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EXPERIMENTAL ANALYSIS OF RSSI-BASED OUTDOOR LOCALIZATION IN WIRELESS SENSOR NETWORKS

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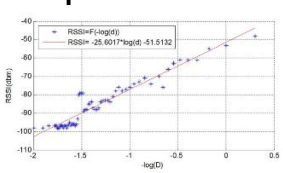
Graphical abstract



Abstract

To estimate the distance and localization in the wireless sensor networks (WSN), the RSSI (Received Signal Strength Indicator) value is generally assumed to have a linear relationship with the logarithm of distance communication. This is true in the absence of obstacles and wireless interference, as is the case in the free space. In this paper, the principle of nodes localization in wireless sensor networks is analyzed on the basis of RSSI as metric for estimating distances in outdoor environment. The measure of nodes distances and localization process are described. CC2530 RF module is used as a hardware platform of nodes on the location experiment. The results of localization algorithms (Trilateration and Multilateration) in Wireless Sensor Networks are presented. Test results show that the mean errors are around 4.9 m in a real-world environment for the Trilateration algorithm and around 0.5 m for Multilateration algorithm.

Keywords: Wireless sensor network, RSSI, outdoor localization, trilateration, multilateration

1.0 INTRODUCTION

Radio localization is one of the important applications in our daily life and WSNs is popularly selected to be used for localization system.[1]The precision of localization is strongly influenced by distance estimation. The imprecision of distance estimation causes an inaccuracy in the positions of nodes. Several techniques are developed for estimating distances between neighboring nodes. Among which we find those based on radio devices, such as the method of received signal strength "Received Signal Strength Indication (RSSI)," and the technique for estimating the distance by the number of radio hops "Radio hop count".

A number of methods based on the strength of the received signal (RSSI) have been proposed in literature.[2] Since the RSSI in a transmission between nodes can be calculated directly by the radio transceivers, this approach does not need any external device to track the position of the sensor nodes in a wireless network. In this paper we programed a Triangulation and Multilateration algorithm for the localization. CC2530 RF module is used as a hardware platform of nodes on the location experiment based on the IEEE 802.15.4 Zigbee protocol, and we studied the influence of the frequencies and power on the localization.

The paper is organized as follow: Section 2 presents the description of the algorithm model. Section 3 presents the materials and methods used in the experiment. Results and discussions are described in Section 4. Finally, in Section 5, we conclude this paper with plans for future work.

2.0 DESCRIPTION OF ALGORITHM MODEL

2.1 Attenuation Modeling RSSI = *f*(*d*)

RSSI is a measure of dBm, which is ten times the logarithm of the ratio of the power (*P*) at the receiving end and the reference power (*Pref*) i.e., RSSI a 10 log(*P*/*Pref*).[1] Power at the receiving end is inversely proportional to the square of distance (*d*), i.e. RSSI a log(1/d^2). Simplifying this relation further we can conclude that RSSI = *f*(–log (*d*)).[3]

Thus if we were to plot the RSSI measured and plot it against log of distance we should be able to obtain an inverse linear relation as it is shown in (2):

$$RSSI = - A.\log(d) + k \quad (1)$$

$$d = 10[(k - RSSI) / A] \quad (2)$$

Where A is the slope of the standard plot, and *k* is an estimated constant parameter.

A graph thus generated would serve as a standard curve that can then be employed by a receiving mote to estimate the distance at which a sending mote would be located.

2.2 Trilateration Algorithm

Trilateration[4] is a geometry-based algorithm. The distance di estimated from the RSSI values is used to compute circles centered in the three reference nodes. The radius r of the circles is supposed to be equal to *d*. ideally; the target should be exactly at the intersection of the circles Figure 1.[2]

Given the coordinates of the center of the i^{th} circle (x_i ,y_i) and its radiusr_i, the equation of a circle is

$$(x - x_i) + (y - y_i) = r_i^2 \quad (3)$$

And the intersection of the three circles is calculated by solving the following system:

$$\begin{cases} (x - x_1) + (y - y_1) = r_1^2 \\ (x - x_2) + (y - y_2) = r_2^2 \\ (x - x_3) + (y - y_3) = r_3^2 \end{cases} \quad (3)$$

Nevertheless, in most of cases the radius r_i is not sufficiently accurate the intersection of the circles can result an area instead of a point, or the intersection could not exist at all. If the circles do not intersect, two circles are drawn around two anchor nodes in this case, the radius are increased proportionally until their intersection is a unique point. On the other hand, if the circles intersect in two points, the coordinates estimated are the nearest one to the third anchor node chosen according to [5].

2.3 Multilateration Algorithm

One of the most common methods for deriving a position, Multilateration enables to find the coordinates of a node from the known anchors coordinates, and the estimated distances between these anchors and the target node.

