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Research Article

On Location Estimation Methods for Mobile Wireless Sensor Nodes

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Abstract: This study presents an energy-efficient location estimation method aimed for mobile nodes in wireless sensor networks. The proposed method is a combination of two operations. Trilateration method is combined with a vector based incremental updates which is implemented by using a digital compass and a speedometer to estimate the location of the mobile node. This combined operation decreases the power consumed from the mobile node trying to locate itself. The proposed method has been implemented on an arduino-based mobile robot with wireless communication peripherals. The implementation shows that the location estimation accuracy is between 0.69-1.97 m from the actual location of the mobile node. The average location estimation error is comparable to other proposed methods for locating mobile sensor nodes. Based on the actual measurement of the test system, the energy consumption of the proposed method is 20% less than the trilateration method alone.

Keywords: Digital compass, energy, localization, trilateration, wireless sensor networks

INTRODUCTION

Localization of mobile nodes in Wireless Sensor Networks (WSN) is an important process as it reveals the location of the event of interest that is being monitored (Boukerche *et al*., 2007). Location estimation methods proposed for WSNs vary from hardware additions to the mobile node such as Global Positioning System (GPS) chip, to the utilization of range based location estimation methods such as trilateration and triangulation (Boukerche *et al*., 2007; Chan and Boon Hee, 2011).

Knowing the location of the deployed sensors can enhance the operation of the network. For example, routing efficiency can be improved by using the proximity information of neighboring nodes. The data transmission can then be deviated towards the destination node in question. An efficient and accurate location estimation method can improve the energy utilization of the mobile nodes because of the improved routing. Hence, the lifetime of these energy-constrained battery-operated mobile nodes can be improved (Chan and Boon Hee, 2011).

To address the energy consumption issue, this study proposes an energy efficient location estimation method aimed for mobile WSN nodes. The proposed method utilizes two main concepts of location estimation. First, trilateration is used to determine the initial location of the node; this requires three stationary beacon nodes with known locations. This is followed by incremental location updates based on the node's angle of movement (digital compass) and speed of movement (speedometer). Using vector mathematics, the next location update can be determined. Triangulation is performed periodically to reset the accumulated error introduced by the incremental location updates.

The results of this implementation show that the nodes consume 20% less power compared to trilateration alone as the source of rapid location estimation. The location estimation error is between 0.69-1.97 m from the actual location which is comparable to the accuracy reported in Amundson *et al*. (2011) and Kim and Choi (2008).

LITERATURE REVIEW

Localization for WSNs is an active field and has gained immense interest by researchers. Location estimation method can use hardware attachment (Boukerche *et al*., 2007) such as a GPS module. GPS modules consumes high amount of energy. If the location is frequently required, it can reduce battery lifetime for the deployed nodes. In addition, GPS modules cannot work indoors.

Other approaches for estimating the node's location is by utilizing range based methods. Time of Arrival (TOA) is an example of range based location estimation method (Guvenc and Chia-Chin, 2009). TOA utilizes two types of signals transmitted between

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two nodes. From the time of arrival of each signal, the node can then estimate its current location. TOA is another example of augmenting hardware modules to perform specific tasks to estimate the required location. There can be different types of signals used for example microwaves, acoustic waves or light waves. Each signal type requires a specific hardware to be embedded in the node.

Another approach is Angle of Arrival (AOA) (Amundson *et al*., 2011). Location estimation using AOA method depends on the angle of signal's arrival. The node can be equipped with hardware modules as in TOA. Using one type of signal requires the addition of special beacon nodes. Beacon nodes have fixed locations; they periodically transmit signals toward the mobile wireless node. The mobile node can then estimate its distance from the signal originating beacon (s). Such methods that utilize this technique are trilateration (Boukerche *et al*., 2007) and triangulation (Chan and Boon Hee, 2011; Mao *et al*., 2007). These methods use RF signals as the distance estimator. Using one specific distance estimator makes the location estimation method cheaper because of the reduced hardware requirement. Trilateration requires the availability of the distances from the beacon nodes and their actual location to estimate the mobile node's current location.

