A Survey of Localization using RSSI and TDoA Techniques in Wireless Sensor Network: System Architecture

Nur Aisyah Azmi, Shafiqa Samsul, Yoshihide Yamada, Mohd Fitri Mohd Yakub
Department of Electronic System Engineering (ESE),
Malaysia - Japan International Institute of Technology,
University Teknologi Malaysia Kuala Lumpur,
Jalan Sultan Yahya Petra,
54100 Kuala Lumpur, Malaysia
aisyah.azmi@yahoo.com, shafiqasamsul@gmail.com,
yoshihide@utm.my, mfitri.kl@utm.my

Mohd Ismifaizul Mohd Ismail, Rudzidatul Akmam Dziyauddin
Ubiquitous Broadband Access Networks Research Group,
Razak School of UTM in Engineering
and Advanced Technology,
University Teknologi Malaysia Kuala Lumpur,
Jalan Sultan Yahya Petra,
54100 Kuala Lumpur, Malaysia
ismifaizul@gmail.com, rudzidatul.kl@utm.my

Abstract—In the new global economy, localization study has become a central attraction for tracking objects, such as children, pets or assets located either indoor or outdoor environment. The object environment somehow has a significant effect to the degree of the accuracy offered by the localization algorithms. This paper initially reviews localization techniques that are broadly categorized into two sub-categories, which are range-based and range-free techniques. In addition to that, three main algorithms used in localization, which are trilateration, multilateration and triangulation, and also the wireless technologies employed are also discussed. Referring to the previous literature, this paper proposes for the localization a design architecture of transmitter and receiver using long range (LoRa). The proposed system can be used to develop for a small low-cost low-power LoRa tracking device without global positioning satellite (GPS).

Index Terms—WSN, WBSN, Dumb node, Beacon node, WSN localisation,

I. Introduction

Localization study has been a trend in finding and estimating a node [1]. GPS is one of the straight forward method to obtain localization position, but requires direct line of sight (LOS). It seems unfeasible to be implemented for shadowing environment [2]. Various applications [3] such as missile guidance systems, habitat monitoring, medical diagnostics and objects tracking employed wireless sensor localization. Fig. 1 shows the localisation methods taxonomy. Localization can be divided into two subcategories, which are target localization and node self-localization. Target localization estimates the target position from multiple noisy sensor measurement [4]. In target localization, we can classify into two techniques:
(i) single target localization (ii) multiple target localization. Meanwhile, node self-localization categorized into range-based and range-free algorithms [3]. Range-free is a method that determine node position merely by finding the beacon nodes in its proximity, which the methods are namely centroid, DV-hop and geometry conjecture techniques. The other node self-localization is range-based includes several techniques: (i) received signal strength indicator (RSSI), (ii) angle of arrival (AoA), (iii) time of arrival (ToA), and (iv) time difference of arrival (TDoA).

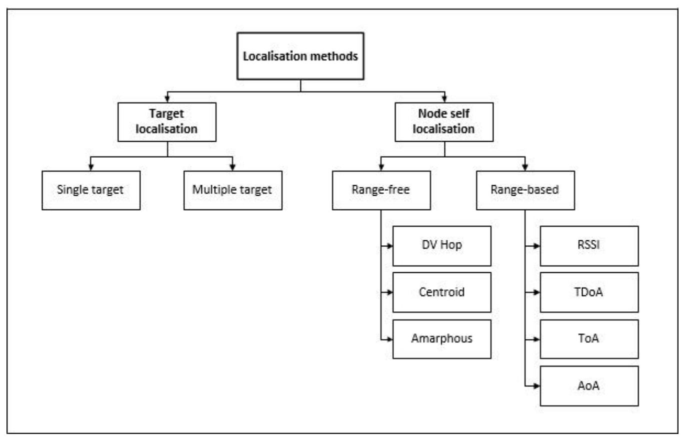

Fig. 1. Localisation methods taxonomy

The main objective of this paper is to review previous localization techniques using RSSI and TDoA. The reason of choosing RSSI because the hardware is simple and low cost. Meanwhile, the advantage of TDoA over ToA is that the former does require knowledge of the time at a transmission at the non-line of side (NLOS). Furthermore, TDOA-based localization technique requires synchronization between base stations in order to improve the accuracy of localization. The main contribution of this paper is the design and development of WSN localisation system, which are connected to wireless LoRa transceiver module. The proposed design can be developed for small low-cost low-power LoRa tracking device later.

