Optimal Techniques of Localization in Wireless Sensor Networks

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Abstract-Localization in wireless sensor networks is an open challenge. The work is based on the localization of mobile nodes in wireless sensor networks (WSN) by using the Received Signal Strength Indicator (RSSI) method. A trilateral localization algorithm based on RSSI has been proposed to localize the mobile sensor nodes. It is advantageous to apply RSSI based algorithm as it has solved the problems of cost, power utilization and reliability in wireless sensor networks. Furthermore, RSSI based algorithm has been compared with the existing techniques. Results shown in the paper are the evident of the situations where RSSI is considered best techniques of localization.

Keywords-WSN, RSSI, Localization, Attenuation, Beacon node.

I. INTRODUCTION

In the modern era everything is the part of wireless networks because of the universal truth that every activity of human being affects the system due to time varying nature of the channel. This effect can be analyzed in term of multi path fading, noise and Doppler Effect. Now a days there are small computing devices which have memory, processor, transceiver and battery(most important), these devices are called node [i]. Wireless sensor network will be the part of everyone's life in future because it is emerging and newly born field. A lot of work has also been done to enlarge the computing capability and sensing range of the nodes and a development for miniaturization and optimization of the hardware. At this point, there is need to learn about localization of wireless sensor nodes in a wireless sensor network, because if you want to communicate with something it is necessary to having information about its location. And in wireless sensor networks concept of getting the information about the location is called as localization[ii] . In a more sophisticated way localization can be define as, "To determine the physical coordinates of a group of sensor nodes in a wireless sensor network (WSN) is called localization" [i].Localization can be classified into two different classes;

- Distributed and Centralized
- Range-based and Range-free

In centralized approach all the calculations related to the localization are worked out at the base station[iii-iv]. There is information sharing process among the wireless sensor nodes and base station, and the information at the base station is used to calculate the coordinates of the nodes. Whereas in distributed approach all the calculations are made on the node so base station is not required . Complex mathematical algorithms in centralized approach lead to use a powerful centralized node. Main difference between centralized and distributed approach is processing. In centralized approach migration of inter-node ranging and connectivity of the data is required, which is transferred to a powerful central node. After processing the data, information about the localization is migrated to the concerning node. In range based localization algorithms are required to determine the distance among the wireless sensor nodes [iii].

Range based localization scheme requires extra hardware so it is costly as compare to range free localization scheme. Applications like missile tracking need high level accuracy. So, there is a need to implement this localization scheme because it gives us more accurate results as compare to range free localization. Some important terms related to range based localization has been defined [i- ii, v- vi]. In range based localization, received signal strength indicator (RSSI) is the most important factor that shows the relation between the distance and level of received power. Power of the transmitted signal decreases as it travels away from the base stations, called attenuation. TOA is the travel time of a radio signal from a solitary transmitter to a distant single receiver [i].

The relation between speed of light in vacuum and the carrier frequency of a signal is used to measure the time for the calculation of distance between transmitter and receiver. Time difference of arrival (TODA) uses the concept of synchronization therefore, an extra time is required. Ultrasound, Light rays, RF signal and microwaves are used in TODA approach. Accuracy of TODA depends upon the line of sight (LoS).

TODA is hardware based algorithm and mostly implemented by using the sensor which have integrated speaker and microphone. Chirp signal concept is used here for time difference. Angle of Arrival (AoA) also used for the purpose of localization but in this approach an array microphone or radio is used but it can be implemented by using the optical communication approach [iv] .

In contrast to range based localization range technique of localization is easier. In range free localization technique there is no need of time of arrival, time difference of arrival and angel of arrival [i-ii]. The cost of implementing this technique is lower but there is a compromise over accuracy. Range free localization technique can further be classified into two categories.

A. Local Technique

Local technique works on the concept of beacon nodes. In this technique area is divided into triangular shapes and beacon nodes (whose positions are known) are placed at the edges of the triangles. When a mobile node enters in the sensing range of the beacon nodes it transmits some messages. Beacon nodes receive the messages and extract the position. Accuracy of the technique can be increased by increasing the node density.

B. Hope Counting Technique

In hop counting technique those nodes whose localization is being performed gets the value of hop size from the neighbor beacon node and try to get least hop counts by using the diverse protocols. In this way every node gets its hop count and by using this information an estimated distance is calculated from its neighbor [ii]. Node density also affects the localization results, as hop counting based localization scheme results are very accurate if there is high density of nodes is used. Thus node density is very important factor of designing an algorithm because it may charge high price to implement an algorithm with high density of nodes. From the above discussion, we can conclude that following should be considered in case of wireless sensor node,

1. For a node it is essential to avoid the complex and time consuming computations because it would reduce the energy supply rapidly.
2. The computations should consider the error (appeared in the measurements), which can be large [vii].

