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Lateration-Specific Localization Algorithm for Wireless Sensor Networks

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Abstract: **The Received Signal Strength Indicator (RSSI) is a low-cost ranging technique that is commonly used to locate nodes in outdoor Wireless Sensor Networks (WSNs), however it can sometimes provide erroneous position estimations. This is mostly due to the interplay between the reference nodes' influence on distance estimation mistakes and localization geometry. Analysis of distance estimation errors and localization geometry is necessary for the development of methods for decreasing location error. This work seeks to enhance the quality of range-based trilateration localization for WSN nodes in a variety of outdoor environments in order to meet these difficulties. Analyses of the localization error caused by range error and localization geometry have been performed using actual RSSI measurement data. An Adaptive Range-Based Localization (ARBL) technique is suggested that utilizes trilateration and reference node selection to enhance location accuracy and precision; its performance is then assessed by analyzing the gathered data. The technique makes use of a number of different permutations of reference nodes in order to determine the most accurate way to predict a node's position at any given instant. Based on the findings, it seems that the suggested method is effective in lowering the location error. As such, it may be concluded that range-based trilateration localization can provide enough location precision.**

Index Terms: **Wireless Sensor Networks, ARBL Method, Trilateration, Reference Node Selection, Localization, Anchor Nodes.**

I. INTRODUCTION

Over the last two decades, academics have become more interesting in the challenge of pinpointing individual nodes inside WSNs. Knowledge of node locations is helpful or perhaps required for many operations, services, and applications in wireless sensor networks [1-3], making localization one of the key services in WSNs. As a result of their purpose-built nature, WSNs are limited in how they may be configured compared to generic networks [1, 4].

Also, the nodes in a WSN are under far more severe resource limitations (e.g., limited communication range, and limited energy, processing, memory, and storage capacity). Localization methods and protocols in WSNs are also subject to these limitations. Global Navigation Satellite Systems (GNSS), like GPS and GLONASS, provide a standard method for pinpointing a specific position. However, on a wide scale, installing a GNSS receiver on every node in a WSN is neither a viable option nor a very efficient use of resources. In addition, the receiver's range is reduced in some natural settings, such as thick vegetation or urban canyons. Because of this, it was needed to look for substitute approaches. Reference nodes (anchors, beacons, landmarks, or seeds) are used in anchor-based localization since their positions are known in advance [2, 3, 5-7].

Reference nodes either has a Global Navigation Satellite System (GNSS) receiver installed or has their positions defined manually. In order to determine their own positions, unknown (unlocalized) nodes require a localization technique to combine the coordinates of reference nodes with distance (or angle) estimations and other information. Wireless sensor network localization methods are often split between range-based and range-free categories [2, 6-10]. In localization, range-based algorithms rely on estimated inter-node lengths or angles, whereas range-free methods make advantage of connection (through hop counts, for instance) or pattern matching (by fingerprinting, for instance) to pinpoint a device's precise location. Time of Arrival (ToA), Time Difference of Arrival (TDoA), Angle of Arrival (AoA), and received signal strength indicator are all ranging techniques that may be used in range-based localization to provide distance or angle estimations (RSSI). An unknown node's position can be estimated using a location computation technique such as Lateration [5, 11] (trilateration or multilateration), Min-max (bounding box) [11, 12], or a probabilistic approach based on the distance estimations to the reference nodes and the reference nodes' coordinates (e.g., maximum likelihood).

The advantages and disadvantages of RSSI-based localization are comparable to those of other range-based methods. On the one hand, it is an inexpensive and energy-efficient method that can be used to sensor networks with the addition of only a radio transceiver. However, this method is very dependent on ambient circumstances, therefore it frequently provides erroneous range and position estimations [13-16]. The accuracy of a localization method that uses a range mostly is determined by the interaction between the ranging error and the localization geometry, or the positions of the reference nodes in relation to the unknown node. This is because the range errors and localization geometries shift based on the reference nodes that are employed, and so the magnitude of the localization error also shifts. As an added bonus, certain methods of location calculation are less sensitive to range faults and/or localization geometries than others.

