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# A New Refinement Method for Mirror Error in WSN Localization

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Abstract. *To improve the performance of ranging algorithm in localization accuracy, RMMS (a new refinement method for mirror error based on semi-circle model) algorithm in wireless sensor networks is proposed in this paper. Firstly, we present semi-circle model to compute error nodes' minimum residence area. Secondly, we present determination method for error nodes' minimum error position. Finally, we use MatLab version 7.0 to simulate its performance, simulation result shows that the algorithm can obtain a better position accuracy and fault tolerance in large scale network. And it can weaken the mirror error effectively.*
**Keywords:** Refinement method, Mirror error, WSN, Determination method.

1. **Introduction.** With the rapid development of wireless sensor network, the field application is expanding, for instance, military target tracking, navigation, forest fire prevention and precision agriculture [1, 6]. Thus, how to optimize the precision of nodes position is of great significance. In the localization process of wireless sensor network, the error is inevitably brought by surrounding environment, mirror error and the irregular distribution of sensors.

Recently, some science researchers have been focus on these factors and obtained some achievements [7, 10]. Existing localization algorithms for mirror error are focus on weakening this error. For example, Iterative Inflexible Body Merging algorithm (IIBM) [11], Iterative Processing Method Based on Triangular Node Blocks (IP-TNB) [12] and refinement algorithm based on the idea of magnetic pole (RAMP) [13]. IIBM algorithm presents a localization method, which weakens the mirror error based on body merging, but this method exists a deformation owing to using various shapes and increases computational complexity. Thus, in order to solve this problem, Dong presents IP-TNB algorithm. The algorithm uses the stability of triangle node blocks and the whole network connectivity information, but it doesn't have a good fault tolerance and isn't sensitive to range error. In this paper, we aim to weaken the mirror error of nodes localization by presenting a new refinement algorithm.

2. **The Mirror Error Analysis.** For an unknown node, we always employ the trilateration method to compute its position, but when three reference nodes are almost collinear, the position of unknown node can be reflected by a mirror formed from the three reference nodes. The inaccurate position will cause a large localization error.

Fig. 1 shows the sketch map of node mirror error, nodes A, B and C are three reference nodes with known location information respectively, $d_{ap}, d_{bp}$ and $d_{cp}$ are the measured distance between the reference nodes and the unknown nodes respectively. The three reference nodes are approximate to collinear, we draw two circles with the centers A, B and radiuses $d_{ap}$, $d_{bp}$ respectively. Thus, the reality position of the unknown must be one of the two intersection $P$ or $P'$, if we employ the mistake position as the practical coordinate, the localization accuracy of the unknown node will be greatly reduced and the average node's position error will become larger at the same time.

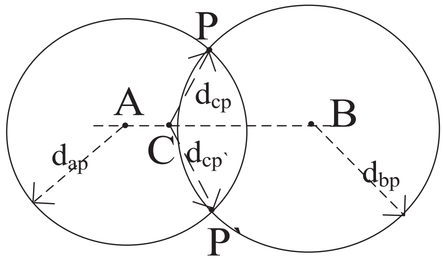



Figure 1. The sketch map of node mirror error.

3. **The Refinement Algorithm Based On The Semi-circle Model And Determination Method.** In this section, we present a new refinement algorithm based on semi-circle shape model to weaken the node mirror error, the algorithm involves two steps: the detection step, which can determine an unknown node with the mirror error, and the refinement step.

In the detection step, we adopt the "hop count-distance contradiction" theory from literature [13], if the distance between unknown node and its neighbor nodes exceeds the largest communication radius or the distance between unknown node and its two-hops node is less than the largest communication radius, then, we deem that the unknown node exists hop count-distance contradiction. In order to describe the error level, a function is presented, that is

$$E_i(k) = \begin{cases} \sum\limits_{j \in (N_i^1 - L_i^1)} \partial_{ij}(k) + \sum\limits_{j \in (N_i^2 - L_i^2)} \beta_{ij}(k), & i \notin (L + A) \\ Nu, & i \in L, i \notin A \\ 0, & i \in A \end{cases} \tag{1}$$

where $L$ represents the set of all lonely nodes, $L_1$ and $L_2$ represent the set of all lonely nodes from one hop neighbor nodes and the set of all lonely nodes from two hops neighbor nodes, respectively. $\partial_{ij}(k)$ and $\beta_{ij}(k)$ represent the weight value, it is defined as:

$$\partial_{ij}(k) = \begin{cases} u, & \|n_i^k - n_j^k\| > R \\ 0, & otherelse \end{cases} \tag{2}$$

$$\beta_{ij}(k) = \begin{cases} u, & \|n_i^k - n_j^k\| \le R \\ 0, & otherelse \end{cases} \tag{3}$$

