Three-Mobile-Beacon Assisted Weighted Centroid Localization Method in Wireless Sensor Networks

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Abstract—**Localization is one of the key technologies in wireless sensor networks, and the mobile beacon assisted localization method is promising to reduce the cost. The methods with only one beacon introduce collinearity problem which degrades performance. This paper proposes a weighted centroid localization method using three mobile beacons. These beacons preserve a special formation while traversing the network deployment area, and broadcast their positions periodically. The sensor nodes to be localized estimate the distances to these beacons, and utilize weighted centroid localization scheme to calculate its position. Simulation shows that this method is superior to trilateration and weighted centroid algorithm with single mobile beacon.**

Keywords- wireless sensor network; localizatioin; mobile beacon; weighted centroid localization

I. INTRODUCTION

Location information is critical fundamental to make sensed data geographically meaningful in many applications, such as locating the animal's position, observing microclimate changes, target tracking. Meanwhile, location information supports many fundamental network services such as network routing, coverage control etc.

The beacon-based methods need some beacons aware of their positions to provide geographic information to ordinary sensor nodes to localize, whose precision increases with the number of beacons. However, the beacon is more expensive than ordinary nodes. A promising method is to use mobile beacon instead of static beacons. A mobile beacon is aware of its position, and traverses the network deployment area while broadcasting beacon packets to generate a number of virtual beacons. The ordinary sensor nodes estimate their locations by measuring the geographic information (e.g., distance or angle) of the virtual beacons.

In this paper, we propose a weighted centroid localization scheme using three mobile beacons in two-dimensional area, The rest of the paper is organized as follows: Section II gives a brief survey of mobile beacon assisted localization schemes. Section III describes the localization method with three mobile beacons. Section IV presents the simulation.

II. RELATED WORK

The mobile beacon assisted localization methods can be classified into range-based and range-free. Range-based methods are based on the assumption that the absolute distance between sender and receiver can be measured. The MAL (Mobile-Assisted Localization) [1] utilizes TDoA (Time Difference of Arrival) of RF and ultrasonic signals to measure distances between node pairs until these distance constraints form a "globally rigid" structure that guarantees a unique localization. The MBAL (Mobile Beacon-Assisted Localization) [2] is a trilateration localization scheme which involves a movement strategy of mobile beacon. In [3], Bahi et al. proposed a range based method which uses Hilbert space filling curve as the trajectory for the mobile beacon. MBL(ndc) (Mobile Beacon Assisted Localization based on Network-Density Clustering) [4] combined node clustering, incremental localization and mobile beacon assistance together. The virtual ruler approach [5] employed a vehicle equipped with multiple ultrasound beacons to travel around the area to measure distances between pairwise sensors. Beside these deterministic location results, there are some probabilistic approaches. Sichitiu et al. [6] proposed a localization mechanism that uses RSSI (Received Signal Strength Indicator) to range and Bayesian inference to estimate sensor node locations. The parametric and non-parametric probabilistic estimation techniques presented in [7] utilizes ToA (Time of Arrival) to range. Caballero et al. [8] presented a particle filtering localization method for the three-dimension outdoor network.

The range-free algorithms always use area or borderline measurement techniques. Galstyan et al. [9] presented an online-distributed algorithm in which sensor nodes improve their location estimates by incorporating both connectivity constraints and constraints imposed by a moving target. The ADAL (Azimuthally Defined Area Localization) [10] method utilizes a mobile beacon with a rotary directional antenna to send message in a determined azimuth periodically, and an unknown node uses the centroid of the intersection area of several beacon messages as its position. Xiao et al. [11] proposed a scheme using the ADO (Arrival and Departure Overlap) area, which is a possible area delimited by two circles with the same radius at different centers. Lee et al. [12] proposed a method based on geometric constraints utilizing three reference points. Ssu et al. [13] described a scheme using the geometry conjecture (perpendicular bisector of a chord) by which the unknown nodes estimate their locations. The BLI

This study is supported in part by the National Natural Science Foundation of China under grant 60802030; the Natural Science Foundation of Shandong under grants ZR2009GQ002 and ZR2010FQ014; the Research Project of SDUST "Spring Bud" under grant 2010AZZ175.

(Border Line Intersection Localization) method [14] utilizes a mobile beacon equipped with a directional antenna, and the unknown nodes record the first and last beacon messages to determine the border to calculate locations. MBL (Mobile Beacon Assisted Localization) and A-MBL (Adapting MBL) [15] adopt probabilistic methods which give an area where a sensor might reside, along with the likelihood of such an estimate. A-MBL adopts an adapting mechanism to improve the efficiency and accuracy of MBL.