Trilateration is a common low-cost method for calculating locations, although it is very dependent on the accuracy of the rangefinder and the positions of the reference nodes. Depending on the chosen set of reference nodes, this might lead to unexpected discrepancies in the position estimations. Furthermore, the same set of reference nodes may succeed

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in identifying one unknown node but fail in identifying another. Consequently, if you want to get sufficient location accuracy, you need to pick relevant reference nodes in each scenario. Findings show that the ARBL method may significantly cut down on location error, achieving results that are very near to ideal for a given set of reference nodes. This demonstrates that practical and precise position estimations may be achieved, despite tough and variable outside settings, by making use of appropriate methodologies and data. In conclusion, our research sheds light on the viability of RSSI- and range-based localization in wireless sensor networks.

The specific organization of the article is as follows. Related techniques to the ARBL algorithm are presented in Section II. In Section III, a general overview of localization techniques is presented. Section IV introduces the network setup and simulation results of the proposed algorithm and Section V draws the conclusions.

II. RELATED WORKS

Various recent reviews (e.g. [2, 5-10, 17, 18]) have categorized and presented some of the many localization algorithms and strategies introduced in recent years for use in WSNs. Several articles pertinent to our approach are discussed below; these studies examine localization techniques based on trilateration and make use of reference node selection.

A. Anchor- and Range-based Trilateration Localization Algorithms

Numerous algorithms and methods for localization based on anchors and ranges have been developed in recent years, and many of them rely on trilateration [2, 5, 6, 8]. The impact of localization geometry on location inaccuracy has been researched extensively yet is ignored by most range-based (and range-free) techniques. An integral aspect of range-based localization, especially for trilateration-based localization, is the selection of reference nodes. The quality of the localization is significantly impacted by the choice of reference nodes and so cannot be neglected.

B. Reference Node Selection Algorithms

Few researches have been done on reference node selection methods, despite the popularity of anchor-based localization. As an example, see [19-23] and [24] for further reading on this topic. An approach for selective anchor node localization (SANLA) is proposed in [19]. In SANLA, an unidentified node determines its position using a series of Trilaterations, in which one of the anchor nodes is fixed (the reference node), and two are the combinations of the other anchors. The fixed reference node's position is then calculated using the same anchor combinations as before, but this time applied to the unknown node.

The unknown node can then be informed of the coordinates that created the least amount of inaccuracy when compared to the genuine ones. The unknown node may now determine which of its previous location estimations yielded the most accurate result and use that coordinate as its own.

In [11], the authors suggested a Trilateration-based approach for selecting reference nodes. To determine if any of the reference triplets may form a nearly equilateral triangle, the unlocalized node calculates the distances between each pair of nodes. Next, the location estimates are calculated using all the feasible equilateral triangles, and the mean is used as the final estimate.

In [16], the CIL algorithm, or confidence-based iterative localization, is presented. Quality of Trilateration (QoT) is the foundation of CIL; it is a probabilistic metric that reflects the precision of a given trilateration by quantifying the geometric connection between the reference nodes and the range errors. Each node in CIL is assigned a confidence value that reflects how sure the network is about that node's location estimate.

For trilateration, a node's confidence is calculated by multiplying its Quality of Trilateration (QoT) with the confidence of its reference nodes. Ttrilaterations are used to iteratively move from high-confidence nodes (beacons with positioning devices) to low-confidence nodes (others) in the localization process to accomplish this. Reference nodes (localized nodes) send location data to an unlocalized node with varying degrees of certainty.

An unidentified node uses the most reliable trilateration to pinpoint its current location at each successive step. If a more precise position becomes available at any moment, the initial estimate can be updated accordingly. The experimental and computational findings demonstrate that CIL considerably enhances the precision of location estimates.

A study [12] presented an error-based distributed reference node selection technique for trilateration localization. The programme follows three guidelines for making the most informed decision when choosing anchor nodes for trilateration. Two related rules stipulate that the reference triangle's smallest internal angle must be more than 13 degrees, and that its shortest edge must be as long as feasible. The third principle stipulates that the distances between the unknown node and the reference nodes should be as comparable as feasible, as this also influences the accuracy of the localization. Simulations proved the algorithm's competitive performance. Although the simulations show promise, the distance errors imposed may be overly optimistic, especially if RSSI is employed for ranging.