This work is supported by the Universiti Teknologi Malaysia under PAS, with cost center no Q.K130000.2740.00K70.

Section II is discusses the wireless sensor node (WSN) localisation technique. The localisation algorithm for RSSI and TDoA is explained in Section III. Then, Section IV discusses the wireless sensor network (WSN) technology applied in localisation method. The system design and architecture is explained in Section V. The system block diagram and process flow for WSN development are described in Section VI and VII. Section VIII concludes this paper.

II. A Review of Localization Techniques

Recently, the study of localization in wireless sensor net-works, target localization and node self-localization play vital role in node positioning. A node self-localization can be broadly categorised into range-free and range-based methods. This paper highlights the range-based, which are RSSI, AoA, ToA and TDoA for WSN localization and positioning. The advantages of node self-localization which are dumb node, settled node, and beacon node are cost-efficient, easily deployed and low power consumption. Dumb node is a node that does not know its position and eventually find its location and position from the output of localization algorithm, meanwhile settle node is a node that managed to find its position using the localization algorithm and initially known as dumb. Beacon node is a node that can recognize its position without use of localization algorithm [10]. However, self-node localization methods have high accuracy and required additional hardware.

Table I compares range-based techniques and range-free techniques in node localization. Refer to the table, only RSSI does not require special hardware and low in cost, but attenuation occurs. In addition, AoA has high cost due to antenna array required in this technique [5]. On the other hand, ToA and TDoA techniques have medium cost due to the cost is lower than AoA but higher than RSSI. In addition, it has low attenuation problem despite that both require special hardware in the localization process. These two techniques costly compared to RSSI because it requires accurate sensors to obtain accurate clock.

Next, the range-free techniques include DV Hop, Centroid and Amorphous algorithms without requiring special hardware because the operating cost is low although all of them have high attenuation problem in localization.

A. Received Signal Strength Indicator (RSSI)

RSSI is one of the range-based techniques in localization. RSSI is categorized as range-based techniques because it is based on signal attenuation. Normally, it uses trilateration algorithm to find the position or location of an anchor or target node. RSSI techniques do not require external or additional hardware to perform localization. Thus, it become less costly. However, there are some errors during the distance estimation due to the inconsistency in Radio Frequency (RF) signal propagation. The other factors that influence the RSSI calculation are multipath fading, shadowing effects and attenuation of signals [1]. There will be significant shadowing errors when there are obstacles present.

TABLE I
Comparison of WSN Localization methods

	Principal of Operation	Special Hardware	Attenuation problem	Cost
Range-based techniques				
RSSI [1]	Signal strength measurement	Not required	High	Low
AoA [5]	Angle of signal arrival	Required	Medium	High
ToA [5]	Time of arrival	Required	Low	Medium
TDoA [6]	Time difference in propagation at different points	Required	Low	Medium
Range-free techniques [10]				
DV Hop	Heterogenous network that consists of sensing nodes and anchors	Not required	High	Low
Centroid	Use anchor beacons containing (Xi, Yj).	Not required	High	Low
Amorphous	Takes different approach from DV-Hop for average single hop.	Not required	High	Low

Fig. 2 illustrates how RSSI in localization using trilateration algorithm. The dumb node and beacon node are deployed by using trilateration algorithm to determine the position of a target node. In trilateration at least three transmitters are required to calculate the position. The intersection of three circles around the beacon yields that gives a point indicates the position of the transmitter node [15].

