Selective Anchor Placement Algorithm for Ad-hoc Wireless Sensor Networks

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Abstract

This paper proposes a new anchor placement algorithm for improving localization performance. Motivated from the result obtained on the anchor placement error analysis [8], an near-exhaustive search is done on anchor placement for localization variance. Based on the best anchor area found in the search, we design a selective mobile anchor placement scheme (SAP). Simulation result shows that the SAP anchor placement scheme is effective in a sensor network with a small anchor ratio. Localization simulation result shows both the position variance and accuracy are improved by more than 10% of the radio range.

1. Introduction

Localization systems in wireless sensor networks provide position information of nodes with unknown positions, with the help of anchors. Among the factors that shape the localization performance in sensor networks, anchor placement is not heavily investigated. Most localization algorithms usually adopt one or more anchor deployment strategies [9, 5, 4, 1, 7]. But few has studied the relationship between anchor placement and localization performance thoroughly except in [7], which compared the error variance of corner anchor placement and the inside case. The reason for the lack of interest in anchor deployment strategy, as pointed out in [3], is that natural environments makes rearranging anchor nodes either infeasible or undesirable. However, for mobile sensor networks, location changes of anchors can be managed at the network level, thus making anchor redeployment feasible and profitable.

Our goal is to find a feasible anchor placement strategy to improve localization accuracy and precision. Based on an anchor deployment comparison in a grid-layered approach [8], a more fine-grained near-exhaust anchor placement search simulation on random-deployed networks is set-up. The result shows that, unlike the outmost corner placement conclusion presented in the error analysis study [7], there is a ring area adjacent but not on the perimeter of the network that performs the best. More detail can be found in Section 3.

Cramer-Rao Lower Bound (CRLB)[6] is a lower bound on the variance of estimators of a deterministic parameter. We use CRLB to bound and measure a localization algorithm on the precision performance. Based on the result obtained by the exhaustive search, Section 4 presents a selective anchor placement scheme (SAP). Simulation result of SAP shows that CRLB can be reduced by more than 13%. The localization accuracy can also be improved by more than 10%.

2. Impact factors of anchor placement

Several factors need to be considered when applying anchor placement scheme on improving localization variance or accuracy.

1. Anchor density.

Adding more anchors in a network is generally not a cost-effective idea. However, a carefully designed technique can increase the accuracy by adding a limited number of anchors. Bulusu et al. [2] in their adaptive anchor placement algorithm, propose to work on the density factor by empirically adding a few beacons in steps based on the localization result. This kind of algorithm manage to use density as a tool and at the same time keep the cost under control.

2. Anchor mobility.

Mobility can be a replacement factor for density since a limited number of mobile anchors can act as more anchors when they move around the unknowns. Ssu et al.[10] propose a mobile-anchor based localization algorithm with mobile anchor points no more
than 5% of the total number of sensor nodes. The cost of adding mobility seems to be more favorable than adding more nodes since the number of anchors can be drastically cut down to a few. Another advantage of having a few mobile anchors is that the configuration and management cost can be lowered, too.

3. Anchor position relative to the unknowns.

Most of anchor-based localization has a trilateration or triangulation phase for raw-position estimation. With erroneous range information and multi-hop communication, the placement or position arrangement of the known and unknowns affect the localization result considerably. Savvides et al. [7] in their error analysis paper suggest that the four corners of a square network are the best anchor positions. Wang et al. [11] propose a specialized circular anchor placement scheme based on the unknowns’ positions.

The proposed selective anchor placement scheme is a centralize position arrangement approach. The final positioning can be achieved by either anchor mobility or manually move the anchors to their expected positions.

3. A near-exhaustive search in anchor placement

In [8], simulation result shows that the anchors at the second outmost layer corners have the best CRLB performance. But more detailed work need to be done on the effects of the number and the placement of anchors.

An exhaustive search would be a straight-forward approach. For example, an exhaustive search for the best anchor placement among all possible \(n\) anchor combinations of 400 nodes in a 1000 \(\times\) 1000 sensor network can be done to find the best possible anchor placement. However, the huge computation required makes this approach unfeasible. To overcome this problem, a near-exhaustive search is designed by adding a filter to cut off the low-performance anchor placement. Our preliminary result (see Figure 1) shows that anchors covering a smaller area has higher \(CRLB\) than the larger ones. Therefore, the area of the convex formed by all anchors can be a performance parameter. The cut-off area value for our search is \(q = 250000\). Any anchor placement with a convex less than \(q\) is not searched. To further cut down the searching time, the number of anchors is \(n = 3\).

Simulation parameters are as following:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Network size</td>
<td>1000 (\times) 1000</td>
</tr>
<tr>
<td>Number of anchors</td>
<td>3</td>
</tr>
<tr>
<td>Number of nodes</td>
<td>400</td>
</tr>
<tr>
<td>Anchor area threshold</td>
<td>250000</td>
</tr>
</tbody>
</table>

CRLB is computed on the following categories on each possible anchor deployment, where

\[ A_m \] is the \(m\)th anchor set searched.
\[ P_{ijk} \] has the coordinates of anchor \(i, j, k\) as \((x_i, y_i), (x_j, y_j), (x_k, y_k)\) in anchor set \(A_m\).
\[ C_m \] is the CRLB vector of all unknown for anchor set \(A_m\).

