센서 네트워크상의 새로운 자동 위치결정 방법

A New Auto-Localization Scheme in Sensor Networks

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Abstract : Many sensor network applications require that each node's sensor data stream be annotated with its physical location in some coordinate system. Equipping GPS on every sensor node is often expensive and does not work in indoor deployments. Recently, cricket-based localization system is often used for indoor localization system. It is very important to know the exact position of beacons in cricket-based localization system for identifying moving sensor node's position. In this paper, a new method, Mobile Listener Detect Algorithm (MLD) which can automatically calculate the unknown newly installed beacons is proposed. For the verification of the feasibility of the proposed scheme, we have conducted several experiments.

Keywords : cricket-based localization, Mobile Listener Detect algorithm(MLD), PDA

I. Introduction

One of the critical issues in Wireless Sensor Network (WSN) is to determine the physical positions of sensor nodes. It is because sensed data are meaningful only when they are annotated with geographical position information. Also position information is essential to many location-aware sensor network communication protocols, such as packet routing and sensing coverage [1].

The existing localization algorithms can be classified into two categories: range-based and range-free. Range-based algorithms use distance or angle information for localization. The range information can be obtained by different means such as received signal strength indicator(RSSI), time of arrival(TOA), time-difference of arrival(TDoA), or arrive of angle(AOA). They have higher location accuracy but require additional hardware on sensor nodes.

Range-free algorithms do not need absolute information, so the accuracy is less than the range-based but satisfy many applications' requirements. They are more economical, cost-effective and feasible for the large-scale WSN.

In non-urban outdoor environment, sensor nodes may obtain location information using an existing infrastructure such as GPS. GPS may be too expensive, too large for the desired applications. Therefore, in most indoor environments, GPS is not available. One solution to this problem is an alternative location infrastructure such as Active Bat [2] or Cricket [3] that works in places that GPS does not work.

Recently, Cricket which employs hundreds or thousands of inexpensive position beacons to provide location information over extended areas has got used for indoor localization. It uses TDoA between a radio and an ultrasonic signal (together termed as a beacon signal) for distance ranging [4].

For cricket system to be successful, it must be pervasive. The beacons' installation procedure should be quick and easy according as the usage of cricket system becomes widespread.

However, large number of beacon nodes in Cricket raises a deployment issues: how can an extended deployment be efficiently configured for initial operation, and efficiently maintained for continuous operation. Autonomously operating location-aware sensor network faces the same problems.

In this work, an effective method called Mobile Listener Detect Algorithm (MLD) to facilitate large-scale deployment of location-aware sensor network is presented. The proposed MLD does not require any extra hardware except for three fixed beacons and one mobile listener initially. A mobile listener can run an MLD algorithm with the PDA locally, interacting only with neighboring beacon nodes to calculate the position of a newly introduced beacon node. By doing this in an automated manner, large-scale sensor networks can eliminate the cumbersome and unscalable process of manually configuring beacon nodes with their location.

This paper is composed of 5 Sections. Section I introduces the overall content of this paper. Section II overviews the Cricket and compares with the existing beacon auto-localization algorithms. Section III introduces the basic concept and details of MLD. Section IV practically implements the new method into Cricket system, and certifies its performance through beacon auto-localization results. Section V provides a conclusion of this paper.

II. Basics of Cricket and related work

Traditional location system such as GPS requires a dozens of satellites and ground-based monitoring centers to provide location information for outdoor navigation. However, GPS is quite ineffective especially for indoor application because walls in buildings block the signals transmissions. To overcome this problem in GPS, location infrastructure such as Cricket has been proposed.

Cricket is an indoor location system that provides two kinds of information, space identifiers and position coordinates. The position coordinates are (x, y, z) Cartesian coordinates [5,6].