Other systems proposed the usage of other types of signals like laser-beam signals or acoustic waves signals (Boukerche *et al*., 2007) because the equipment that produces such signals consumes less power than GPS modules. A study on joint RSS-based estimation of unknown location coordinates was performed by Xinrong (2006). The results of the study show the possible errors of distance calculation if the RF value is dependent on RSSI. An extended work done by Xinrong (2007), investigates the usage of RSSI in a collaborative localization method which merges the operation of two localization algorithms called the Multidimensional Scaling (MDS) and Maximum-Likelihood Estimator (MLE). The result is an algorithm of collaborative approach that has the strength of both methods to avoid the inherent signal-modeling error in MDS method. The method is suitable for stationary WSN deployment. Cooperative localization examples can be followed by the following proposed methods in Xinrong (2007), Win *et al*. (2011) and Jingjing *et al*. (2011).

Mao *et al*. (2007), also indicated the easiness of using and implementing RSSI as a distance estimator with precautions as the error produced by the estimation is dependent on the propagation model used in the calculations. The field of RF estimation has tremendous number of proposals because of their availability in implementation (e.g., the wireless interface of the node) than other types of signals (Paul and Wan, 2009; Jingjing *et al*., 2011).

Acoustic waves were proposed as an alternative for RF signals and an example of using these signals is implemented by Kim and Choi (2008). They implemented an indoor localization system that utilizes acoustic wave as distance estimators of the nodes from the beacon point. The system is aided by a digital compass to determine the direction of the mobile object. Because the environment is indoor, the system implements a band-pass filter to avoid the noisy effect that the acoustic waves can produce in indoor location.

Sun *et al*. (2011) proposed Cortina, an indoor localization system that utilizes both RSSI and Rtof-based (Round-trip Time-of-Flight) techniques to estimate the required distances. Various algorithms were applied to override the multi-path problem; the complex calculation can result in high power consumption for the wireless node. Indoor location estimation caught high interest in the field of indoor sensor networks because of the challenges that come with such environment. A proposal to improve the RSS estimation by Jie Yang (2011) implements two methods to achieve accurate signal propagation; regression-based and correlation-based. The proposed methods are aimed for indoor environments.

Oberholzer *et al*. (2011) is a location estimation system proposed for WSN which includes the information of both distance and the angle of sensor node by using ultrasound-based transmitter and receivers in all compass directions. The node is also equipped with a digital compass to indicate the direction of the node. By collecting the information from both sources, it is possible to calculate the location of the required node. The system requires one anchor node to operate. It also requires the nodes to be equipped with two types of modules: the ultrasound transmitters and the digital compass. The node can consume high power depending on how frequent the location information is required.

Chia-Ho (2011), proposed a localization method for WSN using mobile anchor nodes. Each anchor node is equipped with four directional antennas, digital compass and a GPS module. The anchor node roams around the deployed stationary sensors and through sending beacon messages, the receiving node would be able to determine their coordinates according the sender antenna of the anchor node. The method aims to be efficient in power consumption of the nodes and low location estimation error. The directional antenna based mobile or stationary anchor localization scheme is highly proposed in this research area as several works described by Baggio and Langendoen (2008), Khan *et al*. (2009) and Chia-Ho (2011).

Triangulation needs the same type of information as in trilateration. Rather than finding circles intersection point as in trilateration, triangulation forms triangles to estimate the node(s) location. An implementation done by Amundson *et al*. (2011), proposed a localization approach for mobile WSN by using AOA. The sensor nodes are equipped with a digital compass to assist the localization of mobile nodes; however, it is not a crucial part of the localization process. The proposed method requires the anchor nodes to have an array of nodes; one is the primary node and two more assisting nodes are combined together to make one anchor node. The mobile node performs regular localization using AOA. The rapid change in mobile node position increases the request for triangulation location estimation process which leads to high power consumption on the sensor node's behalf. The speeds of mobility in the performed simulations are between 100 and 400 mm/sec. The recorded location error average is 0.95 m.