In [14], the authors offer an enhanced trilateration localization technique called ITL-MEPOSA, which reduces the spread of uncertainty by choosing anchor nodes with maximum efficiency. Uncertainty data is defined by the authors as the standard deviation of sequential distance estimations between an unknown node and an anchor node.

When choosing anchor nodes, it's best to pick the three with the lowest product of the mean distance estimate and the related uncertainty information. Trilateration makes use of these anchor nodes and the related mean distance calculations. In contrast, the impact of localization geometry is ignored.

III. LOCALIZATION TECHNIQUES

Some ranging approach (RSSI, ToA, TDoA) is used to estimate the internode distances, and an appropriate location computation technique is used to calculate unknown node positions; these are the two main components of a typical range-based localization procedure. In this setting, any ranging approach can be used to acquire the distance estimations required for localization. Since the focus of this research is on estimating distances using RSSI, it was necessary to go through some of the standard methods for doing so. Additionally, a brief discussion is provided on some of the most important parameters influencing the precision of RSSI and range-based localization.

A. RSSI-based Ranging

RSSI-based ranging methods work on the idea that a radio signal decays (its amplitude lowers) as it moves away from the transmitter. The log-normal shadowing model is often applied to represent radio signal route loss, and it is stated in [10, 15]). :

$$P_r(d) = P_r(d_0) - 10n\log\left(\frac{d}{d_0}\right) + X_\sigma \tag{1}$$

where, Pr(d) (or RSSI(d)) is the received power in dBm at distance d [m] from the transmitter, $Pr(d_0)$ (or RSSI(d_0)) is the received power in dBm at the reference distance d_0 (usually 1 m) from the transmitter, n is the path loss exponent (PLE), and X is the zero-mean Gaussian random variable with the variance of 2, that is, X N Various methods exist for estimating $Pr(d_0)$, including the Friis free-space equation, theoretical models, and empirical measurements. Also, the PLE *n* can be determined ahead of time or estimated afterwards, either offline or live, based on known distances between reference nodes that are kept in a stable position [16].

In the log-distance route loss model, the average received power at a distance d from the transmitter is expressed as Eq. (1), omitting the stochastic factor X. In order to calculate an approximation of the distance d [m] between any two nodes in a network, that may utilize the log distance path loss model.

$$\hat{d} = d_0 10^{(P_r(d_0)-P_r(d))/10n} \tag{2}$$

B. Lateration

Using three (trilateration) or more (multilateration) reference nodes with known locations and the measured distances (e.g., based on the RSSI) to them as shown in Figure 1, the position of an unknown node may be calculated [3, 11, 13]. In order to find a unique solution in 2D space, distances to at least three non-collinear reference nodes are needed.

The effect of mistake in the positions of reference nodes on localization error is clearly obvious, as shown by the lateration equations, and it leads to inaccurate distance and localization geometry estimations. Whether or not range error is present, distance estimations will be off if the reference nodes' positions utilized in the computation are inaccurate. Furthermore, the localization geometry is impacted by an inaccuracy in the reference nodes' positions since the locations utilized in the location computation are distorted. As a result, DOP and positioning precision and accuracy vary. When illustrated in [8], location accuracy suffers as uncertainty grows in the positions of the reference nodes. An effort to minimize the inaccuracy in the position of GNSS-based stationary reference nodes was the subject of one publication [14].

C. Factors Affecting Localization Accuracy

Some of the most important aspects that influence the precision (or accuracy) of node localization based on RSSI are discussed here. The vast majority of them are applicable to localization techniques that don't require an anchor, such as range-based methods. For instance, the extent of the influence on the localization error is determined by the interaction between the components and the localization method [9, 11]. Distance estimation error and localization geometry are the two primary classes into which these elements fall. Additionally, location precision might be impacted by computational inaccuracy.

