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Path Parameters Effect on Localization Using a Mobile Anchor in WSN

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Abstract. Finding the physical positions of sensors after random deployment is called localization. One of the localization techniques is to use a mobile anchor that moves along a path to help unknown nodes to locate themselves automatically. In this paper, we study the impact of three essential parameters on the performance metrics of path planning models for mobile anchor-based localization to help configure the localization system for achieving better results. These parameters include path degree, mobile communication range and distance estimation errors. For this purpose, we analyzed four path planning methods: SCAN, HILBERT, Zcurve and LMAT in terms of localization accuracy, localization ratio, path length and cost of communication. Simulation results confirm the importance of path parameterization in the quality of the localization system with a mobile anchor node.

Keywords: Localization · Mobile anchor · Path planning model · Wireless sensor network

1 Introduction

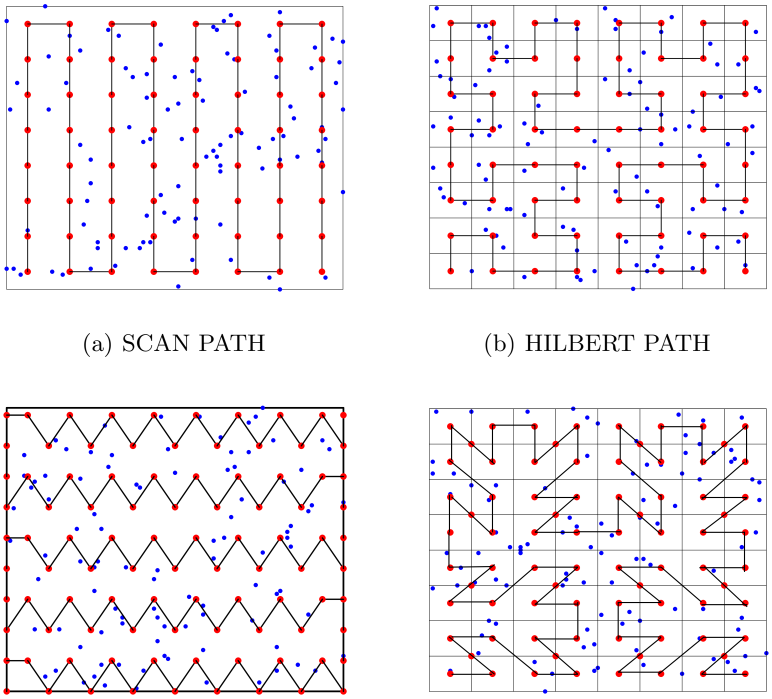
The development of technology in the miniaturization of machines and communication media has led to the emergence of a new generation of micro-sensors provided with a processor and a wireless communication device. The characteristics of wireless sensor networks have opened very large and varied applications in many fields such as military [1], medicine [5], home automation and environmental applications [12, 4]. The deployment of network sensors is usually random either because of the hostility of the area to be monitored or because of its vastness, which poses the problem of localization. The latter consists of assigning geographical positions to the sensors. It plays an important role in many network operations such as geographical routing and data exploitation [8]. This is why it is necessary to locate all the unknown nodes with the best precision. Several localization algorithms have been invoked in the literature and they were classified according to various criteria [9]:

- *Use of GPS*: localization without GPS (anchors-free) and localization with GPS (anchors-based).
- *The material capacity and distance estimation mechanisms*: range-based and range-free.
- *Distribution of the calculation process*: centralized localization systems and distributed localization systems.
- *Node mobility*: static networks (static anchors and nodes), static anchors and mobile nodes, mobile anchors and static nodes and mobile networks (mobile anchors and mobile nodes) [2].

The main idea of mobile anchors node localization algorithms is to use a mobile anchor equipped with GPS moving in the area of interest and broadcasting its current location to help unknown nodes to self-locate. This approach reduces the WSN cost and provides higher localization accuracy. In this work, we analyzed four different path planning models proposed in the literature to study the influence of metrics and path parameters on the degree of satisfaction of localization criteria. The remaining paper organized as follows. Section 2 explains the localization process using a mobile anchor. Section 3 describes the localization algorithm. Section 4 defines the environment and simulation parameters. Section 5 presents and discusses the results. Finally, Section 6 concludes the work.

2 Mobile anchor assisted localization

The process of localization using a mobile anchor is composed of three essential steps [8]: the first one is path definition, the second is distances estimation and the third is positions derivation of nodes using a localization algorithm.


