# Positioning Strategy for Wireless Sensor Networks

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*Abstract:* - Many applications in wireless sensor networks require sensor nodes to obtain their positions. In this paper, we focus on the design of a hierarchical localization strategy. The advantage of these methods is that they can reduce cost in the considerable extra hardware common in sensor networks. Through simulation experiment, the evidence confirmed the proposed methods can effectively improve localization accuracy and enhance the localization rate of estimated nodes.

*Key-Words:* - Wireless Sensor Network; TOA; TDOA; Global Positioning System; Wireless Ad Hoc network

## 1 Introduction

During recent years, the Wireless Sensor Network (WSN) has become a hot topic and has been broadly discussed and studied. In the WSN universe, Location-Aware deserves our special attention. Location information of transducers has a positive impact on deployment of sensor network, coverage area, routing, location service and track of target [2], [6].

To date, in location positioning system research, the Global Positioning System (GPS) [3] and base station wireless positioning are the methods that have been discussed the most. Currently, GPS is the most accurate technology. We consider the situation that GPS is not available, such as indoor or can not receive satellite signals by the shadowing effect. Another factor, if all the sensors are equipped with GPS receiver, the cost of sensor network will become a big burden and reduce the lifetime of network. We considered that uses the wireless positioning technology substitute for GPS.

Wireless positioning can roughly be divided into Range-based and Range-free types [4]. Between these two types, Range-based gives more accurate data, and we will both discuss and use the type of Wireless positioning is this paper. Due to the congenital limitations of WSN (low computation capability, limited resources, short radius of transmission, etc.), the transmission distance of most sensors is within one hundred meters. Thus, more base stations are needed to find the location of all nodes, which increase manufacturing costs. In this paper, we put forward a hierarchical localization strategy, using few nodes equipped with GPS or nodes whose locations are known to firstly lay at the surroundings of the sensor network, making other nodes with unknown locations gather enough information to accomplish positioning, while nodes not receiving enough information make use of nodes whose positioning is done to accomplish the hierarchical positioning.

The outline of this paper is: Section 2 discusses related research; Section 3 depicts the method of blending scalar positioning and discusses how analyze and correct measurement error; Section 4 gives the experiment results; Section 5 is the conclusion.

## 2 Related Works

TOA and TDOA methods are based on time measurements. TOA measures the propagation delay ($A_t$) of electromagnetic waves between nodes (A and B) and obtains the distance ($\tilde{d}_{\overline{AB}}$) between two nodes by multiplying the speed of electromagnetic wave ($C$). The formula is:

$$\tilde{d}_{\overline{AB}} = A_t * C \tag{1}$$

TDOA is based on the TOA, which uses timing to measure the corresponding relative arrival time from one to another node. TDOA needs at least three position-known nodes as its bases. The equations for the aforementioned are shown, respectively, as:

$$\begin{cases} \Delta\tilde{D}_{toAC} = (T_1 - T_3) \times C = \tilde{d}_{\overline{DA}} - \tilde{d}_{\overline{DC}} \\ \Delta\tilde{D}_{toAB} = (T_1 - T_2) \times C = \tilde{d}_{\overline{DA}} - \tilde{d}_{\overline{DB}} \end{cases} \tag{2}$$

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$\Delta\tilde{D}_{toAC}$ is the difference of *DA* and *DC*, $\Delta\tilde{D}_{toAB}$ is the difference of *DA* and *DB*. Suppose there are three known coordinate nodes around node *D*: *A*($x_a$,$y_a$), *B*($x_b$,$y_b$), and *C*($x_c$,$y_c$). The Euclid Distance Formula can be used to define the following formula:

$$\begin{cases}(x-x_a)^2+(y-y_a)^2=(\tilde{d}_{\overline{DA}})^2\\(x-x_b)^2+(y-y_b)^2=(\tilde{d}_{\overline{DB}})^2\\(x-x_c)^2+(y-y_c)^2=(\tilde{d}_{\overline{DC}})^2\end{cases} \quad (3)$$

Substitute (3) into (2): The relative coordinate of an unknown node can be gained. Both the above methods, TOA and TDOA, do not need too much extra equipment, which conforms to the requirement of low cost of sensor network._TDOA does not need exact time synchronization and its accuracy is higher than that of TOA.

