location accuracy

1 Introduction

MEMS:微电子机械系统
perceive:感知，理解，认识
the coverage of:...的覆盖范围内

The development of MEMS, chip systems and wireless communications technology has fostered, low-powered and multi-function sensor nodes, which can integrate information collection, data processing, wireless communications and other functions together within the small storage, to gain rapid progress [45]. WSN is a multi-hop self-organizing network, where a large number of sensor nodes are deployed. The aim of WSN is to perceive, collect and process the information of sensor nodes within the coverage of the network [1].

As a bridge between the physical world and the digital world, WSNs are widely used to deal with sensitive information in many fields. Application scenarios of WSNs include military, industrial, household, medical, marine and other fields, especially in natural disasters monitoring, early warning, rescuing and other emergency situations. For example, by a smart dust network, suspended nodes in the air space can detect pressure, temperature and other information of different positions to monitor the quality of the atmosphere. Sensor nodes buried under the bed at different depths can collect temperature, pressure and other data to observe the activity of the glacier [37]. Sensor nodes in the birds' nests can help users to further research the living habits of birds [36]. In above-mentioned applications, all collected information is based on the accurate location of sensor nodes. Therefore, localization is one of the basic and core technologies in WSNs. Efficient location technology and its optimization methods urgently need to be further resolved in depth. Mak-

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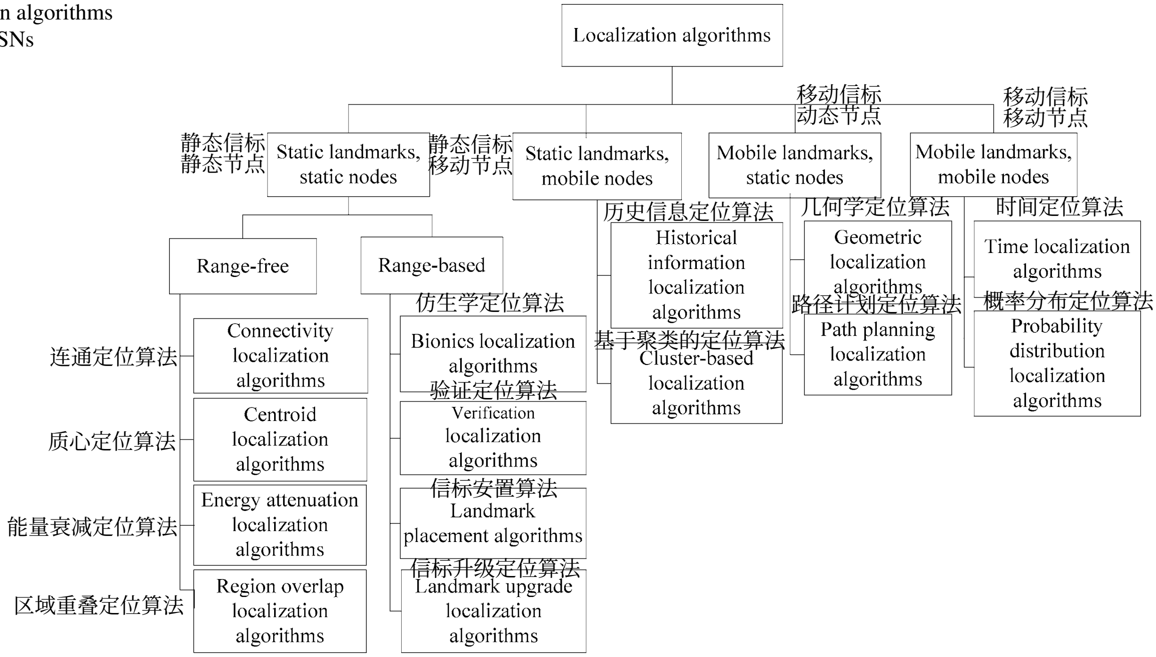
Fig. 1 Localization algorithms classification in WSNs



ing a study of the localization technology is very essential for WSNs' theoretical research and realistic applications [48, 55]. estimation:估计量

Up to now, the most existing localization algorithms of WSNs are classified into two categories: range-based [5, 30] and range-free [47, 62]. Range-based techniques use distance or angle estimates in their locations estimations, while range-free techniques only use connectivity information between unknown nodes and landmarks. Range-based techniques have used Received Signal Strength (RSS) [10], Time of Arrival (TOA) [13], Time Difference of Arrival (TDoA) [9], or Angle of Arrival (AoA) [41]. Landmark node can obtain its own location information in advance by GPS systems or the artificial deployment information. In this paper, a node that has got its own location information is called a landmark. Otherwise, it is an unknown node.

This paper is organized as follow: In Sect. 2, we briefly introduce the classification of localization algorithms in a new way. In Sects. 2, 3, 4, 5 and 6, we analyze and summarize the typical localization algorithms. In Sect. 7, we discuss and summarize the future research direction for the localization algorithms.

2 Classification of localization algorithms

There has been a large body of research on localization for WSNs over the last few years. The localization process of an unknown node can be described as the node determines its position by limited communication with several landmarks using some specific localization technologies. However, in many WSNs applications, the unknown node can also calculate its position based on the connectivity information between unknown nodes and landmarks. Currently, there are four kinds of localization schemes: (1) range-based and range-free localization algorithms; (2) landmark-based and landmark-free localization algorithms; (3) fine-grained and coarse-grained localization algorithms; (4) incremental and concurrent localization algorithms [14, 23, 54]. The above-mentioned algorithms are classified based on the characteristics of landmarks. However, those classifications are not distinct enough for further research of the localization algorithms without considering the mobility state of sensor nodes. Thus, in this paper, we reclassify the localization algorithms based on the mobility state of landmarks and unknown nodes, as shown in Fig. 1.

In Fig. 1, localization algorithms are classified into four categories: (1) static landmarks, static nodes, (2) static landmarks, mobile nodes, (3) mobile landmarks, static nodes and (4) mobile landmarks, mobile nodes. The common feature of the four categories is that they all need landmarks to locate the unknown node. In next section, we analyze and summarize the typical localization algorithms of each category.

3 Static networks—static landmarks and nodes

Localization algorithms of static landmarks and nodes are applied in WSNs, where all the nodes are static. The algorithms can be classified into two categories according to whether they need physical measurements to obtain distance or angle information [23]. Localization algorithms within each category can be further classified as range-based or range-free [14]. Range-based algorithms need to measure the distances between unknown nodes and landmarks. Then, the measured distances are used to calculate the coordinates of the unknown node. Range-free algorithms can indirectly obtain the distances between unknown nodes and landmarks by the connectivity information or the exchanged multi-hop routing information. Then, the indirectly obtained distances are used to calculate the coordinates of unknown node. Generally speaking, range-based algorithms can achieve higher localization accuracy; however their performance is limited by the high hardware cost and the heavy power consumption. In contrast, range-free algorithms lower the costs and are much more efficient in the localization process of unknown nodes.

3.1 Range-free localization algorithms

superimposed region:重叠区域

Range-free algorithms do not need to measure the distance or angle information between unknown nodes and landmarks, which estimate the distance between two nodes by the connectivity information, the energy consuming information, or the area information of the superimposed region of the landmarks. In this paper, range-free localization algorithms can be divided into four categories: connectivity localization algorithms [30, 52], centroid localization algorithms [5, 20, 27, 47], energy attenuation localization algorithms [44, 46, 58] and region overlap localization algorithms [21, 35, 56].

3.1.1 Connectivity localization algorithms

sequel:续集

These localization algorithms combine the connectivity of the ideological graph theory with the node's localization. For example, in an undirected graph G, if vertex V_i has path to connect vertex V_j, then V_i and V_j are connected. If G is a directed graph, then the paths of V_i and V_j have the same direction. If any two points of the graph are connected, then G is called a connected graph [3]. The Connectivity localization algorithms of WSNs are closely related to their network topology [30]. The detailed information of typical algorithms [28, 30, 40, 52] is described in the sequel.

