Available online at www.sciencedirect.com

ScienceDirect

Procedia Computer Science 57 (2015) 1432 – 1439

Procedia Computer Science

3rd International Conference on Recent Trends in Computing 2015 (ICRTC-2015)

A Hybrid Localization Algorithm for Wireless Sensor Networks

Aarti Singh, Sushil Kumar, Omprakash Kaiwartya*

School of Computer & Systems Sciences, Jawaharlal Nehru University, New Delhi-110067, India

Abstract

The continuously widening range of Wireless Sensor Networks (WSNs) applications requires exact node location which needs efficient and error free localization methods. Localization methods developed in the past are completely based on very fine numerical computation of various network parameters such as transmission range, propagation shape, transmitted or received power, sending or arrival time, connectivity information etc. These parameters are prone towards environmental situation and presence of obstacles in environment. Recently, research in localization is focused towards minimization of localization error in the available techniques. In this paper, the cause and behavior of errors in AOA and RSSI localization techniques have been mathematically analyzed. Based on the error analysis of both the existing techniques, a hybrid localization algorithm is proposed. The hybrid localization algorithm is based on existing Angle of Arrival (AOA) and Received signal strength indicator (RSSI). The algorithm is named as Minimum AOA Error with Minimum RSSI Error (MAE with MRE). Analysis of results obtained through simulation show that the hybrid localization algorithm performs better than AOA and RSSI techniques in terms of error percentage probability with varying number of known sensors, unknown sensors and shadowing effect percentage.

Peer-review under responsibility of organizing committee of the 3rd International Conference on Recent Trends in Computing 2015 (ICRTC-2015)

Keywords: Localization, Angle of arrival; Minimum AOA error; Minimum RSSI error; Error estimation; WSNs.

1. Introduction

New developments in the hardware technology and wireless communications field have promoted the advancement of WSNs for a large field of natural-world purposes and applications, that includes disaster-relief, battlefield surveillance, medical-disorders or problems, environmental monitoring, site-security and many more

* Corresponding author. Tel.: +91-9013311302
E-mail address: omokop@gmail.com

1877-0509
Peer-review under responsibility of organizing committee of the 3rd International Conference on Recent Trends in Computing 2015 (ICRTC-2015)
doi:10.1016/j.procs.2015.07.464

[1]. In such type of arrangements (fig.1), thousands of small number of sensor nodes is arranged haphazardly in a field of interest to identify specialized events. After the identification of an event, the sensed information is forward by the sensors to a remote sink, which advances the knowledgeable data in conformation with specification of distinct application. WSN is a predicament of information technology in a decade which combines sensors, signal information processing, computer science and many more areas of technology. A sensor node (fig.2) usually composed of four fundamental constituents: a communication unit, a processing unit, a power unit and a sensing unit [2]. A WSN generally have a single or more data sinks or base stations which are situated close to or within the sensing area and contains a large number of sensor nodes densely arranged in a field of interest. Then the sink sends commands or queries to sensor nodes in sensing area whereas sensor nodes work together to achieve sensing task and send the sensed data to sink. For example, internet: in internet data is collected with the help of sensor nodes, and simple processing is performed on obtained data, and then compatible data is sent via Internet to users who have requested the data [7]. Generally many sensor networks contain a large number of sensor nodes, from hundreds to thousands or even more [3]. In many applications, sensor nodes are scattered haphazardly in a calculated area or dropped densely over unavailable or unfavorable area. Sensor nodes are combined independently themselves into a communication network before a sensing task is performed. Sensor nodes are combined independently themselves into a communication network before a sensing task is performed.

