Positioning Scheme using Acceleration Factor for Wireless Sensor Networks

Na-Yeon Park, Cheol-Su Son, Sung-Jae Lee, In-Moon Hwang, Won-Jung Kim, *Member, KIMICS*

Abstract**—**Locations of nodes as well as gathered data from nodes are very important because generally multiple nodes are deployed randomly and data are gathered in wireless sensor network. Since the nodes composing wireless sensor network are low cost and low performance devices, it is very difficult to add specially designed devices for positioning into the nodes.

Therefore in wireless sensor network, technology positioning nodes precisely using low cost is very important and valuable. This research proposes Cooperative Positioning System, which raises accuracy of location positioning and also can find positions on multiple sensors within limited times.

Index Terms**—**Positioning, Wireless Sensor Networks, Multi-hop.

I. INTRODUCTION

Wireless Sensor Networks (WSN) are composed of multiple low power and low performance sensor nodes. In WSN, sensor nodes measure and gather data such as temperature, humidity, pressure, slope, and strength and then send them to sink nods through wireless network. It is very important to know position of each sensor node as well as gathered data.

Methods of node positioning are very diverse based on which equipment and which technology are implemented. Positioning systems such as GPS[1], Active Badge[2], Active Bats[3], MotionStar[4] implement radio, infrared light, ultrasonic waves, and video devices.

The technologies utilized to the above positioning system are proximity, ToA(time of arrival), TDoA(time difference of arrival), AoA(angle of arrival), signal strength of radio frequency, and scene analysis, etc. Most of positioning systems use specially designed equipment to get location of nodes. These equipment need lots of costs in order to install and operate and so recently many researches are performed to find out methods of low cost positioning utilizing existing wireless network infrastructure [5, 6, 7].

RADAR[8] does not use dedicated positioning equipment but utilizes existing wireless local area network infrastructure environments and obtains RSSI(received signal strength indicator) from wireless devices such as wireless LAN card and AP(access point) and finds out locations by converting RSSI into distance. Reducing the errors included in the distance obtained by converting RSSI is a task to be solved in positioning system using RSSI.

The purpose of this research is to propose a positioning system that improves accuracy, performance, and scalability in wireless sensor network composed of multiple nodes.

II. RELATIVE STUDIES

There are two methods to calculate positioning of certain sensor node. One is beacon-based positioning method that location is determined by measuring distances between beacon nodes of locations known. Other is cooperative positioning system that location is determined by measuring distances between nodes including location of nodes not determined [9, 10].

In beacon-based positioning system, power consumption is needed more because signals of radio waves should be strong and performance of each node should be excellent. In cooperative positioning system, it is effective in multi-hop environments since only part of nodes can communicate with beacon and the rest of nodes communicate with neighbor nodes to measure distances and thus costs and energy consumption are less.

Figure 3 shows method of positioning assuming that nodes exist on two dimensions. Locations of three beacon nodes are (x1, y1), (x2, y2) and (x3, y3) and d1, d2, and d3 are distances between beacon nodes and the node to be measured. We want the location (x, y) of the node to be measured. The location (x, y) of positioning node can be determined like (1) by Triangular measurement method.

$$\begin{aligned}(x_1-x)^2+(y_1-y)^2&=d_1^2\\(x_2-x)^2+(y_2-y)^2&=d_2^2\\(x_3-x)^2+(y_3-y)^2&=d_3^2\end{aligned} \quad (1)$$

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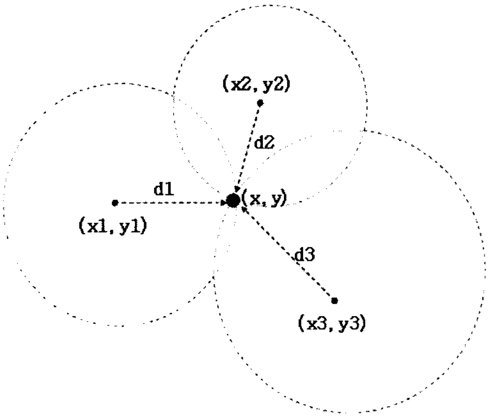

Fig. 3 Triangular Measurement Method.