(a) SCAN PATH (b) HILBERT PATH

(c) LMAT PATH (d) ZCURVE PATH

Fig. 1. The different paths.

2.1 Path definition

Path definition is the mobile anchor path specification to traverse the entire area. In this work, we have not concentrated on the choice of the path but how to choose the right parameters to obtain the best result. In that regard, four path planning methods are evaluated including SCAN [6], HILBERT [6], LMAT [3] and Zcurve [13]. An illustrative example of these paths is given in Fig. 1.

2.2 Distance estimation

This phase includes measurement techniques to estimate the distance between the mobile anchor and the unknown nodes. Some of the popular techniques are: RSSI (received signal strength indicator) [7], AOA (arrival angle) [11] and TdoA (arrival time difference) [14]. Regardless of the technique used, there is a distance estimation error and we studied its influence on the average localization error in Section 5.1.

2.3 Position derivation

To calculate the positions of unknown nodes, we use *trilateration* [10] which is a technique of finding the position of a node according to its distances to three anchors. Let S be an unknown node to be localized by computing its position $S(x, y)$. Suppose that S receives three packets containing three different positions of the anchor nodes referred to for example as $X(x_1, y_1)$, $Y(x_2, y_2)$ and $Z(x_3, y_3)$. Then, S calculates the distance d_1, d_2 and d_3 between its position and the current position of each anchor X, Y and Z respectively, each time it receive a packet (see Fig. 2). Thus, the position of S can be determined by solving the following system of equations (see equation 1).

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 = (d_1)^2 \\ (x - x_2)^2 + (y - y_2)^2 = (d_2)^2 \\ (x - x_3)^2 + (y - y_3)^2 = (d_3)^2 \end{cases} \tag{1}$$

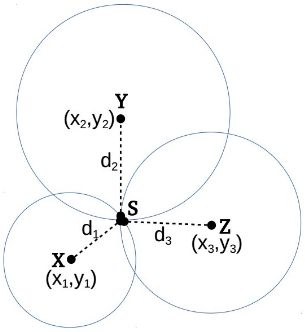


Fig. 2. Trilateration.

3 Localization algorithm

The process of localization algorithm (presented in Fig. 3) is as follows:

- The network consists of a set of N unknown nodes randomly deployed, and one mobile anchor.
- The choice of the mobile anchor path (SCAN, Zcurve, HILBERT, and LMAT).
- The configuration of system parameters, for example, the distance between diffusion points (path degree), the mobile anchor communication range..., depending on the area size, and our materials.
- In each diffusion point of the path, the mobile anchor broadcast the coordinates of it position.

- Each unknown node located in the coverage area of the mobile anchor receives a packet.
- The unknown node accepts the packet if it has not already received three accepted packets. It accepts the third packet if the packet contains a non-collinear position or it has already received three accepted packets, but the distance is smallest than one of the already recorded distances, otherwise, it is ignored. For each accepted packet, the unknown node calculates the distance with different estimation error values (see Table 1).
- If the unknown node receives three accepted packets, it calculates its position using the trilateration method.

4 Simulation environment and parameters

Our problem is a distributed localization algorithm, of which it exists at a given moment, several nodes calculate their position in parallel, the performance analysis of this system has been evaluated by a series of simulations using our simulator developed in python3. The simulation parameters are given in Table 1

Table 1. Simulation parameters.

Parameters	Symbol	Value
Network size (S)	S	96m*96m
Number of unknown nodes	N	100
Number of mobile anchors	M	1
path degree	L	6,12,24,48
Resolutions	R=r/L	1/2, 3/4, 1,5/4, 3/2,7/4, 2
Distance estimation error	E	0.05,0.1, 0.16, 0.2, 0.3, 0.4
Simulation Run	SR	50