In [40], the core idea of DV-Hop is that the nodes exchange the traditional distance vector packets, so that each node has the minimum hops and the coordinates of all landmarks. Then, each landmark broadcasts its average distance of each hop with data packets. When the unknown node receives the average distance of each hop, it calculates the distance to each landmark according to the recorded hop information. As shown in Fig. 2, the actual distances between landmark i and other two landmarks j and k are d_{ji} and d_{ik}, respectively. Hop number h_{ij} and h_{ik} are 3 and 4, respectively, then landmark i can calculate the average distance to each hop, which is $c_i = (d_{ji} + d_{ik})/(h_{ij} + h_{ik}) = (d_{ji} + d_{ik})/(3+4)$. Therefore, the unknown node p obtains the average value of each hop to landmark i, and calculates the distances to landmarks *i, j, k* are c_i, $3c_i$, $4c_i$ respectively. Then p calculates its coordinates using trilateration or maximum likelihood estimation (MLE) [22]. Simulation results show that DV-Hop does not need the distance to be measured. Compared with the Centroid location algorithm [4], DV-Hop can meet localization requirement in the sparse network. When the ratio of landmarks increases, the localization error of DV-Hop also decreases.

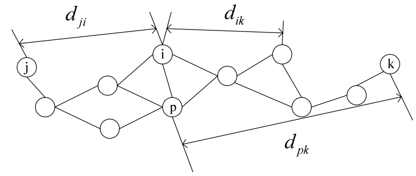


Fig. 2 DV-hop localization algorithm

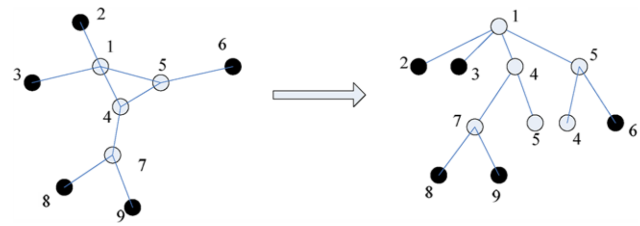


Fig. 3 Formation of the BN tree

In [30], the researchers propose the concept of Localizable Collaborative Body (LCB). LCB is a kind of distance-related methods using the graph theory to implement localization. The unknown node using this kind of algorithms can locate itself with multi-hop landmarks. Therefore, LCB can overcome the restriction of at least three neighbor landmarks needed to locate the unknown nodes. LCB first needs all the landmarks to broadcast their location information. Any unknown node that receives the related location information can change the model of the network into a ~~BN-tree~~. In a BN-tree, only the root node has at least three sub-root nodes, other parent nodes have at least two child nodes. LCB evolved from the BN-tree can complete the localization using the location information of landmarks and the relative location relationship between unknown nodes and landmarks.

As shown in Fig. 3, nodes 2, 3, 6, 8, 9 are landmarks, and nodes 1, 4, 5, 7 are unknown nodes. The left graph is the position relationship of WSNs, and the right graph is the BN tree based on graph theory.

LCB can reduce the computation overload and communication cost in the localization process. However, LCB also has a shortcoming that can result in cumulative error, the corresponding cooperative localization between unknown nodes can cause the localization error of one unknown node to have great impact on the localization error of other unknown nodes.

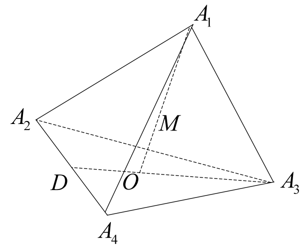


Fig. 4 Tetrahedron method

3.1.2 Centroid localization algorithms

exceed 超过
centroid 质心
polygon 多边形

The core idea of the centroid localization algorithms is to use the connectivity relationships among nodes to calculate the unknown node's position information. These algorithms are Range-free localization algorithms. In these algorithms, the landmark periodically broadcasts its coordinates information, which contains landmark's ID and location information, to the neighboring unknown nodes. When the location information received by the unknown node exceeds a certain threshold in a period of time, then the unknown node and landmarks can be interconnected. The estimate location of the unknown node is the centroid of the polygon which formed by several landmarks. The detailed information of typical algorithms [5, 6, 20, 26, 47] is described in the sequel. tetrahedron 四面体

The researchers in [5] propose the tetrahedron localization algorithm. As shown in Fig. 4, nodes A_1, A_2, A_3, A_4 are four landmarks. The algorithm calculates the centroid of each tetrahedron, and then the average value of the centroid is the estimate position of the unknown node.

The tetrahedron localization algorithm estimates the coordinates of the unknown node by calculating the centroid of tetrahedron. Simulation results show the localization error of tetrahedral algorithm is higher than that of traditional centroid algorithm [4]. The localization error of tetrahedral algorithm is $0.54R$, and the localization error of traditional centroid algorithm is $0.7R$. Compared with traditional localization algorithms, the localization accuracy of tetrahedron localization algorithm improves by 29%. However, the coordinates of unknown node need to be calculated many rounds, thus the calculation and the energy consumption are large.

In [47], the algorithm combines DV-Hop with Assumption Based Coordinates (ABC) to locate unknown nodes. First, the algorithm calculates the distance between unknown nodes and landmarks by DV-Hop, and then calculates the coordinates of the unknown node using ABC algorithm, as shown in Fig. 5, where n_0, n_1, n_2 are landmarks, n_3 is an unknown node. Landmark n_0 is located in the coordinate origin, n_1 is in Y axis and n_2 is in XOY plane. We can calculate the coordinates of node n_3 based on the geometric relationship of the landmarks. The main feature of the algorithm is that only simple computation is needed. However, the localization error of the algorithm is high when the node is irregular placed in a WSN.

assumption 假设，假定

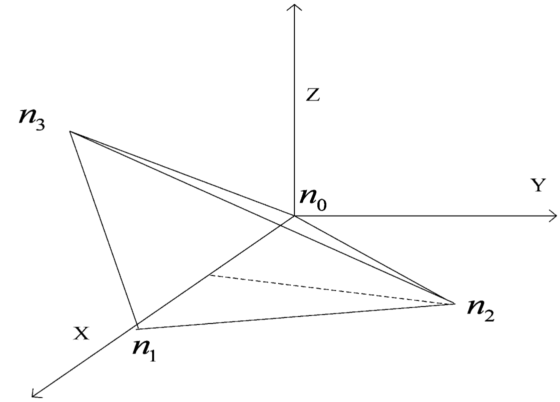


Fig. 5 ABC method

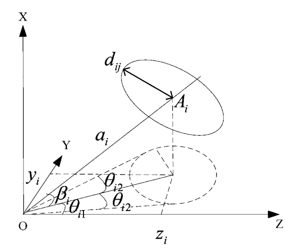


Fig. 6 Three-dimensional centroid algorithm

The main difference of literature [47] and literature [5] is mathematical method. The former uses ABC method, while the latter applies tetrahedron method. Simulation results show that the average localization error of literature [47] is $0.46R$, and that of literature [5] is $0.54R$.

~~A novel three-dimensional centroid algorithm~~ [20] is proposed for unknown nodes in a 3-D WSN, which assumes that geometric relationships and communication constraints between unknown nodes and landmarks are founded based on the assistant three-dimensional coordinates system. The three-dimensional graph is constructed by calculating several profiles and curving planes. In order to decrease the communication and computational overload, the three-dimensional graph is converted into a plane graph, which is composed of several profiles. As shown in Fig. 6, d_{ij} represents the communication range of landmark A_i, and $\theta_{i1}, \theta_{i2}, \beta_i$ denote the slopes of the three-dimensional graph. The plane graph can be constructed by the slopes of three-dimensional graph. Finally, the centroid of plane three-dimensional graph is the estimated position of the unknown node. denote 表示
the slopes of ...的斜率

Simulation results show that the localization ratio of the algorithm is close to 99% when landmark density is greater than 6. This means that the algorithm has low requirement on landmark density, which is suitably used in sparse network environment.