1. Minimum: \(C_i^{\text{min}} = \min(\min(C_m)), \forall i \in A_m\)
2. Maximum: \(C_i^{\text{max}} = \max(\max(C_m)), \forall i \in A_m\)
3. Average: \(C_i^{\text{avg}} = \frac{\text{avg}(\text{avg}(C_m))}{\forall i \in A_m}\)

The simulation result are as follows:

- Average CRLB: in Figure 2(a), Figure 2(b), the \(z\) coordinate shows the average CRLB of each anchor position for all the result; The \(x, y\) coordinates are the position of that anchor. This is consistent with the result obtained in [8], which shows that there is a close-to-edge inner circle (the green one in Figure 2(b) as an approximation) that has the anchors with the best average and minimum CRLB on position estimation of all

![Figure 1. CRLB: Large anchor area vs. small anchor area](image-url)
other nodes. A possible explanation for the better performance of close-to-edge rather than the edge itself is due to two effects that outsider anchors have: larger unknown nodes coverage which is a positive factor for localization performance, and greater error rate due to multi-hop and longer distances between the outmost anchors and the unknowns in the center. The close-to-edge placement is a combined result from the two effects.

- Minimum CRLB: Figure 3(b) shows that the smallest CRLB of a unknown can be achieved by using anchors close to the center. However, performance on unknown nodes at the outer area will be sacrificed, which is shown as the average in Figure 2(b).

- Maximum CRLB: in Figure 3(b), some inner islands are formed showing the minimum of the maximum CRLB, which might be associated with the area filtering threshold. All the outmost and inmost anchor positions perform badly. It seems that the nodes in the center and the edges of the polygon are more likely to have larger CRLB than the nodes in other positions.

4. SAP: Selective anchor placement

Based on the near-exhaustive search result, a new selective anchor placement (SAP) scheme for CRLB improvement is found. Since the best CRLB performance comes from a close-to-edge ring area, anchors can be placed or moved to this area when the network is deployed. The target anchor area (TA) is a ring (shown as the green circle in Figure 2(b)) with a diameter of 80% of the width of a square network.

In SAP, the randomly-deployed anchors select the best anchor placement based on their knowledge of the edges of the network. We assume that all \( n \) anchors are mobile and they know the locations of the boundary edges of the network. The circle of TA is divided into \( n \) sectors and each division point is a new location for the anchors. To save energy and time, shortest movement is considered in the new anchor position creation process. The starting point of the split is the closest circle-to-anchor distance among all the anchors. Beside the closest anchor, each other anchor chooses their closest new position. This can be achieved by either a centralized or distributed approach with scheduling of mobile events.

As a summary, the SAP approach has the following key points:

- Anchors stay in TA. This guarantees best performance.
- Even distance between anchors. This keeps the anchor placement balanced and maximizes the contribution of each anchor.

Figure 2. Anchor Placement and CRLB: Average

- Shortest movement of anchors. Energy saving is essential in WSNs since each node has very limited resources.
- Number of anchors needed is small. As a side-effect of the above techniques, the benefit of each anchor is maximized in localization, which lowers the total cost of anchor deployment.

5. Simulation result

Simulation setup is as follows:

1. Network size: \( 1000 \times 1000 \)
2. Number of Nodes: 100
3. Number of Anchors: \( 3 \sim 7 \)
4. Sigma for path-loss exponent: 0.15 \sim 0.40
5. Radio Connectivity Radius: 250 \sim 400
6. Number of networks (runs): 100
7. Type of node deployment: grid, random
8. Localization algorithm: QuantizedRSSIBased SensorNetworkLocalization

Comparison is made between random anchor placement (RAP) and SAP. The simulation result in Figure 4(a), and Figure 4(b), shows the various CRLB result of SAP and RAP using various network parameters such as path-loss exponent (leading to range-error), radio range (network connectivity) and the number of anchors. The result shows that SAP can reduce the CRLB of RAP by more than 10%. SAP in a randomly-deployed network works more effectively than in a grid network. As shown in Figure 5(a) and Figure 5(b), a smaller number of anchors in SAP performs similar or better as more anchors in RAP. Also, it is obvious that the performance gain ratio decreases when the number of anchors increases. Therefore, SAP is useful when the anchor ratio is small.

In addition to CRLB computation, localization simulation is done using our RangeQ-APS algorithm. Figure 6(a) shows the average localization variance of 60 networks using 10 set of random anchor placement respectively. It is consistent with the theoretical result. Figure 6(b) shows the localization accuracy with the same simulation setup of Figure 6(a). Not only does SAP improves variance by up to 40% of network communication radius, but it add accuracy in a similar ratio as well.

6. Summary

An near-exhaustive search is done on anchor placement for localization variance. Based on the best anchor area found in the search, a selective anchor placement scheme SAP is designed to reduce the cost of anchors and improve localization performance. Simulation result shows that the SAP anchor placement scheme is effective in a sensor network with a small anchor ratio. The improvement of SAP over RAP is most significant when the least number of possible anchors is used. Theoretical result shows it can reduce CRLB from a random anchor placement (RAP) by more than 10%. Localization simulation result shows that both the position variance and accuracy are improved more than 10% of the radio range.
References