According to the state of nodes, Cricket nodes can be divided into two categories: beacons and listeners. Actively transmitting beacons are fixed on the indoor ceilings with their own definite coordinates and listeners are attached to host devices (handhelds,

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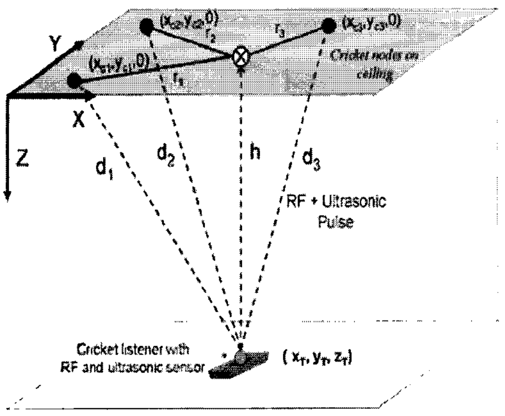

그림 1. 리스너는 근처의 비콘을 통해 측정된 거리값을 통해 위치를 계산한다.

Fig. 1. A listener calculates its position by using distance measurements from nearby beacons.

laptops, etc.) whose location needs to be obtained. The coordinates of any listener is still unknown before being computed whether it is moving or static.

Each beacon is equipped with ultrasonic, RF and temperature sensors. Because RF travels about 10^6 times faster than ultrasonic, the listener can use the time difference of arrival between the start of the RF message from a beacon and the corresponding ultrasonic pulse to infer its distance from the beacon.

For the listener to determine its latitude and longitude, the beacons need to know their respective latitudes and longitudes. In the same manner, when an application calls for an (x, y, z) Cartesian coordinate of listener, the each beacons must know their (x, y, z) Cartesian coordinate [7].

Triangulation algorithm is generally used for determining the absolute position of listener and is shown below.

$$(X_T - X_{Ci})^2 + (Y_T - Y_{Ci})^2 = r_i^2, i = 1,2,3 \quad (1)$$

$$r_i = \sqrt{d^2_i - h^2}, \ i=1,2,3. \quad (2)$$

$$X_{T_{12}} = X_{c1} + 1/d^2_c [d_{X_c} d^2_r \pm |d_{y_c}| \sqrt{r^2_2 d^2_c - d^4_r}]$$
$$Y_{T_{12}} = Y_{c1} + 1/d^2_c [d_{Y_c} d^2_r \pm |d_{X_c}| \sqrt{r^2_2 d^2_c - d^4_r}] \quad (3)$$

Where,

$$d_{X_c} = X_{C1} - X_{C2}, \quad d_{Y_c} = Y_{C1} - Y_{C2}$$
$$d^2_c = d^2_{X_c} + d^2_{Y_c},$$
$$d^2_r = (r^2_1 - r^2_2 - d^2_c)/2$$

$$X_{T_{23}} = X_{c2} + 1/d^2_c [d_{X_c} d^2_r \pm |d_{Y_c}| \sqrt{r^2_3 d^2_c - d^4_r}]$$
$$Y_{T_{23}} = Y_{c2} + 1/d^2_c [d_{Y_c} d^2_r \pm |d_{X_c}| \sqrt{r^2_3 d^2_c - d^4_r}] \quad (4)$$

Where,

$$d_{X_c} = X_{C2} - X_{C3}, \quad d_{Y_c} = Y_{C2} - Y_{C3},$$
$$d^2_c = d^2_{X_c} + d^2_{Y_c}$$
$$d^2_r = (r^2_2 - r^2_3 - d^2_c)/2$$

In the equation, (X_{Ci}, Y_{Ci}) is each Cricket node position of the system, d is the distance between the listener and each Cricket node, r is the radius of circle that is drawn with each Cricket node position as its center including a listener (X_T, Y_T).

Cricket-based location system which is composed of three beacons and one listener only can cover a small area. If we want to extend the coverage of listener's locations, some more beacons should be additionally installed. There have been many researches on the distributed localization problems. Distributed localization algorithm can be classified into two categories. The first one is according to whether or not they rely on anchor nodes, which are nodes that are preconfigured with their true position. The second one is based on whether they are incremental or concurrent.

