Hierarchical Localization Strategy for Wireless Sensor Networks

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Abstract: - Wireless Sensor Network (WSN) is an emerging network technology. Among the varying research focused upon WSN, Location-Aware is a topic worthy of study. We are putting forward a hierarchical localization strategy. By using wireless localization and a few GPS, sensor networks can be more economical and localization can be more accurate. Our strategy includes two aspects: first, getting a relatively good measurement error value from the survey distance between two nodes by way of simple statistics and then correcting the survey distance to get a more accurate node location; second, using relaying nodes to fulfill hierarchical positioning 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; GPS; Wireless Ad Hoc network; AOA; TOA; TDOA

1 Introduction

During recent years, the Wireless Sensor Network (WSN) has become a hot topic and has been broadly discussed and studied. This emerging network technology composes hundreds of thousands of sensors and a wireless ad hoc network. Each sensor not only has the function of detecting its surroundings, but also has several terrific features, such as small size, low cost and wireless communication. In the WSN universe, Location-Aware deserves our special attention. Location information of transducers has a positive impact on deployment of sensor network [17], coverage area, routing, location service and track of target [7], [9], [13], [22].

To date, in location positioning system research, the Global Positioning System (GPS) [3], [8] and base-station wireless positioning [9], [18-19] are the methods that have been discussed the most. Currently, GPS is the most accurate technology. But there are several disadvantages in using GPS: First, a GPS chip must be installed at the receiving end, which consumes extra electric power in the sensor. If all sensors are equipped with GPS receivers, the cost of sensor net-works will become a big burden and reduce network lifetimes. Second, GPS can perform the positioning function only when it simultaneously receives at least four satellite signals. GPS does not work well if it is affected by the shielding effect and buildings. Therefore, GPS cannot be used in all circumstances. Wireless positioning should be used in cases where GPS cannot be used [20].

Wireless positioning can roughly be divided into Range-based and Range-free types [11]. 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

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analyze and correct measurement error; Section 4 gives the experiment results; Section 5 is the conclusion.

2 Related Works

In recent years, some WSN positioning technologies have been proposed, including Received Signal Strength (RSS) [6], [12], Angle of Arrival (AOA) [5], [7], Time of Arrival (TOA) and Time Difference of Arrival (TDOA)[2], [4], [10], [14].

RRS uses the signal strength received to measure the distance between targets. However, it is easily affected by noises, such as shielding effect and multi-path fading, which cause relatively large error in distance measurement. AOA uses hardware like sector antennae or an antenna array to help judge the angle of signal reception between a base station and its nodes. However, this method can only give accurate measuring outcomes under the existence of line of sight (LOS) between transmitter and receiver. 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. Geometrically, two lines are considered as two equations. The intersection of these two equations is the position of the unknown node. The equations for the aforementioned are shown, respectively, as:

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

$\Delta\tilde{D}_{toAC}$ 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:

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

Substitute (3) into (2): The relative coordinate of an unknown node can be gained. This method is not like TOA, which needs exact time synchronization. The advantage of TDOA is that using relative arrival delay to replace absolute arrival delay can eradicate the difficulty of time synchronization and error caused by measurement.

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. There are obstacles (for example, buildings) and non-line of sight (NLOS) [15-16], [21], for example, the signal reflection and diffraction) disturbances in realistic environment, which may reduce the precision of the whole positioning system and causes relatively large error. Moreover, those noises would cause large error and reduce the precision of positioning when measuring distance using AOA and RSS.

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 NLOS and multi-path delay [1], [15], [16]. To improve the precision of node positioning, we must cut back on the possible distance error.

3.1 Estimation Error Correction

Multicasting of wireless network causes multi-path delay. Packets perhaps pass through many paths to reach a source node or a destination node. Hoping to overcome this kind of time delay, we add a parameter, called Hop_Count, into the packet to record how many times the packet has been relayed. To avoid accumulation of error, we only take 1-hop relaying into account. 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:

$$R = d + e \tag{4}$$

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).

