Improving APS with Anchor Selection in Anisotropic Sensor Networks

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Abstract

Sensor networks are useful for environmental monitoring, military applications, disaster management, etc. In many applications, sensors are supposed to know their geographic locations. Some localization methods of sensor networks have been developed. In these methods, nodes equipped with special hardware to obtain precise location information, namely the anchor nodes, are employed to derive the locations of other nodes. Most of the existing work focus on increasing the accuracy in position estimation by using different heuristic-based or mathematical techniques. In this paper, we show that selection of anchor nodes is a significant factor to the problem. We first demonstrate that using all anchor nodes does not give the most precise position. We then identify criteria of selecting "good" anchor nodes to achieve more accurate position estimation in anisotropic sensor networks. We develop a simple heuristic-based algorithm to select "good" anchor nodes and evaluate its performance using simulations.

1 Introduction

A wireless sensor network is a network consisting of thousands of sensors that span a large geographical region. These sensors are able to communicate with each other to collaboratively detect objects, collect information, and transmit messages. Sensor networks have become an important technology especially for environmental monitoring, military applications, disaster management, etc [2] [6]. However, as sensors are usually small in size, they have many physical limitations. For example, due to its limited size, a sensor does not have a very powerful CPU and is limited in computational power and memory. On the other hand, a sensor is powered by a battery instead of a power outlet. This limitation in energy puts extra constraints in the operations of sensors. As recharging is difficult, sensors should smartly utilize its limited energy in collecting, processing, and transmitting information.

In many applications, sensors have to know their geographical locations. Theoretically, Global Positioning System (GPS) can be used for a sensor to locate itself. In reality, it is not practical to use GPS in every sensor node because a sensor network consists of thousands of nodes and GPS becomes very costly. To solve the problem, many localization methods have been developed. Instead of requiring every node to have GPS installed, all localization methods assume only a few nodes (≥ 3) are equipped with GPS hardware. These nodes are called *anchor* or *beacon* nodes and they know their positions without communicating with other nodes. Other normal sensors then obtain distance information through talking to each other and derive their positions based on the information. A good localization protocol should reduce the error in position estimation by using reasonable number of messages. The computation and memory required should be limited as well due to the nature of sensor networks mentioned above.

Most of the existing work focus on increasing the accuracy in position estimation by using different mathematical techniques such as triangulation [5], multilateration [7], multidimensional scaling [9, 8, 3], convex optimization [1], etc. In these methods, information provided by every anchor node is used, without considering the position of that anchor. To the best of our knowledge, there is only limited research on studying the significance of anchor node selection, particularly for localization algorithms in anisotropic sensor networks [1]. In this paper, we show that the accuracy of a localization algorithm also depends on this factor. We first demonstrate that in most situations, using a subset of anchor nodes is better than using all anchor nodes when applying the Ad-hoc Positioning System (APS) [5], a distributed and hop-by-hop localization algorithm, to estimate node positions in anisotropic sensor networks [4] as illustrative examples to demonstrate the feasibility of our proposal. Basically, anisotropic sensor networks possess challenging

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[1] A network is isotropic if measurements in all directions are exhibiting the same properties; otherwise, it is anisotropic

properties to certain localization algorithms such as the APS due to various limiting factors including the geographical shape of the involved region, different node density, irregular radio patterns, etc. In such challenging anisotropic cases, we then identify the criteria of ”good” anchor nodes and develop an algorithm for selecting these nodes. Of course, our proposal described in this paper can also be applicable to other general sensor networks. Lastly, we evaluate the performance of our algorithm using simulations.

This paper is organized as follows. Section 2 reviews our initial investigation on the significance of anchor node selection in the APS for localization in anisotropic sensor networks. In Section 3, we describe our algorithm in detail. Section 4 gives the experimental results of our algorithm. Lastly, we conclude our work in Section 5.