5 Results and discussion

5.1 Performance analysis metrics

To evaluate the static path planning, four performance analysis metrics are used: (1) the localization accuracy, (2) the localization ratio, (3) the path length and (4) the cost of communication. These analysis metrics depend on three essential parameters, r: the communication range of the mobile anchor; L: Path degree is the distance between two successive diffusion points; and E: the distance estimation error. The resolution value of the path indicates the relation between r and L. Thus, the resolution is given by (2):

$$R = \frac{r}{L} \tag{2}$$

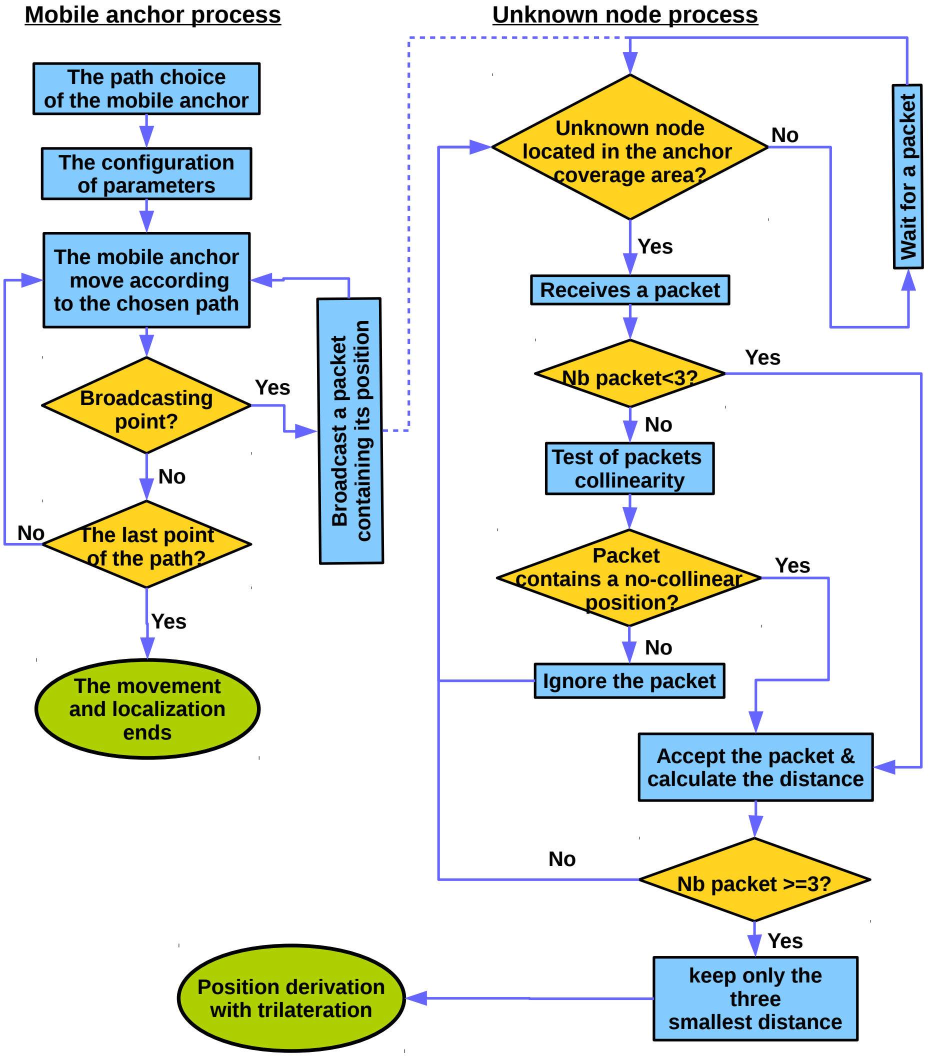


Fig. 3. The process of localization algorithm.

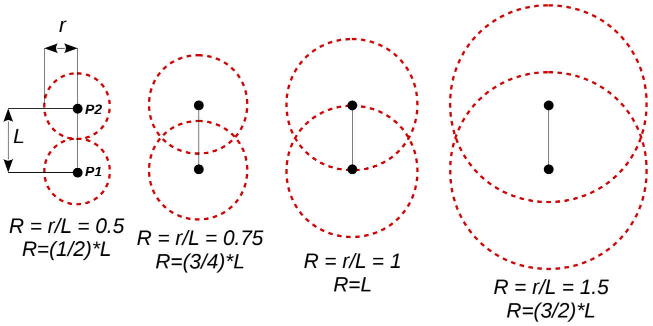


Fig. 4. The graphical presentation of the path resolution R.

Fig. 4 shows a graphical representation that clarify the meaning of the path resolution R. It is assumed that L is the distance between two diffusion points p_1 and p_2, and r is the communication range of the mobile anchor, the radius coverage is indicated by a circle.

If $R = 0.5$, The intersection between two circles is a single point, and while R increase, the coverage will be larger, as explained in Fig. 4.