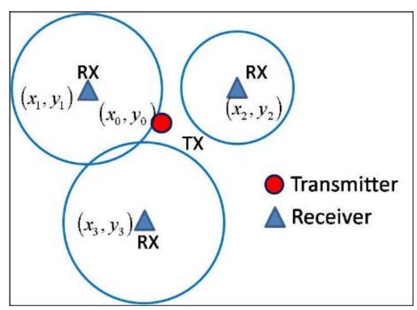

Fig. 2. RSSI in localization using trilateration technique [6]

Table II compares the RSSI-based algorithms for WSN localisation system. Furthermore, RSSI has several algorithms: (i) Min-Max, (ii) Multilateration, (iii) Maximum Likelihood, (iv)Ring Overlapping based on Comparison of Revived Signal Strength Indicator (ROCRSSI). Min-Max is one of the RSSI-based algorithms, it offers simplicity of implementation. The accuracy of min-max algorithm is dependent on the intersection area, which the smaller area increases the accuracy of sensor node location. While, the multilateration algorithm is a simple algorithm in localising the sensor node.

However, this algorithm is slightly complex compared to min-max algorithm. The benefit of the multilateration algorithm gives better performance beside implemented sophisticatedly. The Maximum likelihood is rather complex compared with multiliteration, however this algorithm minimizes the variance of error estimation. Finally, ROCRSSI algorithm has high complexity as a trade-off to good performance achieved.

TABLE II
RSSI-BASED ALGORITHMS COMPARISON

Algorithm	Complexity	Accuracy	Error
Min-Max [4]	Low	Low	Low
Multilateration [5]	Medium	Medium	High
Maximum Like-lihood [6]	High	High	Low
ROCRSSI [6]	High	Medium	Medium

B. Time Difference of Arrival (TDoA)

The TDoA is one of the most well-known methods to perform WSN localization. This method conducted by simple measure the distance between two nodes by analysing the time difference of the anchor and beacon nodes. The method can be divided into two categories, which are multi-signal and multi-node TDoA. The multi-signal TDoA uses a signal transmitted from nodes by measuring time of arrival (ToA) between dumb and beacon nodes. Meanwhile, the multi-node TDoA requires at least three beacon nodes for the time synchronisation. The multi-node of TDoA is shown in Fig. 3. The intersection of the hyperbola on indicates the node location S.

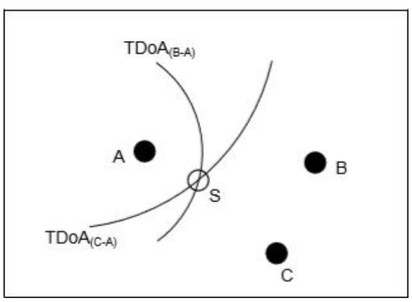

Fig. 3. Multi-node of time difference of arrival [6]

However, the multi-signal TDoA does not require beacon nodes to transmit at the same time. The TDoA requires additional hardware to estimate its distance from another node, as shown Fig. 4. The TDoA method will measure the distance between receiver and transmitter. The transmitted signal will be delayed based on the distance between transmitter and receiver.

In TDoA technique, several studies have shown different algorithms achieve certain accuracy degree of identifying the node position Table III. Component TDoA algorithm namely (i) approximate maximum like hood, (ii) Taylor series, (iii) two-stage maximum like hood, (iv) genetic algorithms. The performance of the algorithmsrely on the network topology and the position of the target node [12]. Meanwhile, AM,

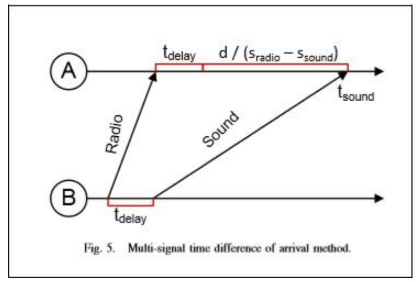

Fig. 4. Multi-signal of time difference of arrival [6]

AML, and GA algorithms have high complexity in computation but perform high accuracy in node positioning. From the table, TSML algorithm performs medium in complexity with medium accuracy.

TABLE III
TDOA ALGOITHMS COMPARISON [12]

Methods n Characteristics	Complexity	Accuracy	Error
Analytical method (AM)	Low	Low	Low
Approximate Maximum Likehood (AML)	High	High	Low
Taylor Series (TS)	High	High	Low
Two-stage max-imum likehood (TSML)	Medium	Medium	Medium
Genetic (GA)	Low	High	Lowest

III. LOCALISATION ALGORITHMS

In order to determine the node position, algorithm is essential in the position computation. There are three main algorithms in node localization techniques, namely trilateration, triangulation and multilateration.