# 3 Hierarchical Localization Strategy

To improve positioning of sensor nodes and lower costs, based on TDOA measurement, we propose a hierarchical positioning strategy. Our strategy focused on two elements: First, estimation error's correction. Second, position computing and hierarchical localization. We use simple statistics for the correction of error of distance measurement in order to reduce the consumption of energy and to improve the precision of positioning. When nodes are deployed in real environments, diverse noises will delay signal transmission. The more noises exist, the larger the error in the estimated location will be. Thus, the exactness of propagation delay measured between two nodes is extremely important. Main causes of time delay of packets transmission is multi-path delay and non-line of sight (NLOS) [1], [5]. Multicasting of wireless network causes multi-path delay. Packets perhaps pass through many paths to reach a source node or a destination node. To avoid accumulation of error, we only take 1-hop relaying into account. To improve the precision of node positioning, we must cut back on the possible distance error.

## 3.1 Estimation Error Correction

Time delay caused by NLOS is the most difficult to overcome. Up to now, there has been no effective way to eliminate this error. NLOS is a kind of time delay due to reflection and diffraction when a wave meets an obstacle. This causes a packet's propagation delay, which affects the precision of distance measurement. The consequence is the increase of error due to the longer transmission time of a packet. In order to improve the measurement of survey distance, we designed a new distance formula:

$$R = d + e \quad (4)$$

*R* is the survey distance between two nodes, *d* is the true distance, *e* is the error variable of measurement. We use multiple times measurement and the concept of standard deviation to obtain a relatively reasonable error term. Suppose we measure *k* times of distance between two nodes, and we express *k*-times measured distance by one-dimensioned vector (*L*).

$$L = [R_1, R_2, ...., R_k]_{1\times k}$$

We analyzed the possible error occurring in the measuring process and, furthermore, subtracting the error term from the survey distance. Use vector *L* to calculate the standard deviation of survey distance:

$$\sigma = \sqrt{\frac{1}{k}\times\sum_{i=1}^{k}\left\| R_i - \overline{R}\right\|^2} = \sqrt{\frac{1}{k}\times\sum_{i=1}^{k}\left\| e_i - \bar{e}\right\|^2} \quad (5)$$

We can get a pure error value from formula (5). Since the survey distance is bigger than the true distance, we expect to get a value extremely close to the true distance. We thus use the minimum survey distance to subtract standard deviation. The modified formula is,

$$d' = R_{\min} - \sigma \quad (6)$$

*d'* in formula (6) is the new survey distance between two nodes.

## 3.2 Position Computing

When an unknown node modifies the survey distance, substitute the modified distance value into formula (2) to estimate the best location of the unknown node. Suppose unknown node (x, y) has got enough location information (x1 , y1), (x2 , y2), (x3 , y3), and the measurement distances after modification are $d_1'$, $d_2'$, $d_3'$. The new formula is:

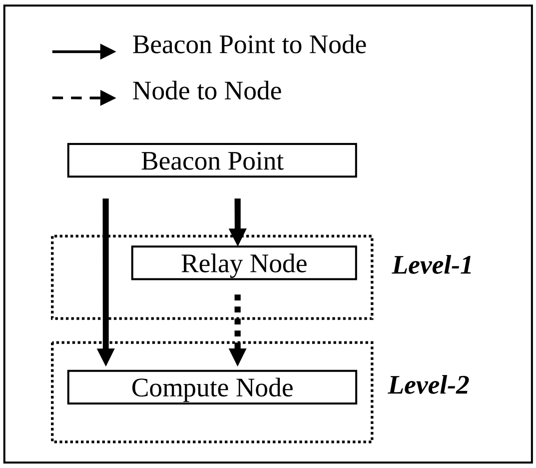


Fig. 1 Hierarchical Localization methods

Given $\Delta L_{12} = (d_1^{'})^2 - (d_2^{'})^2$ , $\Delta L_{13} = (d_1^{'})^2 - (d_3^{'})^2$

$$\begin{cases} (x_2 - x_1)x + (y_2 - y_1)y \\ = \frac{1}{2} \times ((\Delta L_{12} + x_2^2 - x_1^2 + y_2^2 - y_1^2) \\ \\ (x_3 - x_1)x + (y_3 - y_1)y \\ = \frac{1}{2} \times (\Delta L_{13} + x_3^2 - x_1^2 + y_3^2 - y_1^2) \end{cases} \quad (7)$$