Distances d1, d2, and d3 converted from RSSI can not help but contain errors in reality. Thus, errors e1, e2, and e3 should be added to converted distances like (2).

$$\begin{aligned}(x_1-x)^2+(y_1-y)^2+e_1&=d_1'^2\\(x_2-x)^2+(y_2-y)^2+e_2&=d_2'^2\\(x_3-x)^2+(y_3-y)^2+e_3&=d_3'^2\end{aligned} \quad (2)$$

In beacon-based positioning method, location (x, y) can be determined by linear programming since location of only one node by referring to beacon node is measured. But in cooperative positioning system, since each node refers to each other in positioning, the location should be determined by minimizing of summation of differences between measured distance d' and calculated Euclidean distance d'' like (3). Linear programming is difficult to apply for this problem and so nonlinear programming should be used to get the optimal value.

$$\sum_{i=1}^{n}\left|d'_i-d''_i\right| \quad (3)$$

III. Analysis of the existing studies

In cooperative positioning system, an algorithm of 2W (WiPS[9] and WiCOPS[10]) using nonlinear programming to measure locations is introduced and defects are analyzed in this chapter.

A. Notations

Notations for expression in this paper are below.

N_A : Set of nodes neighboring Node A

G_A : Set of AP neighboring Node A

N'_A : Set of locations initialized already in N_A

$n(G_A)$: Number of nodes in G_A

$n(N'_A)$: Number of nodes in N'_A

p_A : Location of node A

n : Total number of nodes including nodes and APs

$l_{i,j}$: Estimated Euclidean distance between *i*th nodeand *j*th node

$d_{i,j}$:Measured distance between *i*th node and *j*th node

$n'(G_i)$: Set which difference between estimated distance and measured distance is not equal to zero in G_i

$n'(N_i)$: Set which difference between estimated distance and measured distance is not equal to zero in N_i

$u_{i,j}$: Unit vector of ith node and jth node

$f(i,j)$: Difference between $l_{i,j}$ and $d_{i,j}$

B. Introduction to existing studies 2W

The existing 2W(WiPS and WiCOPS) positions nodes cooperatively considering signal strength of neighboring wireless nodes as well as signal strength between wireless nodes and access points by utilizing nonlinear programming under the typical WLAN infrastructure circumstances composed of small number of fixed access points and multiple wireless nodes. Many researches show that 2W raises accuracy by measuring locations of nodes cooperatively [9, 10].

The existing 2W positioning algorithm is described below.

Step 1) Nodes and access points transmit to server RSSI list of neighboring nodes and access points.

Step 2) Server converts RSSI received from nodes into distance. When RSSI is converted into distance, errors are applied within 20% range in terms of normal distribution.

Step 3) Sever approximately decides initial locations of nodes based on measured distances to neighboring access points and neighboring initialized nodes. Initial location of each node is decided by (4) in order.

$$p_A=\frac{\sum_{X\in G_A}p_X+\sum_{X\in N'_A}p_X}{n(G_A)+n(N'_A)} \quad (4)$$

Step 4) In order to minimize (5), (6) is performed iteratively and locations of nodes are modified.

$$E=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\left|l_{i,j}-d_{i,j}\right| \quad (5)$$

$p_i^{(k)}$ is a modified location of ith node which has k times iterations and is calculated by (6).

$$p_i^{(k+1)}=p_i^{(k)}+\alpha\nabla(i) \quad (6)$$

$\nabla(i)$ in (6) is defined in (7).

$$\nabla(i)=\sum_{j=0}^{n}u_{i,j}\cdot f(i,j) \quad (7)$$

C. Problems of the existing 2W Studies

Problem of the existing 2W studies is that convergence adjustment factor α, which is used to move each node repeatedly in order to reach specified error range, is decided not by calculation but by heuristic. Since the value is fixed, performance is not good when number of nodes is increased and it is not converged to location but diverged if number of nodes is over certain number.

