Mobile anchor assisted localization and path–planning techniques in wireless sensor networks: Challenges and Solutions

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Abstract. Localization is one of the most significant technique in wireless sensor networks (WSNs). The location information of nodes can be provided by Global Positioning System (GPS), but the cost is huge if every node equips GPS. This problem can be solved by deploying a set of mobile anchors which can exchange information with other nodes that estimating their locations. Planning an adaptive path can reduce the cost by using smaller number of mobile anchors and estimate the location of other nodes precisely in WSNs. In recent years, many path planning algorithms have been proposed. In this paper, a comprehensive survey is presented to point out key problems and challenges of mobile anchors. We compare the differences among the algorithms. Also, we make a discussion for future research and show new challenges in this field.

1. Introduction

Wireless sensor networks (WSNs) are intelligent self-organizing network systems that can autonomously collect and transmit various sensing data [1]. WSNs are consist of sensor nodes which randomly deployed in different environment that users can obtain variety data (et. temperature, humidity) conveniently. In WSNs, every node communicates in a short distance via a wireless medium and work together to complete a same task, for example, industrial process control, military surveillance, and environment monitoring [2].

With the development of WSNs, more and more applications need the information of sensor’s location. WSNs usually randomly deployed in a wide area. Recording every sensor node’s location personally is unrealistic. Sensor nodes are usually located by Global Positioning System (GPS) [3]. However, the energy of sensor node is limited. It will cost much energy that reduce the lifetime of sensor node if sensor node equips GPS. Also, the number of sensor node in WSNs is huge, it will cost lot of money if every sensor node equips with GPS. Besides, GPS only work in an open field [4], sensor node might be deployed in some enclosed areas that GPS does not work. Equipping GPS on every sensor node is not practical.

There is a reasonable solution that allow a little part of mobile sensor node to be equipped with GPS. We call them mobile anchors which coordinates are known. Mobile anchors travel the network that visiting all the nodes. The current coordinates of Mobile anchors are broadcasted while mobile anchors are traveling. Other sensor nodes receive the beacon messages which form from mobile

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anchors coordinates. While a sensor node has received enough beacon messages, it can estimate its location after calculating the beacon messages.

Considering to practical benefits, the least mobile anchors are used in WSNs, the less cost is generated. Since the communication range of mobile anchor is limited and in order to guarantee reliable coverage and good localization accuracy [5], it is significant to plan the path of the mobile anchors carefully. The movement trajectory designed in path-planning problem should satisfy several properties:

1. Since the communication range of mobile anchor is limited, it should move closely to the sensor nodes which location is unknown that lets them fall as many as possible within communication of mobile anchor.
2. Mobile anchor should provide at least 3 beacon messages for each sensor node so that sensor nodes can estimate their location precisely.
3. The path should be designed in the shortest length that will reduce energy cost of mobile anchors and extend their lifetime.

We classify the localization and path-planning techniques into two categories, static and dynamic. In this paper, we analysis the latest static path-planning algorithm and dynamic path-planning algorithm, comparing their advantages and disadvantages [7].

Our paper is shown as follows: related work of mobile anchor will be discussed in section 2. We discuss and study existing localization techniques of mobile anchor in section 3. Section 4 evaluates the proposed localization techniques. The challenge we face and the future work of mobile anchors will be discussed in section 5. We draw the conclusion in section 6.

2. Related work

Random path model, static path model and dynamic model are the three kinds of path-planning model. Random path model is the simplest model in path schemes. [6] proposes the Random Waypoint (RWP) mobility model which is random path model. In this model, waypoints are randomly deployed in sensing area without a certain rule [7]. Since waypoint is random deployed in simulation area, the entire monitoring area cannot be covered completely that some sensor nodes cannot be localized.

There are three static path models of mobile anchor which are presented by Koutsonikolas in [8] to overcome the drawback of Random path model, which are SCAN, DOUBLE SCAN and HILBERT [8]. SCAN is the simplest model, which movement trajectory as shown in Fig 1(a). DOUBLESCAN is an upgraded version of SCAN, which movement trajectory has two direction (X and Y) that localizes sensor nodes more accurately which is shown in Fig 1(b). However, DOUBLE SCAN needs more mobile anchors and travels more distance than SCAN. HILBERT provides more non-collinear point compared with DOUBLE SCAN and SCAN, which movement trajectory as shown in Fig 1(c). These three path models can cover entire monitoring area compared with random path model. Researcher in [9] proposed CIRCLES and S-CURVES model to avoid the collinearity of virtual anchors. The problem of path planning is transformed to get an optimal path, not just cover the monitoring area. Path planning problem is transformed into traveling the graph, and find an optimal path by utilizing backtracking greedy algorithms and breadth-first algorithm [10]. Paper [11] proposed a localization algorithm which based on network-density clustering and obtain an optimal path after clustering sensor nodes.