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

We analyzed the possible error occurring in the measuring process and, furthermore, subtracting the error term from the survey distance. Below is the formula we used to measure the error:

$$\overline{R} = \frac{1}{k} \times \sum_{i=1}^{k} R_i = \frac{1}{k} \times (\sum_{i=1}^{k} d + \sum_{i=1}^{k} e_i) \tag{5}$$

The above formula can be converted to:

$$\overline{R} = d + \overline{e} \tag{6}$$

Use formula (6) to calculate the standard deviation of survey distance:

$$\begin{aligned} \sigma &= \sqrt{\frac{1}{k} \times \sum_{i=1}^{k} \left\| R_i - \overline{R} \right\|^2} \\ &= \sqrt{\frac{1}{k} \times \sum_{i=1}^{k} \left\| e_i - \overline{e} \right\|^2} \end{aligned} \tag{7}$$

We can get a pure error value from formula (7). We cannot get an absolutely true error value due to limited condition of measurement. Here we take σ as the relatively good error value at NLOS's transmission. Below is the formula:

$$\begin{cases} NLOS, & \sigma \neq 0,\ e = \sigma \\ LOS, & \sigma = 0,\ e = 0 \end{cases} \tag{8}$$

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,

$$d' = R_{\min} - \sigma \tag{9}$$

d' in formula (9) 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:

$$\begin{cases} ((x-x_1)^2 + (y-y_1)^2) \\ -((x-x_2)^2 + (y-y_2)^2) = (d_1^{'})^2 - (d_2^{'})^2 \\ \\ ((x-x_1)^2 + (y-y_1)^2) \\ -((x-x_3)^2 + (y-y_3)^2) = (d_1^{'})^2 - (d_3^{'})^2 \end{cases} \tag{10}$$

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

Change formula (10) to,

$$\begin{cases} (x_2 - x_1)x + (y_2 - y_1)y \\ = \frac{1}{2} \times ((\Delta L_{12} + x_2^2 - x_1^2 + y_2^2 - y_1^2) \\ \\ (x_3 - x_1)x + (y_3 - y_1)y \\ = \frac{1}{2} \times (\Delta L_{13} + x_3^2 - x_1^2 + y_3^2 - y_1^2) \end{cases} \tag{11}$$

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

$$A = \begin{bmatrix} (x_2 - x_1) & (y_2 - y_1) \\ (x_3 - x_1) & (y_3 - y_1) \end{bmatrix} \tag{12}$$

$$x = [x \quad y]^T \tag{13}$$

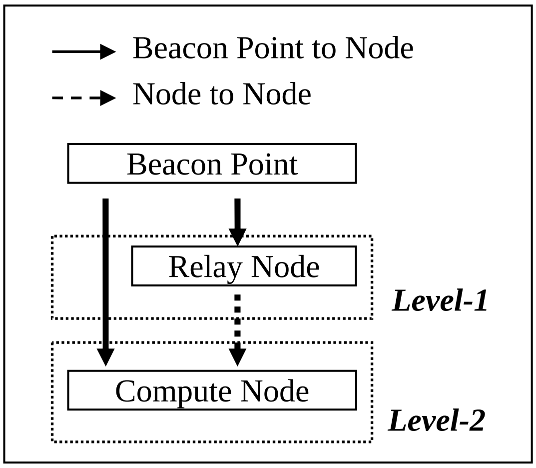

Fig. 1 Hierarchical Localization methods

$$b = \begin{bmatrix} \frac{1}{2} \times (\Delta L_{12} + x_2^2 - x_1^2 + y_2^2 - y_1^2) \\ \frac{1}{2} \times (\Delta L_{13} + x_3^2 - x_1^2 + y_3^2 - y_1^2) \end{bmatrix} \quad (14)$$

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. We simulated how a survey distance error is modified and the node positioning is done. 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.

4.1 System parameters of simulation

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. In the experiment, we set the noise parameter as follows: one is in a larger scale of noise, adding a random error between 0.2 to 1 to true distance between two nodes; the other is in a smaller scale of noise, adding a random error between 0.05 to 0.1 to true distance.