In order to solve the above problem of WiPS, in(8) WiCOPS decides location convergence adjustment factor α by calculation using acceleration factor β and number of related nodes which affects to location convergence process of nodes. This solves the problem of divergence and performance is better than WiPS.

$$\alpha_i=\beta\frac{1}{n(G_i)+n(N_i)} \quad (8)$$

But acceleration factor β of WiCOPS is decided not by calculation but heuristic and so it has problems in expansion and performance.

IV. SCOPS

This research proposes cooperative positioning system SCOPS which improves accuracy and performance. SCOPS utilizes nonlinear programming for calculation.

Accuracy: This research shows that accuracy can be improved by using cooperative positioning system in wireless sensor network existing small number of beacon nodes.

Performance: In cooperative positioning system, if number of nodes becomes large, then accuracy is increased but performance is decreased. It becomes problems. Thus, in this research, to solve this low performance problem, a method is tried to improve performance of positioning by analyzing relationship between nodes.

A. Improved positioning convergence adjustment factor

Both WiPS and WiCOPS use (9) to decide k+1th locations to first node in positioning.

$$p_1^{(k+1)}=p_1^{(k)}+\alpha_1\sum_{j=0}^{n}u_{1,j}\cdot f(1,j) \quad (9)$$

Modification of location of a node affects positioning of that node and neighboring node. On the other hand, location of certain node affects positioning of neighboring nodes in previous step.

In Figure 4, G1, G2 and G3 are beacon nodes and N1, N2, N3 and N4 are nodes that have to be positioned. Location movement of from N1 to N'1 is decided by neighboring nodes G1, G2, N2 and N3. Also, if N1 moves to N'1, it affects positioning of N2 and N3. Therefore, there are co-relationship between convergence adjustment factor and number of nodes which affect positioning.

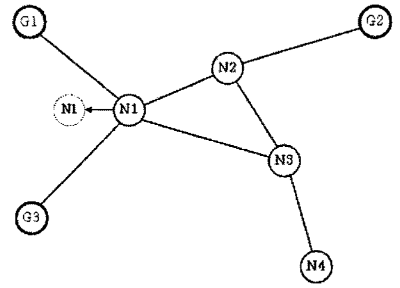

Fig. 4 Affection relation between nodes

Number of nodes which affects ith nodes can be obtained by (10).

$$impactNumber(i)=n(G_i)+n(N_i) \quad (10)$$

When location of one node is decided, if location is decided by moving value of (7), it is not converged but diverged or vibrated. Thus, the value of convergence adjustment factor α of (8) should be decided appropriately. If value of α is above 1, probability of divergence is higher than that of convergence. Therefore, value of α should be above 0 and below 1. Thus, value of stable convergence adjustment factor in probability is (8).

However, (10) calculates number of nodes affecting positioning of certain node by simply number of that node and neighboring nodes. Figure 5 shows certain step that has been adjusted repeatedly to locate a node. Node N1 neighbors on N2, N3, N4, N5, N6, and N7. Differences between estimated distance and measured distance of each node are assumed -1.5, 1.7, 1.2, 1.2, 0, and -1, number of nodes neighboring N1 is 6 but actual affecting nodes is 5, because difference between estimated distance and measured distance of N1 and N6 is 0.

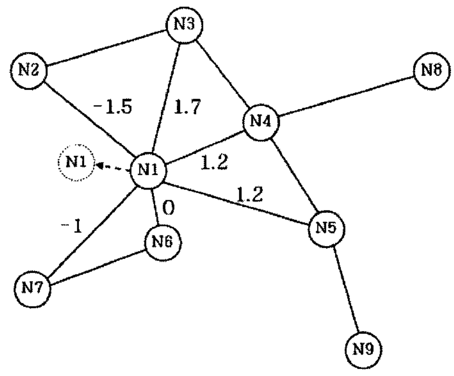

Fig. 5 Actual affection relation between nodes

Therefore, convergence speed can be high by only considering number of nodes that give affection actually in iteration like (11). (11) is convergence adjustment factor applying number of nodes that give effects to i th nodes actually in k th iteration.