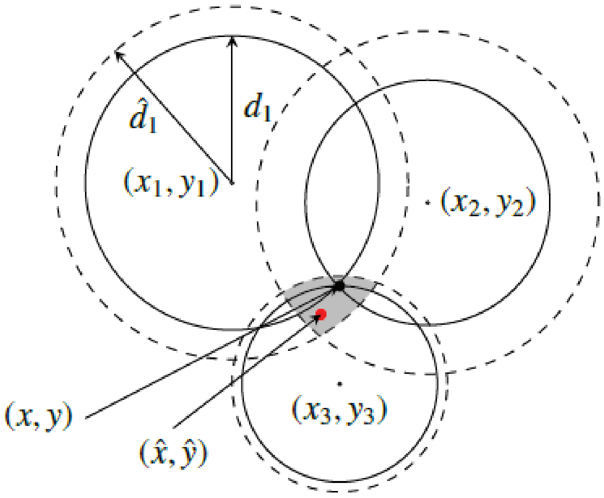

Figure 1. An example of trilateration with accurate and inaccurate distance estimates.

D. Distance Estimation Error

Due to the RSSI's susceptibility to variations in ambient and meteorological conditions, ranging error is likely the most significant and defining element that reduces the accuracy of RSSI-based localization. Looking at the lateration equations also makes evident the impact of distance estimations on location precision. Improving distance estimate and positioning precision requires lowering ranging error [17,18]. It is the emphasis of certain articles [15, 16] to identify the sources of the mistake in RSSI-based ranging and to suggest methods for correcting it. In multihop scenarios, the localization error is affected indirectly by the node degree (connectivity, the average number of neighbours) due to the mistake introduced by the distance estimation process. More measurements may be taken and faster routes can be found to reference nodes if a node's degree (the number of its neighbours) is larger. Increases in the mean number of neighbours typically result in less overall location error [11, 20].

Localization errors are indirectly affected by network topology via distance estimate errors. An anisotropic network (one with gaps or blocks between unknown nodes and reference nodes) introduces mistakes into distance estimates [19].

IV. NETWORK SETUP AND RESULTS

As a means of studying RSSI-based localization and testing the suggested method under different situations, a WSN is set up to gather RSSI data in order to conduct extensive experiments. To gather the empirical data, a network was setup with eight WSN nodes, each of which was outfitted with an Atmel ZigBit 2.4 GHz wireless module (ATZB-24- B0) and an AT86RF230 radio transceiver that complies with IEEE 802.15.4 standards. In addition, there was a database server and a gateway (an Atmel ZigBit 2:4 GHz sink node and a Raspberry Pi 3). (MongoDB). The sensor nodes were installed on mounting racks and affixed to light poles in a parking lot at a height of three metres [18, 20]. Secondary batteries charged by solar panels and intermittent mains electricity provided energy for the nodes (controlled with a timer and a PECU switch). The gateway was a weatherproof box with an Ethernet connection that was installed on the terrace of the university building and supplied by the building's main power supply. As shown in Figure 2, the network infrastructure has been set up.