2. Preliminaries

In this section, we firstly review the APS algorithm [5] based on the triangulation technique used in GPS to estimate the positions of other sensor nodes with reference to the fixed positions of anchor nodes dispersed inside any general sensor network. However, as explained in Section 1, due to the challenging properties of anisotropic networks that may incur extra estimation errors for localization algorithms like the APS, we will later consider the impact of anchor selection in such challenging cases of anisotropic sensor networks.

2.1 Ad Hoc Positioning System (APS)

APS [5] is one of the earliest methods developed for localization. It bases on the triangulation used in GPS and is a distributed protocol that requires reasonable computation, memory, and message overhead. APS assumes there are at least three anchor nodes in a sensor network. Each normal sensor tries to find out its distance to the anchor nodes. When the distance information to three or more anchor nodes is obtained, the sensor node can compute its own position using triangulation.

The key question APS answers is how a node finds out its distances to the anchors. Three methods are described: *DV-hop*, *DV-distance*, and *”Euclidean” propagation*. Among them, DV-hop and DV-distance receive most attention. Both DV-hop and DV-distance measure distance in a hop-by-hop manner. Each sensor is required to communicate with its immediate neighbors only. In DV-distance, an anchor node A starts out by sending a broadcast message that contains its identity and its geographical location. By the signal strength of the message, a neighbor of A can then determine its physical distance to A. Each neighbor then broadcasts a message indicating that its distance from A. A node that receives this message will determine its distance to A by adding its distance to its neighbor and the distance of its neighbor to A, which is carried in the message. Subsequently, every node in the network can identify the distance to A. DV-hop works in a similar manner except the physical distance is not derived from signal strength measurement but from *average distance per hop between anchor nodes*.

Theoretically, a normal node requires only distance and position information of three anchor nodes to perform triangulation. When there are more than three anchor nodes, a normal node can use the information of all the nodes to calculate its location or it can select only three. APS does not study this issue in detail. However, intuitively, different choices should yield different estimations of positions. An anchor node which is isolated in a remote area is not a good one since the distance estimated using DV-hop or DV-distance is usually deviate a lot from the real physical distance. We study the effect of selecting different anchor nodes using simulations.

2.2 The Impact of Anchor Selection

In general, the selection of anchor nodes should be impactful to the precision of position estimation in most localization algorithms, especially true for the APS or specifically DV-distance algorithm in the presence of measurement error in anisotropic networks. Of course, the importance of anchor selection for localization algorithms in general sensor networks should readily be another interesting direction for future investigation. Nevertheless, as an initial study on the significance of anchor selection to APS in anisotropic sensor networks, we randomly generate altogether 2 C-shape topologies, with 1 case for each of the 10% and 20% nodes as anchors respectively due to the limited time, and then compare the results achieved by the original APS that *blindly* considers all the available N anchor nodes during the position estimation of each individual sensor node against the results obtained by a modified APS that will *selectively* considers the *best* 3 anchor nodes after performing an enumerative search to compare the computed results among all the possible combinations ($_NC_3$).

As an initial investigation, since the modified APS selecting the best 3 anchors requires a fairly long time for each simulation run after checking every possible combination of available anchor nodes, we test both the original and modified APS on only one case for the C-shape topology, a typical example of anisotropic topology, with anchor ratio of 10% and 20% respectively, and no measurement error. Among all the test cases, we find that the modified APS using the best 3 anchors for computation in general outperforms the original APS in terms of the average error of position estimation. For the specific C-shape topology we tested with 10% anchors, the original APS obtained an average error of $1.0698R$, where R denotes the radio range, whereas the modified APS achieved an average error of $0.0604R$ only. For the case with 20%, the original APS achieved a slightly reduced average error of $1.0309R$ that was much outperformed by the modified APS with an average error rate of $0.0151R$.