If the $E_i(k)$ value of one unknown node conform to the following formula:

$$\frac{E_i(k)}{W_i} > 0.25, i \notin L \tag{4}$$

$W_i$ represent all the neighbor nodes of node $i$, then the node will be regarded as "error node" (mirror error exists) and need to refine its position. Otherwise, it will be treated as "valid node".

3.1. **Semi-circle model.** In the refinement step, to weaken the mirror error, semi-circle model employs a new shape that leads to a smaller residence area (the residence area represent a geographical region containing the error node).

As shown in Fig. 2, nodes A, B and C are reference nodes, meanwhile, they are near to collinear. $R$ represents the largest communication radius (assuming all nodes with the same communication radius). Let us now draw three circles centred at A, B, C respectively, with the same radius that equals to $R$. Thus, the error node lies on the intersection of three circles. Note here that a node only can hear from the neighbor nodes with a range of the largest communication radius circle area, and the near-far relationship can be indicated by RSSI value. If the error node lies on the $P$ point, then, its coordinate will be erroneously assumed to be $P'$ point that owes to using the negative information (caused by mirror error).

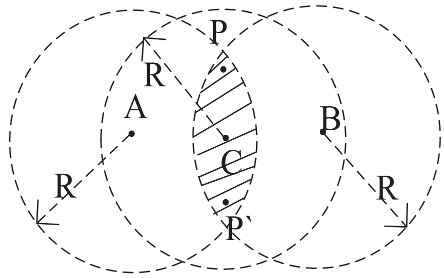
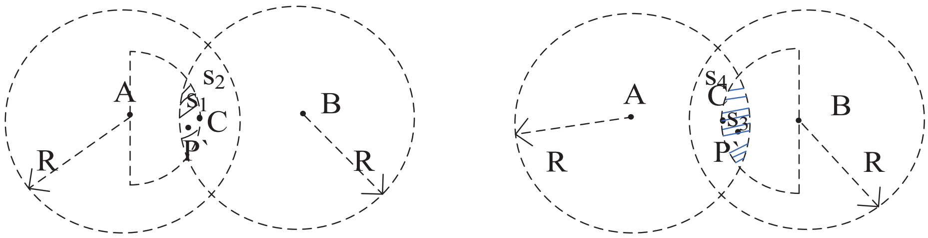



FIGURE 2. The sketch map of error node's residence area.

Let $\boldsymbol{U_v} = \{U_1, U_2, \ldots, U_v\}$ be a set of neighboring "valid nodes" of node P in two dimension euclidean plane. If node C is nearer to node A than node B, then, let us draw a semicircle centred at A with the radius of the euclidean distance $d_{ac}$. Otherwise, the semi-circle centres at B with the radius of the euclidean distance $d_{bc}$, as shown in Fig. 3(a) and (b). First, let us analyse case 1, the intersection between the semi-circle and the Vesica piscis(the error node's largest residence area) can be expressed as $S_1$, and $S_2$, which represent the residual area from the Vesica piscis. Therefore, the error node's position has two situations, (i) $P$ lies in $S_1$; (ii) $P$ lies in $S_2$. To derive the error node $P$ position, we use the RSSI value as indicator. Then, let us consider the following two conditions:

(1) If $P$ is in $S_1$. This condition can be checked by comparing $RSSI_{AC}$ with $RSSI_{PC}$, if only if $RSSI_{AC} > RSSI_{PC}$, then $P$ lies in $S_1$ and the error node's residence area can be narrowed down to $S_1$.
(2) If only if $RSSI_{AC} < RSSI_{PC}$, then $P$ is in $S_2$ and the error node's residence area can be narrowed down to $S_2$.
(3) In case 2, the same test method is employed to check node $P$'s position, if $RSSI_{BC} > RSSI_{PC}$, then $P$ lies in $S_3$. Otherwise, it lies in $S_4$.

