Path Planning of a Mobile Beacon for Localization in Underwater Sensor Networks

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***Abstract*—In underwater sensor networks, localization is one of the most important issues because sensor nodes are considerably difficult to be deployed at determined locations. Localization schemes using a mobile beacon have fine-grained localization accuracy because one mobile beacon can replace a lot of static beacons. In localization with a mobile beacon, the movement of a mobile beacon determines the deployment of the beacons used for localization and the deployment influences the localization accuracy. To improve the localization accuracy for localization with a mobile beacon, the study on the path of a mobile beacon is necessary. In this paper, we propose a static path to improve the localization accuracy by considering the path of a mobile beacon and the deployment of the beacons. Simulation results show that the determined static path provides higher localization accuracy than a random path and other static paths.**

***Keywords*-Localization, mobile beacon, static path, range-free, underwater sensor networks.**

I. Introduction

Localization is the process to find out the locations of sensor nodes which are randomly deployed in underwater environments, to specify where a certain event takes place. Localization is an indispensable issue in underwater sensor network, because the location information of a sensor node is used to identify where the reported events happen in order to cope with the events timely and assists location-based routing, coverage, geographical routing, and environmental monitoring. Localization with a mobile beacon is inherently more accurate than localization using static beacons, because one mobile beacon can play the role of many static beacons and a sensor node can receive the beacon messages from a mobile beacon with a single-hop connection. Localization schemes can be divided into range-based and range-free schemes depending on whether measured or estimated information is used. Range-free schemes can localize sensor nodes without power-consuming and expensive devices for measuring distance or angle information, while range-free schemes generally have coarser localization accuracy than range-based schemes. Since the use of a mobile beacon supplements the weakness of range-free schemes in localization accuracy, if we consider both the localization accuracy and the cost, range-free schemes with a mobile beacon can be promising localization schemes in sensor networks [1]-[6].

When we use static beacons, the localization accuracy depends mostly on the deployment of beacon nodes. In the case of the use of a mobile beacon, the path of a mobile beacon determines the deployment of the beacons. In papers to propose a localization scheme with a mobile beacon, a mobile beacon is assumed to move randomly. The assumption of the random movement is beneficial for performance evaluation of the proposed scheme, because the random movement can provide various cases to influence the localization accuracy. However, the random movement can cause the beacons used for localization to be located very closely to each other, which causes a large location error. In addition, a mobile beacon may visit the same area more than necessarily or not visit at some area. To improve the localization accuracy for localization schemes with a mobile beacon, the study on the path planning of a mobile beacon is needed. In [4], three different types of static paths are studied in relationship to a range-based localization scheme using the Received Signal Strength Indicator (RSSI) for ranging. In [5], the work by [4] is extended to design additional static paths and the more general Cramer Rao Bound (CRB) is used as the metric to compare different paths. In [4] and [5], static paths are studied for range-based localization schemes. To the best of our knowledge, there is no study on static path planning of a mobile beacon for range-free schemes.

In this paper, we study the static path of a mobile beacon to improve the localization accuracy for a range-free localization scheme, proposed by Lee et al. [6], with a mobile beacon in underwater sensor networks. We first determine a type of the static path and then compute the range of a parameter in the static path for all the sensor nodes to be localized. Finally, we analyze the relationship between the static path and the localization accuracy. Simulation results show that the determined static path obtained by the analysis improves the localization accuracy than other static paths.

II. Static Path Planning

In this section, we first explain Lee's scheme and then introduce a type of the static path for Lee's scheme. After determining a type of the static path, we should determine a parameter related to the path. We compute the value of a parameter for all the sensor nodes to be localized, then

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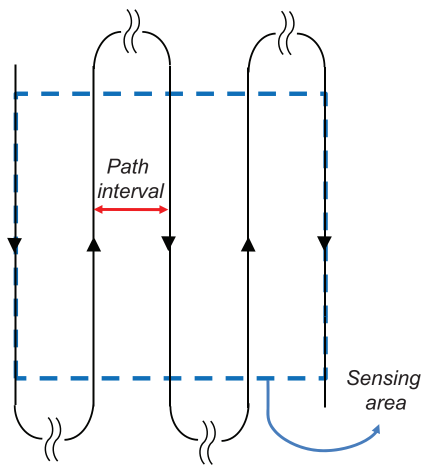


Figure 1. Static path over the sensing area and the path interval.