Section 2 describes the work related to the articles that is previously done. Section 3 provides a solution to the aforementioned problems. Section 4 gives the model of RSSI based algorithm. Section 5 includes the implementation of the system and section 6 concludes the whole work done for the wireless sensor networks.

II. MOTIVATION AND RELATED WORK

Previous discussion shows the work that has been done. But, still there is a potential to find out more and more new techniques to localize the wireless sensor nodes. To solve the problem of localization in outdoor environment Global Positioning System (GPS) is mostly used. GPS module is used in vehicles to track the position of the vehicle. GPS is also used in wireless sensors network for localization currently, but economically it will not be a good way to use GPS module at each sensor node [viii].

Therefore, there are a lot of schemes has developed to solve the problem of localization which are very efficient and cost effective especially for the case of WSN. As we know that WSN is formed by the deployment of large number of nodes. These nodes are so small that they have a limited memory, processing and most important one limited resources of energy [i] , [iv-v]. There are different techniques such as triangular [iii], or statistical inference [v] used to calculate the coordinates of mobile node w.r.t beacons nodes.

Due to the unpredictable nature of radio propagation behavior the RSSI based localization scheme severely suffers with error . If ultrasound is used for the purpose of localization values need to be calculated ToA and TDoA and these values can further be used for the purpose of localization. For indoor localization we can use RFID tag, ultrasonic, infrared, WLAN and Bluetooth technologies. Multipath, reflections, interference and dead spots effects the localization in indoor cases [i].

To improve the localization results in indoor cases RSSI and Link Quality Indicator can be used. LQI and RSSI are used to see the effects of environment on the received signal strength. So LQI and RSSI are helpful to handle the noise effect on the received signal. In all approaches there are a lot of computations involved, such as minimum mean square error method, system of complex equation and Kalman filter.

RSSI is the most realistic model for sensor network communication. But due to the environmental effects it is unrealistic to calculate the correct result by taking on one reading from the beacon node in RSSI mode. Location prediction mechanism is an extension of multicast and multipath routing [xii].

Therefore node location is estimated by taking small number of reading [vii]. There is another approach exist which is FM Radio base localization scheme. In FM based localization the strength of the signal from the set of FM broadcasting station outdoor environment is measured [x]. If FM Radio signals and GSM signals spectrum is analyzed it is reported that both the techniques achieve the similar accuracy level. In the next session we discussed some well-known localization schemes. IR light can also be used for the purpose of localization. In this technology images are taken by the camera and after a lot of image processing on these images localization is achieved. Furthermore, power tuning anchors algorithm includes the localization of mobile nodes on the basis of minimum power received from the neighbors [xi].

Ultrasound waves have also used for the purpose of localization [i, iv]. Ultrasonic sensors for a specific environment have a specific field pattern. If there is any obstacle then it will change the pattern and from this pattern changes information about the location of the object can be extracted. Cricket, Bats and Dolphin utilize ultrasonic wave to localize their prey.

III. Localization Techniques

Localization can be performed by using the different type of sensor nodes. A change in the sensor type technology also changes the localization. Sensors are selected according to the applications and environment. There are some constraints in every localization technology as well as merits and demerits. These technologies are shown below in Fig.1.

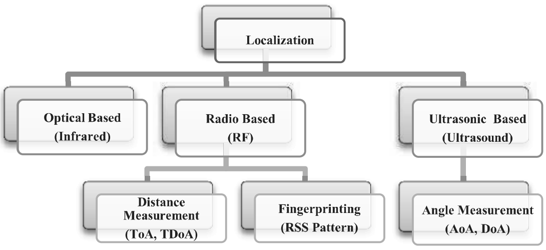

Fig. 1: Different Localization Schemes

A. Optical Based Localization

Optical based localization is also possible. In this technology light signal is used for localization purpose. Infrared light which is special type of light is used for this purpose. IR light is also used for the purpose of tracking in many applications. Sun is also an infrared light source which radiates the infrared light within similar frequency band. Therefore this localization technology can be implemented in that case if there is no sun light. In this technique a lot of image processing is required. Images are taken by special type of cameras.

B. Ultrasonic Based Localization

As everyone knows that ultrasonic wave is similar to sound wave but frequency is higher than 20 kHz. Ultrasonic sensors are used in this approach. Ultrasonic sensors are placed in such a way that they send a field pattern and then receive back these waves and the change of field pattern is used to extract the information about the object which we want to localize. Angle of Arrival (AoA) and Difference of Arrival (DoA) of these waves are used to get the coordinates of the localization.