Let $\boldsymbol{M_n} = \{M_1, M_2, \ldots, M_n\}$ be a set of valid nodes of reference node C, supposing $\mathbf{SCS}(\boldsymbol{M_n}, C) = \{SCS(M_1, C), SCS(M_2, C), \ldots, SCS(M_n, C)\}$ to be a set of semi-circle shape centred at $\boldsymbol{M_n}$ with the radius of $d_{\boldsymbol{Mn},C}$ (the euclidean distance between valid node $M_n$ and reference node C). For example, as shown in Fig.4, $SCS(M_1, C)$ represents a semi-circle shape centred at $M_1$ with the radius of $d_{M1,C}$, the intersection between




(a) (b)

FIGURE 3. Possible residence areas, (a) case 1: a semi-circle with $d_{ac}$, (b) case 2: a semi-circle with $d_{bc}$.

$SCS(M_1, C)$ and $S_1$ can be expressed as $S_5$, let us employ the above test method to check the error node P's position.

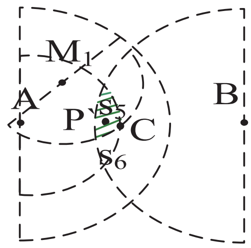



FIGURE 4. The error node's new residence area.

In conclusion, every time we draw a semi-circle, we can obtain a new error node's residence area by comparing $RSSI_{MnC}$ with $RSSI_{PC}$. Eventually we can obtain a minimum error node's residence area, for example, Fig. 5 shows the minimum error node's residence area $S_f$ (the yellow area).

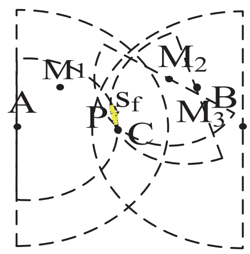



FIGURE 5. The sketch map of minimum error node's residence area $S_f$.

3.2. **Determination method for error nodes' minimum error position.** In order to determine the error node's coordinate, a determination method for error nodes' minimum error position was presented. We draw a set of circles centred $U_v$ (neighboring "valid nodes" of node $P$) with the radius of $d_{Uv,p}$. Then, we can obtain a set of intersection points. At last, we need to choose some points (in the minimum error node's residence area $S_f$) from these intersection points and meanwhile define a minimum error function to check one point (obtain a minimum localization error) out. The minimum error function is defined as follows:

$$f_{\min} = \arg\min \sum_{(i,j)\in w\cap(i\neq j)} (\|n_i - n_j\| - d_{ij})^2 \qquad (5)$$

Where $w$ represents a set of all neighbor nodes, $d_{ij}$ represents measuring distance between node $i$ and node $j$.

The minimum error node's residence area can be an irregular shape by geometrical analysis. Then we employ a method to check the point in the irregular shape, this method can be expressed as follows:

Step 1: Using one undetermined point's vertical axis $k$ draws a straight line, then we can obtain a set of intersection points between the straight line and the irregular shape. The formula is shown as follows:

$$y = k, k \in C \tag{6}$$

Step 2: If the number of intersection points lying on the both sides are odd number, then, we deem that these points are inside the shape, otherwise, it is outside the shape.

3.3. **Algorithm process.** Through the analysis mentioned above, the refinement algorithm can be summarized as follows:

Step 1: Using formula (4) to test whether an unknown node is a error node or not.

Step 2: Determining the largest error node's residence area by drawing circles with the largest communication radius.

Step 3: Using the semi-circle model to narrow the node's residence area. In addition, we draw a set of circles centred $\boldsymbol{U_v}$ with the radius of $d_{Uv,p}$ and choose these intersection points, which is inside the node's minimum residence area.

Step 4: Using the determination method to determine and screen all intersection points to be inside the minimum error node's residence area or not, choosing the minimum localization error point from these points, then, using the point's coordinate to be the error node's final coordinate, and stop.