4.2 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 different noise conditions and the minimum distance was chosen as the comparison baseline. The experiment results for measured distance are shown in Fig. 2 and Fig. 3. Red lines represent the original distance difference between minimum distance and actual distance. Blue lines represent the difference of the distance measurement with error correction from the actual distance. In Fig.2 where the scale of noises is bigger, after error modification of distance measurement the average error of 200 rounds is 0.95981 (m), the comparison group being 7.006523 (m). In Fig. 3 where the scale of noises is smaller, after error modification of distance measurement the average error of 200 rounds is 1.186104 (m), and that of the comparison group is 1.654109 (m). The experiment shows that the measured distance between two nodes is closer to the actual distance. Especially in surroundings of more noise, a more accurate survey distance can be gained. The actual position and estimated position

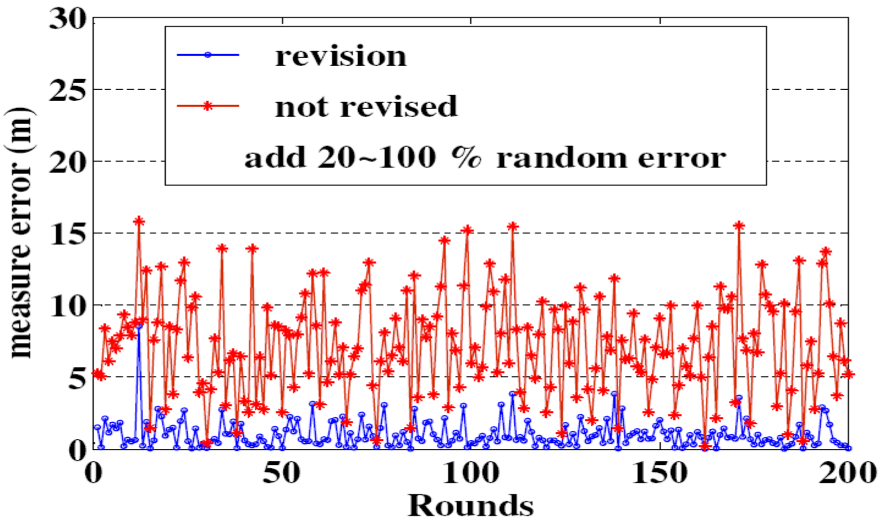

Fig.2. The revision and has not revised error's comparison.

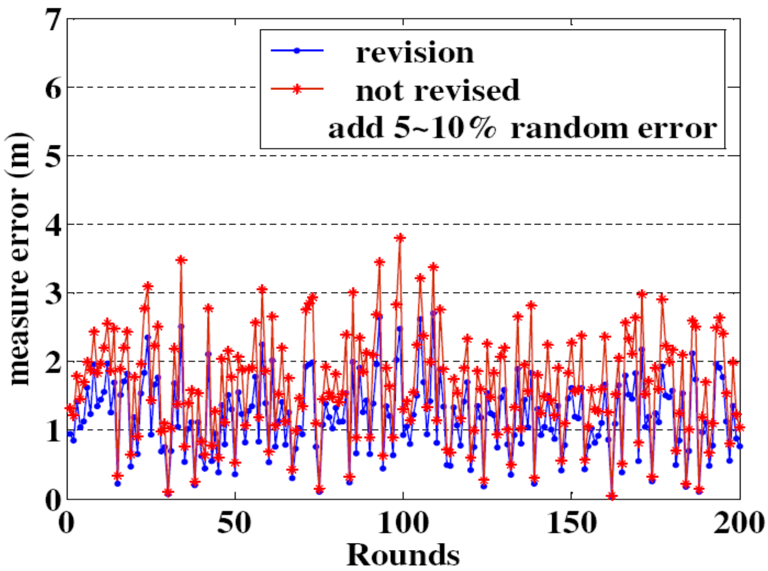

Fig.3. Comparison of distance error for lower noise.