3.1.3 Energy attenuation localization algorithms

When an unknown node is covered by a landmark, the signal amplitude of the landmark becomes smaller as its trans-

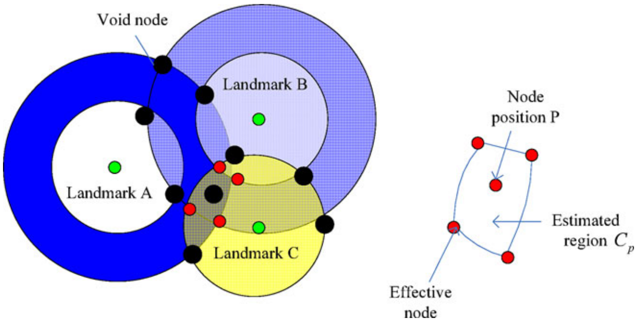


Fig. 7 Energy grade overlap graph

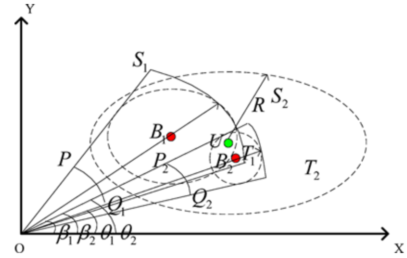


Fig. 8 Sketch map of target region

mission distance increases. And the beacon energy of the landmark which the unknown node receives also becomes smaller. In energy attenuation localization algorithms, the unknown node calculates the distance with the landmark based on the energy attenuation of the beacon. The typical algorithms have sound energy attenuation localization algorithm [58] and energy range localization algorithm [44, 46]. The details of those algorithms are described in the sequel.

In [58], the distance between the unknown and the landmark can be calculated based on the source energy attenuation of the beacon of the landmark. First, the algorithm determines the objective's function by constructing the maximum likelihood method and then calculates the estimated position of the unknown node using Gauss-Newton function. Simulation results show with Signal-to-Noise Ratio (SNR) and signal power increase, the positioning accuracy of the unknown node can be improved greatly. The algorithm reflects that the noise has impact on the localization. The localization error of the unknown node decreases from 6 m to 2 m, when SNR increases from 36 dB to 45 dB.

In [46], a novel Beacon Signal Ring (BSR) localization algorithm is proposed, in which each landmark continuously transmits beacons to the unknown nodes with different power. The transmission time intervals of two landmarks obey a normal distribution. The algorithm can reduce the interference of two different landmarks. The information packet of each landmark contains its ID, coordinates and transmitting power P_i. Each unknown node monitors and collects the power information of the landmark. The unknown node determines the signal scope based on its received information. As shown in Fig. 7, landmarks *A, B, C* transmit signal with different energy grades. The overlap scope of energy (C_P) is the estimated region of the unknown node. Then the centroid of C_P is the estimated coordinates of the unknown node. The localization accuracy of the algorithm is higher than the literature [58]. However, the algorithm needs much more energy to transmit different power beacons. scope:范围，视野，眼界

A novel energy attenuation localization algorithm for WSNs is presented in [44], which estimates the coordinates of the unknown nodes based on the Logit normal distribution model of energy attenuation. A new "3σ" principle is proposed in the algorithm, which can be used to establish the region mapping between the received signal power and the transmission range. With the region mapping technique, an unknown node gets the energy section based on its received signal strengths (RSS) and determines which the transmission range of the landmark is belonged. Then, the algorithm transforms the region information with distance constraints to overlap region. The overlapping region is the minimum area of the unknown node's position. Finally, the centroid of the region is regarded as the coordinates of the unknown node. As shown in Fig. 8, nodes B_1 and B_2 are two landmarks, while node U is an unknown node. Node U estimates the energy overlap region based on its received signal strengths and calculates the estimated coordinates. The localization accuracy of the algorithm is high. However, the algorithm needs many round calculations, thus the energy consumption is large.

3.1.4 Region overlap localization algorithms

communication overhead:通信开销

The core idea of region overlap localization algorithms is to calculate the centroid of the overlapping region as the estimated coordinates of unknown nodes. These algorithms do not need to calculate the distance between unknown nodes, thus reduce network communication overhead and save the node's energy consumption. The detailed information of typical algorithms [21, 35, 56] is listed as follows.

A new HiRLoc localization algorithm is proposed in [21]. The algorithm reduces the overlapping region by changing the transmission power and directional antennas of unknown nodes. As shown in Fig. 9, two nodes L1 and L2 form a region $O(t)$. The algorithm can obtain the location information of the unknown node by calculating the centroid of the overlap region, in which the landmark's information includes the coordinates of landmark, the angle of directional antennas and communication radius R. The traditional algorithms rely on the neighbor node's information to locate unknown nodes, therefore its communication cost increases as the sensor region increases. However, the algorithm does not depend on the deployment of landmarks. Simulation results show that when the number of information packets is 15, the localization error can reach $0.2R$. In order to achieve the

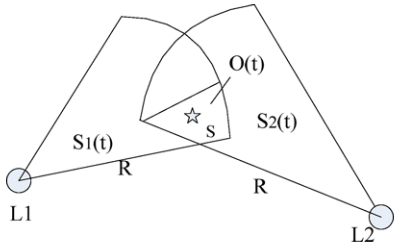


Fig. 9 Region overlapping

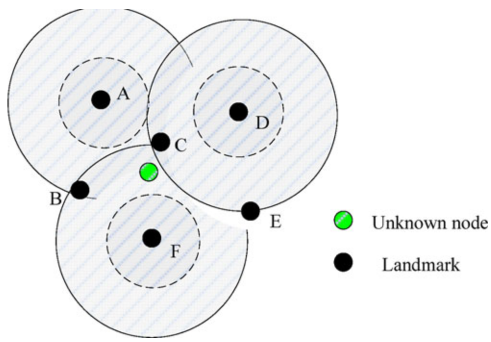


Fig. 10 Spherical shells overlap

spherical: 球形的，球面的 concentric:同中心的 radii:半径（复数）

same localization accuracy, APIT algorithm [50] requires 200 information packets.

In [35], spherical shell overlap localization algorithm is proposed for WSNs. It divides the whole space into concentric spheres with different radii. In particular, a landmark is located in the center of ball and the distance between two landmarks is the ball radius. The unknown node determines the thinnest layer spherical shell by judging whether the sphere contains itself, as shown in Fig. 10. This thinnest layer spherical shell is the possible region, and its center of gravity is the estimated location of the unknown node. The advantage of the algorithm is to only require landmarks broadcasting location information that other unknown nodes use to locate themselves. Thus, the cost of network communication could be reduced to save the energy consumption of unknown nodes.

A novel localization algorithm for WSNs is proposed Based on ~~Voronoi graph~~ [56]. The algorithm first sorts received signal strength receiver (RSSI) of landmarks based on descending order, and then calculates the Voronoi region of each landmark using Unit Disk Graph. Then, the centroid of the Voronoi overlap region is regarded as the coordinates of the unknown node, as shown in Fig. 11. In the process of calculation, all nodes of Voronoi region have the weight value defined as the received signal strength value of the landmark. The location of the node with maximum weight value is the estimated location of the unknown node. Simulation results show the localization error of the algorithm decreases with the increase of the communication radius and landmark density. When the communication radius and node

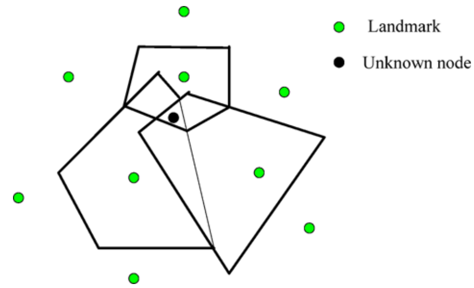


Fig. 11 Voronoi graph

density increase, the information of landmarks increases. Thus, the localization accuracy of the unknown node is more precise.

3.2 Range-based localization algorithms

Range-based localization algorithms have highly localization accuracy. But they usually require more hardware in order to measure the distance between sensor nodes. The typical distance measurement techniques include RSSI, TOA, TDOA, AOA, and etc. Range-based localization algorithms use the above different measurement techniques to locate the unknown node. In this paper, range-based localization algorithms can be divided into four categories: bionics localization algorithms [31, 62], verification localization algorithms [56, 57], landmark placement localization algorithms [11, 49] and landmark upgrade localization algorithms [8, 32].