C. Global Positioning System (GPS)

Global Position System is also used for localization purpose. There are 27 different satellites which are revolving around the earth which are used for localization. Global position system also uses radio frequency for this purposed of communication between the transmitter and receiver. GPS technology of localization is costly as compared to other localization technologies. GPS technology is mostly used for the purpose of vehicle security. GPS performance is environment dependent i.e. the localization results for outdoor and indoor are very different. When GPS is used for indoor localization error in the results is increased.

D. Radio Based Localization

In Radio based localization scheme Radio Frequencies are used between the receiver and transmitter for the purpose of communication. As we know that the received power strength decreases with the distance as shown in Fig. 3. And we also have seen a relationship between the received signal power and RSSI value which shows that RSSI value is large when power received is large and its value decreases with the decrease in received power value. In RSSI based localization technology no extra hardware is required which is the main advantage of this technology. RSSI value changes with time due to time varying nature of channel.

E. Received Signal Strength Indicator

In IEE 802.11 100mW of the power is transmitted by a base station, but in IEEE 802.15.4 52mW to 29mW power is transmitted per station. There are many IEEE 802.15.4 radios used so in such networks RSSI localization is used. This approach of localization is not good for those applications where high level of accuracy is required. Equation 1 shows a relationship between the distance and RSSI value . A graph is also shown in fig. 1 which shows the same relationship.

$$RSSI = -(10 * n * log_{10}(d_{bs}) + A_o) \quad (1)$$

Where,

n = Propagation constant and its value can vary with the environment.

d_{bs} = It is the distance from base station.

A_o = Reference value of received signal strength at one meter of distance.

In below graph value of n is considered 2 and A_0 value is- 3dbm.

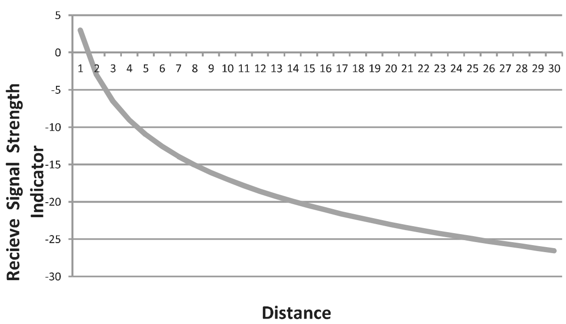

Fig.2: RSSI VS Distance

It is the basic law of propagation that the power received Pr at a distance d is inversely proportional to the square of distance and directly proportional to the transmitted power Pt. This basic law is represented by a relationship of Pr, Pt and d which is known as Friis equation;

$$Pr = \frac{Pt\ Gt\ Gr}{1}\left(\frac{\lambda}{4\pi d}\right)^2 \quad (2)$$

Where

P_r = Received at distance d.
P_t = Power Transmitted.
G_t = Gain of Transmitting Antenna.
G_r = Gain of Receiving Antenna.
λ = Transmitted Signal Wave Length.
d = Distance between the Transmitter and Receiver.

From the above relationship it can be concluded that, the larger the distance from the transmitter the smaller power will be received. This fact is shown in below Fig. 3.

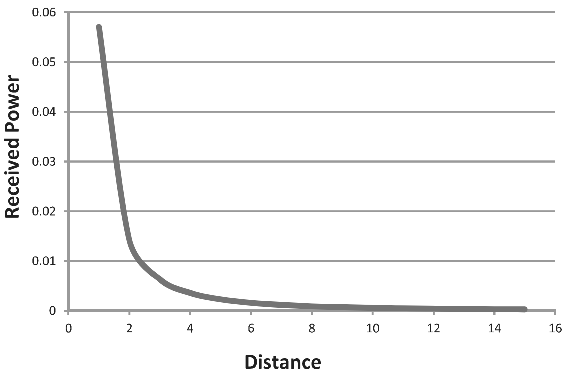

Fig. 3: Received power VS Distance

In the above graph value of Pr is calculated with the *Gt*=*Gr*=1, *Pt*=100mw and $\lambda = 3$.