Static path model is not useful in mobile wireless sensor networks or irregular topology, which may localize sensor nodes inaccurately. Therefore, Researcher in [12] proposed a heuristic dynamic path planning model, which uses the directional antenna technology that receive beacon messages from different regions. [13] proposed a MBAL algorithm, which limited the area of request nodes that shorten the moving distance.
3. Localization and path-planning techniques

In this section, we discuss the model of mobile anchor and localization techniques that recently proposed and classify them into two categories: static and dynamic.

3.1. Static

- **H-Curves**

A novel static path planning model is proposed in [15] which is called H-Curves. This model ensure that all sensor nodes can receive the localization information and localize the nodes more accuracy than other similar static models. As its name, this model movement trajectory is designed that consist of multiple sloping H-shaped path, which as shown in Fig 2. In this model, mobile anchors start from corner of the monitoring area, traveling in straight line with the distance of D which will not change. Then, mobile anchor reaches second corner point and change its direction of traveling (e.g. direction x change to direction y) and traveling in this direction with the same distance d. In order to make a different between the rows and avoid rows correspondence. Mobile anchor only travels half of the distance D at its first move when it reaches the next row. Which can decrease the number of point and form a triangular communication area.

In addition, compared with random models and other traditional static models, the coverage rate of H-Curves is higher and H-Curves improve the precision of WCL and WCWCL localization techniques [16].
Figure 4. The hexagonal network system model of FLPPL

- Static search-and-decide
  There is a novel static path-planning algorithm for mobile anchor that proposed in [17], which name is static search-and-decide (SSD). In this algorithms, mobile anchor will stop several times to create stop point when it is traveling.
  As the name of the algorithm, there are two phases in the proposed algorithms, search-phase and decide-phase respectively. In search-phase of SSD, mobile anchor movement trajectory is SCAN which proposed in [8]. Mobile anchor broadcasts its coordinate when it reaches each stop point and collets the message from its neighboring sensor nodes. Each stop point of anchor is separated by the radius R of the communication range [17]. Trilateration is used in the decision-phase of SSD to localize the sensor nodes. Mobile anchors are placed next to the sensor nodes in each communication grid. As shown in Fig 3, the blue line is the trajectory of mobile anchors in decision-phase and the grid areas are the intersection zones. If there are sensor nodes in the intersection zones that an anchor is created at the blue point as. Adding the stop points of anchor in search-phase, there are 3 point to localize the sensor node.

3.2. Dynamic

- Dynamic search-and-decide
  Dynamic search-and-decide is also proposed in [17], which is the dynamic version of SSD. DSD is proposed to improve the coverage of mobile anchor in monitoring area and localize sensor nodes more accurately. The search-phase of DSD is similar to SSD, mobile anchor travels that following the SCAN model. Mobile anchor broadcasts its location information when at each stop point and collets the messages from the neighboring sensor nodes. In the decision-phase of DSD, mobile anchor moves freely in a circular grid, if there are not sensor nodes, mobile anchor pass this grid strange straightly. Otherwise, an anchor position is generated according to the perpendicular bisector strategy (PBS) [19].

- Hilbert based PSO and HPSO
  Researchers in [18] two algorithms, which use moving single anchor for locating that called Particle Swarm Optimization (PSO) and H-Best Particle Swarm Optimization (HPSO). We call it HBPHP in this paper. PSO is proposed by Kennedy and Eberhart in [20]. HPSO is the variant of PSO that improve the PSO [14].
  In this localized algorithm, which uses a single mobile anchor node that follows the Hilbert path model to localize sensor nodes. When mobile anchor detects the sensor nodes which fall in its communication range, there are six virtual anchors that projected around the mobile anchor. These six virtual anchors form a regular hexagon and mobile anchor is the center of regular hexagon. Then, using the direction information of two virtual anchor which is closest to the target sensor node to localize its 2D coordinates. If there are more than three nodes in the communication range of target node, then PSO and HPSO based optimization algorithm is used to calculate the distance errors.
between actual node’s coordinate and estimated node’s coordinate [14]. This localization technique uses only one mobile anchor that the energy consumption of this method is very low. Hilbert trajectory guarantees the coverage of monitoring area and PSO, HPSO algorithms reduce the error of localization.