3.2.1 Bionics localization algorithms

The core idea of bionics localization algorithms is to combine the model of biological motion with the localization process of unknown nodes. The localization algorithms establish the position relationship between unknown nodes and a landmark ~~according to the laws of biological motion~~, thus the algorithm can calculate the coordinates of unknown nodes. The detailed information of typical algorithms [31, 62] is described in the sequel. nectar:花蜜 cosine law:余弦定理

In [62], the researchers propose a localization algorithm based on nectar using the living habits of bees in the physical world. The algorithm first acquires the distance information between the landmark and the unknown node according to signal strength, then calculates the relative angle using the cosine law and obtains the relative position of the unknown nodes according to mobility model of bees, finally obtains the coordinates of the unknown node. This algorithm has relatively high localization accuracy. Simulation results show when the distance error is 15%R and the number of landmarks is 20, the localization error can reach 0.14R. However, the algorithm has high requirement for hardware and energy consumption in the localization process. Thus, it is more vulnerable to acquired temperature, humidity, obstacles and other environmental factors.

Triangulation :三角测量
equilateral triangle:等边三角形

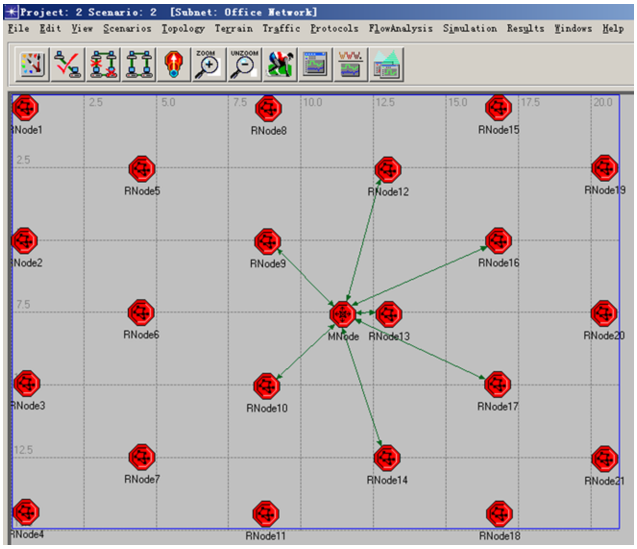


Fig. 12 Placement of landmarks

3.2.2 *Verification localization algorithms*

The core idea of these localization algorithms needs to verify the distance value between unknown nodes and landmarks using RSSI value. As a result, the distance measurement is the key factor in the localization process. The applications of RSSI are used very widely and fit the actual environment in WSNs. The detailed information of typical algorithms [56, 57] is described in the sequel.

take into a ccount:把..考虑在内

Wang proposes a weighted RSSI localization algorithm in [57]. Taking into account the impact of environment factors in WSNs, the localization algorithm verifies the weight value of a node by the signal strength information and the actual distance. So the algorithm can increase the adaptability in different environments and improve the localization accuracy. Firstly, the algorithm applies RSSI value to calculate the distance between the nodes. Then, the algorithm uses the distance and the RSSI value to verify the weight value of node. Finally, the algorithm calculates the coordinates of unknown nodes. Simulation results show the probability of the localization error of less than 1.5 m is over 85%, while the probability of the weighted centroid algorithm [56] achieves only about 75%. Using the same simulation conditions, the average localization accuracy can be improved by 25.48% in comparison with that of the weighted centroid algorithm.

adaptability：适应性

3.2.3 *Landmark placement localization algorithms*

Landmark placement has great relationship with the localization error of unknown nodes. Therefore, the geometry relationship of landmarks is used to improve the localization accuracy of unknown nodes. The detailed information of typical algorithms [11, 49] is described in the sequel.

In [11], Han et al. propose Reference Node Selection algorithm based on Triangulation (RNST) that the unknown node's localization error is the least when three landmarks form an equilateral triangle, as shown in Fig. 12.

Traditional multilateral location algorithm [53] adopts a random placement and choices several different landmarks to locate the position of unknown nodes. Generally, most sensor nodes work in the resource-constrained environment with limited computing, storage and communication capabilities. The energy resource is extremely limited. In the localization process, the computation overload is large and the convergence speed of error is slow. It is difficult for unknown nodes to achieve its position in a resource-constrained situation. When three landmarks form an equilateral triangle, the localization accuracy of RNST decreases by 34.9% than that of the traditional method [53]. RNST can effectively improve the localization accuracy of unknown nodes. convergence:收敛

3.2.4 *Landmark upgrade localization algorithms*

coverage:范围

Taking the cost of WSNs into account, the number of landmarks is limited as the communication range of each unknown node is difficult to have more than 3 landmarks. However, if the node is to obtain high precision and high coverage, WSNs need to contain a large number of landmarks. In the case of no increase in the number of landmarks, the algorithms upgrade several unknown nodes to landmarks. Therefore, the unknown node can receive more information as a landmark and improve the localization coverage. The detailed information of typical algorithms [8, 32] is described in the sequel. refinement:细化，提纯

A novel landmark upgrade localization algorithm is proposed in [8], which upgrades a node with high localization precision to a landmark. Unknown nodes are located using cycle refinement according to the updated location information of landmarks and control the round number of circulation by estimating the variance of coordinate value. As shown in Fig. 13(a), in the two hop communication ranges of the unknown node U_0, the unknown node U_2 uses trilateration method to determine its position coordinates according to the distance of three landmarks (L_1, L_2, L_3) to node U_2. Then, node U_2 can be upgraded to a landmark by a number of one- and two-hop landmarks. As shown in Fig. 13(b), node U_2 is upgraded to a landmark. Node U_0 only obtains the distance between two landmarks L_1 and L_2. Thus, node U_0 cannot determine its coordinates. However, in Fig. 13(b), since node U_2 is upgraded to a landmark, node U_0 can get the distance of three landmarks (L_1, L_2, U_2). Therefore, node U_0 can use trilateration method to determine its coordinates.

Simulation results show that this algorithm can improve the localization accuracy with low density of landmarks in

WSNs [32]. It is significant that the algorithm can reduce the dependence of landmarks. However, the algorithm needs heavy communication and computation. The reason is that the algorithm continually sends the updated location information of landmarks and iteratively computes the coordinates of unknown nodes.

3.3 Summary

In contrast with Range-based localization algorithms, Range-free localization algorithms do not need the distance and angle information except the connectivity information of unknown nodes. The former requires more complex equipment and consume heavy computation and communication to obtain a relatively accurate location, such as honey-based localization algorithms [62] and energy attenuation localization algorithms [57], etc. Meanwhile, the latter has gained more and more attention with the advantages of energy consumption, such as connectivity localization algorithms [30, 52], energy attenuation localization algorithms [44, 46, 58] and region intersection localization algorithms
intersection:交叉

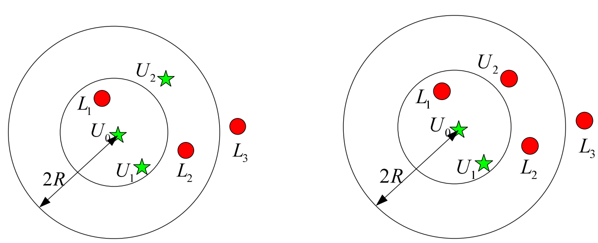


Fig. 13 (**a**) Initial position diagram. (**b**) U_2 update as landmark diagram

[21, 35, 56], etc. We have analyzed the static landmarks and static unknown nodes localization algorithms in the aspect of localization accuracy, node density, landmark density and energy consumption, as shown in Table 1.

In Table 1, we can see that the localization accuracy of connectivity localization algorithms is average and the requirement of node density is greater. But the requirement of landmark density is smaller. On the contrary, the localization accuracy and energy consumption of energy attenuation localization algorithms are good, while their requirements of node density and landmark density are average. In the case of region overlap localization algorithms, the localization accuracy is better; however the requirement of landmark density is higher. The idea of bionics localization algorithms is novel; however the localization accuracy is average. Verification localization algorithms have average localization accuracy and energy consumption, but the requirement of landmark density is higher. The localization accuracy and energy consumption of landmark placement localization algorithms are good; in contrast, the requirement of landmark density is higher. Finally, landmark upgrade localization algorithms can improve position coverage in the case of sparse landmark density, but the localization accuracy is average and the energy consumption is higher.