of nodes are shown in Fig. 4. 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 for larger scales of noise. The result is shown in Fig. 5, 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

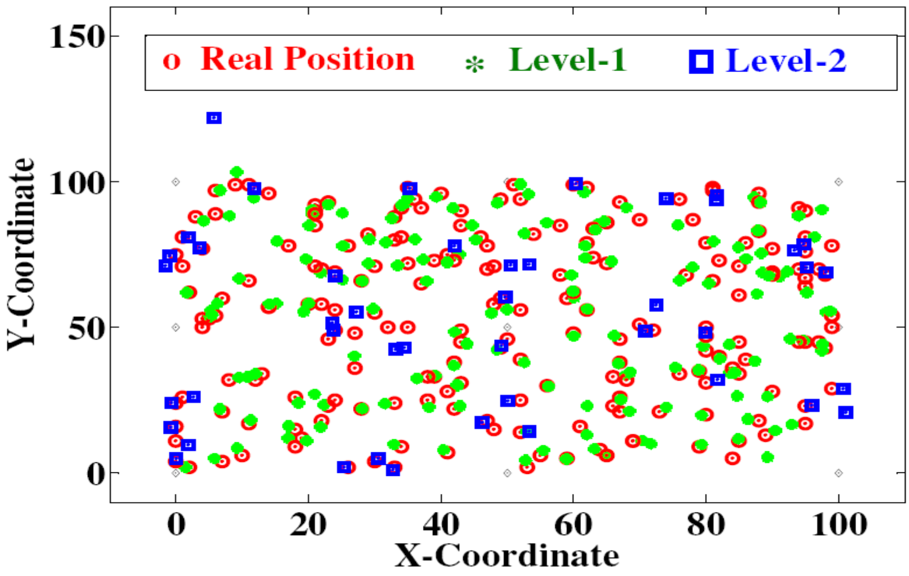

Fig.4. Estimated and real position of nodes.

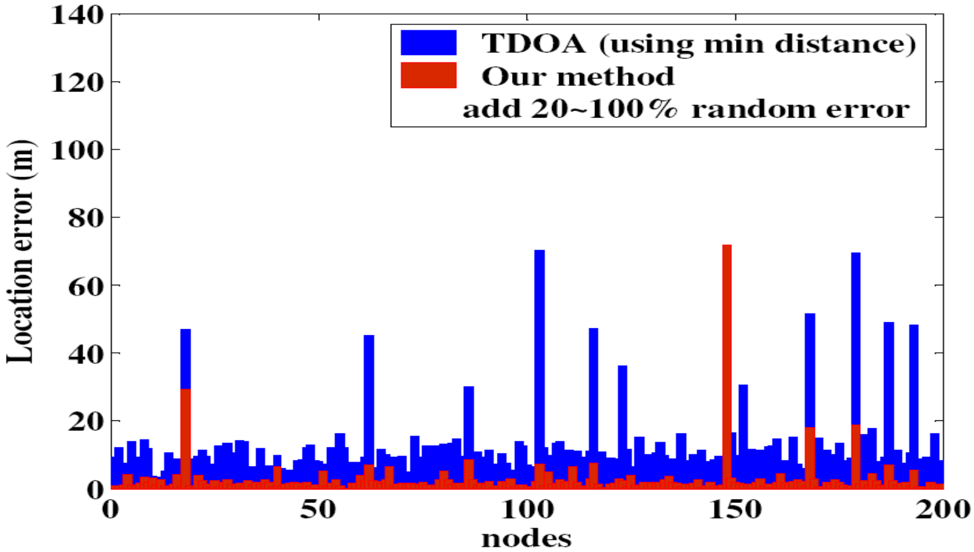

Fig.5. Location error of each node for higher noise.

method obviously obtains a more precise location. To further prove that better results can be achieved with our method, simulation was done 100 times in two different surroundings and the estimations were averaged for analysis. First, a simulation was undertaken 100 times under a larger scale of noise, and the average estimation errors of nodes belonging to Level-1 are shown in Fig. 6. The average