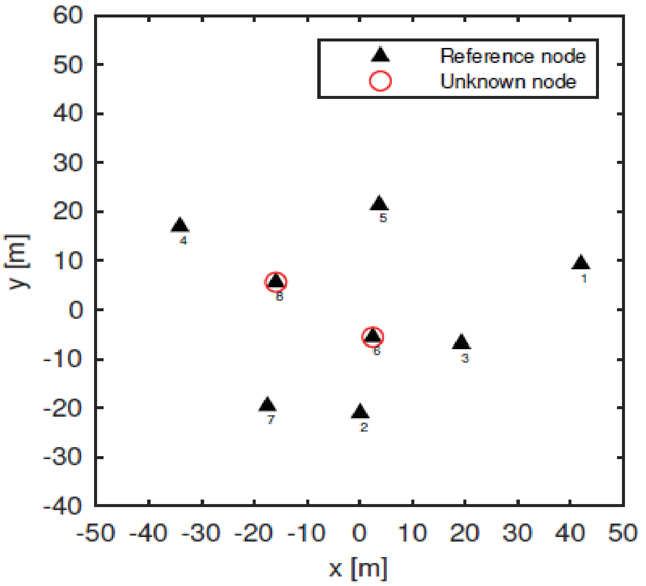

Figure 2. Network setup of the nodes

Laser distance meter (Leica DISTO D8) to measure the distances between nodes in order to conduct research and assessment has been used. Trigonometry was used to calculate the unmeasured distances, whenever it was feasible. With the use of conventional multidimensional scaling, it was able to determine the relative positions of the nodes by analyzing their distances to one another. The configuration matrix is created from a distance matrix using the cmdscale function in MATLAB. As a reference for evaluating the accuracy of the estimations, the relative positions of the nodes were used as the ground truth. The average absolute discrepancy between the observed distances and the distances based on the coordinates was 0.02 m (maximum = 0.06 m) for the reconstruction.

The adaptive RSSI-based ranging algorithm proposes a method for estimating distances between nodes. However, the localization approach presented in this study does not critically depend on the range technique employed. Estimates of the range can be produced using any method that seems reasonable. Each two-way link is assigned a single RSSI value for use in range and localization. At first, one hour's worth of raw RSSI readings were averaged across all channels (n=3 or 4). Second, an average of these RSSI readings over all 16 channels was calculated. Third, the average RSSI values in each direction were used to determine the two-way link's RSSI value.

Localization error Δˆxi for sample *i* is defined as:

$$\Delta\hat{x}_i = \|\hat{\mathbf{x}}_i - \mathbf{x}\| = \sqrt{(\hat{x}_i - x)^2 + (\hat{y}_i - y)^2}, \quad (3)$$

where ˆxi = (ˆxi, ˆyi) and x = (x; y) are the estimated and ground truth locations, respectively. The mean and the standard deviation of localization error, Δˆx and sΔˆx, respectively, are defined as:

$$\overline{\Delta\hat{x}} = \frac{1}{n}\sum_{i=1}^{n}\Delta\hat{x}_i, \quad s_{\Delta\hat{x}} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(\Delta\hat{x}_i - \overline{\Delta\hat{x}})^2}, \quad (4)$$

where *n* is the number of location estimate samples.

Ranging error Δdˆi for sample *i* is defined as:

$$\Delta\hat{d}_i = \hat{d}_i - d, \quad (5)$$

where *dˆi* and *d* are the estimated and the true distances, respectively, as shown in Figure 3.

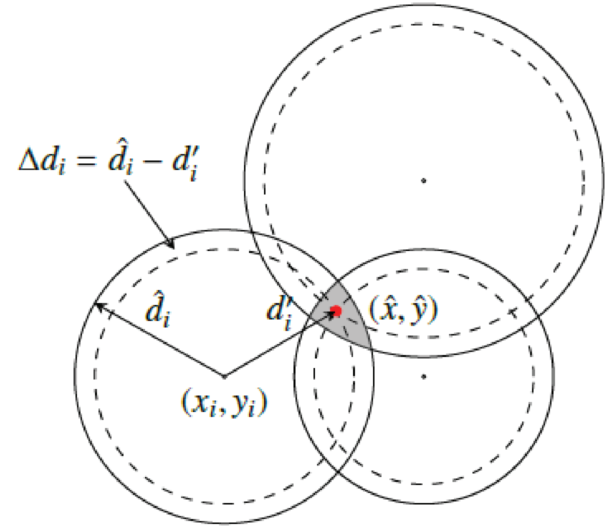

Figure 3. Principle of computing the difference (Δdi) between the distance estimate (dˆi) and the distance based on the location estimate (d0i).

The unknown node must be inside the reference nodes' convex hull. The argument as to whether or not the node is inside or outside the convex hull is questionable because all are position estimations, which are likely to go wrong. Furthermore, the reference nodes' appropriateness cannot be described just by convexity. In some cases, an outlying node may have a higher-quality localization geometry than an in-convex-hull node.