4 Static landmarks and mobile nodes

In the real application environment of WSNs, such as monitoring the living of human or animal, many unknown nodes

Table 1 Comparison of static landmarks and nodes localization algorithms

Localization algorithms		Localization accuracy	Node density	Landmark density	Energy consumption
Connectivity localization algorithms	DV-Hop [40]	Better	Greater	Smaller	Greater
	LCB [30]	Average	Greater	Average	Average
Centroid localization algorithms	Centroid [5]	Average	Smaller	Greater	Greater
	ABC [47]	Better	Smaller	Average	Average
	Three-dimensional centroid [20]	Better	Smaller	Smaller	Greater
Energy attenuation localization algorithms	Source energy attenuation [58]	Average	Average	Average	Average
	BSR [46]	Better	Average	Average	Greater
	Energy intervals [44]	Better	Average	Average	Greater
Region overlap localization algorithms	HiRLoc [21]	Average	Smaller	Average	Average
	APIS [35]	Better	Smaller	Greater	Smaller
	Voronoi [56]	Average	Smaller	Greater	Average
Bionics localization algorithms	Honey bee orientation [62]	Average	Average	Smaller	Greater
Verification localization algorithms	weighted centroid algorithm [57]	Average	Average	Greater	Average
Landmark placement localization algorithms	RNST [11]	Better	Smaller	Average	Smaller
Landmark upgrade localization algorithms	Landmark sparse [32]	Average	Smaller	Smaller	Greater

are mobile. The application of mobile unknown nodes is closely related to our life. Thus, static landmarks and mobile nodes localization algorithms are introduced in this section, which can be divided into historical information localization algorithms [29, 34, 38, 42] and cluster localization algorithms [12]. The former focuses on the historical information of unknown nodes and the latter focuses on interaction relationship between landmarks.

4.1 Historical information localization algorithms

The idea of these algorithms is to predict the coordinates of mobile unknown nodes based on their recorded historical information. The algorithms can save energy computation and are applied to real applications in WSNs. The detailed information of typical algorithms [29, 34] is described in the sequel.

A distributed mobile localization algorithm is proposed in [29]. When the number of neighboring landmarks is less than 3, the algorithm proposes the idea that unknown nodes use the predictability of mobility to locate themselves. In the algorithm, each unknown node first maintains a history queue which saves the information of three latest locations, and then we can obtain the linear motion equations of the unknown node according to the history records. We assume that the unknown node is a linear motion in short time interval and the acceleration is constant. As shown in Fig. 14, the node $((X_A, Y_A), (X_B, Y_B))$ are the points of intersection between tangent L and the circle, and we can acquire the estimated coordinates (X_c, Y_c) of the unknown node in the next time. As a consequence, the coordinates of the unknown node should is $((X_A + X_B + X_C)/3, (X_A + X_B + X_C)/3)$.

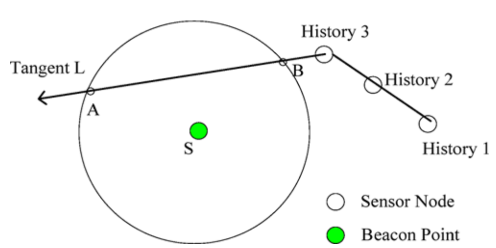


Fig. 14 Distributed mobile localization algorithm diagram

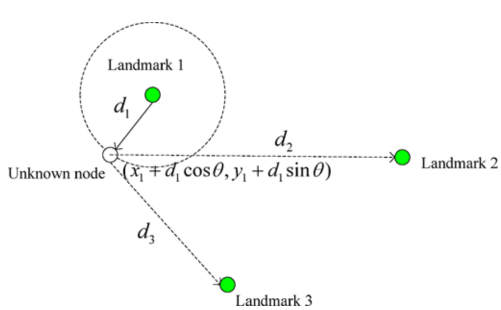


Fig. 15 DTN localization algorithm

The simulation results show that [29], the positioning coverage of the algorithm can achieve 99%. When the ranging error increases to 40%, the localization error of the algorithm is only 33% and that of the traditional localization algorithm [61] can reach to 50%.

A Dynamic Triangular (DTN) algorithm, which calculates the coordinates by predicting next RSSI value of the unknown node, is proposed in [34]. As shown in Fig. 15, DTN first finds the possible location of the unknown node using the position information of the landmarks, then calculates the estimated distances between the unknown node and two landmarks, and estimates the distance measurement error between the actual distance and the possible distance. Finally, the algorithm selects the coordinates with the least measurement error value as the estimated coordinates of the unknown node. Simulation results show the localization algorithm can eliminate the RSSI fluctuation to some extent, thereby improve the localization accuracy of the unknown nodes. The average localization error of the algorithm is 1.2 m. However, due to the fact that positioning result has great relationship with the recorded historical information of the landmarks, thus the accumulative error of the algorithm is larger. fluctuation:波动，起伏

4.2 Cluster-based localization algorithms

Cluster-based localization algorithms are suitable for WSNs with low computation complexity. First, these algorithms divide a WSN into several clusters, and each landmark respectively locates the unknown node in its cluster. Then, the position information of the unknown node is merged in each cluster. Finally, all unknown nodes can be estimated by the algorithm. The details information of typical algorithms [12] is listed as follows.

A new distributed target tracking localization algorithm is proposed in [12], which divides a WSN network into several clusters and each cluster has a landmark which is responsible for finding target, assigning task, and establishing communication between clusters. When an unknown node moves into a new cluster, the cluster estimates the coordinates of the unknown node. If the unknown node moves into a next cluster, the next cluster is responsible for locating its position. Finally, the mutual cooperation of all clusters locates the unknown node. As shown in Fig. 16, eight landmarks are deployed in the monitoring region, which broadcast the beacon to the unknown node and receive its feedback beacon. The algorithm calculates the distances between the unknown node and landmarks, and then determines the coordinates of the unknown node using trilateration method.

Figure 16 shows that there exists interference when all landmarks work at the same time. There is possibility that

Table 2 Comparison of static landmarks and mobile nodes localization algorithms

Localization algorithms		Localization accuracy	Node density	Landmark density	Energy consumption
Historical information	Distributed mobile localization	Better	No effect	Smaller	Average
localization algorithms	algorithm [29]	Better	No effect	Smaller	Average
	DTN [34]	Better	No effect	Average	Greater
Cluster-based	Target tracking localization	Average	No effect	Greater	Smaller
localization algorithms	algorithm [12]	Average	No effect	Greater	Smaller

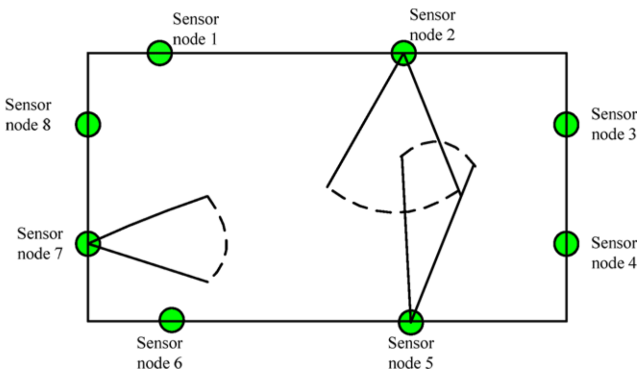


Fig. 16 Target localization algorithm

some beacons can be received by other landmarks without the reflection of signal. The received signal of the unknown node may be the reflection of other signals. In order to avoid the mutual interference, the algorithm makes eight landmarks working in turn in a very short time. Simulation results show cluster-based localization algorithm has lower computation complexity than the convex programming algorithm [53].

convex programming:凸规划
in turn:按次序

4.3 Summary

In a real WSN application, due to the mobility of objects or users, the position information of mobile nodes is important. In this section, static landmarks and mobile nodes localization algorithms can be divided into two categories: historical information localization algorithms and cluster-based localization algorithms. The core idea of literature [29, 38] is based on recorded historical information of mobile nodes. The difference is that the former uses various transmitting power, while the latter uses the geometric algorithm between nodes. Historical information localization algorithms consume a lot of energy due to frequently record problem. Cluster-based localization algorithms can save energy in some extend. Table 2 is the summary of static landmarks and mobile nodes localization algorithms in the aspect of localization accuracy, node density, landmark density and energy consumption.