Another method (Kim and Choi, 2008) proposes indoor location estimation for wireless nodes using ultrasonic sensors and a digital compass. The ultrasonic sensors are used to perform the localization process. The digital compass is only used as in Amundson *et al*. (2011) to retrieve the orientation of the node's movement. The movement speed applied is 0.2 radians/sec (0.1 and 0.2 m/sec for 0.5 m radius and 1 m radius movements). The main issue that the proposed location estimation methods did not present is energy consumption. The methods presented by Kim and Choi (2008) and Amundson *et al*. (2011) did not include energy analysis. Another complementary issue is mobility speed. Estimating nodes location for a higher mobility speed can enlarge the scope of applications to suit a normal human walking-pace which averages at 1 m/sec.

This study proposes a location estimation method aimed for mobile WSNs. The method utilizes the concept of trilateration and the nodes are equipped with digital compass. The method has been implemented using simulations in Al-Jemeli *et al*. (2012). The nodes can retrieve their relative movement speed by a speedometer attached to the mobile part of the node. The following sections explain the proposed methodology.

PROPOSED METHODOLOGY

The proposed location estimation method is based on two aspects merged together to determine the location of the mobile node (s). The first is trilateration. Trilateration requires the availability of beacon nodes provided that their own exact locations are known (Fig. 1). The location of the unknown node is found by finding the intersection of the three circles.

In Fig. 1, the beacon nodes are N_1, N_2 and N_3. Their actual locations are $(X_1, Y_1), (X_2, Y_2)$ and (X_3, Y_3) (assuming Cartesian plane). Their distances from the unknown node $N\ (X_N, Y_N)$ are represented by R_1, R_2 and R_3 in Eq. (1)-(3):

$$\left(X_1 - X_N\right)^2 + \left(Y_1 - Y_N\right)^2 = R_1^2 \quad (1)$$

$$\left(X_2 - X_N\right)^2 + \left(Y_2 - Y_N\right)^2 = R_2^2 \quad (2)$$

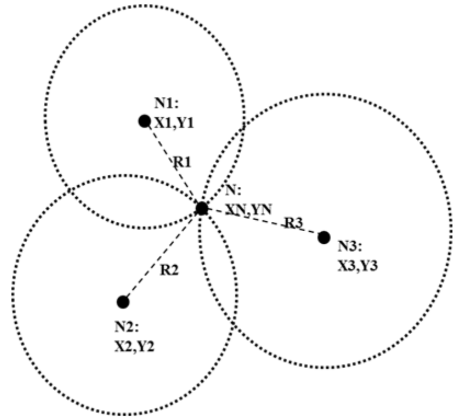

Fig. 1: Trilateration

$$\left(X_3 - X_N\right)^2 + \left(Y_2 - Y_N\right)^2 = R_3^2 \quad (3)$$

The distances from the beacons are estimated by utilizing the Received Signal Strength Indicator (RSSI) from the wireless interface of the node. In this implementation, the free-space model is used to estimate the distances:

$$R = \sqrt[2]{(P_t G_t G_r \lambda^2 \ /\ ((4\pi)^2 P_r\ L))} \quad (4)$$

where,
P_t = The transmission power
P_r = The received power (from converting RSSI dB value to its W value)
G_t, G_r = Antennas gains for both transmitter and receiver
λ = The wave length
L = System loss

After the first location is determined using trilateration, the location is updated using compass (direction of movement, θ) and speedometer (velocity, V), which are more energy-efficient than RSSI-based trilateration method. The location update is determined by using vectors as in Fig. 2. The resulting equations are given in (5) and (6):

$$X_D = X_N + Sin\,(\theta) \times V \times (t_1 - t_2) \quad (5)$$

$$Y_D = Y_N + Cos\,(\theta) \times V \times (t_1 - t_2) \quad (6)$$

where,
X_N, Y_N = The location of the mobile node
X_D, Y_D = The updated location
t_1 = Time of the previous location update
t_2 = The current time

The location estimation works as follow:

- The first location of the mobile node is established from stand still or on the move using trilateration