The above localization methods only utilize a single mobile beacon. Patro [16] proposed a method that uses four mobile beacons to determine a square being the unknown node at the center, and the node takes square centroid as its position. Zhang et al. [17] presented a scheme using GMAN (a Group of Mobile Anchor Nodes) to move through the network area, and the sensor nodes determine beacon point set based on RSSI to estimate positions.

III. Localization with Three Mobile Beacons

The main drawback of single-mobile-beacon based localization methods is the co-linearity due to the straight line moving trajectory of the mobile beacon, but a sensor node deployed in two dimensional scenarios can estimate its location only if it receives three noncollinear beacon messages. On the other hand, range based localization methods rely on the distance measurement technology heavily, and these technologies have drawbacks that hamper their usage. Weighted centroid localization method (WCL) [18] uses weights to attract the estimated position to close reference points provided that coarse distances are available.

The relative position relationship among three mobile beacons should be considered in first when designing proposed method. Let three beacons be B_1, B_2 and B_3, whose transmission ranges are ideal circles with radius R. Since the beacons cannot be collinear, they should be in a triangular relationship. The most proper shape is the equilateral triangle with side length R. Given the coordinates of one mobile beacon, it is easy to compute the position of the others.

Generally, three mobile beacons assisted WCL method consists of three phases: (1) The mobile beacons traverse the deployment area while transmitting beacon messages. (2) The ordinary nodes record beacon messages to estimate their positions. (3) The unlocalized sensor node in previous phase sends a request to its neighbors, and utilizes the location of them to estimate its position.

The beacons keep their relative positions when they move throughout the deployment area. Let S_i be a sensor node whose estimate location is $(\hat{x}_{si}, \hat{y}_{si})$. The positions of B_1, B_2 and B_3 are (x_{B1}, y_{B1}), (x_{B2}, y_{B2}) and (x_{B3}, y_{B3}) respectively. The WCL method estimates the location of S_i as:

$$S_i\left(\hat{x}_{si}, \hat{y}_{si}\right) = \frac{\sum_{j=1}^{m} w_{ij} V_j\left(x_{vj}, y_{vj}\right)}{\sum_{j=1}^{m} w_{ij}}, w_{ij} = \frac{1}{\left(d_{ij}\right)^g} \tag{1}$$

V_j: j^{th} virtual beacon; d_{ij}:distance between S_i and V_j; g : adjustable degree

In order to use WCL, we should determine V_j and w_{ij}. There are six cross points including three beacons. Let the other three points be A_1, A_2 and A_3. Then, if S_i receives the messages from all the three beacons, $\{V_j|j=1,2,3\}=\{B_1,B_2,B_3\}$ in (1); if S_i only receives the messages from two mobile beacons, such as $\{B_1,B_2\}$, $\{V_j|j=1,2,3\}=\{B_1,B_2,A_1\}$. It is easy to infer positions of the other five cross points via B_1.

According to (1), w_{ij} depends on d_{ij} and g. the distance between S_i and B_j can be inferred based on the relationship between RSSI and distance as:

$$P_{rx} = P_{tx} \cdot G_{tx} \cdot G_{rx} \cdot \left(\frac{\lambda}{4\pi d}\right)^2 \tag{2}$$

P_{tx} : Transmission power of sender

P_{rx} : Remaining power of wave at receiver

G_{tx} : Gain of transmitter

G_{rx} : Gain of receiver

λ : Wave length

d : Distance between sender and receiver

The distance between S_i and A_j can be obtained by geometry knowledge with the distance to the corresponding two beacons.

Ref. [18] carried out an experiment to determine the optimal g, the simulation showed that a very small transmission range and g=1 produces best localization results, but in other configurations g=3 yields in best results.

In summary, the WCL method with three mobile beacons is shown as algorithm 1.

Algorithm 1: WCL with three mobile beacons

procedure *Beacons*(B_j)
  repeat
    Move to a new position;
    Broadcast a packet including its ID, location, time stamp;
  until finish
end procedure
procedure *UnknownNode*(S_i)
  repeat
    Receive message from beacons B_j;
    Calculate d_{ij} according to (3);
  until finish
  Sort the beacon messages on time stamp;
  for all the messages MS with same time stamp
    if |MS|==3
      Estimate position according to (1);
    elseif |MS|==2
      Calculate the distance to A_k via (4);
      Estimate position according to (1);
    else
      Discard MS;
  end for
  Use average of all estimated positions as the final value;
end procedure

In algorithm 1, the beacons execute the procedure *Beacons*, and three beacons should preserve the equilateral triangular formation. The unknown nodes execute the procedure *UnknownNode*. The condition of “finish” means the beacons finish traversing the deployment area.