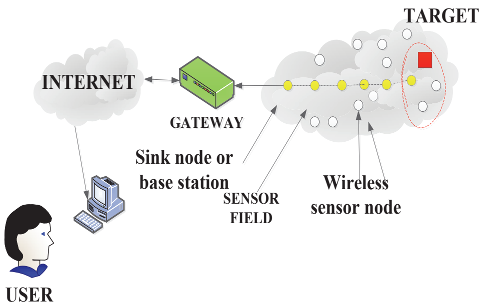

Fig. 1 Wireless sensor networks

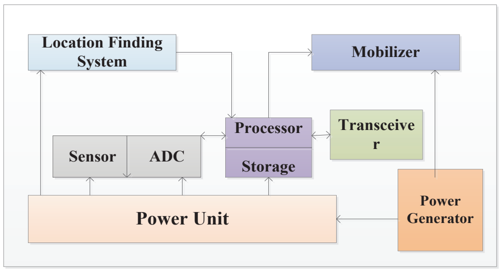

Fig. 2 Components of a sensor node

A WSN have been categorized [2] as:

- Unstructured WSN: Unstructured WSN contains a condensed combination of sensor nodes which are haphazardly arranged into the region of interest and the network is left neglected for performing monitoring and reporting function, therefore, making network maintenance (managing connectivity and detecting failures) problematic.
- Structured WSN: In structured WSN, predetermined sensor nodes are allocated at permanent positions. Therefore, main benefit of structured network is that lesser nodes are arranged with reduced network conservation and management cost.

All the techniques are completely based on very fine numerical computation of various network parameters such as transmission range, propagation shape, transmitted/received power, sending/arrival time, connectivity information etc. These parameters are prone towards the environmental situation and presence of environmental obstacles. Recent researches in localization are mainly approaching towards the minimization of error in available techniques. In this paper, we have proposed a hybrid localization technique for WSNs. Each component that causes errors and behavior of error has been mathematically analyzed. Based on the error analysis of both the existing techniques, a hybrid localization algorithm has been developed. The hybrid based on existing Angle of Arrival (AOA) and Received signal strength indicator (RSSI) has been proposed. The hybrid localization algorithm is named as Minimum AOA Error with Minimum RSSI Error (MAE with MRE). First, we proved that localization error in AOA is directionally proportional to the ratio of signal arrival angles from known sensors. This result is to select those known sensors which have lowest ratio during AOA utilization. Second, we find out the three error components in RSSI which is used to select those known sensors which gives lowest error during RSSI utilization. Thirdly, we presented a novel localization algorithm based on our error analysis of AOA and RSSI.

The rest of the paper is organized as follows. Section 2, gives the highlight of prior and current research work in localization techniques. Section 3, describes all conceptual detail of error analysis of AOA and RSSI and the development of MAE with MRE algorithm. Simulation results are discussed in section 4. In section 5, we have concluded the paper.

2. Related Work

The Research of Time Difference Of Arrival based (TDOA) Self-localization Approach in WSNs introduces a self-localization analysis which depends on TDOA, which uses average value of time difference by involutioning average to reduce the estimated error, and utilizes unconstrained least squares (LS) estimator to obtain accurate localization. Time of Arrival (TOA) requires crucial time synchronization of complete network and needs to know signal propagation time. And TDOA uses TDs of signal propagation between foreign nodes and anchor nodes, not propagation time itself. Likewise, TDOA method decreases the requirement for time synchronization. There are two ways to get the TDOA in WSNs. In the earlier method, TOA can be estimated from a foreign node to two different anchor nodes, and calculate the TD. In second method, distance between an anchor node and a foreign node can be obtained by the foreign node by sending two different signals to anchor node and by evaluating location of foreign node by triangulation, trilateration or maximum likelihood estimation method. Since, this technique requires that the foreign node must send and receive signals twice for one distance value. Therefore, it utilizes much energy [4].