4. **Experimental Results And Analysis.** MATLAB version 7.0 is used to simulate the proposed algorithm and the performance of RMMS algorithm to RAMP, IP-TNB and IIBM. Localization accuracy in whole network and fault tolerance are two most important performance indexs in evaluating localization schemes, thus, in this paper, we adopt these two indexs. The performance of RMMS algorithm is evaluated based on two radio propagation models: the free space model and the log-distance path loss with shadowing. In this paper, we adopt the log-distance path loss with shadowing, the model is shown as follows:

$$RSSI(d)[dBm] = RSSI(d_0)[dBm] - 10\lambda \lg(\frac{d}{d_0}) + \delta_\tau \tag{7}$$

Where $RSSI(d)$ and $RSSI(d_0)$ represent the received power in $dBm$ at distance $d$ and $d_0$ respectively. $\lambda$ is the path loss exponent, $\delta_\tau$ represents a Gaussian random variable with zero mean and $\delta$ standard deviation.

4.1. **Simulation setup and parameters.** In our experiment, we assume that the largest communication range $R$ is set to 30 meter and 400 nodes are uniformly deployed in a 200m $*$ 200m region, according to preliminary experiments.

4.2. **Simulation result and analysis.** The paper performance is given in this section, assuming that there are $N$ unknown nodes, the real position and the estimated position for the unknown node $i$ are $X_{est}^i, X_{real}^i$ respectively. The average localization error after K times can be denoted as

$$\overline{error} = \frac{1}{NK} \sum_{t=1}^{K} \sum_{i=1}^{N} \left\| X_{est}^i - X_{real}^i \right\|_F \tag{8}$$

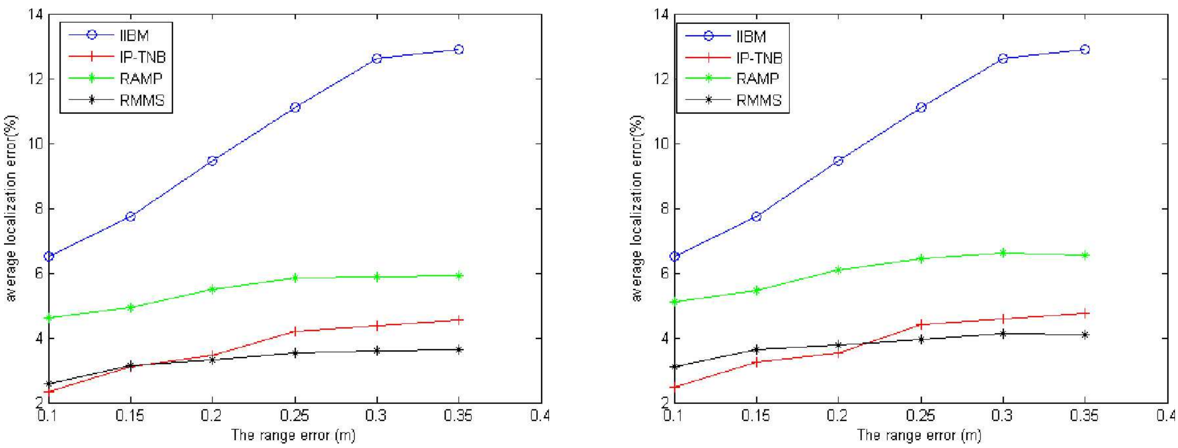
And the normalized location error can be denoted as

$$e = \frac{\overline{error}}{R} \tag{9}$$

Fig. 6 shows that RMMS algorithm can have a better localization accuracy, comparing with IIBM algorithm and RAMP algorithm, when the range error is over 0.2 meter, the paper localization accuracy exceeded IP-TNB algorithm. And in Fig. 7, we assume there are $Q$ error nodes, the average ratio localization nodes can be denoted as

$$Ratio_{average} = \frac{q}{Q} \tag{10}$$

where $q$ is the number of error nodes' decline. We can know that IP-TNB algorithm's fault tolerance is inferior to that of RMMS algorithm, IP-TNB algorithm's average ratio localization nodes declined sharply with the increase of nodes' range error, and in this paper, the area arranges a large number of sensors, thus, it can have larger range of error, and the RMMS algorithm is more suitable than these algorithms.