IV. Performance Evaluation and Simulation

We evaluate the performance of mobile beacon assisted localization algorithm based on the following criteria:

1) Number of localizable unknown nodes in one-hop. It refers to the number of unknown nodes can be localized only with beacon messages. We use two kinds of moving trajectories in our simulation: RWP (Random Waypoint) model [19] and straight lines. In this model, the beacon begins the simulation by remaining stationary for pause time seconds, and then selects a random destination in the deployment area and moves to that destination at a speed distributed uniformly between zero and some maximum speed. Upon reaching the destination, the node pauses again for pause time seconds, selects another destination and speed, and proceeds there as previously described. To avoid speed decay, the pause time is set to 0 and the minimum beacon speed is set to 0.1 [20]. The straight line moving trajectory composes of a series of straight lines parallel to x or y axis.

2) Localization error. The localization error is defined as the distance between the real and estimated position of a sensor node.

We use Matlab 7.0 to simulate the proposed algorithm. The sensor network is deployed in a 173*100m^2 area with 200 sensor nodes are uniformly distributed at random. The communication range of beacons and sensor nodes is an ideal circle with R=5m, 10m, 20m and 25m respectively.

In the RWP model, v_{min}=0.1m/s, v_{max}=Rm/s. In the straight line moving trajectory, the speed of beacons is (R/2)m/s, and the distance between two successive lines is (3R/2)m. The results of RWP model are averaged over 5 runs with 10 different run times, which are 1~10 minutes. When the localization method needs range between beacon and sensor node, there are 10% error to measure the distance.

We compare the three mobile beacons assisted WCL method with the four mobile beacons assisted centroid method [16], GMAN method [17], and the range-based trilateration method. For convenient, let TMB, FMB and TRI stand for the method proposed in this paper, the method proposed in [16], and the range-based trilateration method.

1) Number of localizable unknown nodes in one-hop. Fig. 1 illustrates the number of localizable sensor nodes in one-hop with RWP model as the moving trajectory. None of them can localize all the unknown nodes, but the TMB method localizes the most nodes under all conditions, and the TRI method localizes the least nodes. The other two methods, FMB and GMAN, localize approximately same nodes. For example, when R=25m and the localization methods run 10 minutes, TMB localizes 98.7% unknown nodes, while TRI only localizes 29.4% nodes. The ratios of localizable nodes with FMB and GMAN are 63.7% and 69.1% respectively.

Moreover, all of these four methods can localize more sensor nodes with longer run time and larger communication range. As an example, R=25m, TMB method only localizes 68.6% unknown nodes when it runs 1 minute, and it can localize 98.7% nodes when it runs 10 minutes. And the ratios of localizable nodes are 83.8%, 94.8%, 98.3% and 98.7% respectively, where R=5m, 10m, 20m, 25m and run time is 10 minutes.

The straight line covers the whole network deployment area, so all of the four methods localize all the sensor nodes.

2) Localization error. Table I shows the average localization error under RWP model and straight lines with difference communication range. With RWP model as moving trajectory, TMB has the minimal error, which is about 33% of TRI, and 50~70% of FMB and GMAN. Using straight lines as moving trajectory, TMB still has the minimal error. Comparing the errors with same localization method and different trajectory, we can find that the straight lines outperform RWP model.

References

[1] N.B. Priyantha, H. Balakrishnan, E.D. Demaine amd S. Teller, “Mobile-Assisted Localization in Wireless Sensor Networks,” Proc. IEEE International Conference on Computer Communications (INFCOM 2005), IEEE Press, March 2005, Vol. 1, pp. 172-183, doi: 10.1109/INFCOM.2005.1497889.

[2] K. Kim and W. Lee, “MBAL: A Mobile Beacon-Assisted Localization Scheme for Wireless Sensor Networks,” Proc. 16th International Conference on Computer Communications and Networks (ICCCN 2007), IEEE Press, 2007, pp. 57-62, doi: 10.1109/ICCCN.2007.4317797.