RSSI values are fit into a parabola function of AoA between 0° and 90° by quadratic regression analysis. In this two directional antennas are also set up with perpendicular orientations at the same position and fit the differences of the received signal RSSI values of the two antennas into a linear function of AoA between 0° and 90° by linear regression analysis. RSSI fitting functions, are proposed for a novel localization scheme, called ALRD [5]. Determining Radio frequency (RF) angle of arrival using COTS antenna arrays elements are already phase-aligned in traditional phased antenna arrays - which face the challenges of aligning individual SDRs during field arrangement in order to ensure coherent phase detection [7]. Received Signal Strength Indicator (RSSI) Based Location Estimation in WSN presents exploratory results that are brought to inspect the sensitivity of RSSI estimation in outdoor and indoor environment. Calibration model is used for distance estimation that distinguished the RF radio channel which is evaluated. The legitimacy of calculated distance is confirmed to find the position of sensor node within an indoor environment [8].

3. MAE with MRE Localization

The continuously widening range of WSNs applications that requires exact node location fumes the need of efficient and error free localization methods. Most techniques are completely based on very fine numerical computation of various network parameters such as transmission range, propagation shape, transmitted/received power, sending/arrival time, connectivity information etc. These parameters are prone towards the environmental situation and presence of environmental obstacles. Recent researches in localization are mainly approaching towards the minimization of error in available techniques. Our work is also a step towards the comparative study of available localization methods in terms of percentage error or error probability, effect of environmental situation and combined performance in results. We have considered following two known localization techniques for our study.

- Angle of arrival (AOA)[6]
- Received signal strength indicator (RSSI) [9].

3.1. Error Analysis in AOA

The AOA localization technique is based on angle measurement capability of sensor nodes. Each unknown sensor position is calculated using the angle of incoming signal from unknown node to at least two known sensor nodes. The intersection point of at least two incoming signal is assumed to be the unknown sensor's exact position (cf. Fig.3).

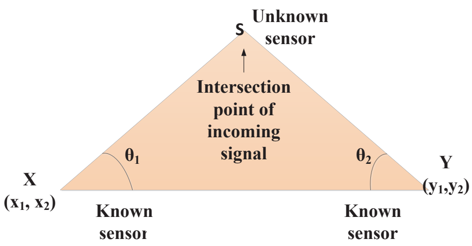

Fig.3 Localization using AOA

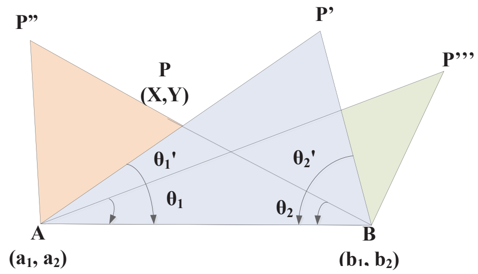

Fig. 4 Error Possibilities in AOA

The AOA localization technique is susceptible to measurement noise and insufficient number of beacon sensors (known sensors). The different positioning technique tries to solve the above problems differently. The different error possibility of AOA is explored in the Fig. 4.

The impact of AOA measurement error in the positioning of unknown sensors can be studied by analyzing the displacement of p into p', p'', p'''. These displacements are actually reflects the amount of localization errors (LE_{AOA}). The various displacements d can be measured as $pp' = \sqrt{(x-x')^2 + (y-y')^2}$, $pp'' = \sqrt{(x-x'')^2 + (y-y'')^2}$ and $pp''' = \sqrt{(x-x''')^2 + (y-y''')^2}$. We have derived following important characteristics about the behavior of these displacements. As soon as the $\theta_1{}'$starts decreasing and $\theta_2{}'$ starts increasing, the displacement or localization error starts increasing. Thus, we get

$$LE_{AOA} \propto \frac{\theta_{2}{}'}{\theta_{1}{}'} \tag{1}$$

where $\theta_1{}'$ is approaching towards zero 0° and $\theta_2{}'$ is approaching towards 180^0 in terms of angle measurement. Also, as soon as the $\theta_1{}'$ starts increasing and $\theta_2{}'$ starts decreasing, the displacement or localization error starts increasing. This can be expressed as

$$LE_{AOA} \propto \frac{\theta_{1}{}'}{\theta_{2}{}'} \tag{2}$$

where $\theta_1{}'$is approaching towards $180^0$and $\theta_2{}'$ is approaching towards 0° in terms of angle measurement. The result of (1) and (2) can be combined as

$$LE_{AOA} \propto ratio\ of\ AOA\ measurment \tag{3}$$

3.2 Error Analysis in RSSI

In RSSI based localization technique at least three beacon sensors (known sensors) measures the power of received radio signal ($\mathrm{p_r}$) coming from an unknown sensor. The power of received radio signal is further used to calculate the distance of unknown sensor from at least three sensors. These distances are used to draw three circles and the intersection point of these three circles is considered to be the final location of unknown sensors (cf. Fig. 5).