We solve *x* and *y* by matrix equation as follows:
Given,

$$A = \begin{bmatrix} (x_2 - x_1) & (y_2 - y_1) \\ (x_3 - x_1) & (y_3 - y_1) \end{bmatrix} \quad (8)$$

$$x = [x \quad y]^T \quad (9)$$

$$b = \begin{bmatrix} \frac{1}{2} \times (\Delta L_{12} + x_2^2 - x_1^2 + y_2^2 - y_1^2) \\ \frac{1}{2} \times (\Delta L_{13} + x_3^2 - x_1^2 + y_3^2 - y_1^2) \end{bmatrix} \quad (10)$$

To solve equation *Ax=b*, we can get the relative coordinate value (*x, y*) of the unknown node.

### 3.3 Hierarchical Localization

All nodes are divided into three categories in our proposed method, as shown in Fig.1. The first category is beacon points (BPs) whose relative locations are known. We scatter BPs throughout the whole network. The second category is relay nodes (RNs) which can obtain information from at least three different BPs. Both BPs and RNs are defined in the Level-1. The third is compute nodes (CNs) which have yet to be positioned. These nodes cannot gather information from at least three different BPs. If they cannot obtain sufficient information from BPs then they retain what they have obtained and try to collect the information they need from RNs. If CNs are unable to collect any information from BPs, then they need to collect all necessary information from surrounding RNs. The level of CNs is Level-2 by definition. All the nodes belonging to Level-1 will be located as top priority throughout the whole positioning process.

## 4 Simulation and Results

In order to prove that the method we put forward cannot only reduce cost but also offer more reliable location information on a sensor node, we used a simulation to conduct an experiment. Furthermore we used simulation to compare our methods and TDOA and show the differing simulation results, including the difference between estimated location and the true location of an unknown node and the modification of survey distance error. The simulator is developed by MATLAB. The system parameters are as follows: the network size is 100×100 square meters ($m^2$), the relative location of *BPs* are (0, 50), (0, 0), (50, 50), (50, 0), (50, 100), (100, 50), (0, 100), (100, 0) and (100, 100), the effective communication range is 50 meters, the number of sensor nodes is 200, randomly distributed in the network, the distances between all the nodes are different and the occurrences of distance measurement are 20. The noise parameter is designed to be a random error between 0.2 and 1 in addition to true distance between two nodes.

### 4.1 Simulation Results

First, we ran the modification experiments for the measured distance between two nodes to ensure that the measured distance after modification can approximate more to the true distance that the distance without modification does. The simulation ran 200 times under minimum measured distance was chosen as the comparison baseline. The experiment results for measured distance are shown in Fig. 2. Red lines represent the original distance difference between minimum measured distance and actual distance. Blue lines represent the difference of the distance measurement with error correction from the

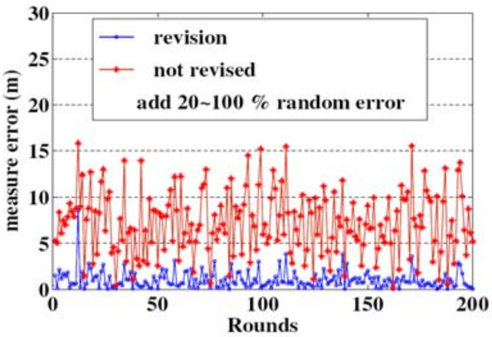

Fig.2. Comparison of distance error for higher noise.