1. Anchor-based Algorithms

Anchor-based algorithms assume that a certain minimum number of fraction of the nodes know their position, e.g., by manual configuration or using some other location mechanism [8-11], The final coordinate assignment of individual nodes will be valid with respect to another global coordinate system. There are three drawbacks in this localization algorithm: First, establishing anchors is a manual deployment task, and may be cumbersome. Second, the numerical stability of anchor-based approaches is questionable, since they give more weight to anchor position estimates, and errors in those estimates will have undue effect on the global solution. Finally, anchor-based approaches may not scale well, since to combat the instability described above, a large number of anchors may be required to configure an unbounded working area.

2. Anchor-free Algorithms

Anchor-Free Localization (AFL) [12] is a decentralized algorithm to determine a consistent coordinate system for nodes in a network, using only distances between neighboring nodes. AFL works by initially assigning a rough polar coordinate system to beacons by counting connectivity "hops" around the network. (A node is considered to be 1 hop away from its neighbor if it can measure the distance between itself and its neighbor). Following the initial coordinate assignment, AFL works by incrementally decreasing the global energy, calculated using the sum of errors between estimated and measured distances between nodes. Nodes must cooperate continuously to calculate the global energy. AFL has the advantage of being completely decentralized, so it can work without any human intervention. Additionally, AFL almost always converged on the correct graph. Unfortunately, due to Cricket hardware limitations, AFL cannot be applied if beacons are coplanar on the ceiling. The ultra sound transmitters and receivers are directional, which prevents lateral distance measurements between coplanar beacons if the beacons are facing the direction normal to the plane [7].

3. Incremental Algorithms

Another class of algorithms proceeds incrementally, starting from a small core set of nodes that know their location, and adding nodes to the existing nodes, and configures network one at a time or in groups [11]. This can be done if a node attempting to join the existing network can successfully estimate its distances to three or four nodes that are already configured.

However, there are two major problems in such incremental approaches: first, they may not solve the problem even when a

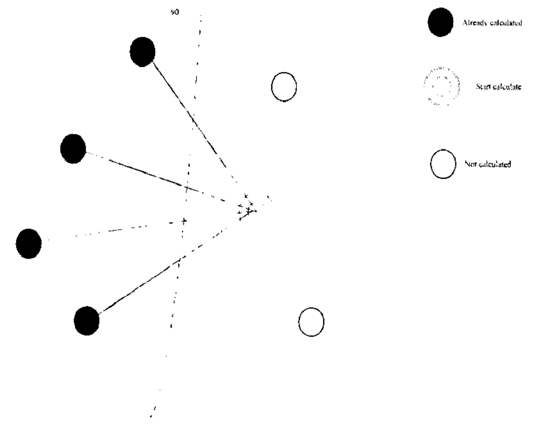

그림 2. 전형적인 incremental optimization.

Fig. 2. Nodes involved in a typical incremental optimization.

valid coordinate assignment exists, and second, errors in local distance estimates often tend to cascade, leading to large global error. Due to the Cricket node using the method TDoA to measure the distance, the TDoA requires the line-of-sight between the transmitter and receiver.

In these existing algorithms, this shortage may prevent the Cricket nodes from obtaining direct node-to-node distances.

Therefore, for improving the performance of the previous works, we propose a new type of Beacon auto-localization. The key point of this algorithm is to use a mobile listener and the existing framework of the Cricket system to calculate the position of the unknown beacons.

III. Mobile Listener Detect (MLD) Algorithm

In many applications based on the Cricket system, it is very important to know each node's physical position in some coordinate system. Manual measurement and configuration methods for obtaining location are not suitable for scale and are error-prone, and equipping sensor nodes with GPS is often expensive and does not work in low-cost Cricket system. As the last section introduces, the previous work to solve the beacon auto-localization problem has their shortages. Comparing with the other existing algorithms, we want to contribute a new method MLD.

Our new method considers the constraints that are imposed on sensors, such as hardware framework, limited power, low cost. We want to just use the Cricket system itself to solve this problem. With the help of the accuracy of the localization from the Cricket system and the mobile listener, we don't need to add any extra hardware. In our proposed scheme, each location-unaware sensor node discovers its position assisted by the moving listener. The MLD algorithm is composed of the following steps.