[3] J.M. Bahi and A. Makhoul, “A Mobile Beacon Based Approach for Sensor Network Localization,” Proc. 3rd IEEE International Conference on Wireless and Mobile Computing, Networking and Communications (WiMob 2007), IEEE Press, 2007, pp. 44-48, doi: 10.1109/ WIMOB.2007. 4390838.

[4] F. Zhao, H. Luo and Q. Lin, “A Mobile Beacon-assisted Localization Algorithm based on Network-Density Clustering for Wireless Sensor Networks,” Proc. 5th International Conference on Mobile Ad-hoc and Sensor Networks (MSN 2009), IEEE Press, 2009, pp. 304-310, doi: 10.1109/MSN.2009.12.

[5] Y. Ding, C. Wang and L. Xiao, “Using Mobile Beacons to Locate Sensors in Obstructed Environments,” Journal of Parallel and Distributed Computing, Vol. 70, 2010, pp. 644-656, doi: 10.1016/j.jpdc.2010.03.002.

[6] M.L. Sichitiu and V. Ramadurai, “Localization of Wireless Sensor Networks with a Mobile Beacon,” Proc. IEEE International Conference on Mobile Ad-hoc and Sensor Systems (MAHSS 2004), IEEE Press, 2004, pp. 174-183, doi: 10.1109/MAHSS.2004. 1392104.

[7] G. Sun and W. Guo, “Comparison of Distributed Localization Algorithms for Sensor Network with a Mobile Beacon,” Proc. IEEE lnlemationd Conference on Networking, Sensing & Control (ICNSN 2004), IEEE Press, 2004, pp. 536-540,doi: 10.1109/ICNSC. 2004. 1297496.

[8] F. Caballero, L. Merino, I. Maza and A. Ollero, “A Particle Filtering method for Wireless Sensor Network Localization with an Aerial Robot Beacon,” Proc. IEEE International Conference on Robotics and Automation (ICRA 2008), IEEE Press, 2008, pp. 596-601, doi: 10.1109/ROBOT.2008.4543271.

[9] A. Galstyan, B. Krishnamachari, K. Lerman and S. Pattem, “Distributed Online Localization in Sensor Networks Using a Moving Target,” Proc. 3rd International Symposium on Information Processing in Sensor Networks (IPSN 2004), IEEE Press, 2004, pp. 61-70, doi: 10.1109/IPSN.2004.1307324.

[10] E. Guerrero, H.G. Xiong, Q. Gao, R. Ricardo and J. Estévez, “ADAL: A Distributed Range-Free Localization Algorithm Based on a Mobile Beacon for Wireless Sensor Netwoks,” Proc. International Conference

on Ultra Modern Telecommunications (ICUMT 2009), IEEE Press, 2009, pp. 1-7, doi: 10.1109/ICUMT.2009.5345556.

[11] B. Xiao, H. Chen and S. Zhou, “Distributed Localization Using a Moving Beacon in Wireless Sensor Networks,” IEEE Transactions on Parallel and Distributed Systems,Vol. 19, 2008, pp. 587-600, doi: 10.1109/ TPDS.2007.70773.

[12] S. Lee, E. Kim, C. Kim and K. Kim, “Localization with a Mobile Beacon Based on Geometric Constraints in Wireless Sensor Networks,” IEEE Transactions on Wireless Communications,Vol. 8, 2009, pp. 5801-5905, doi: 10.1109/TWC.2009.12.090319.

[13] K.F. Ssu, C.H. Ou, and H.C. Jiau, “Localization With Mobile Anchor Points in Wireless Sensor Networks,” IEEE Transactions on Vehicular Technology, Vol. 54, 2005, pp. 1187-1197, doi: 10.1109/TVT.2005. 844642.

[14] B. Zhang, F. Yu and Z. Zhang, “A High Energy Efficient Localization Algorithm for Wireless Sensor Networks Using Directional Antenna,” Proc. 11th IEEE International Conference on High Performance Computing and Communications (HPCC 2009), IEEE Press, 2009, pp. 230-236, doi: 10.1109/HPCC.2009.15.

[15] G. Teng, K. Zheng and W. Dong, “Adapting Mobile Beacon-Assisted Localization in Wireless Sensor Networks,” Sensors, Vol. 9, April 2009, pp. 2760-2779, doi:10.3390/s90402760.

[16] R.K. Patro, “Localization in Wireless Sensor Network with Mobile Beacons,” Proc. 23rd IEEE Convention of Electrical and Electronics Engineers(EEEI 2004), IEEE Press, 2004, pp. 22-24, doi: 10.1109/ EEEI.2004. 1361078.