In Table 2, we can draw a conclusion that node density has no effect to static landmarks and mobile nodes localization algorithms. The positioning accuracy of historical information localization algorithms is good, but the energy consumption is higher. The localization accuracy of cluster-based localization algorithms is average and the energy consumption is low, but the requirement of landmark density is high.

5 Mobile landmarks and static nodes

trajectory:轨迹，轨线

At present, some localization algorithms use mobile landmarks to locate static nodes according a specific trajectory. The algorithms are divided into two categories: geometric localization algorithms [7, 43, 59, 60] and path planning localization algorithms [16–19, 25].

5.1 Geometric localization algorithms

Geometric localization algorithms change the localization problem of unknown nodes into a geometry problem, and calculate the coordinates of the unknown nodes based on the geometry relationship between mobile landmarks and static nodes. The detailed information of typical algorithms [7, 43, 60] is described in the sequel.

In [60], a mobile Location Assistant (LA) according to a specific trajectory periodically broadcasts its position information to unknown nodes. The unknown node calculates the distance to the LA using RSSI technique, and then determines its own location based on trilateration method, as shown in Fig. 17, LA is a mobile landmark. Simulation results show that when the distance error is 10% of the communication radius, the average localization precision is 11.2%. The shortcoming of the algorithm is that it mainly relies on the LA equipment. The robustness and security of LA are the key factors, which needs the precise hardware requirement of the LA. The iteration process of the algorithm increases the network computation and also need to satisfy the requirement of higher storage capacity.

A sphere-based localization algorithm is proposed in [7], which changes the localization problem into the multiple linear equations to estimate the coordinates of unknown

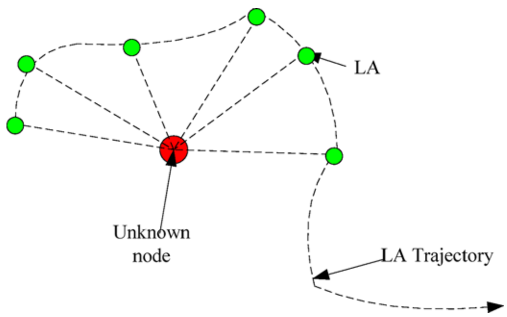


Fig. 17 LA localization algorithm

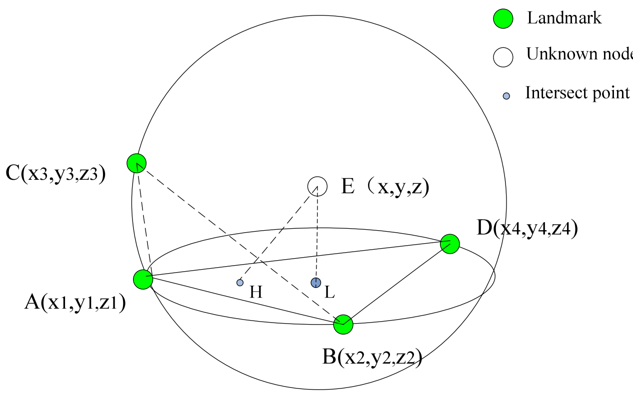


Fig. 18 Sphere-based localization algorithm

nodes. The algorithm does not need the measurement device and other supporting facilities, unknown nodes can only locate themselves through interaction with a mobile landmark. As shown in Fig. 18, the mobile landmark broadcasts the position information at positions A, B, C, D, an unknown node E calculates its coordinates based on four received beacons. Simulation results show that when the communication radius of the node is 10 m, the landmark density is 10%, the localization error of the unknown node is 50.17%. The algorithm uses the least square method to estimate the node position and the filtering strategies method to reduce the localization error. Thus, the positioning accuracy of the unknown node can be improved about 32.12%.

A novel flying landmark localization algorithm is proposed in [43], in which each landmark is equipped with a GPS receiver and broadcasts its location information as it flies through the sensing space. Then each unknown node in the sensing space estimates its own location based on the basic geometry principles and the received position information packets from the flying landmark. The unknown node receives more than four position information packets, and then the four positions form two intersecting circles. There are two lines through the center of two intersecting circles and perpendicular to the intersection circle. The intersection points of the two lines are the estimated location of unknown node. As shown in Fig. 19, A is a mobile landmark, S is an

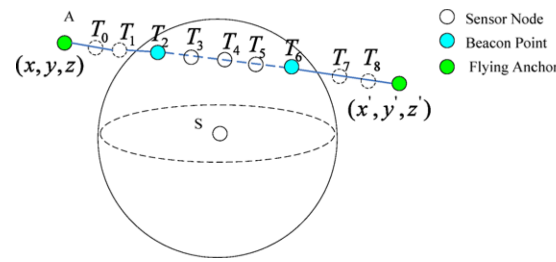


Fig. 19 Flying landmark localization algorithm

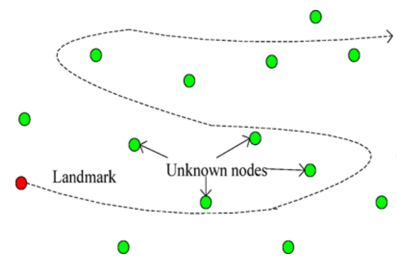


Fig. 20 S shape trajectory

unknown node. In the communication range of the unknown node, the landmark A moves along the straight line of graph, and periodically broadcasts information packets. Simulation results show that when the transmission radius is 15 m, the localization error of the algorithm is 1.6 m, however the localization error of the centroid algorithm is 2.4 m.

5.2 Path planning localization algorithms

In path planning localization algorithms, a mobile landmark moves along a specific trajectory and sends information packets which contain its position information. The unknown node receives the information packet to locate itself. This approach not only can reduce the cost of WSNs, but also get higher localization accuracy. However, how to find the optimal path is the basic problem. The detailed information of typical algorithms [16–19, 25] is described in the sequel. optimal:最佳的；最理想的 accordance:一致；和谐

The researchers in [17] propose that a mobile landmark moves in accordance with S shaped trajectory, as shown in Fig. 20. The unknown node in sensing region periodically receives the position information of the mobile landmark to estimate its coordinates. Simulation results show that the travelling trajectory of the mobile landmark in the algorithm is shorter and the energy consumption is lower. However, the unknown nodes on the edge of sensing area in a WSN cannot be located, due to the fact that it cannot receive adequate position information from the mobile landmark.

In [18], Dimitrios et al. proposed three different trajectories for a mobile landmark, namely SCAN, DOUBLE SCAN, and HILBERT, as shown in Fig. 21. The advantages and disadvantages of the three trajectories are compared in