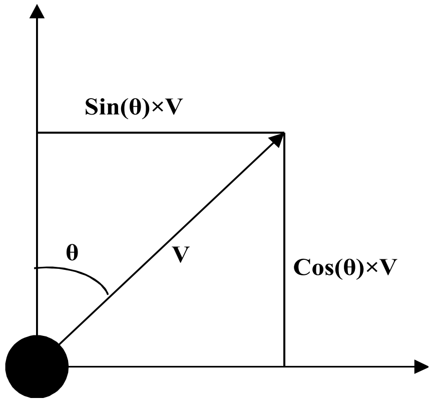

Fig. 2: Vector update process

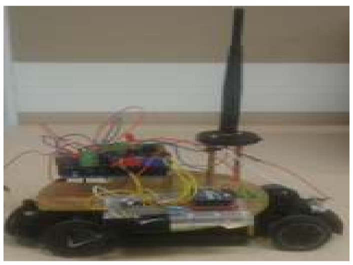

Fig. 3: Wireless mobile node device

(in the implementation process, the first location is obtained when the mobile node was stationary).

- The location update is done by utilizing the compass and speedometer readings.
- A periodic trilateration is done for the system to minimize the error generated by location updates.

The advantage of using such composition is to minimize the energy consumption of the mobile node when calculating its current location as the digital compass draws less power than the wireless interface attached to the node. Compass however has an intrinsic error when providing the angle of movement for the mobile node. This is why a trilateration process for the node is done periodically. Distance estimation in trilateration uses RSSI value, which is error prone and can sometimes be unreliable. The reliability is dependent on the equipments used and the deployment environment. This issue increases the challenge in estimating the node (s) location.

Equipments used: The mobile wireless node used in the case study is a remote control toy car attached to a processing unit and a wireless interface. The processing unit is an Arduino Uno board that can run at 16 MHz and has a memory of 32 KB. The wireless interface is a series 1 MaxStream XBee module with 1 mW (0 dBm) transmission power attached to a 5 dB antenna (Fig. 3). The wireless node is also equipped with SparkFun HMC 6352 two-axis digital compass with non-tilt compensation. The speedometer circuit is custom made using an IR transmitter diode and a receiver diode attached to debouncing circuit to count the number of rotations that the toy car wheel made in a period of time. The beacon nodes are equipped the same XBee modules. Each beacon node is attached to a 7 dB antenna. The implementation space has an area of 6×6.5 m where two beacons are placed on the edges and one is placed in the middle of the x-axis of the implementation plane (Fig. 4). Two mobility scenarios

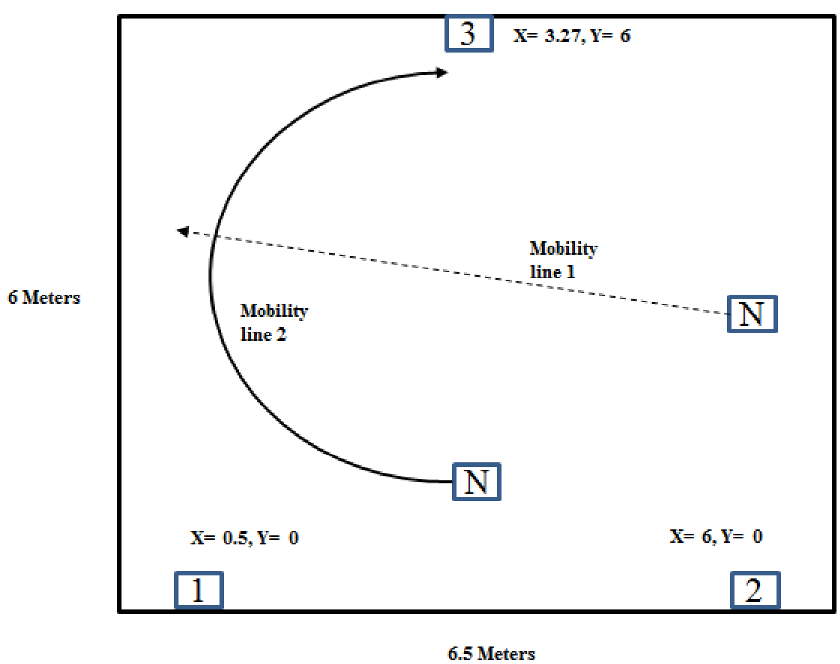

Fig. 4: Implementation scenarios and area

where tested-a straight line 5-m movement and a half circle mobility for a distance of 7 m.