A. Trilateration

Trilateration algorithm formed based on distance measurement between each node which consists of beacon node and target node, as shown in Equation (1). This technique mostly applied in RSSI. The operation resumes when a beacon node broadcasts a signal that is received by the transceiver circuitry and passes send the RSSI is used to determine the power of the received signal.

$$P_r(d) = \frac{P_t\, G_t\, G_t\, \lambda^2}{(4\pi d)^2} \qquad (1)$$

where p_t = transmitted power, G_t = transmitter antenna gain, G_r = receiver antenna gain, and = wavelength of the transmitter signal in meters.

B. Triangulation

Trigonometry laws of sine and cosine used to calculate the nodes position from angle estimated. Fig.5 shows triangulation technique conducted based AoA.

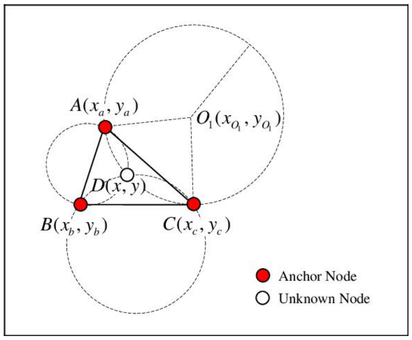

Fig. 5. Triangulation technique [6]

C. Multilateration

This algorithm is applied in the in-distance estimation techniques and ultrasound signal is used. More than three nodes are used consisting of beacon node and receiver nodes. Anchor node sends signal and the beacon node will receive the signal at time, t_{delay}. The signal transferred will be received by receiver nodes at t_{radio} time. Then, beacon node saves time t_{sound} once received the chirp sound from the beacon node. The receiver nodes use this information time to calculate the distance between beacon and itself by using Equation (2).

$$d = (S_{radio} - S_{sound}) \times (t_{sound} - t_{radio} - t_{delay}) \quad (2)$$

d is distance between beacon and anchor node, S_{radio} is signal radio on the air, S_{sound} is signal sound on the air, t_{delay} is time received at beacon node, t_{radio} is time transmitted at anchor node and t_{sound} is beacon node save the time receiving data. Speed of propagation of the sound wave (343m=s) and the speed of the propagation of the signal ($3x10^5$km=s).

IV. Wireless Transceiver Technologies

Wireless sensor network is an ad-hoc network that used to perform various monitoring tasks by deployed randomly in different environments [1]. The definition of wireless sensor network is a device for transmitting data from the sensor node to the base station using wireless radio networks. There are several types of wireless sensor network, such as classic Bluetooth, Bluetooth low energy (BLE), WiFi, ZigBee, General Packet Radio Service (GPRS), LoRa and SigFox. Table IV compares the wireless sensor network technologies.

The classical bluetooth uses 2.4 Ghz and a medium power consumption, which is 250 mW. However, the limitation of this device is short communication, range for sending and receiving data in 10 to 50 meters. In contrast, LoRa has low in power consumption and long communication range. The frequency of LoRa is 869 to 915 MHz, and it is also low in cost. LoRa is suitable to be implemented in agriculture, smart grid, environment control and lighting control. Next is WiFi, the communication range between 32m to 92m generally , but it uses high power consumption and long access time. The other wireless communication technologies are ZigBee, the frequency less used can be 868MHz, 915MHz or 2.4GHz. The power consumption for ZigBee is low and the communication range is very short in distance. The limitation of ZigBee is, line-of-sight (LOS) between the sensor node and the coordinator must be available. Finally, GPRS has the frequency of 900-1800MHz and has wide communication range which are 1 to 10 km. The main concern of GPRS is the power consumption problem.

V. System Design and Architecture

In localization process, at least a transmitter and three receivers are required to obtain high chance accuracy of node position. The hardware must be designed in Proteus software beforehand. The receiver component is combined with (i) GPS module, (ii) Secure Digital (SD) card, (iii) Arduino Nano (iv) OLED display (v) LoRa module, (vi)Real Time Clock (RTC). LoRa module acts as a wireless network technology to transmit the data between neighbouring nodes. On the other hand, the transmitter are equipped with similar components without GPS module. Design an architecture of receivers for localization sensor node is illustrated in Fig. 6.