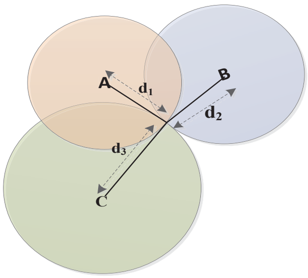

Fig. 5. Localization using RSSI.

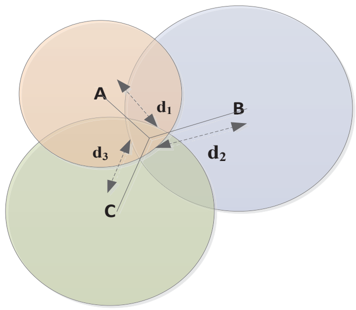

Fig. 6 (a). Erroneous distance computation In RSSI localization

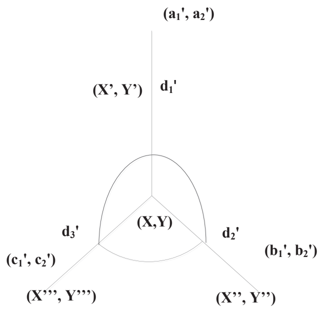

Fig. 6 (b) Inside view of erroneous distance computation in 6(a)

There are various environmental substances causing erroneous measurement of power of received signal. The error in received power measurement directly resulted into erroneous distance computation. An erroneous distance computation has been shown in Fig. 6(a) and 6(b). The error in RSSI has been analyzed and represented in the following three different ways.

- The difference between total actual distance and total computed distance from three unknown sensors represents the total error in distance ($\mathrm{E_{td}}$)computation.

$$E_{td} = \{(d_1 + d_2 + d_3) - (d_1{}' + d_2{}' + d_3{}')\} \tag{4}$$

- The error in individual distance computations are also the components of localization error.

- These individual distance errors ($\mathrm{E_{id}}$) can be represented as

$$E_{id} \propto (d_1 - d_1{}')(d_2 - d_2{}')(d_3 - d_3{}')$$

$$E_{id} = K\ (d_1 - d_1{}')(d_2 - d_2{}')(d_3 - d_3{}') \tag{5}$$

where, K is the environmental constant. The actual amount of error can be analyzed and represented by the error minimization component (E_m). The E_m can be computed as

$$E_m = \left\{\left(\sqrt{(x-x')^2+(y-y')^2}\right)+\left(\sqrt{(x-x'')^2+(y-y'')^2}\right)+\left(\sqrt{(x-x''')^2+(y-y''')^2}\right)\right\} \quad (6)$$

The complete error has been represented as the addition of all these components as

$$LE_{RSSI} = E_{td} + E_{id} + E_m \quad (7)$$

Thus, in RSSI, we should always select the three known sensors that give smallest value for LE_{RSSI} for a sensor localization. Based on the above error analysis of the two existing localization technique, a hybrid localization algorithm has been developed below.