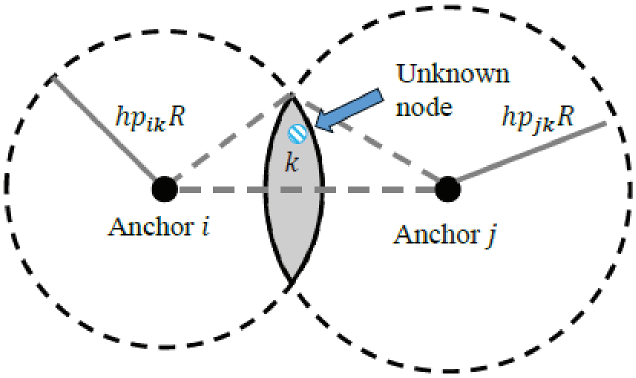

Figure 4. Optimal anchor pair

Figure 4 shows the optimal anchor pair. The optimal anchor pairs provide a clear geometrical relationship, which can be utilized in distance estimation. The reliable anchor pairs provide relatively strong restriction on the potential area of the unknown node. The variance of the location estimation of unknown node is small. Hence, the expected distance between the anchor and the unknown node is considered to be accurate distance estimation.

Figure 5 and Figure 6 show the average location errors for each reference node pair calculated using the ARBL method across the 6 week measurement periods. Based on the data shown in the picture, it is clear that the location inaccuracy varies significantly among different reference nodes. The amount of the difference is notable, particularly on node 8. As the number of reference nodes increases, the average location error decreases (the mean and the standard deviation). However, there are a few excellent permutations that may be obtained with just three auxiliary nodes. The ARBL method appears to locate the appropriate combinations with a high probability and generates fairly accurate and precise position estimations, despite the huge difference between the combinations. The ARBL method has a lower positioning error for node 6 than any individual combination. The ARBL technique yielded a placement error for node 8 that was quite near to the optimal combination.

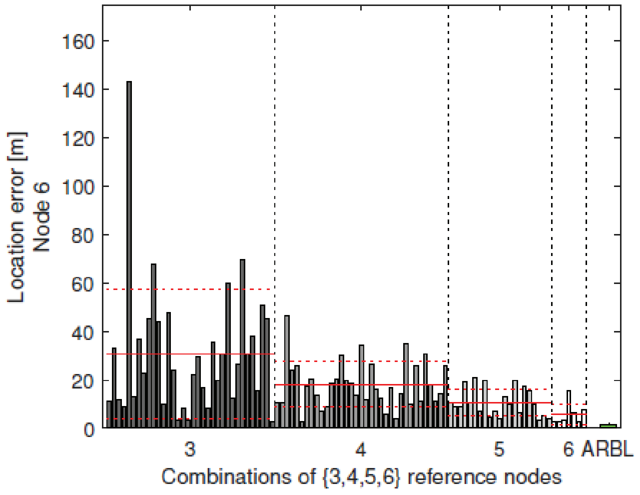

Figure 5. Location Error of the combinations for each number of reference nodes (node 6)

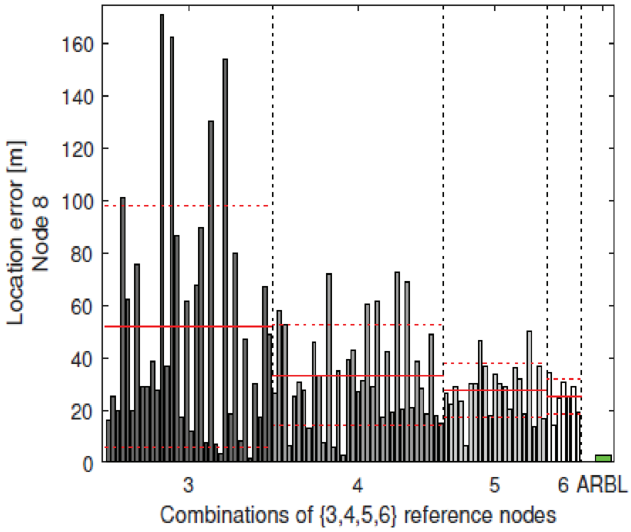

Figure 6. Location Error of the combinations for each number of reference nodes (node 8)