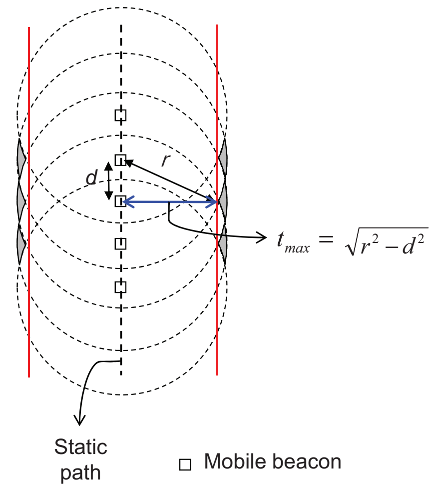


Figure 2. Maximum path interval for all sensor nodes to be localized.

analyze the relationship between the static path and the localization accuracy.

A. Localization Scheme Proposed by Lee et al. [6]

In Lee's scheme, a mobile beacon is assumed to have a GPS and move on the sea water at a constant speed and broadcast a beacon that includes its own absolute location information at regular intervals, called beacon distance (d). Since the sensor node knows its own depth information with a pressure sensor, the received beacons can be projected on the plane parallel to the sea surface where a sensor node locates. Once the received beacons can be projected, localization of sensor nodes located underwater becomes from three dimensional problem to two dimensional problem. A sensor node can estimate its own location with the projected beacons.

Lee's scheme consists of two steps. The first step is to find beacons located in the communication circle of the sensor node, referred to as beacon points, from among many beacons obtained from the mobile beacon. When the mobile beacon pass through the communication circle of the sensor node, the first and the last beacons are selected as beacon points. It is noteworthy that the distance between a beacon point and the sensor node is between the distance $r - d$ and r when the communication range of the sensor node is r. Based on the distance range between a beacon point and a sensor node, the distance between them can be determined as the middle value of the range, $r - d/2$, to minimize the error of the distance estimation.

A sensor node estimates its own location after obtaining only three beacon points, as the second step. The reason that a sensor node localizes itself without obtaining more than three beacon points by receiving more beacons is for reducing energy consumption. Among the three beacon points, two beacon points are used to obtain two candidates for the location of a sensor node. With the third beacon point, one point between the two is determined as the location of the sensor node.

For more accurate estimation, it is needed to consider which two beacon points to select for the two candidates from among the three beacon points. According to [8], when the angle subtended at the sensor node by the two beacon points is $90°$, the expected location error is minimized. To improve the localization accuracy, two beacon points, by which the angle subtended at the sensor node is closest to $90°$ than any two beacon points, among three are selected for the candidates.

B. A type of the static path

Static path planning for range-based schemes focuses on reducing the collinearity, while the problem of the collinearity has no effect on Lee's scheme. In Lee's scheme, the deployment of three beacon points, especially the angles subtended at a sensor node by any two beacon points, has a critical impact on the localization accuracy. Frequent change of direction of a mobile beacon can increase the possibility that any two beacon points are so close, where the location error is generally so large. For that reason, we study a static path of a mobile beacon that has the least change of direction as shown in Fig. 1, where the mobile beacon simply sweeps the sensing area in straight lines from left to right. To remove the effect of the direction change of a mobile beacon on localization of sensor nodes, the mobile beacon changes the direction outside the sensing area. In the static path, the path interval, the distance between two adjacent vertical paths, affects on the deployment of three beacon points. Therefore, the path interval is the key factor for the localization accuracy.