Step 1: Fix three beacons which can act as a reference node on the ceiling. These beacons are called initialization beacons. We can manually measure the initialization beacons' positions with a scale. With these beacons, the basic Cricket localization system can be built up. Therefore, a mobile listener which can move around the space that initialization beacons generate can get its own real-time position in the limited area with the consistent coordinate system of initialization beacons.

Step 2: The listener continues to move around the covering space which is generated by initialization beacons. During this period, listener can know its corresponding positions. And at the same time, the listener can get the distance value from the newly installed beacon fixed on the other place. After the listener measures the distance between itself and the newly introduced beacon at three different places, triangulation algorithm is utilized to calculate the newly installed beacon's position. After calculating the newly installed beacon's position, the position value is saved in the PDA at once.

그림 3. 3개의 설치된 비콘(B1, B2, B3)과 위치가 정의되지 않은 새로운 비콘(B4)과 이동가능한 리스너.

Fig. 3. Three initialization beacons (B1, B2, B3) and one newly introduced beacon (B4) which is unknown their coordinates and one mobile listener.

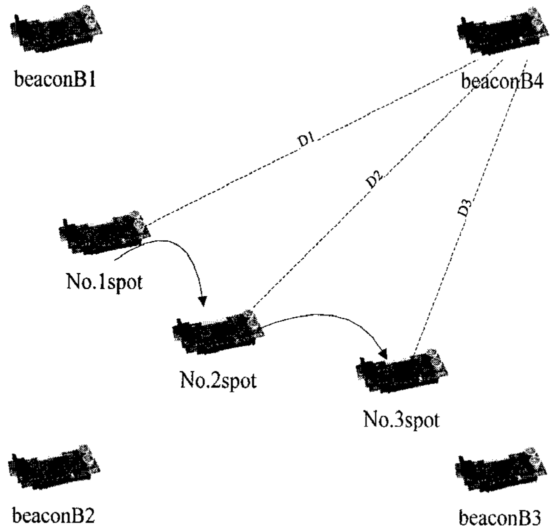

그림 4. 리스너는 3곳의 다른 장소 (장소1, 장소2, 장소3)를 이동하며 새로 설치된 비콘(B4)의 위치를 결정한다.

Fig. 4. Listener moves at three different places (spot1, spot2, spot3) to determine the position of the newly deployed beacon (B4).

Step 3: If a newly installed beacon's position is calculated by step 2, the area which Cricket system can cover gets wider than before. By using the step 2 again, we can successively calculate another newly installed beacon's position.

The details on MLD are as follows.

We assume that three initialization beacons' coordinates are (X_1, Y_1, Z_1), (X_2, Y_2, Z_2), (X_3, Y_3, Z_3), and the listener's coordinates at three different points are (X_{L1}, Y_{L1}, Z_{L1}), (X_{L2}, Y_{L2}, Z_{L2}), (X_{L3}, Y_{L3}, Z_{L3}). A newly introduced beacon's coordinate which is to be calculated is (X_4, Y_4, Z_4). D1, D2 and D3 are the distance value between the listener and the newly installed beacon at three different points.

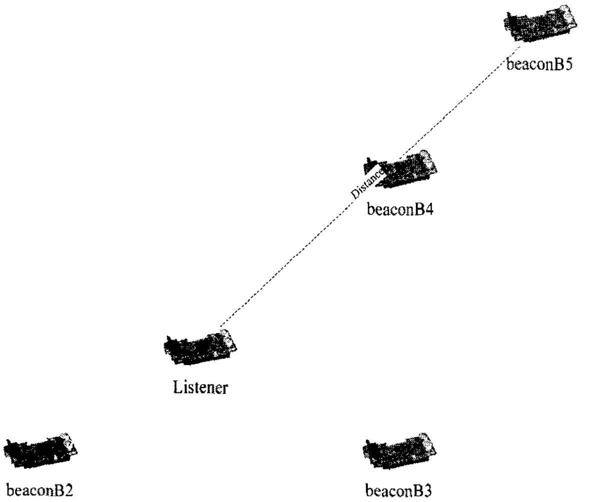

그림 5. 인식된 비콘 B4는 새로운 참조 비콘으로 동작한다. 이러한 동작을 반복적으로 수행할 경우 크리켓 시스템은 보다 넓은 지역을 커버할 수 있다.