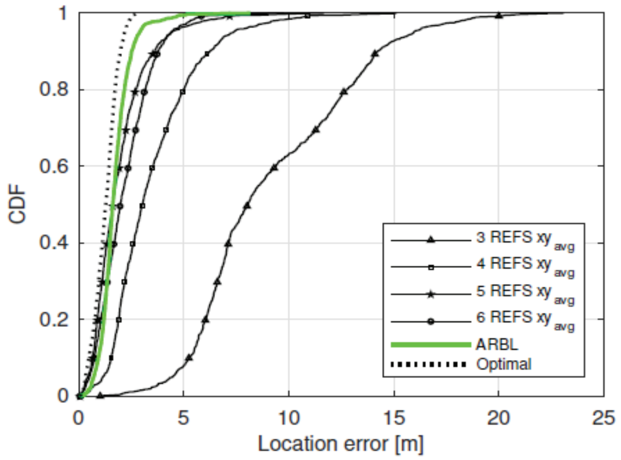

Figure 7. Cumulative distribution function (CDF) of the location error for (a) node 6

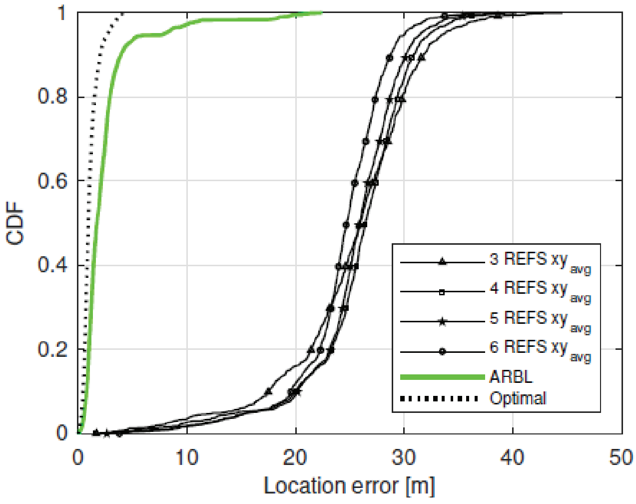

Figure 8. Cumulative distribution function (CDF) of the location error for (a) node 8

The cumulative distribution function (CDF) of the location error at nodes 6 and 8 are shown in Figure 7 and Figure 8 Inaccurate distance estimates can be obtained using RSSI-based ranging, as is well-known. This experiment showed that, depending on the reference nodes utilized, RSSI-based ranging can cause significant location mistakes when used in conjunction with lateration, which is susceptible to erroneous distance estimations and localization geometry. It is difficult to make reliable location predictions when the surrounding environment and weather are constantly changing. As a workaround, a reference node-selection-based ARBL method has been used. To estimate the position of a node that is unknown, the method seeks for the optimal combinations of reference nodes for that node at a particular time and place. It appears that the ARBL method has a much less location error than the average of the individual combinations. The algorithm is particularly effective at adjusting to new parameters and determining the optimal reference node combinations for a given scenario. In practice, the ARBL algorithm may run on nodes in a WSN that have limited processing, memory, and communication resources. Since it is reasonable to assume that there are at least four or five reference nodes in most WSNs, the ARBL method is feasible since there are enough possible combinations.

V. CONCLUSIONS

In this research, strategies to enhance the precision of range-based localization for inexpensive WSN nodes operating in a wide range of environmental settings have been addressed. First, experimental RSSI measurement data have been studied to determine the impact of range error and localization geometry on localization error. To solve this problem, a reference node selection based ARBL method that uses a number of different permutations of reference nodes to determine which is the most accurate in calculating the desired end position has been presented. The evaluations reveal that the localization error was significantly decreased by using the proposed approach. These encouraging results suggest that utilizing appropriate methodologies and data, respectable location accuracy may be achieved using range-based localization for low-cost, resource-constrained WSN nodes. The results also add novel perspectives to the study of anchor- and range-based localization.

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