- Fuzzy-Logic based Path Planning algorithm

A novel dynamic algorithm that called fuzzy-Logic based Path Planning for mobility-assisted Localization (FLPPL) is proposed in [21] for WSN. Fuzzy Logic (FL) is introduced by Zadeh and gain much attention because of its ease of implementation and simplicity [22]. The first step of FLPPL is to separate the monitoring area into a set of symmetric virtual hexagons as shown in Fig 4. The mobile anchor will travel from the blue point (center of virtual hexagon) to other blue point. FL system is used in a decision when mobile anchor is travelling from one center to another center. There are three system inputs which name are received signal strength indicator (RSSI) level, the number of neighbors and the distance to every neighbor that measured from the current location of the mobile anchor in FL system. These three inputs are used to calculate a probability of the next point of mobile anchor from its current location. The mobile anchor will move to the point with the highest probability. The mobile anchor will stop and broadcast its current coordinate in its communication range after each movement. When sensor node has received three different location information that it can estimate its own location.

| Algorithm       | Energy consumption | Coverage | Localization accuracy |
|-----------------|--------------------|----------|-----------------------|
| WCL in H-Curves | High               | High     | Medium                |
| SSD             | High               | Medium   | Low                   |
| DSD             | Medium             | Low      | High                  |
| HBPHP           | Low                | Medium   | High                  |
| FLPPL           | Low                | Medium   | High                  |

4. Evaluation

In this section, three performance benchmarks are used to evaluate the proposed algorithms, which are energy consumption, coverage and localization accuracy. The advantages and disadvantages of all algorithms proposed in section 3 are compared in table 1.

- Energy consumption

Energy consumption is one of significant indicator for evaluating algorithm. Energy consumption will influence the lifetime of sensor node, because sensor has limited energy. If sensor run out its energy it will not work again before charging. As mentioned in section 1, mobile anchor is a sensor that has limited energy. Therefore, energy consumption is important for evaluating the proposed algorithm. H-Curves is a novel static path planning model which has high localization accuracy, but the movement trajectory is not short that mobile anchors will cost more energy in this model. Compared with H-Curves that HBPHP only use one mobile anchor, So its energy cost is very low. HBPHP use PSO and HPSO algorithms reduce the error of localization that localization accuracy is guaranteed.

- Coverage

Coverage is a guarantee of localization accuracy. A good path planning algorithm should ensure the coverage that can cover the whole monitoring area. Therefore, design an adaptive path is important. H-Curves can cover whole monitoring area completely with multiple H-shaped paths. SSD and DSD use SCAN model, but mobile anchor will travel twice in SSD. There is a backward movement trajectory in SSD that mobile anchor will return to the starting point in other trajectory after it reach the ending point. Traveling monitoring area twice that ensures the coverage and generate enough
effective beacons that localizing sensor nodes precisely. Compared with SSD, FLPPL is a dynamic algorithm which without a static path. Mobile anchor travel monitoring area according to FLPPL algorithm that can provide a optimal path which cover all sensor and shorten the journey.

- Localization accuracy

Localization sensor nodes is a fundamental work for mobile anchor. Whether to localize sensor nodes precisely is important for evaluating path planning algorithms. Sensor nodes calculate their coordinates according to the beacon messages they received. So good beacon points and adaptive movement trajectory can ensure the localization accuracy. H-Curves model ensures that every sensor node can receive at less three beacon messages, so this model can localize sensor node accuracy. There are six virtual anchors that projected around the mobile anchor in SSD. Six virtual anchors form a regular hexagon, if any sensor node fall in the hexagon that it must fall in a triangular area and its coordinate can be calculated accurately. FLPPL is similar to SSD, whole monitoring area is separated into a set of symmetric virtual hexagons. However, FLPPL do not follow a static path compared with SSD that the accuracy of FLPPL maybe lower than SSD in some situations.

5. Challenges and future works

Though so many works of path-planning and localization techniques have been done, there still serval problems need to be solved. Which are presented as followed:

- Localization ratio

Most of algorithms are not tested in a real environment. There are many interference factors in real environment, such as swinging of signal, stone or river obstructs mobile anchors when it is traveling. Besides, most of algorithms only apply to a 2D environment, the real environment is 3D that 2D algorithms cannot localize sensors. So future work should consider the 3D environment and some situation in real environment.

- Energy consumption

The distribution range of WSNs is very huge. Mobile anchor might run out its energy before traveling whole monitoring area that some sensor nodes cannot be localized. Design an energy saving algorithm or a algorithm with mobile chargers in future work that is necessary.

- Complexity

Since the moving of anchor cost large energy, the movement trajectory of mobile anchor should be optimized. Besides, the calculative ability of anchor and sensor is limited that the algorithms with high complexity cannot be used on mobile anchor. Therefore, the calculative ability of anchor should be considered in future work on path planning.