sensing space:感应空间
perpendicular:[数]垂直的，正交的；直立的；陡峭的

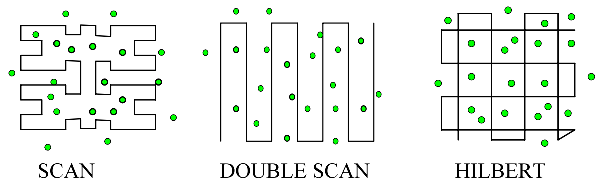


Fig. 21 Three different travelling trajectories

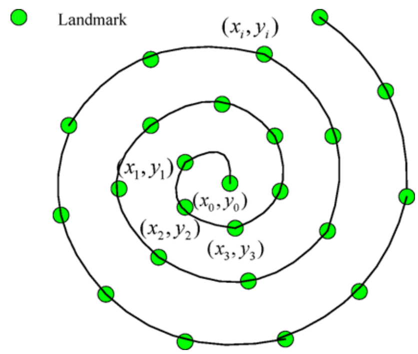


Fig. 22 Spiral trajectory

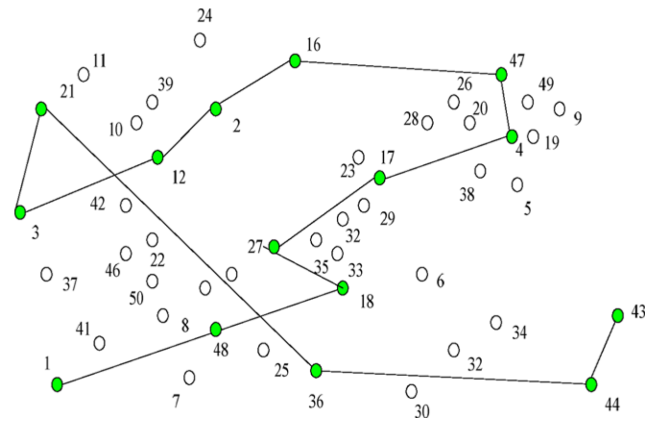


Fig. 23 Backtracking greedy algorithm

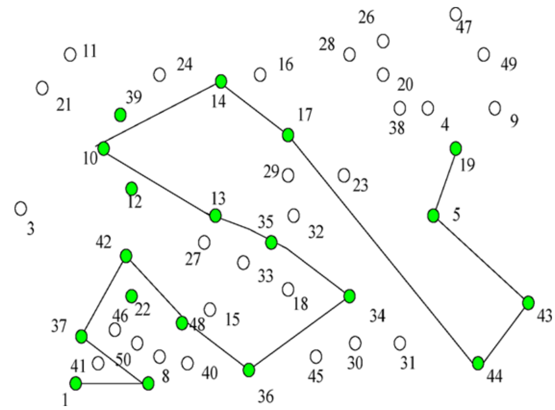


Fig. 24 Breadth-first algorithm

spanning tree:生成树 traversal：遍历

this paper. The travelling trajectory length of SCAN is the shortest, but many collinear beacons (beacon transmitted by the mobile landmark when it moves on a straight line) do not help localization, since the sensor still cannot determine which side of the line, hence at least one non-collinear beacon is necessary. DOUBLE SCAN increases a trajectory along the y-axis direction. This method solves the collinear problem, but the positioning accuracy of the marginal node is low. Therefore, HILBERT increases many turns to solve this problem. Simulation results show that when the sensing region is 420 m $\times$ 420 m, the travelling trajectory length and localization error of SCAN is 3780 m and 0.86 m, respectively. Those of DOUBLE SCAN are 4080 m and 0.85 m, respectively. Those of HILBERT are 3840 m and 0.88 m, respectively.

The researchers in [19] propose a Gaussian-Markov algorithm to optimize the travelling trajectory. Simulation results show that the localization error is 0.9 m and the localization error of traditional centroid algorithm is 4.6 m. But the travelling trajectory length of Gaussian-Markov algorithm is longer and the repeated trajectory is too much, therefore Gaussian-Markov algorithm has higher energy consumption than SCAN, DOUBLE SCAN and HILBERT algorithms.

In [16], a mobile landmark moves along a spiral trajectory and periodically broadcasts its location information packets. When the unknown node receives more than three location information packets from the mobile landmark, the average value of all coordinates is the estimated position of the unknown node. As shown in Fig. 22, the green point is the position of the information packet and the spiral line is the travelling trajectory of the mobile landmark. Simulation results show that the algorithm effectively solves the collinear problem in the localization process. The localization accuracy of the algorithm can be up to $0.2R$.

The researchers in [25] propose the backtracking greedy algorithm and the breadth-first algorithm. These algorithms dynamically adjust the travelling trajectory based on graph theory. The two algorithms regard a WSN as a connected undirected graph, thus the path planning problem can be converted into the spanning tree and traversal problem. The whole WSN is described as a connected undirected graph, where the mobile landmark traverses the spanning tree node using the backtracking greedy algorithm and the breadth-first algorithm and to find the best optimal travelling trajectory. Figures 23 and 24 are the trajectories of backtracking greedy algorithm and breadth-first algorithm, respectively.

Simulation results show that the above two localization algorithm can adapt to a WSN, which the nodes are random deployed on a large scale and efficiently estimate the unknown nodes with high localization accuracy.

5.3 Summary

On the whole, Dimitrios et al. [18] propose SCAN, DOUBLE SCAN and HILBERT path planning. Huang [17] and

Table 3 Comparison of mobile landmarks and static nodes localization algorithms

Localization algorithms		Localization accuracy	Node density	Trajectory length	Travelling speed	Energy consumption
Geometric localization algorithms	LA [60]	Average	No affect	Shorter	Average	Smaller
	Sphere-based algorithm [7]	Better	Average	Average	Greater	Average
	Flying landmark algorithm [43]	Better	Average	Average	Greater	Average
Path Planning localization algorithms	S shaped trajectory [17]	Average	Smaller	Average	Average	Smaller
	SCAN, etc., [18]	Better	Smaller	Shorter	Greater	Average
	Gauss-Markov trajectory [19]	Average	Average	Longer	No affect	Greater
	Spiral trajectory [16]	Better	Smaller	Average	Average	Average
	Intelligent trajectory [25]	Average	Greater	Longer	No affect	Average

Hu [16] propose S-shaped and Spiral trajectory method, respectively. What they have in common is no matter how the unknown nodes distribute, the mobile landmark moves according to a specific trajectory. When the unknown node is close to the travelling trajectory of the mobile landmark, the localization accuracy is the highest. When the unknown node is far away from the trajectory of mobile landmark, the localization accuracy is the lowest or even the position information packets of the mobile anchor node cannot be received. Li [24] discusses the optimal travelling trajectory of a mobile landmark. However, due to many factors affecting the problem, few principles of selecting the optimal trajectory is given. Hongjun [25] estimates the coordinates of unknown node based on the graph theory, which considers a WSN as a connected undirected graph, and changes the path planning problem into the graph traversal spanning tree problem.

In this paper, we have summarized mobile landmarks and static nodes localization algorithms in the aspect of localization accuracy, node density, landmark density, travelling speed and energy consumption, as shown in Table 3. From Table 3, we can see that the localization accuracy of geometric localization algorithms is better and the energy consumption of the algorithm is also smaller. But there is certain requirement of node density and the travelling speed of the landmark is greater. The localization accuracy of the optimal trajectory localization algorithm is better and the requirement of node density is lower. However the travelling trajectory length is longer. The travelling speed of the landmark in Gauss-Markov algorithm and intelligent trajectory algorithm has no effect on the localization process of unknown nodes, but the localization accuracy of unknown nodes is average.

6 Mobile landmarks and mobile nodes

Unknown nodes and landmarks are mobile in a WSN. The localization process of these algorithms is complicated, because it is of great significance to some special environment. We have divided these algorithms into two categories: time-based localization algorithms [39, 51] and probability distribution localization algorithms [20, 40].

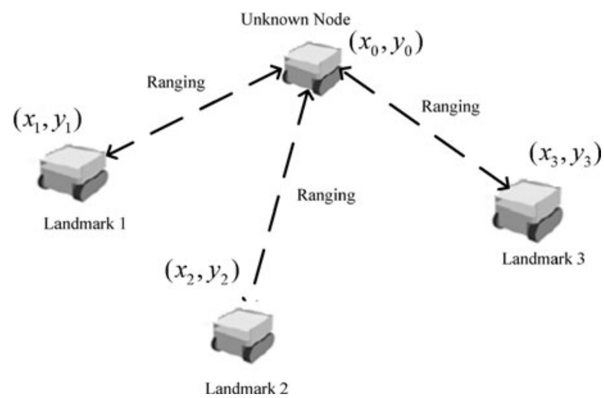


Fig. 25 Self-organizing localization

6.1 Time-based localization algorithms

These algorithms mainly rely on the continuous movement of landmarks to locate unknown nodes. The idea of these algorithms is to calculate the positions of unknown nodes in a very short time interval. The detailed information of typical algorithms [39] is described in the sequel.

A self-organizing localization algorithm is proposed in [39]. Due to the continuous movement of node mobility, the position of the unknown node has not changed much. The algorithm locates the unknown node in a very short time interval. As shown in Fig. 25, the unknown node receives three coordinate information packets of the mobile landmark in a short time, and then calculates its coordinates by trilateration method. Simulation results show that the localization error increases with the increase of the distance. When the distance between landmarks and unknown nodes is 30 m, the localization error of the unknown node is 2.5 m. However, such algorithm requires the travelling speed of the landmark to be as slow as possible.