Figure 1 gives a convincing example of the estimated positions by both the original and modified APS for a particular sensor node against its true position in a specific case. For clarity of presentation, the square is used to denote the true position of the individual node of interest. The "*" symbol represents the estimated position by our modified APS whereas the circle is the estimated position by the original APS. Obviously, the estimated node position by the original APS is far from its true position for which the estimated position by our modified APS is much closer in this particular case. From our empirical experience, we find that similar cases occur for the 'corner' or its neighboring nodes around the two ends of the C-shape. In corners, the estimation error in the accumulated distance along the various paths from *all anchor nodes* as computed in the original DV-distance algorithm of the APS approach can be much more profound and misleading when compared to that of other positions in the C-shape, thus introducing a much higher imprecision in the estimated position as illustrated in Figure 1.

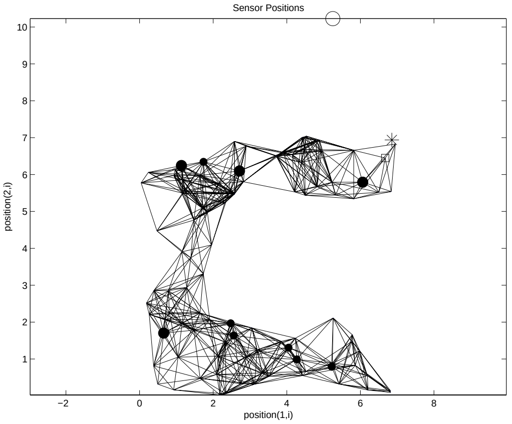


Figure 1. An example showing the benefit of selecting the best 3 anchors rather than all anchors in APS for a particular node

On the other hand, there are few examples where the original APS approach betters our modified approach due to the insufficient information deduced from the best 3 anchors, especially when the best 3 anchors are co-linear to each other that may induce flipping of the estimated position under the triangulation mechanism used in APS. However, we find that such cases of colinear anchors are relatively rare as compared to the possible advantages gained out of our modified APS approach. Therefore, the average estimation error on our specific test cases of C-topologies by 94.35% with 10% anchor nodes, and even by 98.54% in the case of 20% anchors by our modified APS approach using the best 3 anchors when compared to that of the original APS method. Obviously with more anchor nodes available, the impact of carefully selecting the best 3 anchors becomes more obvious. A detailed analysis for such improvement by our modified APS would prompt for further investigation.

3 Our Proposal

As reflected in the empirical results obtained by our modified APS approach using the best 3 anchors in the previous section, the advantage of carefully selecting *less but useful* anchor nodes should be obvious to the original APS method considering all anchor nodes, especially for anisotropic sensor networks. However, the modified APS approach needs to perform an exhaustive search to determine the best 3 anchors, which will surely be very computationally expensive and thus becomes practically infeasible for any distributed localization algorithm or protocol. Moreover, the modified approach requires the true position of each node to determine the *best* 3 anchors for each individual node. However, such information of true position (only available in simulations) would never be available in real-life applications of wireless sensor networks.

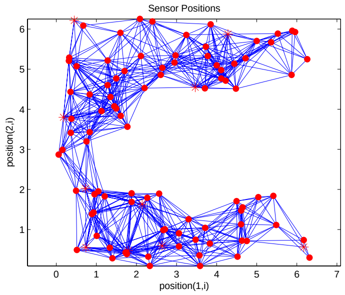
In view of the above concerns for our modified APS, we propose in this paper an *improved APS algorithm*, namely the *APS(Near-3)*, based on a simple yet effective heuristic as follows: the improved APS algorithm will always choose the *nearest 3* anchors with respect to each individual sensor node inside the original APS computation (i.e. the triangulation mechanism) used for its position estimation. Other than using the nearest 3 anchors instead of the best 3 anchor nodes, our improved APS(Near-3) algorithm does not differ much from the modified APS considered in Section 2.2. In fact, our simple heuristic of choosing the nearest 3 anchors has been verified by the previous empirical results obtained in which the best 3 anchors are always found to be very close, if not strictly the nearest, to the individual sensor nodes in most cases. This observation also accords to our intuitive thinking on the general cases where choosing the nearest 3 anchors should always help to minimize the estimation error in the concerned distances between the anchors and the corresponding sensor node. After all, both the modified and improved APS algorithms are intrinsically variants of the original APS method dependent on the triangulation mechanism for position estimation.