6. Conclusions

Localization and path-planning techniques support the application of WSNs. The accuracy and energy consumption of path-planning algorithms affect the effect of WSNs. In this paper, a comprehensive overview on localization and path-planning techniques are presented and serval recent models and algorithms are discussed. We classify localization and path-planning techniques into two categories: static and dynamic, and evaluate the algorithms with three indicators: energy consumption, localization ratio and complexity. The challenges and future works are also presented in this paper.

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References

[1] Prathap U, Shenoy P D, Venugopal K R, et al. Wireless sensor networks applications and routing protocols: survey and research challenges[C]//Cloud and Services Computing (ISCOS), 2012 International Symposium on. IEEE, 2012: 49-56.
[2] Pantazis N A, Vergados D D. A survey on power control issues in wireless sensor networks[J]. IEEE Communications Surveys & Tutorials, 2007, 9(4): 86-107.
[3] Halder S, Ghosal A. A survey on mobile anchor assisted localization techniques in wireless sensor networks[J]. Wireless Networks, 2016, 22(7): 2317-2336.
[4] Shu L, Zhang Y, Yang L T, et al. TPGF: geographic routing in wireless multimedia sensor networks[J]. Telecommunication Systems, 2010, 44(1-2): 79-95.
[5] Yue L, Ding G, Zheng Z. Path planning in sensor localization with mobile anchors: Survey and challenges[C]//Wireless Communications & Signal Processing (WCSP), 2015 International Conference on. IEEE, 2015: 1-6.
[6] Johnson D B, Maltz D A. Dynamic source routing in ad hoc wireless networks[M]//Mobile computing. Springer, Boston, MA, 1996: 153-181.
[7] Han G, Jiang J, Zhang C, et al. A Survey on Mobile Anchor Node Assisted Localization in Wireless Sensor Networks[J]. IEEE Communications Surveys and Tutorials, 2016, 18(3): 2220-2243.
[8] Koutsonikolas D, Das S M, Hu Y C. Path planning of mobile landmarks for localization in wireless sensor networks[J]. Computer Networks, 2007, 30(13): 2577-2592.
[9] Huang R, Zaruba G V. Static path planning for mobile beacons to localize sensor networks[C]//null. IEEE, 2007: 323-330.
[10] Hongjun L, Yanlong B, Han X, et al. Path planning for mobile anchor node in localization for wireless sensor networks[J]. Journal of Computer Research and Development, 2009, 46(1): 129-136.
[11] Zhang L, Cheng Q, Wang Y, et al. A novel distributed sensor positioning system using the dual of target tracking[J]. IEEE Transactions on Computers, 2008, 57(2): 246-260.
[12] Wei Y, Li R, Chen H, et al. Path planning of mobile beacon for localization in wireless sensor network[J]. Journal of System Simulation, 2009, 21(22): 7258-7261.
[13] Kim K, Lee W. MBAL: A mobile beacon-assisted localization scheme for wireless sensor networks[C]//Computer Communications and Networks, 2007. ICCCN 2007. Proceedings of 16th International Conference on. IEEE, 2007: 57-62.
[14] Singh P, Khosla A, Kumar A, et al. Optimized localization of target nodes using single mobile anchor node in wireless sensor network[J]. AEU-International Journal of Electronics and Communications, 2018, 91: 55-65.
[15] Alomari A, Comeau F, Phillips W, et al. New path planning model for mobile anchor-assisted localization in wireless sensor networks[J]. Wireless Networks, 2017: 1-19.
[16] Dong Q, Xu X. A novel weighted centroid localization algorithm based on RSSI for an outdoor environment[J]. Journal of Communications, 2014, 9(3): 279-285.
[17] Erdemir E, Tuncer T E. Path planning for mobile-anchor based wireless sensor network localization: Static and dynamic schemes[J]. Ad Hoc Networks, 2018, 77: 1-10.
[18] Singh P, Khosla A, Kumar A, et al. Optimized localization of target nodes using single mobile anchor node in wireless sensor network[J]. AEU-International Journal of Electronics and Communications, 2018, 91: 55-65.
[19] ZHONG Z, Da-Yong L, Shao-Qiang L, et al. An adaptive localization approach for wireless sensor networks based on Gauss-Markov mobility model[J]. Acta Automatica Sinica, 2010, 36(11): 1557-1568.
[20] Kennedy J. Particle swarm optimization[M]//Encyclopedia of machine learning. Springer, Boston, MA, 2011: 760-766.
[21] Alomari A, Phillips W, Aslam N, et al. Dynamic fuzzy-logic based path planning for mobility-assisted localization in wireless sensor networks[J]. Sensors, 2017, 17(8): 1904.
[22] Fuzzy Logic Toolbox™ User's Guide. 2017. Available online: https://www.mathworks.com/help/pdf_doc/fuzzy/fuzzy.pdf (accessed on 1 June 2017).