VI. System Block Diagram

A block diagram of the wireless sensor device system used in this study is illustrated in Fig. 7. Three main components, namely, sensors, controller board, LoRa wireless transceiver module are employed in the WSN localisation system. The sensor nodes are developed with three sensors (which are compass, GPS and RTC), storage data (SD card) and controller board. The sensor node connected to LoRa wireless transceiver module is called dumb node. The data from a dumb node are sent through wireless to a beacon node for storage, and the RSSI and time difference between dumb and beacon node are then processed at the beacon node.

Three different sensors, namely, HMC5883L compass, GPS module and Real Time Clock (RTC) are investigated in measuring the position of WSN localisation of dumb node. The beacon node measures and storages three different data compass, GPS and RTC. The RSSI data between dumb and beacon node will be stored in the beacon node. In this paper, the LoRa wireless transceiver module from the SX127x family is used LoRa transceiver module is operated in 860-1000 MHz and 137-960 MHz frequency range. However, the frequency of the LoRa transceiver used in this paper is 868 MHz.

VII. Process Flow for WSN Localisation System

The details of the system are explained in the process flow as shown in Fig. 8. The first step is to study the specification of the compass (HMC5883L), GPS and real-time clock (RTC) component for Arduino programming and all the data are stored in the memory card (SD card) at the dumb and beacon

TABLE IV
COMPARISON BETWEEN SEVERAL WIRELESS NETWORK TECHNOLOGIES [14]

Standard	Frequency (MHz)	Communication range (m)	Data Rates (kbps)	Power consumption	Cost	Application
Classic BT	2400	10-50	1000-3000	Medium 215mW	Low	WPANs
BLE	2400	10	1000	Ultra-Low 10mW	Low	WPANs
WiFi	2400 / 5000	100	11000 - 54000 / 150000	High 835mW	High	WLANs
Zigbee	868 / 915 / 2400	100	20 / 40 / 250	Low 36.9mW	Low	WPANs, WSNs and agriculture
GPRS	900 - 1800	1000 - 10000	Up to 170	Medium 560mW	Medium	AMI, demand response and HAN
LoRa	869 / 915	5000	50	Low 100mW	Low	Agriculture, smart grid, environment and lighting control
SigFox	868 / 915	10000	100	Low 122mW	Medium	Agriculture, smart grid, environment control, automotive, building and consumer electronic