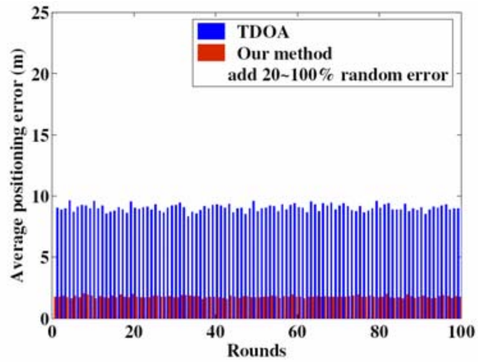

Fig. 5. Average positioning error of level-1 nodes for higher noise.

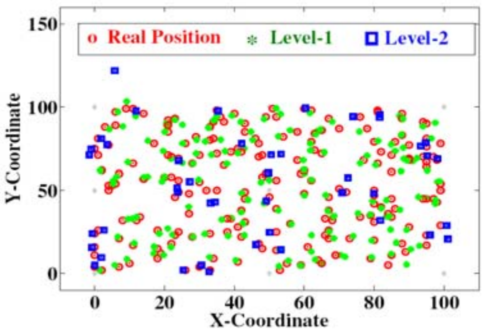

Fig. 3. Estimated and real position of nodes.

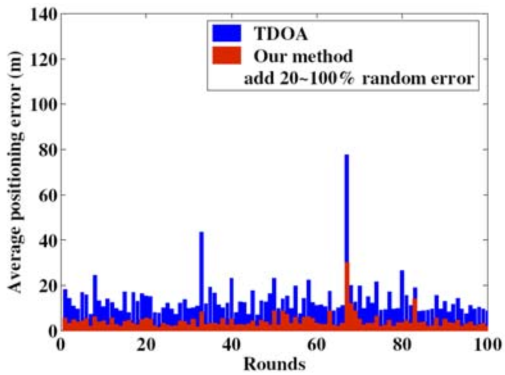

Fig. 6. Average positioning error of level-2 nodes for higher noise.

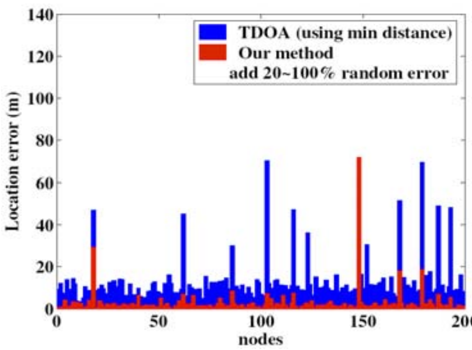

Fig. 4. Location error of each node for higher noise.

actual distance. In Fig.2 after error modification of distance measurement the average error of 200 rounds is 0.95981 (m), the comparison group being 7.006523 (m). The experiment shows that our method is closer to the actual distance. The actual position and estimated position of nodes are shown in Fig. 3. Red circles represent the actual position of nodes. Green asterisks, belonging to level-1, represent the nodes which are estimated from at least three *BPs*. Blue squares represent the estimated locations of nodes, belonging to level-2. In the following simulation process, a comparison is made between our method and TDOA. The result is shown in Fig. 4, in which we can find obvious differences between the two methods. Next, the location estimation of the 200 unknown nodes in single round is compared to TDOA. With our method, the largest location error is 71.9221 (m), the smallest 0.1384 (m) and the average 2.6006 (m). With TDOA, the largest is 70.3803 (m), the smallest 0.2260 (m) and the average is 11.0588 (m). Our method obviously obtains a more precise location. We further ran the experiment 100 times and recorded every positioning biases of nodes in the diverse levels. Then the average positioning biases in all levels for every rounds were showed in the Fig. 5 and Fig.6. Fig. 5 and Fig. 6 show that our method outperforms TDOA. In level-2, the small included the angle between RN and BP induced ill geometry shape and bigger estimated error [1].

## 5 Conclusion

In this paper, we propose a low cost and high positioning rate hierarchical localization strategy for sensor networks. Our strategy, based on TDOA, a few BPs and positioned RNs, is used to assist the localization of a whole network of nodes. The advantage of this method is that it can reduce the considerable cost and energy consumption by reducing extra positioning hardware. In order to enhance the precision of positioning, simple statistics are used to improve the error of survey distance between two nodes. The simulation results show that our method outperforms TDOA.

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