[17] B. Zhang, F. Yu and Z. Zhang, “Collaborative Localization Algorithm for Wireless Sensor Networks Using Mobile Anchors,” Proc. 2nd Asia-Pacific Conference on Computational Intelligence and Industrial Applications (PACIIA 2009), IEEE Press, Nov.2009, pp. 309-312, doi: 10.1109/PACIIA.2009.5406429.

[18] J. Blumenthal, R. Grossmann, F. Golatowski and D. Timmermann, “Weighted Centroid Localization in Zigbee-Based Sensor Networks,” Proc. IEEE International Symposium on Intelligent Signal Processing (WISP 2007), IEEE Press, 2007, pp. 1-6, doi: 10.1109/WISP.2007. 4447528

[19] J. Broch, D.A. Maltz, D.B. Johnson, Y.C. Hu and J.G. Jetcheva, “A Performance Comparison of Multi-hop Wireless Ad Hoc Network Routing Protocols,” Proc. ACM International Conference on Mobile Computing Networking (MOBICOM 1998), ACM Prress, 1998, pp. 85-97, doi: 10.1145/288235.288256.

[20] J. Yoon, M. Liu and B. Noble, “Random Waypoint Considered Harmful,” Proc. IEEE International Conference on Computer Communications (INFCOM 2003), IEEE Press, 2003,Vol. 2, pp. 1312-1321, doi: 10.1109/INFCOM.2003.1208967.

TABLE I. AVERAGE LOCALIZATION ERROR

R	**RWP Model**			
	TRI	***FMB***	***GMAN***	***TMB***
5m	47.03%	27.46%	27.07%	14.97%
10m	54.89%	26.71%	28.21%	19.26%
20m	48.55%	27.23%	29.45%	19.37%
25m	49.33%	30.85%	31.22%	25.99%
R	**Straight Line**			
	TRI	***FMB***	***GMAN***	***TMB***
5m	20.79%	27.99%	37.24%	18.72%
10m	19.77%	29.12%	39.51%	19.53%
20m	18.69%	27.30%	38.86%	20.20%
***R*=25m**	19.23%	28.43%	38.44%	20.66%

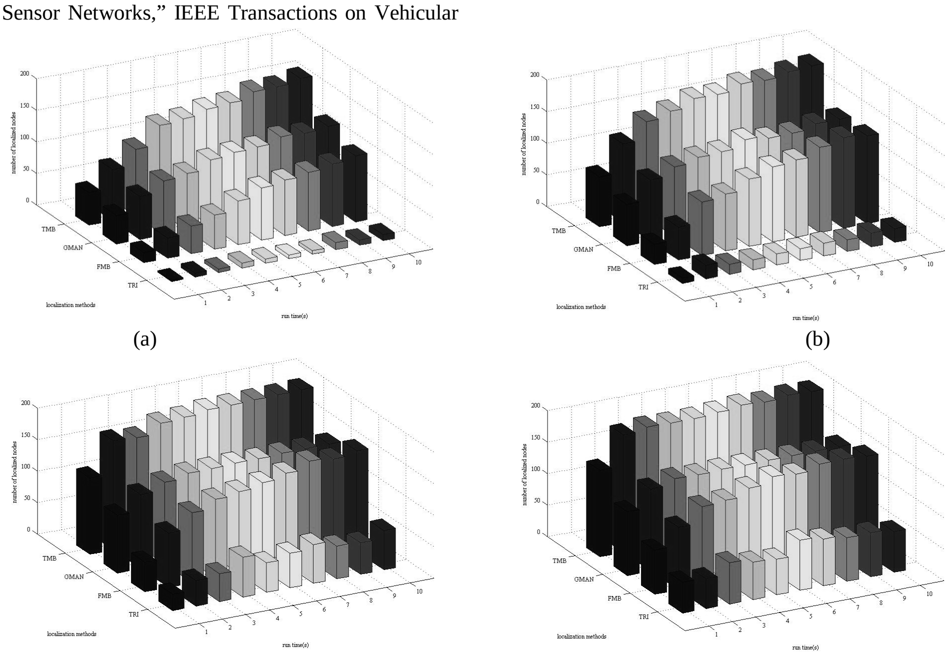

Figure 1. number of localized sensor nodes with different communicaiton range *R*. (a) *R*=5m; (b) *R*=10m; (c) *R*=20m; (d) *R*=25m.