$$\alpha_k = \frac{1}{n'(G_i)+n'(N_i)} \tag{11}$$

B. Convergence Acceleration Factor

In order to improve performance by reducing number of iteration, convergence acceleration factor β is used like (8). If value of convergence acceleration factor β is above 1, convergence speed becomes faster. But if the value is too large, it can be not converged but diverged or vibrated. In WiCOPS, value of convergence acceleration factor β is set to 1, 2, and 3 and simulation is performed. The result shows that performance is best when value of convergence acceleration factor β is set to 2. Like this, in WiCOPS, the value of convergence acceleration factor is determined not by calculation but by heuristics. Therefore, value of convergence acceleration factor β can be determined by calculation and performance should be improved while keeping stability.

Figure 6 is a simulation result of WiCOPS and shows a moving path of first node during location convergence process. In this simulation, number of location-known beacon nodes is set to 4 and number of location-unknown nodes is set to 50. Location is converged after about 80 iterations.

Initialized location is (14.97, 113.55) and converged location is (18.62, 107.27) respectively. Location is converged to almost same direction from the stabilization stage after 5 times iterations. Like this, after the stabilization stage, moving direction is almost constant but convergence speed is quite low.

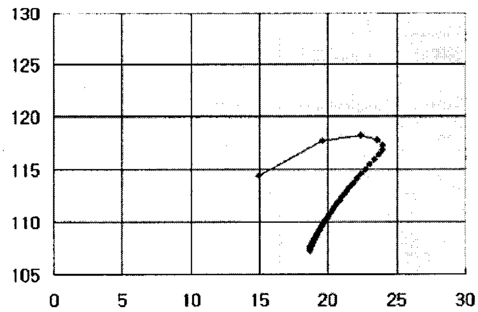

Fig. 6 Location modification path of first node

AS we see from Figure 6, direction is changed significantly until stabilization stage but degree of direction change is very low after stabilization stage. Therefore if value of convergence acceleration factor β is increased dynamically after stabilization stage, then convergence speed will be improved. In order to change the value of convergence acceleration factor β, the following two factors should be determined.

- determination of stability phase
- determination of convergence acceleration factor

Criteria for decision of stability phase are defined to iteration count, progress of moving distance, and progress of direction. But it is difficult to decide by iteration count simply because stability phases are different based on number of nodes and distribution of nodes. Therefore, progress of moving direction is used to decide stability phase in this research

```
IF previousUnitVector ≦ 45 and currentUnitVector ≦ 45
    bStableFlag ← True
Else
    bStableFlag ← False
End if
```

Fig. 7 Decision of stability phase

As shown in Figure 7, if changes of moving direction are below 45 unit vector twice consecutively, it is considered as stability phase. If changes of direction do not meet the criteria, it is considered as non stability phase.

V. SIMULATION

In the existing WiPS and WiCOPS, values of convergence adjustment factor or convergence acceleration factor are determined heuristically to measure locations. In this research, determination methods of dynamic convergence adjustment factor based on number of nodes affecting actually and of dynamic convergence acceleration factor based on progress of moving direction are proposed. Simulation is performed to prove that this proposed method is superior to existing research 2W in terms of performance and stability.

A. Simulation environment

Simulation is performed on the square plane that width is 200 m and length is 200m. Wireless telecommunication distance is set to 100m based on ZigBee that is mainly used to compose wireless sensor network. Number of fixed beacon, whose location is known itself, is 4, 5, or 9. The number of nodes is increased by 5 from 5 to 100. If 4, 5 and 9 nodes of beacon are deployed on certain square plane to normalize deployment of beacon nodes, distances between beacon nodes are approximately 200m, 141m, 100m.

B. Simulation result

Figure 8 shows the screenshot of SCOPS simulator which is set to 4 for number of beacon nodes, 60 for number of nodes, 0.05 for convergence adjustment factor, and 100 for telecommunication distance.