IMPLEMENTATION AND RESULTS

Location estimation validation and results: The advantage of using trilateration as location estimation process is its cost effectiveness because it utilizes the RSSI from the wireless modules implemented. However, RSSI indicator can be erroneous depending on the situation of the mobile device. When the wireless node is moving, the process of estimating the distance becomes very erroneous because of RSSI readings. This effect highly on the quality of the trilateration results as shown in Fig. 5. To decrease the estimation error, a solution has been proposed. Because of the nature of wireless propagation, reflections and refractions attenuate the received power. Theoretically, the signal with the straight line transmission should have the highest level of received power. To employ this, the RSSI filtering is done by sending 10 packets (each separated by a period of 3 msec) from each beacon nodes. The mobile node then performs a search process for the highest received RSSI value and then implements it in the distance estimation formula. The advantage of this process is the location estimation error is lower than the original trilateration process. However, because there is a search process, it adds delay to the location estimation which resulted in less location points.

Figure 6 shows the results of trilateration+location updates using compass and speedometer (the solid line). It is observed that the location estimation is very sensitive to random compass errors. To minimize this irregular error, aluminum based thin shield is used to wrap the compass module to decrease the magnetizing effect of the components surrounding it. In addition, a software based low pass filter is applied to the compass readings to minimize the sudden over shoots in angle estimation. The filter takes the average of two readings and the latest reading is compared to the average. If the difference between the calculated average and the new

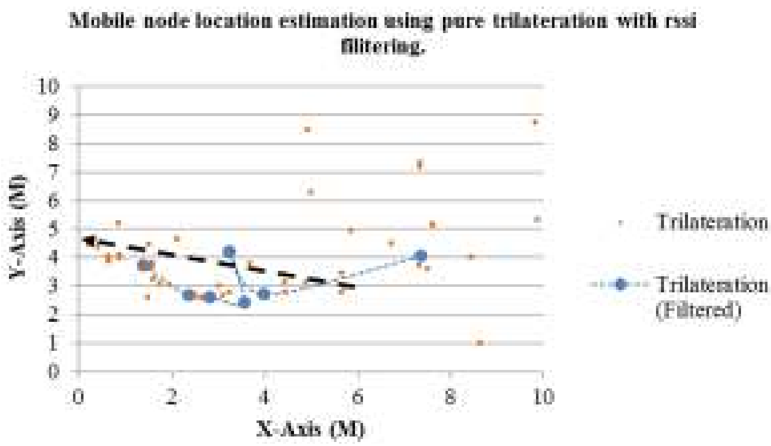

Fig. 5: Location estimation performance for trilateration and trilateration (filtered). The black dashed arrow is the actual movement trace-line

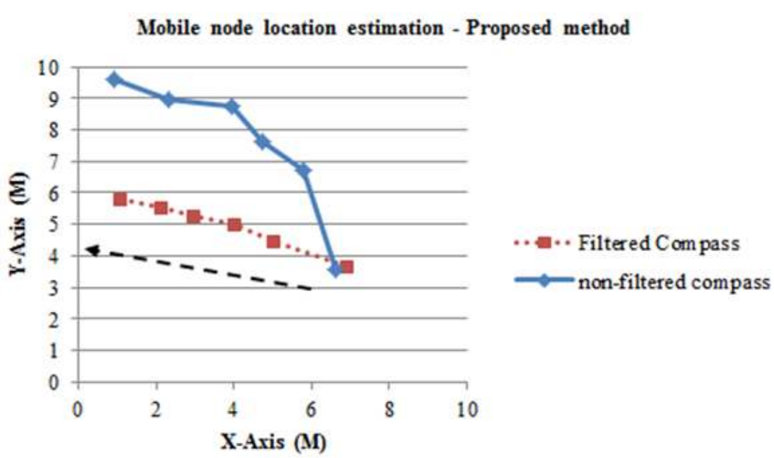

Fig. 6: Mobile node location estimation using proposed method (trilateration and compass/speedometer combination) straight movement. The filtered compass represents the implementation of the metal shielding plus the software low pass filter