It should be noted that as different from the latest work by Lim and Hou [4] that employed a sophisticated projection technique inside an embedding space through the truncated singular value decomposition (SVD) method to achieve more robust estimates of node positions, we propose here to achieve more precise node estimation through carefully selecting the anchor nodes in order to minimize the overall estimation errors. Clearly, our proposal should be simpler for implementation and also requires much less computational or memory overheads when compared to their approach.

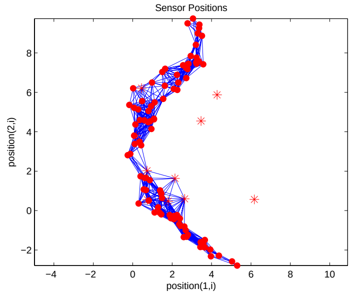
4 Experimental Results

In this section, we discuss about the experimental results and preliminary analysis of our proposal of improved APS algorithm through selecting the nearest 3 anchor nodes in anisotropic sensor networks. To demonstrate the effectiveness of our proposal, we generated 20 random instances of C-shape topologies of anisotropic sensor networks to evaluate the performance of both the original and improved APS using our nearest-3-anchors strategy (APS(Near-3)). Both original and improved APS are based on the DV-distance algorithm [5] as described previously. For all test cases, the ratio of anchors is 10% of the total number N of sensor nodes. Besides, following [5], we assume a uniform distribution of 10% measurement errors across the anisotropic sensor network to test on the robustness of the localization algorithms for comparison. For all the subsequent discussion, the performance of each individual localization algorithm is always considered in terms of the average estimation error as measured in R for the involved radio range. All the localization algorithms are implemented in the Matlab Version $7.0.1$ with their simulation results running on a Pentium IV desktop PC installed with a 3 Ghz processor and 512 Mbytes RAM under the MS Windows XP Operating System.

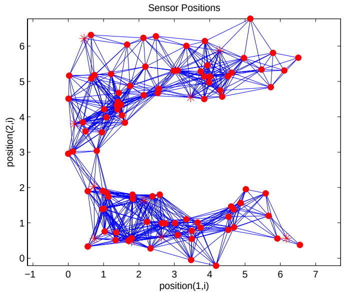
Figures 2 and 3 show the original topologies followed by the results obtained by the original APS and the improved APS using our *nearest-3-anchors* strategy based on the best and worst performance of our proposal among all the 20 test cases. All anchor nodes with precise knowledge of their own positions are marked as "*" for clarity of presentation whereas the remaining dots denote the ordinary sensor nodes. The best resulting topology obtained by our improved APS gives $0.1527R$ as the average error whereas the worst result shows $0.5716R$, producing an overall averaged error of $0.3343R$ for all the 20 test cases. On the other hand, the APS produces $0.7683R$ as the average error for the best case, with the worst result at $1.8731R$, and giving an overall averaged error of $1.0725R$ for all the 20 cases.



(a) The original topology



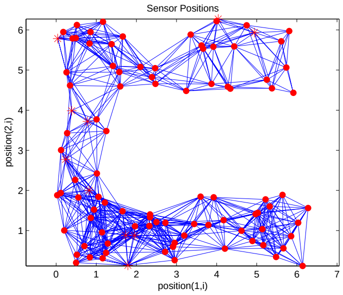
(b) The resulting topology of the original APS



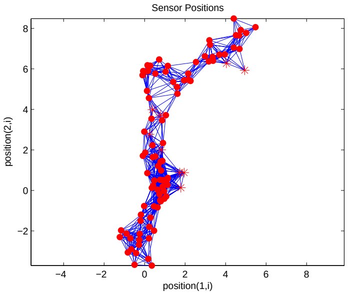
(c) The best resulting topology of the improved APS

Figure 2. The performance of the original APS against the best result of the improved APS(Near-3).