Method WS, CS1, CS2 and SC-AC are respectively WiPS algorithm set to 0.05 for convergence adjustment factor, WiCOPS algorithm set to 2 for convergence Acceleration factor, SCOPS algorithm determining convergence factor and acceleration factor dynamically, SCOPS algorithm applying divide and conquer technique. Figure 9 shows that locations of estimated nodes are displayed by clicking Initialize Button and differences of distances are displayed by drawing lines between actual nodes and estimated nodes. Figure 10 shows the result of simulation completion by clicking Position Button.

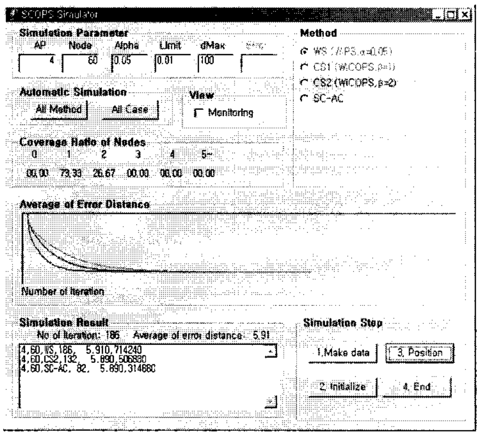

Fig. 8 SCOPS Simulator

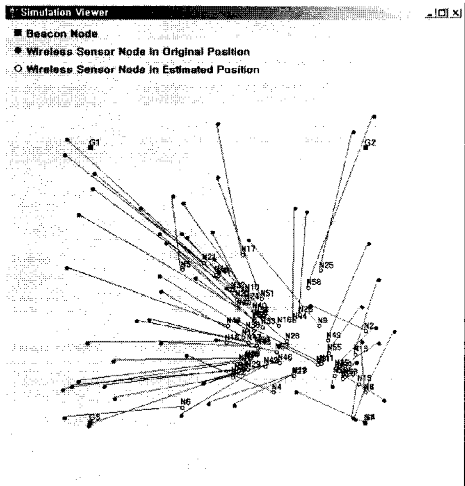

Fig. 9 Location initialization

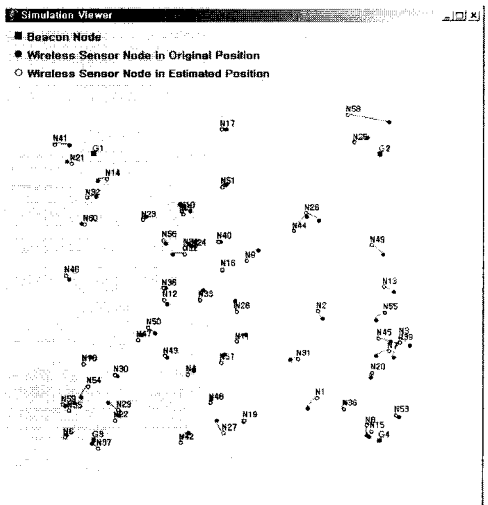

Fig. 10 Simulation result

For the case of WiPS, the reason why error increases from 70 nodes is that value of convergence acceleration factor is relatively too high in comparison with value of convergence adjustment factor fixed to 0.05. The reason like this can be found in Figure. 12. In the case of CS1, CS2 and SC-AC, even though number of nodes increase, vibration hardly occurs. But for the case of WS, location of node can not be positioned and vibration can be seen from over 80 of average number of nodes.