Algorithm: Minimum AOA Error with Minimum RSSI Error (MAE with MRE)

Notations

UNS: Unknown Sensor; KNS: Known Sensor; LE_{RSSI}: Localization Error using RSSI method
ARO: Angular Ratio Approaching Towards One; $SPKS$: Set of pair of known Sensor in all possible ways
SKS: Set of known Sensor; $SUNS$: Set of unknown Sensor; S_i: ith sensors; P_i: ith pair of sensors

Localization Process

for each $S_i \in SUNS$
  create $SPKS$ from SKS
  for each $P_i \in SPKS$
    calculate AOA
  endfor
  select the pair which gives best ARO let P_j
  for each $S_i \in SKS$
    calculate LE_{RSSI} with P_j and S_i
  end for
  select the group which gives lowest LE_{RSSI} let P_j and S_j
  return the position value given by the group P_j and S_j
end for

4. Simulation Results and Performance Analysis

4.1 Impact of Known Sensor Density in Localization Error

We have analyzed the impact of known sensor density in localization error. For this, we have use 100 unknown sensors in region of interest (RoI) and continuously increase the known sensor density from 1000 up to 10000 known sensors in RoI. In each simulation step, we count the number of successful localization of unknown sensors using known sensors. Each data point is the average of at least ten simulations run.

The results in Fig.7 show the localization error percentage as a function of number of known sensors. It clearly indicates that our MAE with MRE localization technique has lesser localization error compared with AOA and RSSI for each of the known sensor density considered. This can be attributed to the fact that MAE with MRE uses lowest error possibility of AOA and RSSI. The result also verifies that RSSI shows better performance compared with AOA, as soon as know sensor density increases from 7000 known sensors. Therefore the performance of MAE with MRE is better than AOA and RSSI in increasing known sensor density.

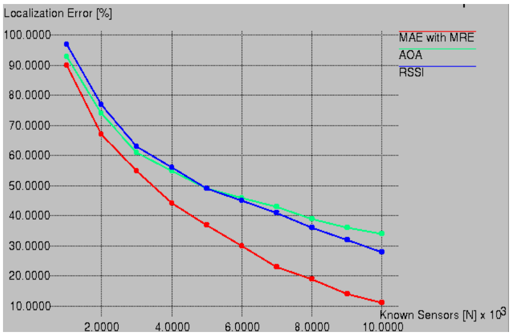

Fig. 7. Localization error versus number of known sensors

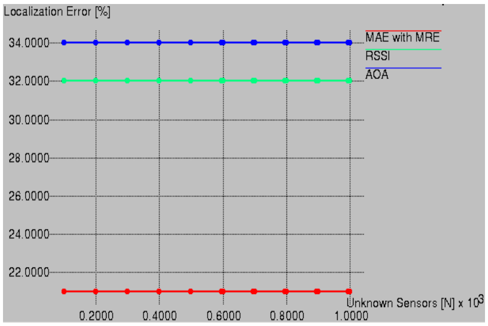

Fig. 8. Localization error versus number of unknown sensors

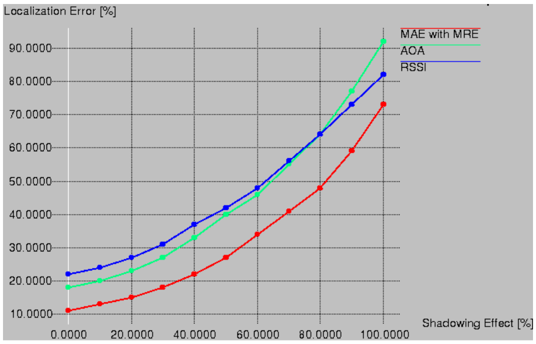

Fig. 9. Localization error versus shadowing effect

4.2 Impact Of Unknown Sensor Density In Localization Error

We have analyzed the impact of unknown sensor density in localization error. For this, we have use 10000 known sensors in region of interest (RoI) and continuously increase the unknown sensor density from 100 up to 1000 known sensors in RoI. In each simulation step, we have counted the number of successful localization of unknown sensors using known sensors. Each data point is the average of at least ten simulations run. The results in Fig. 8 show the localization error percentage as a function of number of unknown sensors. It clearly indicates that all the three techniques have no effect of unknown sensor density once the complete RoI is covered with the known sensor. Further, it verifies that MAE with MRE gives better performance compared with AOA and RSSI in fully covered RoI with known sensors.