Fig. 5. The identified beacon B4 can act as a new reference beacon. By doing this process repeatedly, Cricket system can cover a wide area.

Because the listener moves on the floor, $Z_{L1} = Z_{L2} = Z_{L3} = 0$, and Z_4 is equal the height of the hall.

$$D1^2 = (X_{L1} - X_4)^2 + (Y_{L1} - Y_4)^2 + (Z_{L1} - Z_4)^2 \quad (5)$$

$$D2^2 = (X_{L2} - X_4)^2 + (Y_{L2} - Y_4)^2 + (Z_{L2} - Z_4)^2 \quad (6)$$

$$D3^2 = (X_{L3} - X_4)^2 + (Y_{L3} - Y_4)^2 + (Z_{L3} - Z_4)^2 \quad (7)$$

According to the formulas, we can easily calculate the newly installed beacon's coordinate (X_4, Y_4, Z_4):

$$\begin{aligned} X_4 = \{&[D_2^2 - (Z_{L2} - Z_4)^2 - D_3^2 + (Z_{L3} - Z_4)^2] \\ &(Y_{L2} - Y_{L1}) - [D_1^2 + (Z_{L2} - Z_4)^2 - D_2^2 - (Z_{L1} - Z_4)^2] \\ &(Y_{L3} - Y_{L2}) - (X_{L2}^2 - X_{L3}^2)(Y_{L2} - Y_{L1}) - (Y_{L2}^2 - Y_{L3}^2)(Y_{L2} - Y_{L1}) \\ &+(X_{L1}^2 - X_{L2}^2)(Y_{L3} - Y_{L2}) + (Y_{L1}^2 - Y_{L2}^2)(Y_{L3} - Y_{L2})\} \\ &/2[(X_{L3} - X_{L2})(Y_{L2} - Y_{L1}) - (X_{L2} - X_{L1})(Y_{L3} - Y_{L2})] \end{aligned} \quad (8)$$

$$\begin{aligned} Y_4 = \{&[D_2^2 - (Z_{L2} - Z_4)^2 - D_3^2 + (Z_{L3} - Z_4)^2] \\ &(X_{L2} - X_{L1}) - [D_1^2 + (Z_{L2} - Z_4)^2 - D_2^2 - (Z_{L1} - Z_4)^2] \\ &(X_{L3} - X_{L2}) - (X_{L2}^2 - X_{L3}^2)(X_{L2} - X_{L1}) \\ &-(Y_{L2}^2 - Y_{L3}^2)(X_{L2} - X_{L1}) + (X_{L1}^2 - X_{L2}^2)(X_{L3} - X_{L2}) \\ &+(Y_{L1}^2 - Y_{L2}^2)(X_{L3} - X_{L2})\} \\ &/2[(X_{L3} - X_{L2})(Y_{L2} - Y_{L1}) - (X_{L2} - X_{L1})(Y_{L3} - Y_{L2})] \end{aligned} \quad (9)$$

We can replace one of the initialization beacons to the new identified beacon, and the listener moves to the new coverage area generated by the two initialization beacons and the newly identified beacon, so the movement area is larger. With the new compositive localization system, the listener can get its own real-time position in the extended area. And at the same time, the listener can get the distance from another newly installed beacon, and uses the same method introduced before to detect the new beacon's position. By repeatedly applying this MLD algorithm, more and more beacons' position can be calculated, and the listener's movement area is getting larger. The more beacons are assigned with the consistent coordinates, the more beacons can support the listener to enhance its localization area.

IV. Experiment of MLD Algorithm

In this section, to verify the feasibility of the proposed MLD algorithm, several experiments are executed.