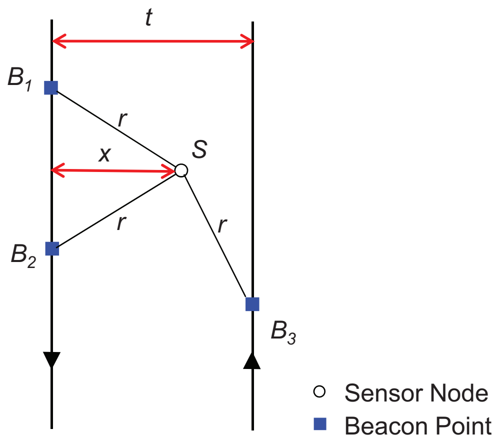


Figure 3. Three angles among three beacon points according to the path interval and the position of a sensor node.

C. Maximum Path Interval

First of all, the maximum value of the path interval should be determined to guarantee that all sensor nodes in the sensing area are localized.

As in Fig. 2, sensor nodes within the shaded areas can obtain only one beacon point. It can be guaranteed that a sensor node can obtain two beacon points when the path interval is equal to and less than $\sqrt{r^2-d^2}$ away from the sensor node, where r is the communication range and d is the beacon distance. For a sensor node to obtain the three beacon points, two paths need to pass through the communication circle of the sensor node, so the two paths need to be located within the distance of $\sqrt{r^2-d^2}$ from the sensor node. For this reason, the maximum path interval t_{max} is $\sqrt{r^2-d^2}$ for a sensor node to obtain the three beacon points. In other words, when the path interval is equal to and less than t_{max}, it is guaranteed that all sensor nodes in the sensing area can localize themselves.

D. Localization Accuracy

The path interval affects on the deployment of three beacon points and the deployment determines the localization accuracy. The deployment of three beacon points according to the path interval can be described by three angles $\angle B_1SB_2$, $\angle B_2SB_3$, and $\angle B_3SB_1$ as shown in Fig. 3; here, the angles are expressed as an acute angle. The expected location error at a sensor node is determined by one of the three angles $\angle B_1SB_2$, $\angle B_2SB_3$, and $\angle B_3SB_1$, as explained in the previous section. By determining the path interval to minimize the expected location errors, we try to improve the localization accuracy.

From Fig. 3, the three angles $\angle B_1SB_2$, $\angle B_2SB_3$, and $\angle B_3SB_1$ among three beacon points at a sensor node can be expressed as follows.

$$\begin{array}{l} i) 0 \le s \le t, \\ \begin{cases} \angle B_1SB_2 = 2\cos^{-1}\frac{s}{r} \\ \angle B_2SB_3 = 180^\circ - \cos^{-1}\frac{s}{r} - \cos^{-1}\frac{t-s}{r} \\ \angle B_3SB_1 = 180^\circ - \left|\cos^{-1}\frac{s}{r} - \cos^{-1}\frac{t-s}{r}\right| \end{cases} \\ ii) t < s \le t\_max, \\ \begin{cases} \angle B_1SB_2 = 2\cos^{-1}\frac{s}{r} \\ \angle B_2SB_3 = \cos^{-1}\frac{s-t}{r} - \cos^{-1}\frac{s}{r} \\ \angle B_3SB_1 = \cos^{-1}\frac{s-t}{r} + \cos^{-1}\frac{s}{r} \end{cases} \end{array}, \quad (1)$$

where t is the path interval, s is the distance between a sensor node and the first path of a mobile node crossing the communication circle of the sensor node. The ranges of the values t and s are

$$\begin{cases} 0 < t \le t_{max} \\ 0 \le s \le t_{max} \end{cases}$$

The expected location error decreases as one among the three angles $\angle B_1SB_2$, $\angle B_2SB_3$, and $\angle B_3SB_1$ be closer to 90°. Fig. 4 shows the differences between 90° and each angle ($\angle B_1SB_2$, $\angle B_2SB_3$, and $\angle B_3SB_1$) according to s and t. The angles $\angle B_1SB_2$ and $\angle B_3SB_1$ have the values close to 90° in the partial range of s regardless of t. The angle $\angle B_2SB_3$ becomes closer to 90° over the all values of s as the path interval t becomes larger. Through observing the three angles, it can be concluded that the localization accuracy is the most improved when the path interval t becomes t_{max}.