Table 4 Comparison of mobile landmarks and mobile nodes localization algorithms

Localization algorithms		Localization accuracy	Node density	Landmark density	Travelling speed	Energy consumption
Time-based localization algorithms	Self-organizing localization algorithm [39]	Average	Greater	Greater	Greater	Greater
Probability distribution localization algorithms	MCL [2]	Better	Smaller	Smaller	Average	Greater

6.2 Probability distribution localization algorithms

The core idea of these localization algorithms is that unknown nodes predict their location using ~~the prior distribution probability method~~, in which can reduce the cost of a WSN. The detailed information of typical algorithms [2, 15, 33] is described in the sequel. filtration:过滤，筛选

A dynamic Monte Carlo Localization (MCL) algorithm for WSNs is proposed in [2], which the node only can detect the position information of current neighboring node at some point. The algorithm contains two stages: prediction and filtration. At the prediction stage, the unknown node predicts its estimated location using distributed switching equipment based on the reserved information and the mobile information of the mobile landmark. At the filtration stage, the unknown node removes the inconsistent information from the estimated location. When the landmark density is low and the network communication condition is extremely irregular, MCL still can provide accurate localization. However, when the unknown node cannot acquire its estimated location, the prediction and filtration stage need to be implemented continually. In addition, once the filtration of the sampling fails, MCL can cause an infinite loop. Simulation results show that MCL algorithm simulates ~~the posterior probability distribution by the discrete sampling.~~ Therefore, the increase in the number of samples can improve the localization accuracy, and also cause overload of the memory space and computation of MCL. The maximum travelling speed of nodes is $v = 50$ m/s. The number of the samples changes from 1 to 500 and the number of the landmarks is 1. At the initial stage, the localization error decreases rapidly. The reason is that the number of the samples is too small. When the number of the samples is up to 100, the localization error of the unknown nodes is relatively stable.

6.3 Summary

Mobile landmarks and mobile nodes localization algorithms can be divided into two categories: time-based localization algorithms and probability distribution localization algorithms. The former calculates the coordinates of unknown nodes during one time-slot in the localization process, which can get the high localization coverage, however it can lead to accumulation error of the unknown nodes. The latter needs continuously sample the localization information of landmarks, thus the energy consumption of the unknown nodes is larger. We have summarized mobile landmarks and mobile nodes localization algorithms in the aspect of localization accuracy, node density, landmark density, travelling speed and energy consumption, as shown in Table 4. From Table 4, we can see that the localization accuracy of time-based localization algorithms is average, the requirement for landmark density and node density is higher, and the energy consumption is greater. The reason is that time-based localization algorithms have great relationship with arriving time difference of the landmarks' localization information. The localization accuracy of probability distribution localization algorithm is better, the requirement for landmark and node density is lower, and the travelling speed of landmarks has little effect on the localization accuracy of unknown nodes. However, the energy consumption of unknown nodes is greater.

7 Summaries and outlook

In this paper, the details of existing localization algorithms are analyzed. Localization algorithms are classified into four categories: (1) static landmarks, static nodes, (2) static landmarks, mobile nodes, (3) mobile landmarks, static nodes and (4) mobile landmarks, mobile nodes. We have summarized mobile landmarks and mobile nodes localization algorithms in the aspect of localization accuracy, localization coverage, localization time, landmark number and energy consumption, as shown in Table 5.

From Table 5, we can see that each algorithm has its own characteristics and none is absolutely the best. On the whole, mobile landmarks and static nodes localization algorithms, such as LA localization algorithm, Sphere-based localization algorithm and Flying landmark localization algorithm, can fully prove that the flexibility of mobile nodes can achieve the impossible task of static nodes. Mobile landmarks first periodically broadcast the position information packets to unknown nodes, and unknown nodes can estimate their positions based on some localization techniques, such

Table 5 Comparison of different categories localization algorithms

Localization algorithms			Localization accuracy	Localization coverage	Localization time	Landmark number	Energy consumption
Static landmarks, static nodes	Connectivity localization algorithms	DV-Hop [40]	Better	Better	Longer	≥ 3	Greater
		LCB [30]	Average	Average	Long	≥ 3	Average
		Novel Centroid [5]	Average	Better	Longer	≥ 3	Greater
	Centroid localization algorithms	ABC [47]	Better	Average	Long	≥ 3	Average
		Three-dimensional centroid [20]	Better	Average	Longer	≥ 3	Greater
		Source energy attenuation [58]	Average	Better	Long	≥ 3	Average
	Energy attenuation localization algorithms	BSR [46]	Better	Average	Longer	≥ 3	Greater
		Energy intervals [44]	Better	Better	Longer	≥ 3	Greater
		HiRLOC [21]	Average	Better	Long	≥ 3	Average
	Region overlap localization algorithms	APIS [35]	Better	Average	Average	≥ 3	Smaller
		Voronoi [56]	Average	Better	Long	≥ 3	Average
	Bionics localization algorithms	Honey bee orientation [62]	Average	Average	Longer	≥ 3	Greater
	Verification localization algorithms	Weighted algorithm [57]	Average	Average	Long	≥ 3	Average
	Landmark placement algorithms	RNST [11]	Better	Better	Average	≥ 3	Smaller
	Landmark upgrade localization algorithms	Sparse landmark [32]	Average	Better	Average	≥ 3	Greater
Static landmarks mobile nodes	Historical information localization algorithms	Distributed mobile localization algorithm [29]	Better	Lower	Longer	≥ 2	Average
		DTN [34]	Better	Average	Longer	≥ 3	Greater
	Cluster-based localization algorithms	Target tracking localization algorithm [12]	Average	Average	Longer	≥ 3	Greater
		LA [60]	Average	Average	Average	≤ 2	Smaller
Mobile landmarks static nodes	Geometric localization algorithms	Sphere-based algorithm [7]	Better	Average	Long	≤ 2	Average
		Flying landmark algorithm [43]	Better	Better	Long	≤ 2	Average
		S shaped trajectory [17]	Average	Average	Average	1	Smaller
		SCAN, etc., [18]	Better	Average	Long	1	Average
	Path planning localization algorithms	Gauss-Markov trajectory [19]	Average	Average	Longer	1	Greater
		Spiral trajectory [16]	Better	Better	Long	1	Average
		Intelligent trajectory algorithm [25]	Average	Better	Long	1	Average
Mobile landmarks mobile nodes	Time-based localization algorithms	Self-organizing localization algorithm [39]	Average	Average	Longer	≥ 3	Greater
	Probability distribution localization algorithms	MCL [2]	Better	Average	Longer	≥ 3	Greater

TOA, TDOA, etc. These above algorithms improve the localization accuracy of unknown nodes, and have the characteristics of strong distribution, scalability, security and energy efficiency. Thus, a new research category is gradually formed.

In recent years, solving the localization problem in WSNS has resulted in many innovative solutions and ideas. However, the research in this field is still at the start-up phase. The study has proposed more and more issues. The future research direction of localization algorithms possibly is static landmarks and static nodes localization algorithms to be combined with the idea of landmark placement localization algorithms and the weighted-based of verification localization algorithms further improve the localization accuracy of unknown nodes. Static landmarks and mobile nodes localization algorithms can be developed based on the issue of landmark placement. Mobile landmarks and static nodes localization algorithms can be developed based on the optimal trajectory of mobile landmarks. Mobile landmarks and mobile nodes localization algorithms can be combined with the idea of node tracking. We believe that in addition to the existing research issues of localization algorithms, the possible hot research topics are: (1) Evaluate the performance model of localization algorithms, and improve the landmark selection and filtering mechanisms to reduce the localization time. (2) Randomly deploy the nodes on the surface of the actual land-based, and study the localization performance of actual land. (3) Find a localization algorithm which is suitable for resource-constrained sensor nodes, and reduce the localization error caused by random distribution of nodes. (4) Research a self-adjustment localization algorithm in the mobile network environment, and simulate the localization algorithm performance in the low mobility of sensor nodes. (5) Research the optimal path planning in which mobile landmarks can traverse the entire network. (6) Research the security issue of localization algorithm. (7) Localization issue can also be used other environment, such as underwater, underground, body, mobile, and multimedia, which are the interesting research issues in the future.

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