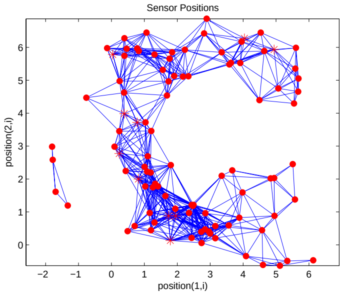
When we compare the original topology in Figure 2(a) against that obtained by the original APS and the corresponding best result achieved by our improved APS in Figure 2(b) and 2(c) respectively, we can clearly see that the improved APS using our nearest-3-anchors strategy is capable of producing a more compact C-shape topology, showing the relatively greater precision and robustness of the estimated positions against the measurement errors introduced for both localization algorithms. Interestingly, even the worst topology produced by our improved APS is still better than the corresponding topology obtained by the original APS when comparing the improved result in Figure 3(c) against the result of the original APS in Figure 3(b) with respect to the original topology shown in Figure 3(a). Again, the improved APS generally shows a more compact C-shape topology except for the 4 distinctively separated



(a) The original topology



(b) The resulting topology of the original APS



(c) The worst resulting topology of the improved APS

Figure 3. The performance of the original APS against the worst result of the improved APS(Near-3).

sensor nodes positioning around the lower left corner of the C-shape. The 4 distinctively separated nodes are possibly due to the accidental co-linearity of the 3 nearest anchor nodes that fail to provide sufficient information for the 4 sensor nodes to more precisely estimate their own positions. After all, a simple check about the co-linearity of the nearest anchor nodes to avoid such, possibly rare but critical, cases should prompt for further investigation.

Figure 4 shows the plottings of the x-axis as the ratio of anchor nodes ranging from 0.0 to 0.9 against the y-axis as the average error in R to summarize the overall performance of the original and improved APS(Near-3) over all the 20 cases of anisotropic sensor networks, with the different graphs showing the various ratio of the measurement errors ranging from 0.00 to 0.5. In general, no matter for the original or improved APS, the higher the proportion of anchors, the lower the estimation error. Besides, the smaller the percentage/ratio of the measurement error, the higher the accuracy of the estimated positions. However, when comparing the overall performance of the original APS against that of the improved APS, the original APS gives an average estimation error in the range of $1.0 - 1.2R$ as clearly shown in Figure 4 whereas the improved APS attains an average estimation error in the range of $0.1 - 0.7R$, with the worst result of our improved APS as almost half of the maximum average error attained by the original APS. This clearly indicates a very significant improvement on the average precision of the estimated positions of all sensor nodes achieved by our proposal due to the careful selection of *useful* anchors to effectively minimize the estimation errors in the computation of APS.

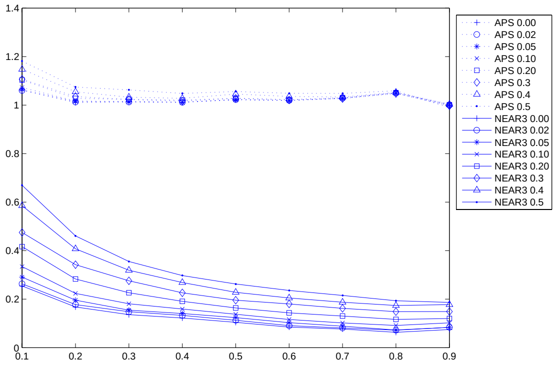


Figure 4. The overall performance of the original APS and improved APS(Near-3)

Moreover, the original APS does not show any significant improvement in the average estimation error even with further increases in the proportion of anchor nodes, or reduction in the measurement errors, thus *prematurely* stabilized[2] within the high range of $1.0 - 1.2R$ of average error in response to any drastic change in the concerned problem features. On the other hand, our improved APS seems to be more *sensitive* to any change in the underlying parameters including an increase in the proportion of anchors, or conversely a decrease in the measurement error. Obviously, this is because relying upon a *much smaller* number (only 3)