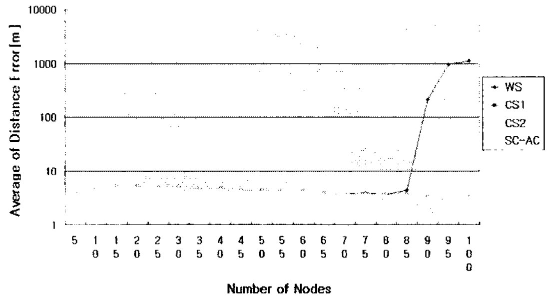

Fig. 11 Average distance error for the case of 9 of beacon nodes

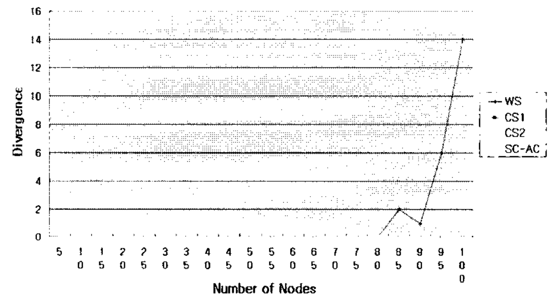

Fig. 12 Divergence Count as increasing number of nodes

Figure 13 shows iteration count until convergence of nodes when number of node increases. SC-AC shows better performance than WS, CS1, and CS2 by changing both convergence adjustment factor and convergence acceleration factor dynamically with considering number of node and moving angle. Specially, even number of nodes becomes large, linear iteration count that result can be predictable is shown.

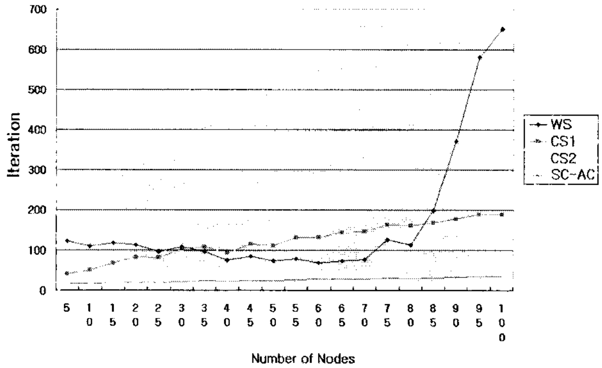

Fig. 13 Iteration count for the case of 9 of beacon nodes

C. Summary of simulation result

SCOPS is similar to WiCOPS in terms of stability and accuracy but SCOPS shows better results than WiCOPS in terms of performance and scalability. Design goal of SCOPS is verified through simulation as below.

Accuracy: In SCOPS, accuracy means that locations of original nodes are converged within expected error scope when performing positioning algorithm. As we see the simulation results in previous Section V, SCOPS guarantees accuracy by occurring errors within certain limits in every case.

Performance: In SCOPS, performance means time until finishing positioning within desired errors. SCOPS shows better performance than previous WiPS and WiCOPS.

Even though accuracy becomes high if positioning is performed simultaneously for all nodes cooperatively, reducing time complexity is more important in order to apply practically. Since accuracy and time complexity have anti-relationship, it is desired to set proper size of group based on desired accuracy and time complexity when implements actually.

VI. Conclusions

In this research, distance base positioning system to measure locations of nodes is studied. This system uses only RSSI obtained from wireless telecommunication device equipped basically to every node, without using separate additional positioning purpose-only device, under wireless sensor network environments.

In order to develop scalable positioning system under wireless sensor network environments composed of numerous nodes, problems of WiPS and WiCOPS, one of existing cooperative positioning system, are analyzed and solutions are found as below.

First, in cooperative positioning system, it analyzes and verifies that deciding value of convergence adjustment factor based on number of nodes which give effects to location change of node is more efficient than simply considering connectivity in terms of affection relationship between nodes during positioning.

Second, In order to improve performance of positioning algorithm, convergence acceleration factor is used to reduce iteration count of nonlinear programming and speed of convergence is improved. When value of convergence acceleration factor is determined, it is more effective by analyzing progress of location convergence and assigning dynamically than by simply assigning certain constant heuristically.

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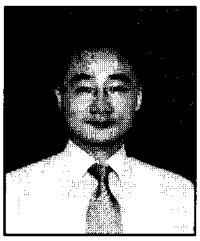

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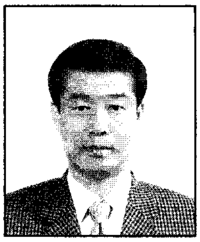

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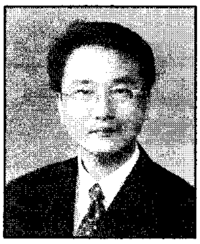

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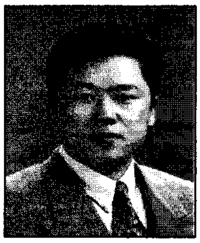

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