We first installed three initialization beacons (B1, B2, B3) on the ceiling with the known coordinate in the building, like in Fig. 6. And we use a PDA equipped with Cricket listener via RS232 interface to calculate the listener's real-time position. The PDA can be thought of mobile listener in this experiment. The listener's real-time position which is calculated by the triangulation algorithm will appear on the GUI screen.

In this experiment, the height of the hall is 250 centimeters. we assume that the coordinates of initialization beacons' position is B1(0, 0, 250), B2(0, 100, 250) and B3 (100,100,250).

The listener's position (black diamond in Fig. 7) can be easily calculated by using triangulation algorithm and the calculated real-time position of the listener appears on the GUI screen of PDA. In the Fig. 7, B4 is a newly introduced beacon of which

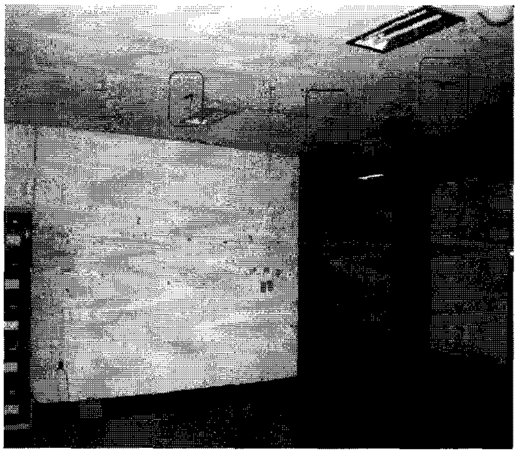

그림 6. MLD 알고리즘의 효용성을 확인하기 위한 테스트 베드 환경.

Fig. 6. Experimental test-bed for verifying the feasibility of MLD algorithm.

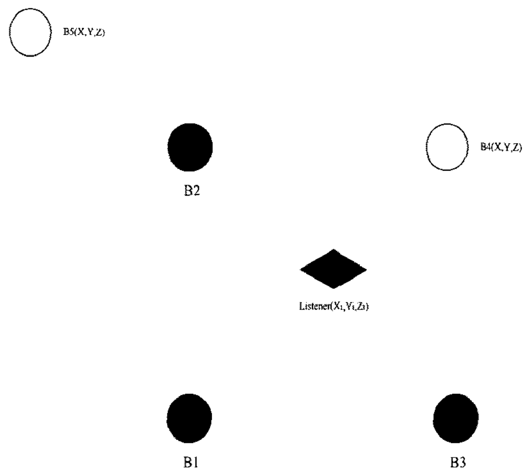

그림 7. 실험을 위한 초기환경.

Fig. 7. The initialization state of the experiment.

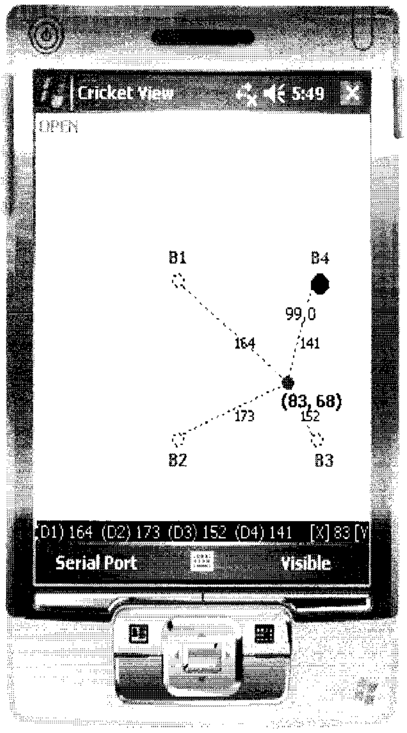

그림 8. 비콘 B4의 좌표계 계산을 위한 PDA 동작 화면 (빨간 점: 리스너, 파란점: 새로 설치된 비콘 B4, 점선위의 숫자: 거리).

Fig. 8. Operation screen on PDA for calculating coordinate of beacon B4 (the red spot is the listener, the number on the dashed line is the distance, the blue circle is the newly installed beacon B4).