4.3 Impact Of Shadowing in Localization Error

We have analyzed the impact of shadowing in localization error. For this, we use 10000 known sensors and 100 unknown sensors in region of interest (RoI). We continuously increase shadowing effect from 0 to 100 in terms of percentage. In each simulation step, we count the number of successful localization of unknown sensors using known sensors in the presence of shadowing. Each data point is the average of at least ten simulations run. The results in Fig. 9 show the localization error percentage as a function of shadowing effect percentage. It clearly indicates that our MAE with MRE localization technique has lower impact of shadowing compared with AOA and RSSI for each of the shadowing effect percentage considered. This can be attributed to the fact that MAE with MRE uses lowest error possibility of AOA and RSSI. The result also verifies that RSSI shows better performance compared with AOA, as soon as the shadowing effect goes higher than 80%. Therefore, the performance of MAE with MRE is better than AOA and RSSI with increasing shadowing effect percentage.

5. Conclusion And Future Work

In this paper, a hybrid localization algorithm named as MAE with MRE has been presented for wireless sensor networks. MAE with MRE can be used in error prone WSNs environment. The performance of MAE with MRE in terms of localization has been proved better than existing AOA and RSSI techniques with increasing number of known sensors in the network. It has been verified that in a fully covered RoI, the density of unknown sensors has no impact on the performance of all the three considered localization techniques. Further, MAE with MRE shows better localization results as compared to existing AOA and RSSI techniques in fully covered RoI. The performance of MAE with MRE in terms of localization has been also proved better in fading environment as compared to AOA and RSSI. We are further working on error estimation of other existing localization techniques and will be integrating it with MAE and MRE localization algorithm to make it more efficient and scalable.

References

[1] De la Piedra, A; Benitez-Capistros, F.; Dominguez, F.; Touhafi, A, “Wireless sensor networks for environmental research: A survey on limitations and challenges,” In EUROCON, 2013 IEEE, pp. 267-274, Zagreb, 1-4 July 2013.

[2] Herring, C.; Kaplan, S. “Component based software systems for smart environments,” IEEE Personal Communications, 7(5), pp. 60 – 61, 2000.

[3] Borges, L.M.; Velez, F.J.; Lebres, AS, “Survey on the Characterization and Classification of Wireless Sensor Networks Applications,” IEEE Communications Surveys & Tutorials, 16(4), pp. 1860-1890, 2014.

[4] J. Xiao, L. Ren “Research of TDOA Based Self- localization Approach in Wireless Sensor Network,” In Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 2035-2036, Beijing China, 9-15 October 2006.

[5] Jiang, J. R., Lin, C. M., Lin, F. Y., & Huang, S. T. “ALRD: AoA Localization with RSSI Differences of Directional Antennas for WSN”, In Proceedings of the International Conference on Information Society, IEEE, pp. 304-309, London, 25-28 June 2012.

[6] Panwar, A; Kumar, S.A, “Localization Schemes in Wireless Sensor Network,” In Proceedings of the International Conference on Advanced Computing & Communication Technologies (ACCT), IEEE, pp. 443-449, Rohtak India, 7-8 January 2012.

[7] Chen, H. C., Lin, T. H., Kung, H. T., Lin, C. K., & Gwon, Y. “Determining RF Angle of Arrival Using COTS Antenna Arrays: A Field Evaluation,” In Proceedings of the Military Communications Conference (MILCOM), IEEE, pp. 1-6, Orlando, 2013.

[8] Al Alawi, R. “RSSI Based Location Estimation in Wireless Sensors Networks,” In Proceedings of the IEEE International Conference on Networks (ICON), pp. 118-122, Singapur, 14-16 December 2011.

[9] Dan, A; Halder, S; DasBit, S, “Localization with enhanced location accuracy using RSSI in WSN,” In Proceedings of the IEEE International Conference on Advanced Networks and Telecommunication Systems (ANTS), pp. 1-6, Bangalore India, 18-21 December 2011.