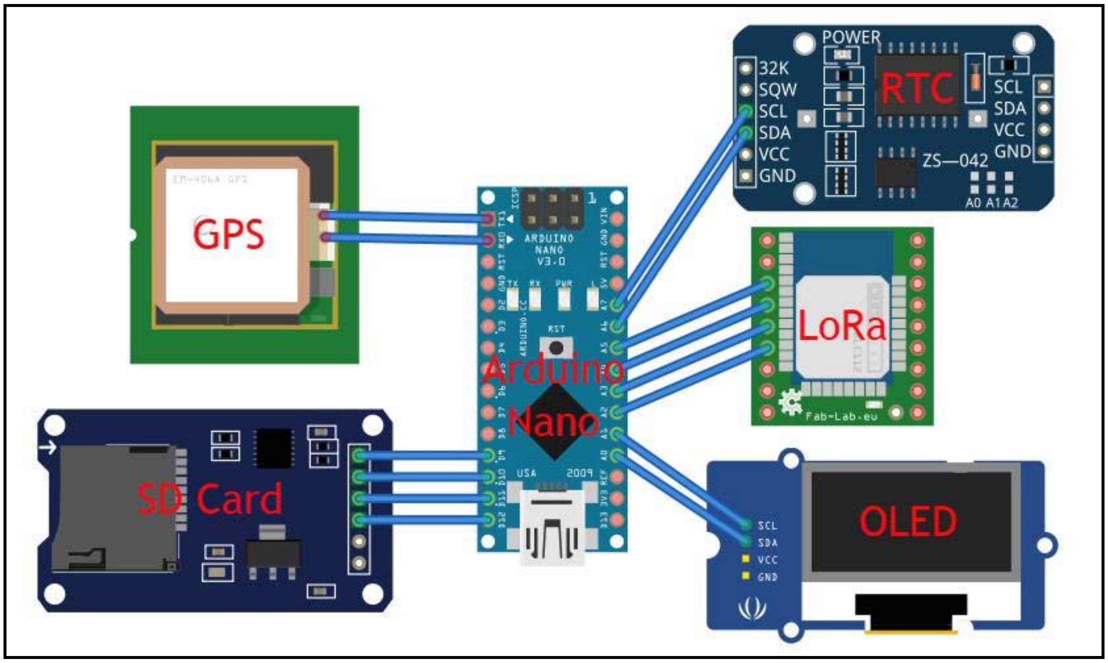

Fig. 6. Circuit design and simulation

nodes. The second step is to design the wireless dumb and beacon nodes that are connected to wireless LoRa transceiver module. Next, write and simulate the Arduino programming on the dumb node. The data from compass, GPS and RTC will be store in the memory card on the dumb node. Then the data from the memory card will be tested. If the data in the memory card is available, the next process will be performed. Next step, write and simulate the Arduino programming on the beacon node and testing the data in the memory card. If the data is available, the process will be proceed to next step. After that, write and simulate programming in the beacon node on RSSI, time transmit, and also receive data in the memory card. Then all data from dumb and beacon nodes will be stored in the memory card at beacon node. The final step is to compute the RSSI data, and time transmit and receive in identifying the location of the wireless dumb node using algorithm [7].

VIII. CONCLUSIONS

This paper discussed review of localization techniques, localization algorithms and wireless transceiver technologies. The paper also proposed the design and development of a wireless sensor node (WSN) for localisation system. The WSN used the LoRa transceiver module for communication between dumb and beacon nodes. We proposed the localisation system using three beacon nodes and one dumb node. Future

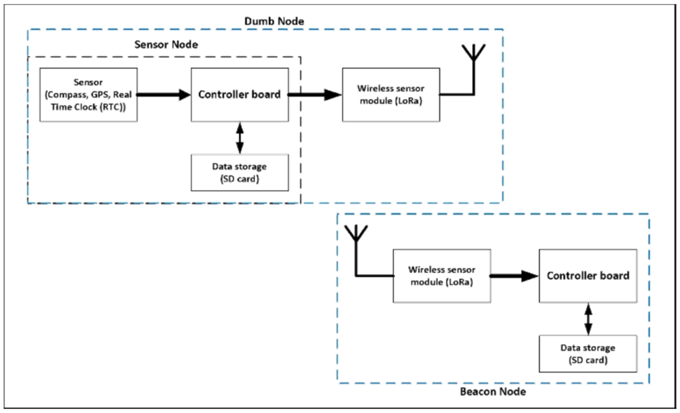

Fig. 7. A Block diagram of the WSN localization system

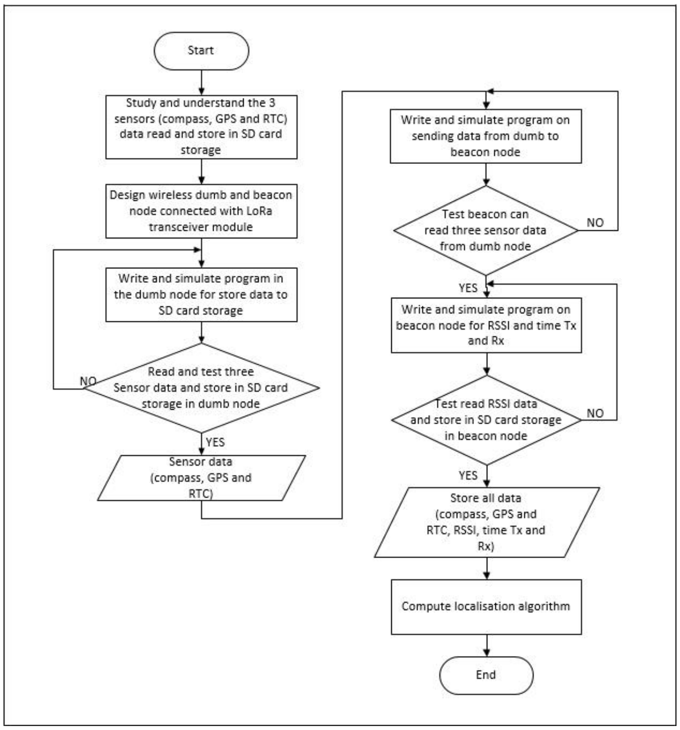

Fig. 8. Flow chart step by step development system

work is the node will be developed for small size and low power consumption with self-power devices.