5.1.1 Localization accuracy: To evaluate a localization algorithm, the accuracy criterion is considered very important. A metric to determine the localization accuracy is the average localization error. It is defined as the Euclidean distance between the real coordinates of the node and those estimated by the localization algorithms. We calculate the average error by equations (3, 4).

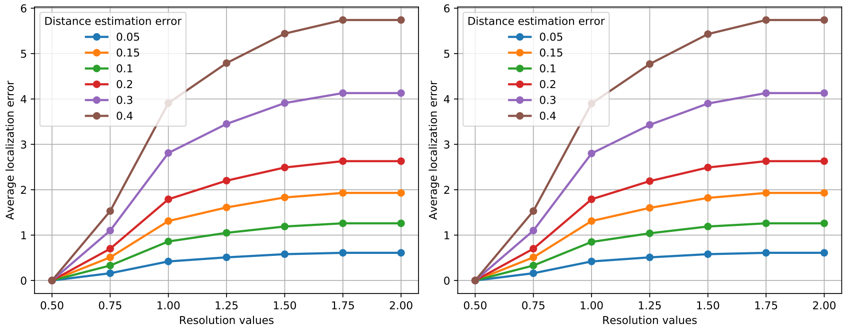
$$L_e = \frac{\sum_{i=1}^{n} Error(i)}{n} \tag{3}$$

$$Error(i) = \sqrt{(x_{ei} - x_i)^2 + (y_{ei} - y_i)^2} \tag{4}$$

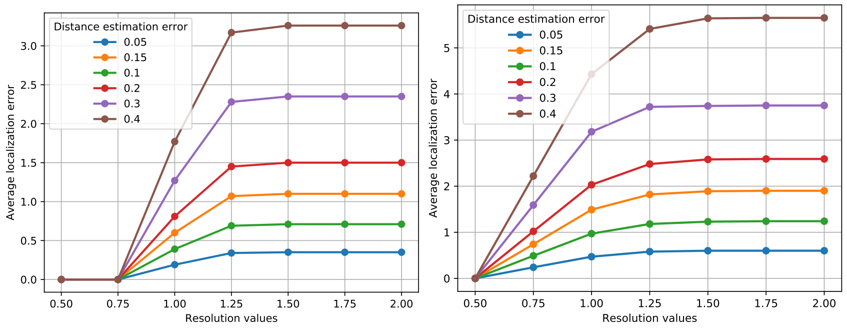
(x_{ei}, y_{ei}) and (x_i, y_i) represent, respectively, the estimated and the real coordinate of the node. L_e indicates the average localization error while n give the number of localized nodes.

The average localization error depends on two parameters, the resolution R and the distance estimation error E. In Fig. 5, we notice that there is a direct proportionality between the average localization error and the two parameters, as the distance estimation error increases, the average localization error increases for the four paths. and if the path resolution increases, the average localization error increases until it stabilizes at the value $R = 1.5$ when the network coverage (Localization ratio) becomes 100%.

5.1.2 Localization ratio: C_R is the ratio of the number of already located nodes N_L to the number of unknowns nodes N_O. This metric also indicates the



(a) SCAN PATH (b) HILBERT PATH



(c) LMAT PATH (d) ZCURVE PATH

Fig. 5. Average localization error based on the resolution and distance estimation error.

coverage degree of the path. Localization ratio is given by the equation (5) which depends on the path resolution.

$$C_R = \frac{N_L}{N_O} \tag{5}$$

Fig. 6 shows the localization ratio with a number of nodes $N = 100$ and the distance estimation error $E = 0.15$, The networks coverage in all paths can go up to 100%, if $R \geq 1.75$.

5.1.3 Path length The path length is based on two variables namely the network size referred as S and the distance between each two broadcasting points (path degree)referred as L. We also define the order of space-filling curves HILBERT and Zcurve by n.Therefore, the path length for each path is calculated using the following equations: 6, 7, 8, 9:

$$D_{LMAT} = \frac{2}{\sqrt{3}} \times S \times \lceil \frac{S}{L} \rceil + (S + \sqrt{3} \times L) \tag{6}$$