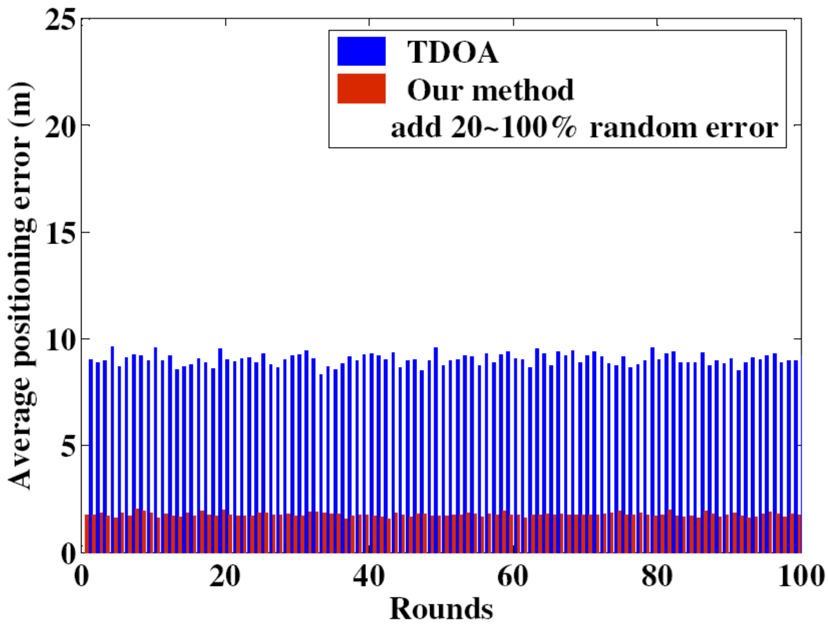

Fig.6. Average positioning error of level-1 nodes for higher noise.

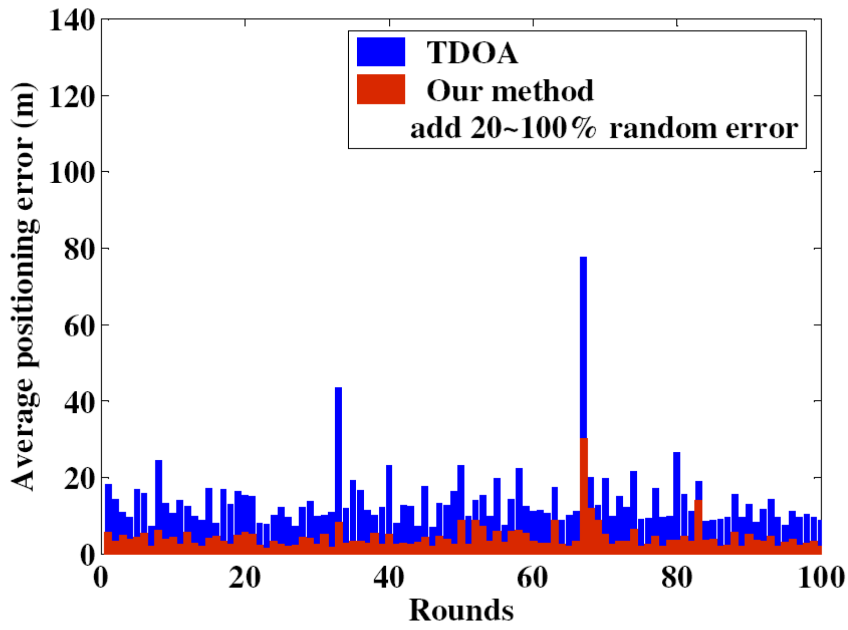

Fig.7. Average positioning error of level-2 nodes for higher noise.

estimation errors of nodes belonging to Level-2 are shown in Fig. 7. Fig. 6 and Fig. 7 show that our method outperforms TDOA. The simulation result of less noise is shown in Fig. 8. The effects are quite close, but our method is still better than TDOA. In level-2, the small included the angle between RN