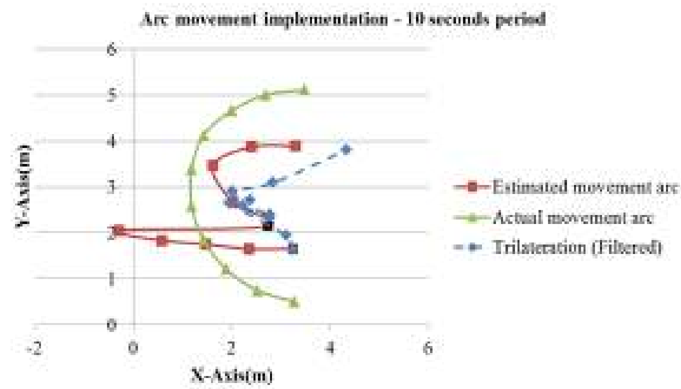

Fig. 7: The proposed method performance for several trilateration processes

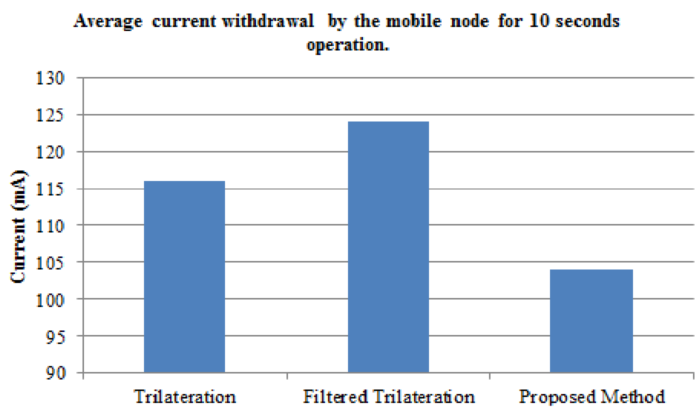

Fig. 8: Current withdrawal by the mobile node for the methods discussed

Table 1: The proposed location estimation method against other proposals in the literature

Localization method parameters	Isaac (Amundson *et al*., 2011)	Trilateration (Lee *et al*., 2008; Chen and Li, 2007)	Proposed localization method
Mobile node speed	0.1 and 0.4 m/sec	0.6 and 1 m/sec	0.6 and 1 m/sec
Location estimation average error	0.95 m from actual location	1.52 m from actual location	0.6-1.97 m from actual location
Power consumption	The author did not specify	123 mA	104 mA

reading is above 5° (which is the threshold used in the implementation), then the node will take the average reading as the direction value. Else the node will use the new direction reading. After implementing the shield and the filter, the estimated location became more stable and the location estimation error has a behavior of an incremental offset (the dotted line).

Figure 7 shows the result of the implementation of the proposed method in half-circle mobility scenario. The average location estimation error of the proposed method is 1.23 m. While the average error of trilateration (filtered) is 1.52 m. The node's velocity varies between 0.6-1 m/sec. Table 1 compares the proposed method location estimation against other methods in the literature.

Energy consumption evaluation: To measure the energy consumption, the mobile node is deployed without movement and the supply current drawn by the system (excluding the drive systems) is measured using a multi-meter during this period, the mobile node continuously performs trilateration, compass/speed detection, location update calculations by the Arduino microcontroller. The results are shown in Fig. 8.

From Fig. 8, it is possible to observe that the proposed method improved the system current consumption by 20% less from filtered trilateration and about 16% from regular trilateration.

CONCLUSION

This study proposed and energy efficient location estimation method aimed for mobile WSNs. Through the process of implementation, several issues where raised that can effect on the quality of location estimation. The first is the quality of RSSI reading when the wireless node is moving. The tests show that mobility can increase the irregularities in RSSI readings and the error of compass reading when the node is moving. The first issue is overcome by introducing a filtering process that acquires only the signal with the highest received power. The second issue was overcome by applying a low pass filter to remove sudden large compass deviations and by covering the compass module with thin aluminum shield to minimize the electromagnetic effect of other components. The results show the potential of the proposed method in terms of location estimation and better energy consumption at a mobility speed of 0.6-1 m/sec.