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[2] Clearly, such a premature stabilization can be a mixed blessing in which some researchers may consider as its strength to give stable performance under any changing problem features. However, it is worth noting that our main aim here is to improve the performance of the original APS computation in terms of the average estimation error. From this perspective, such a premature stabilization definitely represents a shortcoming rather than a strength.

of carefully selected anchors will make the overall performance of our improved APS more vulnerable to any change in the problem features. Thus, this results in a *wider* range of average error for our improved APS, with the range as $(0.7-0.1)R = 0.6R$ exactly triple of $(1.2-1.0)R = 0.2R$ for the original APS. Definitely, how to *more carefully* select a *sufficient* number of *useful* anchor nodes in order to increase the precision of position estimation while making the localization algorithm itself relatively less susceptible to any change to the underlying problem features remains to be a challenge in our future investigation. After all, this leaves us with more room for improvement through a more thorough investigation of the underlying interaction mechanism between a sufficient number of *good* anchors and the vulnerability of our improved localization algorithm in general.

5 Conclusion

Wireless sensor networks are widely applicable to many practical applications including environmental monitoring, military applications, disaster management, etc. in which sensors may sometimes need to know their geographical locations. It is obviously infeasible to have all sensors equipped with special hardware to obtain precise location information often due to cost, space, weather or other physical constraints. Therefore, based on the availability of a few anchor nodes which can precisely determine their own position, some localization algorithms have been developed. Undoubtedly, most of the existing work focus on increasing the accuracy in position estimation by using different heuristic-based or mathematical techniques. An example is the the Ad-hoc Positioning System (APS) [5] proposed by Niculescu and Nath, that works by the triangulation mechanism used in the Global Positioning System (GPS). Basically, APS is a distributed hop-by-hop localization algorithm to estimate node positions through utilizing the position information of all anchor nodes available in any general sensor network. Moreover, 3 possible methods including the DV-hop, DV-distance and “Euclidean” propagation are considered based on the different ways to measure the “distance” of each node to an anchor in using the APS approach.

In this paper, we show that the selection of anchors is a critical factor to consider in solving the localization problems. First, we demonstrate that including all anchor nodes in the original APS does not give the most precise position estimation when compared to that of a modified APS using only the best 3 anchors among all the available anchors in a set of empirical simulation results obtained for anisotropic sensor networks. Then, we propose an improved APS algorithm named the APS(Near-3) based on a simple yet effective heuristic of choosing the nearest 3 anchors with respect to each individual sensor node. To demonstrate the feasibility of our proposal, we implement both the original and improved APS algorithm in the Mathlab Version 7.1, and obtain their simulation results on a set of 20 randomly generated C-shape topologies. Our simulation results clearly demonstrate the capability of our proposal in reducing the maximum average estimation error to almost half of that attained by the original APS method. More importantly, our proposal of improved APS algorithm is simpler for implementation and requires much less communication overheads as compared to the original APS approach.

This work opens up a number of interesting directions that are worth exploring. First, we mainly focus on the impact of selecting *good* anchors for anisotropic sensor networks in this paper. Studying the significance of selecting *good* anchors in uniform sensor networks should readily form an interesting direction for future investigation. Besides, selecting the nearest 3 anchors may not always give the best estimate in position for each individual sensor node. It should be very interesting to consider more sophisticated technique(s) to check for the usefulness of an anchor to the position estimation of each individual node in the APS or other localization algorithm. Lastly, as discussed in Section 4, creating an intelligent localization method that can carefully select a *sufficient* number of good anchors to increase the overall accuracy of position estimation while being less susceptible to measurement or other possible errors on the various types of sensor networks will remain as a challenge in our future investigation.

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