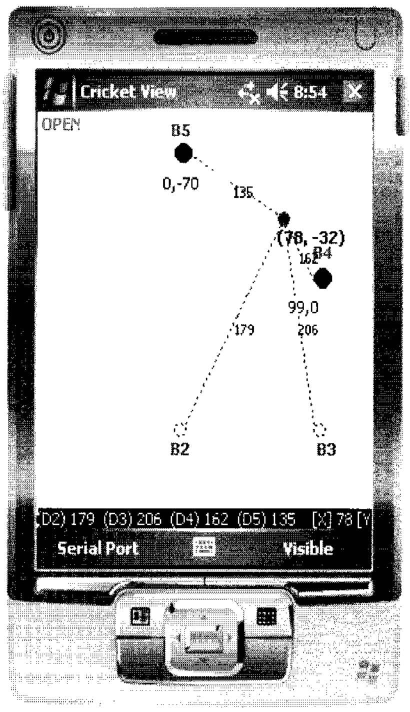

그림 9. 비콘 B5의 좌표계 계산을 위한PDA 동작 화면 (빨간 점: 리스너, 파란점: B4, B5, 점선위의 숫자: 거리).

Fig. 9. Operation screen on PDA for calculating coordinate of beacon B5 (the red spot is the listener, the number on the dashed line is the distance. the blue circles are B4, B5).

coordinate should be calculated by MLD algorithm. Listener moves around the coverage of the initialization beacons, and stops at three different places to get three different distances between B4 and the listener. In the Cricket View program, we can get the listener's coordinate values as the listener moves. We can get the newly introduced beacon's coordinate by using equation (4), (5) in the section 3.

If coordinate of B4 is known, B4's position will be saved in the PDA at the same time. B4 can be used as a reference beacon like B1, B2, and B3 at the beginning time. From this moment on, B2, B3, B4 can be utilized to calculate the coordinate of B5 successively. And then B5's position is saved in the PDA.

With the help of MLD algorithm, the listener's movement area can be extended and at the same time, the listener can detect many newly introduced beacons.

We programmed GUI for MLD algorithm and it is shown in Fig. 8, 9.

In the Fig. 9 the B4, B2, and B3 make up of the basic localization system like the B1, B2, and B3 do at the beginning time. And the listener detects the B5's position with the new localization system.

Bulusu et al. describe a GPS-less scheme that uses the radio connectivity of a node to a set of anchor nodes to determine its coordinates [13]. The coordinates of non-anchor nodes are obtained by calculating the centroid of all the anchors in the nodes radio-range. This is a concurrent algorithm, but it does not use any optimization. In simulations, they achieve about 12% localization error with approximately 12 anchor nodes per non-anchor node.

The ABC algorithm is an incremental algorithm that does not use anchor nodes [14]. ABC first selects several in-range nodes and assigns them coordinates to satisfy the inter-node distances, and then it incrementally calculates the coordinates of nodes using the distances to several nodes with already calculated coordinates. This simple incremental scheme results in error propagation. The authors report that with 5% range error, ABC results in about 60% average position error, which is larger than tolerable in many situations. This is a consequence of cascading errors in incremental solutions.

According to the experiment result of the MLD, the range error between the actual coordinate and the calculated one by using MLD is 10%, which is tolerable in many situations. And the MLD has better performance than some previous research algorithms.

V. Conclusion

Beacon auto-localization in the Cricket based location system is an important problem. Cricket system applications usually require that each node can be annotated with its physical location in some common coordinate system. In our paper, we describe a new method MLD to solve this problem. We only use the existing Cricket system framework and the mobile listener to calculate the newly installed beacons by the triangulation algorithm. There is one important advantage that MLD doesn't need any extra hardware. And furthermore, the speed of the implementation of MLD is faster. From the result of the experiment, the accuracy of MLD has been proved to be good.

In the future work, MLD will be applied to a mobile robot or mobile car applications which can automatically enlarge covering area.

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