$$D_{SCAN} = (\frac{S}{L} + 2) \times S \tag{7}$$

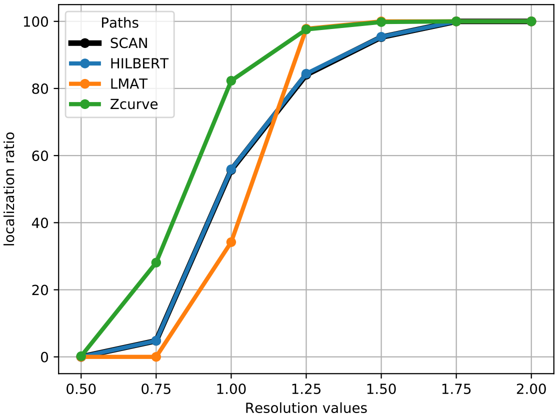


Fig. 6. localization ratio.

$$D_{Zcurve} = \lceil (\frac{5}{8} \times 4^n) - 1 \rceil \times L + \lceil (\frac{3}{8} \times 4^n) \rceil \times \sqrt{2} \times L \tag{8}$$

$$D_{HILBERT} = \frac{(S+L)^2}{L} \tag{9}$$

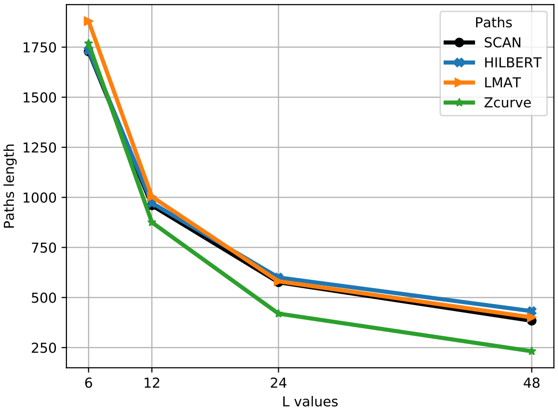


Fig. 7. Path length.

The results presented in Fig. 7 ,with $S = 100$ and $[(L = 6, n = 4)$,$(L = 12, n = 3)$,$(L = 24, n = 2)$,$(L = 48, n = 1)]$,show that if L increases, the path length decreases for the four paths.

5.1.4 The cost of communication Given the limited resources of the sensor network, energy consumption remains a very important parameter when designing a location algorithm. The cost of communication is calculated according to

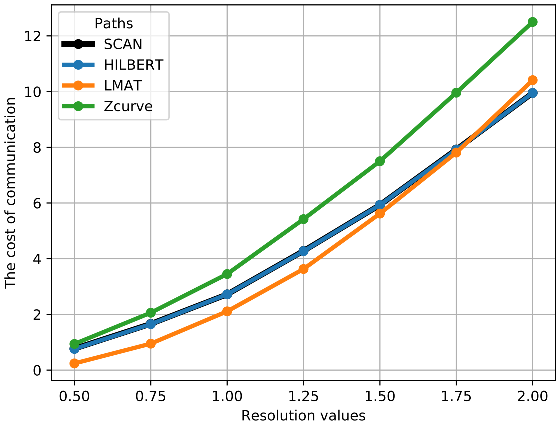


Fig. 8. The cost of communication.

the average number of messages processed by the unknown nodes. The results presented in Fig. 8 show that if we increase the value of Path Resolution R the unknown node receives more messages to process.

As a results of these experiments, the parameters that influence the performance of the localization algorithm can be summarized in two main points:

1. Mobile anchor communication range: while the communication radius of the mobile anchor is larger, it covers more unknown nodes. Thus, unknown nodes receive more packets, but the distance estimation error increases, which increases average localization error.
2. Broadcast interval (path degree): a smaller broadcast interval indicates that the mobile anchor will broadcast its location more frequently, which improves localization performance, but the path length is getting longer. However, the energy consumption is higher.

6 Conclusion

In this work, we have conducted a series of simulations to show the effect and the importance of paths parameterization in the quality of localization system with a mobile anchor node. To confirm our results, we chose four path planning models and analyzed every one using four important quality metrics. The derived results shows that two parameters namely mobile anchor communication range and broadcast interval can greatly influence the performance of the localization algorithm. Moreover, we found that the problem is not only to choose the right path but also how to set the parameters to get the best results. We also note that some parameters are conflicting and improving one parameter could potentially depress another one. Our reported results can help users to configure localization systems according to their needs and intents. As future work, we plan to use other parameters such as the type of equipment, type of environment, different techniques of distance estimation and position derivation methods.

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