IV. RSSI BASED MODEL

Friis equation gives the relationship between the received power and the distance,

$$Pr(d) = \frac{Pt\ Gt\ Gr}{1}\left(\frac{\lambda}{4\pi d}\right)^2 \quad (3)$$

$$Pr(do) = \frac{Pt\ Gt\ Gr}{1}\left(\frac{\lambda}{4\pi do}\right)^2 \quad (4)$$

Dividing (3) by (4), we get

$$Pr(d) = Pr(do)\left(\frac{do}{d}\right)^n \qquad d > do > df \quad (5)$$

Where

$Pr(do)$ = Power received at distance do
do = reference distance
n = path loss exponent
df = Far field Region (Fraunhofer Distance)

But there are some limitations in the use of FRIIS equation that is only valid in far field region. So we can use the following equation which gives us power received at distanced in dBm instead of above equation[ix],

$$Pr(d)\ dBm = Po(do)\ dBm + n10\ log_{10}\left(\frac{do}{d}\right) \quad (6)$$

In free space the value of n path loss factor is 2, which means that the power received at distance d will decrease with the square of distance . Path loss factor n value can vary in between 2 to 6 with different environments. The value of path loss exponent changes with the environment as given below in Table I.

TABLE I
PATH LOSS EXPONENTS

Environment	Path Loss Exponent
In building line of sight	1.6-1.8
Free space	2.0
Obstructed in factories	2.0- 3.0
Inner-city area cellular radio	2.7-3.5
Shadowed urban cellular radio	3.0-5.0
Foiled in building	4.0-6.0

In wireless communication channel affects the signal power in two ways.

1. Time varying nature of the wireless channel causes fluctuations in received signal strength. These fluctuations can vary the mean value of RSSI from ±2 to ±5 dBm as shown in Fig. 4.

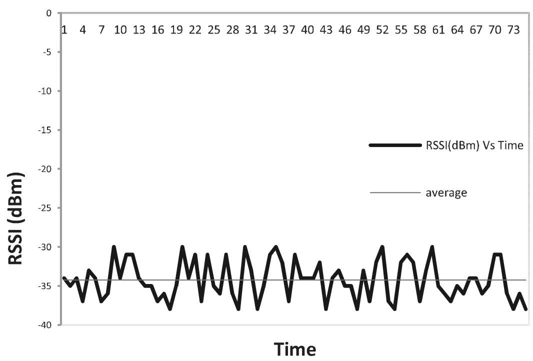

Fig. 4: RSSI VS Time

So it is necessary to minimize the effect of fluctuations in the RSSI value. To eliminate the fluctuations we take average. Hence an average 0f 20 to 30 values is taken to obtain the mean RSSI value. The mean value of RSSI is used to calculate the distance.

1. Waves traveling in the environment are diffracted, reflected and scattered that results in loss of power in radio channel. This effect can be overcome by measuring the exact value of path loss exponent n.

A. Path Loss Exponent

First step is to calculate the value of n which is used to determine the RSSI value used for localization. For this purpose we have to measure Pr (d1) at distance d1 and Pr(d2) at d2. Both are average received powers. And value of n is calculated using the equation (7).

$$n = \frac{(Pr(d_1)\ dBm - Pr(d_2)\ dBm)}{10 * log_{10}(\frac{d_2}{d_1})} \quad (7)$$

From the value of n we can also calculate the distance by using the equation (8) given below .

$$Pr(d)\ dBm = Pr(do)\ dBm + n10\ log_{10}\left(\frac{do}{d}\right) + Xo$$

$$d = (do)(10^{-\frac{(Pr(d) - Pr(do) - Xo)}{(10\,n)}}) \quad (8)$$

On the basis of some important factors regarding the technologies, we can differentiate and compare them in a sophisticated way as shown in TABLE II.

TABLE II
COMPARISON of LOCALIZATION SCHEMES

Factor	Infrared	Ultrasound	GPS	RSSI
Applicable indoor	Yes	Yes	Not recommended	Yes
Need for extra Hardware	Yes	Yes	Yes	No
Cost of Extra hardware	Low	High	High	N.A
Size of extra hardware	Average	Large	Average	N.A
Average expected error	±5 meters	±10 meters	±10 meters	1-3meters

V. IMPLEMENTATION AND RESULTS

Triangular Localization Approach

In triangular approach the three nodes which are called as beacon nodes are placed at the three corners of the triangle whose coordinates are known and another node called anchor node is placed inside the triangle. The coordinates of the anchor node are unknown and can be calculated from special calculations. From these three nodes one node is attached with a computer and is known as base station. This triangular configuration is sh

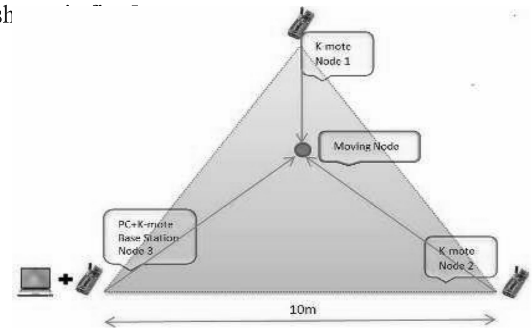

Fig. 5: Triangular Approaches

To find the location of an anchor node following steps will be adopted.