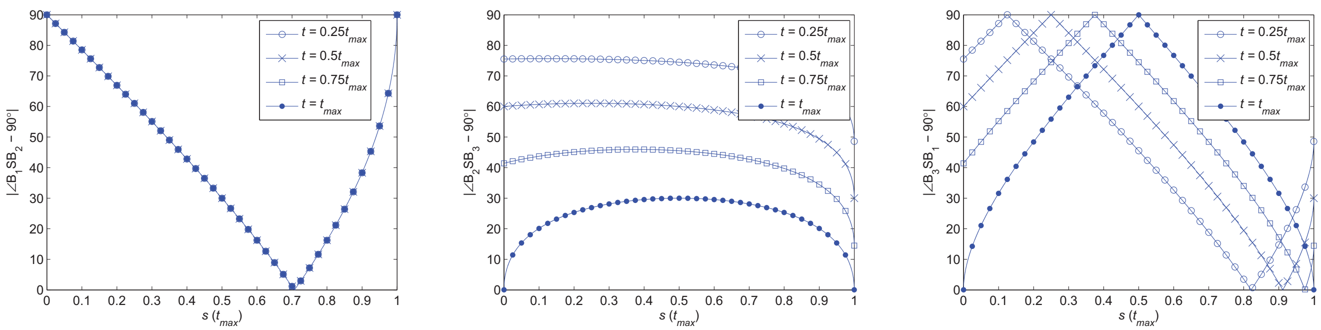
III. Performance Evaluations

In this section, we first describe the simulation parameters, and then verify whether the localization accuracy is most improved at the maximum path interval through simulations.

The sensing field for simulations is a square area of 1 km x 1 km at the depth of 100 m, where 100 sensor nodes are deployed uniformly at random. The communication range r for a mobile beacon and each sensor node is 120m. A mobile beacon is assumed to broadcast its own location at every beacon distance of 5 m.

To evaluate the relationship between the path interval and the localization accuracy, the distribution of location errors is used as a metric, instead of an average location error which is one of the most popular metrics, because an average location error can be seriously affected by a few number of large location errors.

Fig. 5 shows the distribution of location errors according to the four path intervals, $0.25t_{max}$, $0.5t_{max}$, $0.75t_{max}$, and t_{max}, in the static path and a random path. The figure shows that the localization accuracy is most degraded in the random path. As expected, the localization accuracy is most improved at the maximum path interval; i.e., there are about 9% more sensor nodes with a location error below 3 m at the maximum path interval than other path intervals.



(a) $|\angle B_1SB_2 - 90°|$ (b) $|\angle B_2SB_3 - 90°|$ (c) $|\angle B_3SB_1 - 90°|$

Figure 4. Distribution of the three angles according to the position of a sensor node and the path interval.

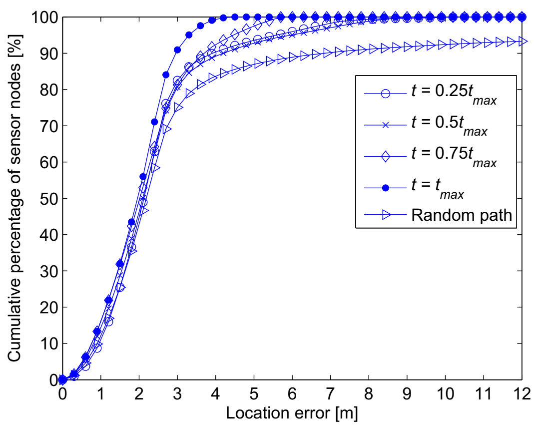


Figure 5. Cumulative distribution of sensor nodes according to the path interval.

IV. Conclusion

In range-free localization schemes with a mobile beacon, the path of a mobile beacon directly affects the localization accuracy, but no study on the static path planning for range-free schemes has not yet been done. In this paper, we proposed a static path planning of a mobile beacon for a range-free localization scheme proposed by Lee et al. [6] to improve the localization accuracy. By analyzing the relationship between a static path and the localization accuracy, a static path to improve the localization accuracy is obtained. The simulation results show that the localization accuracy can be more improved by planned static paths than a random path and the localization accuracy is most improved by the static path with the maximum path interval.

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