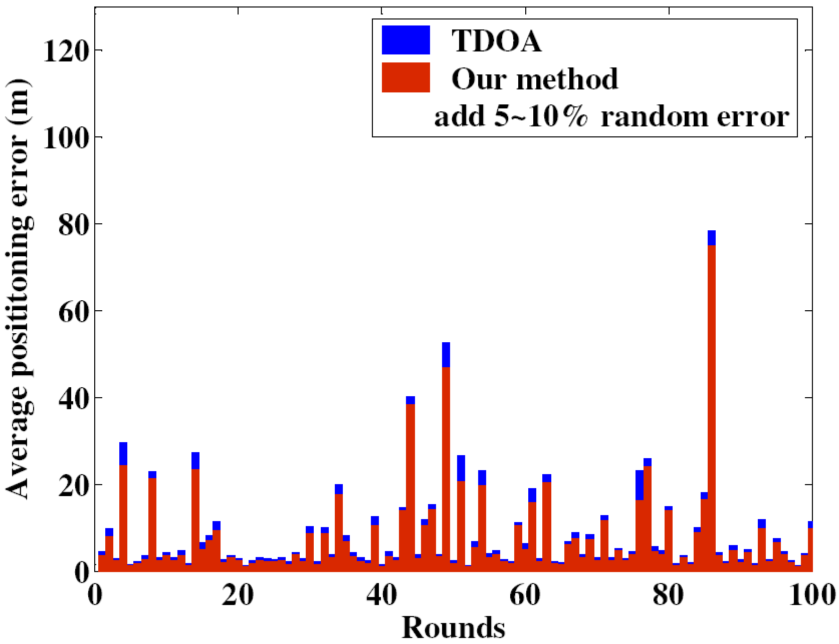

Fig.8. Average positioning error of level-2 nodes for lower noise.

and BP induced ill geometry shape and bigger estimated error [1], [16].There is a potential problem in the level 2. If the relative locations of RNs and CN form an ill geometry shape might cause a bigger estimated error [1], [16]. In the level 2, CN and nearby three RNs may not form the shape showed in the 9 (a), in which three circles drawn from the radiuses of distance from each RN to CN will overlap. True CN is likely to locate in this overlapped area. If the relative locations of RNs and CN are formed as 9(b), 9(c), and 9(d), the error will still exist even the measured distance is modified.
The estimated position will seriously deviate through the aggregate errors.

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.

Acknowledgments

This work was supported by the National Science Council of the Republic of China under Grant NSC96- 2218-E-324-003.

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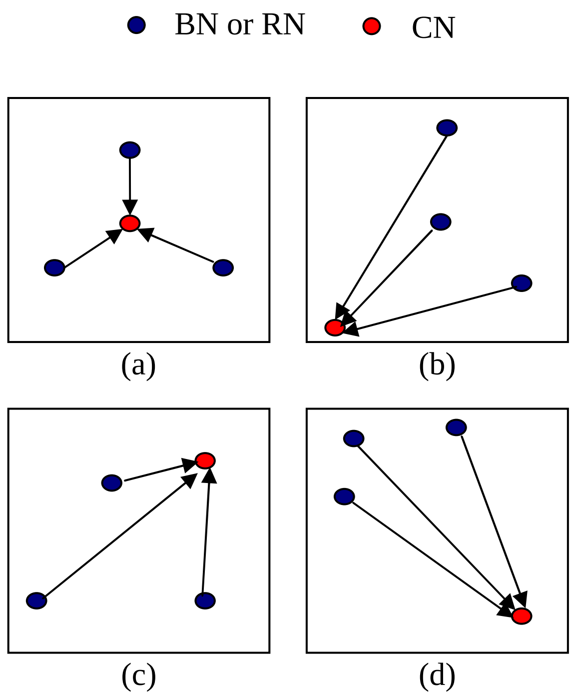

Fig. 9 The distribution of CN and RNs.

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