1. First, anchor node broadcast a message consisting on packets to all other beacon nodes.
2. RSSI value is calculated from the received packets at beacon nodes.
3. Calculated value of RSSI is sent to base station.
4. At the base station RSSI value is used to calculate the distance.
5. Anchor node coordinates can easily be found after calculating the three distances. Suppose l1, l2, and l3 are the three distances values from the beacon nodes 1, 2, 3 respectively. And (x1, y1), (x2, y2) and (x3, y3) are x, y coordinates for the node1, node2 and node3 respectively. Consider that x0 and y0 are the values of coordinates for the anchor node. So from all of the above information we can write three different equations by using the distance formula.

$$l_3^2 = (x_0 - x_3)^2 + (y_0 - y_3)^2 \quad (9)$$
$$l_2^2 = (x_0 - x_2)^2 + (y_0 - y_2)^2 \quad (10)$$
$$l_1^2 = (x_0 - x_1)^2 + (y_0 - y_1)^2 \quad (11)$$

By expanding the above equations (9),(10) and (11)

$$l_3^2 = x_3^2 + y_3^2 + x_0^2 + y_0^2 - 2x_0x_3 - 2y_0y_3 \quad (12)$$
$$l_2^2 = x_2^2 + y_2^2 + x_0^2 + y_0^2 - 2x_0x_2 - 2y_0y_2 \quad (13)$$
$$l_1^2 = x_1^2 + y_1^2 + x_0^2 + y_0^2 - 2x_0x_1 - 2y_0y_1 \quad (14)$$

After simplification we can write the above equations in matrix form as,

$$2\begin{pmatrix}(x_3 - x_1) & (y_3 - y_1)\\(x_3 - x_2) & (y_3 - y_2)\end{pmatrix}\begin{pmatrix}x_0\\y_0\end{pmatrix} = \begin{pmatrix}d_2^2 - x_2^2 - y_2^2 + x_3^2 + y_3^2 - d_3^2\\d_1^2 - x_1^2 - y_1^2 + x_3^2 + y_3^2 - d_3^2\end{pmatrix}$$

(15)

Where we can assume

$$X = 2\begin{pmatrix}(x_3 - x_1) & (y_3 - y_1)\\(x_3 - x_2) & (y_3 - y_2)\end{pmatrix}$$
$$b = \begin{pmatrix}x_0\\y_0\end{pmatrix}$$
$$Y = \begin{pmatrix}d_2^2 - x_2^2 - y_2^2 + x_3^2 + y_3^2 - d_3^2\\d_1^2 - x_1^2 - y_1^2 + x_3^2 + y_3^2 - d_3^2\end{pmatrix}$$

So the equation 15 becomes

$$X\,b = Y$$
$$b = X^{-1}Y$$

Where X^{1} is the inverse of matrix X and after putting the values of (x_1, y_1), (x_2, y_2) and (x_3, y_3) we get the coordinates of anchor nodes this can be seen in below fig. 6.

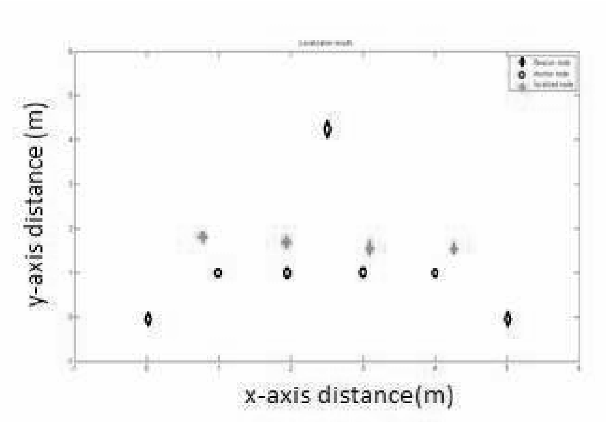

Fig. 6 Triangular Approaches

In the above diagram it can be shown that an error of 1m to 3m is possible which is smaller than other localization schemes.

VI. CONCLUSION

A trilateral RSSI based localization algorithm has been proposed. Analytical model of RSSI is explained and results have shown that proposed technique is more feasible and gives accurate results. RSSI based localization scheme is applicable for both static and dynamic anchor node localization. Furthermore, comparison of RSSI based method with other techniques has shown that it is superior in terms of environment, extra hardware, cost of implementation and accuracy. Satisfactory results of this technique are the evident of the situations in which RSSI performs much better that the other techniques.

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