REFERENCES

Al-Jemeli, M., F.A. Hussin and B.B. Samir, 2012. An energy efficient localization estimation approach for mobile wireless sensor networks. Proceeding of the 4th International Conference on Intelligent and Advanced Systems (ICIAS, 2012). Kuala Lumpur, 1: 301-306.

Amundson, I., J. Sallai, X. Koutsoukos, A. Ledeczi and M. Maroti, 2011. RF angle of arrival-based node localisation. Int. J. Sens. Netw., 9: 209-224, Doi: 10.1504/ijsnet.2011.040241.

Baggio, A. and K. Langendoen, 2008. Monte Carlo localization for mobile wireless sensor networks. Ad Hoc Netw., 6(5): 718-733.

Boukerche, A., H.A.B. Oliveira, E.F. Nakamura and A.A.F. Loureiro, 2007. Localization systems for wireless sensor networks. IEEE Wirel. Commun., 14(6): 6-12.

Chan, Y.W.E. and S. Boon Hee, 2011. A new lower bound on range-free localization algorithms in wireless sensor networks. IEEE Commun. Lett., 15(1): 16-18.

Chen, W. and X. Li, 2007. Sensor localization under limited measurement capabilities. IEEE Network, 21: 16-23.

Chia-Ho, O., 2011. A localization scheme for wireless sensor networks using mobile anchors with directional antennas. IEEE Sens. J., 11(7): 1607-1616.

Guvenc, I. and C. Chia-Chin, 2009. A survey on TOA based wireless localization and NLOS mitigation techniques. IEEE Commun. Surv. Tutorial, 11(3): 107-124.

Jie Yang, Y.C., 2011. Improving localization accuracy of RSS-based lateration methods in indoor environments. Ad Hoc Sens. Wirel. Ne., 11(3/4): 307-329.

Jingjing, G., C. Songcan and S. Tingkai, 2011. Localization with incompletely paired data in complex wireless sensor network. IEEE T. Wirel. Commun., 10: 2841-2849.

Khan, U.A., S. Kar and J.M.F. Moura, 2009. Distributed sensor localization in random environments using minimal number of anchor nodes. IEEE T. Signal Proces., 57: 2000-2016.

Kim, H. and J.S. Choi, 2008. Advanced indoor localization using ultrasonic sensor and digital compass. Proceeding of the International Conference on Control, Automation and Systems (ICCAS, 2008). Seoul, pp: 223-226.

Lee, K.W., J.B. Park and B.H. Lee, 2008. Dynamic localization with hybrid trilateration for mobile robots in intelligent space. Intell. Serv. Robot, 1: 221-235.

Mao, G., B. Fidan and B.D.O. Anderson, 2007. Wireless sensor network localization techniques. Comput. Netw., 51: 2529-2553.

Oberholzer, G., P. Sommer and R. Wattenhofer, 2011. SpiderBat: Augmenting wireless sensor networks with distance and angle information. Proceeding of the 10th International Conference on Information Processing in Sensor Networks (IPSN, 2011). Chicago, IL, pp: 211-222.

Paul, A.S. and E.A. Wan, 2009. RSSI-based indoor localization and tracking using sigma-point Kalman smoothers. IEEE J. Sel. Top. Signa., 3(5): 860-873.

Sun, Z., R. Farley, T. Kaleas, J. Allis and K. Chikkappa, 2011. Cortina: Collaborative context-aware indoor positioning employing RSS and RToF techniques. Proceeding of the 9th Annual IEEE International Conference on Pervasive Computing and Communications (PerCom, 2011). Seattle, WA, USA, March 21-25, pp: 340-343.

Win, M.Z., A. Conti, S. Mazuelas, Y. Shen, W.M. Gifford, D. Dardari and M. Chiani, 2011. Network localization and navigation via cooperation. IEEE Commun. Mag., 49(5): 56-62.

Xinrong, L., 2006. RSS-based location estimation with unknown pathloss model. IEEE T. Wirel. Commun., 5: 3626-3633.

Xinrong, L., 2007. Collaborative localization with received-signal strength in wireless sensor networks. IEEE T. Veh. Technol., 56: 3807-3817.