ACKNOWLEDGMENT

This work is supported by the Universiti Teknologi Malaysia under PAS, with cost center no Q.K130000.2740.00K70. We would also like to thank the Ministry of Higher Education and High Center of Excellence Wireless Communication Center (WCC) for funding the publication of the paper under R.K130000.7840.4J235. We would like to extend our gratitude to U-BAN members for comments on the work.

REFERENCES

[1] X. Zhu and Y. Feng, RSSI-based Algorithm for Indoor Localization, Commun. Netw., vol. 5, no. 2, pp. 3742, 2013.

[2] R. Javaid, R. Qureshi, and R. N. Enam, RSSI based Node Localization using Trilateration in Wireless Sensor Network, vol. 8, no. 2, pp. 5864, 2015.

[3] Labyad Asmaa, Kharraz Aroussi Hatim, M. Abdelazzim, Localization Algorithms research in wireless sensor network based on Multilateration and Trilateration techniques, 2014 International Conference on Innova-tions in Information Technology, 2014, pp. 415420.

[4] A. N. Bishop, B. Fidan, B. D. O. Anderson, K. Doanay, and P. N. Pathirana, Optimality analysis of sensor-target localization geometries, Automatica, vol. 46, no. 3, pp. 479492, 2010.

[5] Sharmilla Mohapatra, Sambit Kar, Sasmita Behera, Different Ap-proaches of Angle of Arrival Techniques In Wireless Sensor Networks, International Journal of Engineering Research and Technology (IJERT), Vol. 2 Issue 2, February- 2013.

[6] a. R. Kulaib, R. M. Shubair, M. a. Al-Qutayri, and J. W. P. Ng, An overview of localization techniques for Wireless Sensor Networks, in 2011 International Conference on Innovations in Information Technol-ogy, 2011, pp. 167172.

[7] O. Ennasr, G. Xing, and X. Tan, Distributed time-difference-of-arrival (TDOA)-based localization of a moving target, in 2016 IEEE 55th Conference on Decision and Control, CDC 2016, 2016, pp. 26522658.

[8] X. Zhu and Y. Feng, RSSI-based Algorithm for Indoor Localization, Commun. Netw., vol. 5, no. 2, pp. 3742, 2013

[9] S. He and X. Dong, High-accuracy localization platform using asyn-chronous time difference of arrival technology, IEEE Trans. Instrum. Meas., vol. 66, no. 7, pp. 17281742, 2017.

[10] S. P. Singh and S. C. Sharma, Range Free Localization Techniques in Wireless Sensor Networks: A Review, Procedia Comput. Sci., vol. 57, pp. 716, 2015.

[11] G. Zanca, F. Zorzi, A. Zanella, and M. Zorzi, Experimental compar-ison of RSSI-based localization algorithms for indoor wireless sensor networks, Proc. Work. real-world Wirel. Sens. networks, pp. 15, 2008.

[12] G. Shen, R. Zetik, and R. S. Thom, Performance comparison of TOA and TDOA based location estimation algorithms in LOS environment, in 5th Workshop on Positioning, Navigation and Communication 2008, WPNC08, 2008, pp. 7178.

[13] Nabil Ali Alrajeh, Maryam Bashir, and Bilal shams, Localization Tech-niques in Wireless Sensor Network, International Journal of Distributed Sensor Networks, volume 2013, 2013.

[14] H. Jawad, R. Nordin, S. Gharghan, A. Jawad, and M. Ismail, Energy-Efficient Wireless Sensor Networks for Precision Agriculture: A Review, Sensors, vol. 17, no. 8, p. 1781, 2017.

[15] R. Javaid, R. Qureshi, and R. N. Enam, RSSI based Node Localization using Trilateration in Wireless Sensor Network, vol. 8, no. 2, pp. 5864, 2015.