(a) (b)

FIGURE 6. The relationship of nodes average localization error with nodes' range error. (a) The ratio number error nodes is 4%; (b) The ratio number error nodes is 6%.

From the Fig.8, we can know the relationship of nodes average localization error with the ratio number error nodes. When the ratio number error nodes is under 8%, RMMS algorithm's average localized error is smaller than that of IP-TNB algorithm. And RMMS algorithm's average localized error increased sharply with the ratio increase of number error nodes. That is because the number of error nodes can decide the minimum error node's residence area, which can influence on the localizing precision of unknown nodes.

5. **Conclusion.** The paper presented a new refinement method to weaken the mirror error in nodes localization in WSN. First we analysed the source of error, and then we introduce the algorithm theory, at last, we verify its performance by MatLab. From the simulation result, we can draw a conclusion that a better position accuracy and fault tolerance can obtained by using the RMMS algorithm. But this algorithm is only appropriate for large scale network and the error still exists, we need to improve the accuracy in the future work.

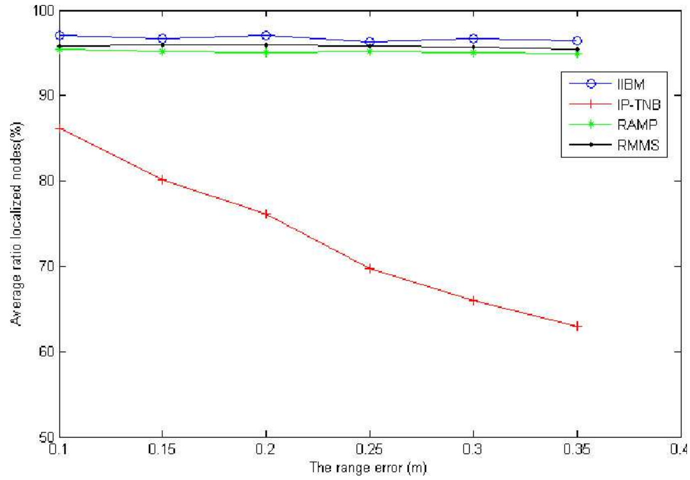
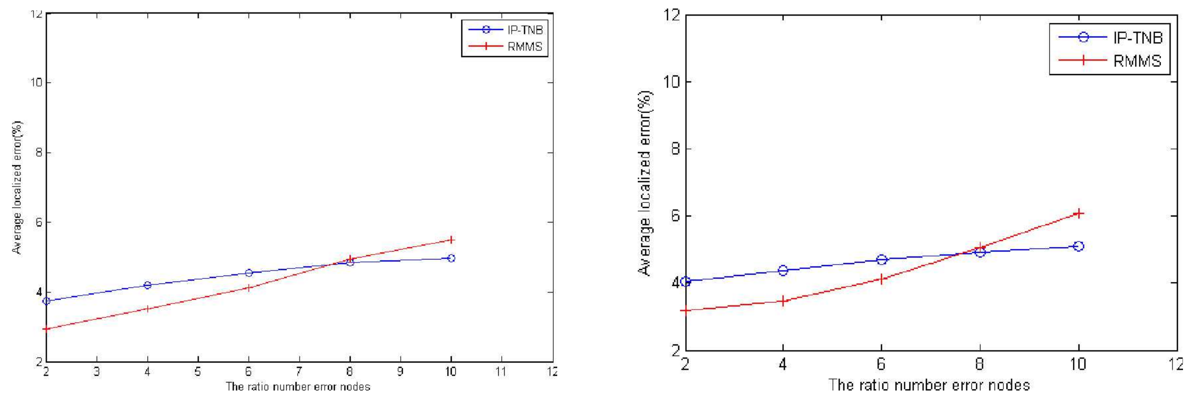



FIGURE 7. The relationship of average ratio localization nodes with nodes' range error.




(a) (b)

FIGURE 8. The relationship of nodes average localization error with the ratio number error nodes. (a) The nodes' range error is 0.25 meter; (b) The nodes' range error is 0.3 meter.

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