2.3.1 Multilateration Principe

To explain the principle of Multilateration, it is simpler to consider a problem in two dimensions, as in the case of a planimetric survey (topometry 2D). The aim is then to determine the position of an object *P* from the geometrical distances separating point P of two known points P_1 and P_2 (Figure 2).

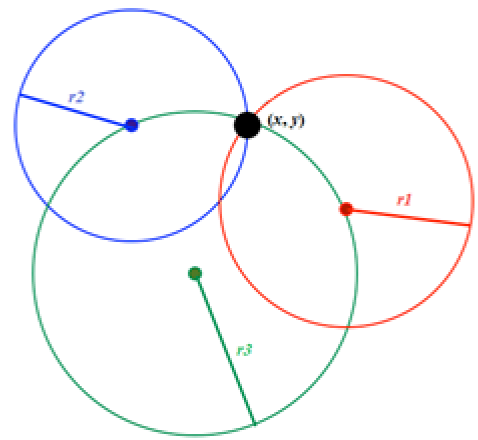


Figure 1 The trilateration algorithm

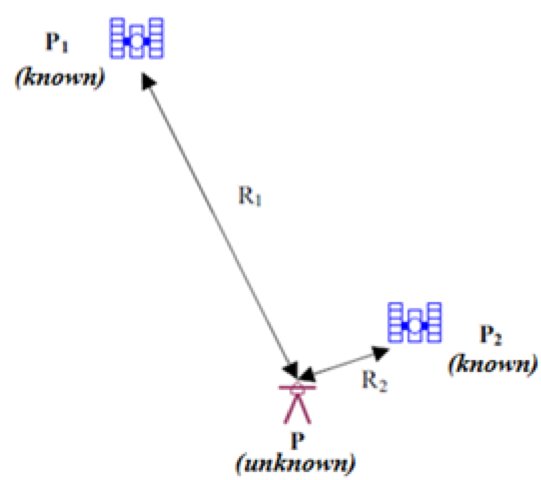


Figure 2 Sensors positioning

As indicated in the Figure 3, by measuring the distances PP_1 and PP_2 we can define two circles of radius R_1 and R_2 respectively centered at P_1 and P_2. In practice, the coordinates of the two points of intersection are obtained by expressing the geometric distances PP_1 and PP_2 based on Cartesian coordinates of the points P, P_1 and P_2.

The system with two equations and two unknowns obtained is then solved and linearization around an approximate position of the point P. The receiver measures the distance between two known points. Each distance allows defining two circles centered on the points P_1 and P_2. To calculate the receiver position, it is sufficient to determine the intersection of two circles.[6]

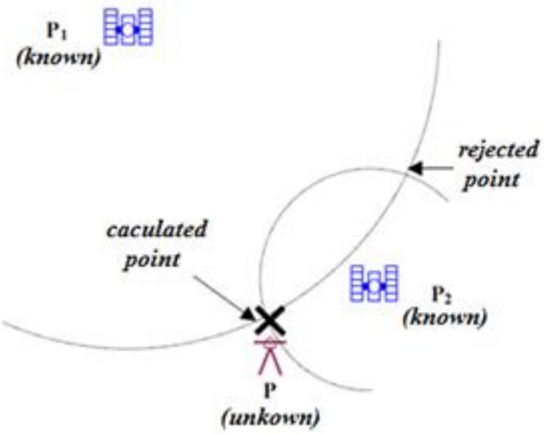


Figure 3 Computing the intersection of the circles

2.3.2 Multilateration Theory

A detailed description of this algorithm can be found in[7,8].

Assuming a target (a) which we want to find the position, and let m anchors which we know the positions. We derive the following system of equation:

$$\begin{gathered}(x_{11}\text{-}x_{a1})^2+(x_{12}\text{-}x_{a2})^2+\ldots+(x_{11}\text{-}x_{ap})^2=d_{1a}^2\\ \vdots\\ (x_{m1}\text{-}x_{a1})^2+(x_{m2}\text{-}x_{a2})^2+\ldots+(x_{1p}\text{-}x_{ap})^2=d_{ma}^2\end{gathered}\tag{5}$$

Where d are estimated distances between the different anchors and the target, assumed are known.

The system can be linearized by subtracting the last equation from the previous m-1 equations:

$$\begin{aligned}&x_{11}^2-x_{m1}^2-2(x_{11}-x_{m1})x_{a1}\\ &+x_{12}^2-x_{m2}^2-2(x_{12}-x_{m2})x_{a2}\\ &\qquad+\ldots\\ &+x_{1p}^2-x_{mp}^2-2(x_{1p}-x_{mp})x_{ap}=\hat{d}_{1a}^2-\hat{d}_{ma}^2\\ &\qquad\vdots\\ &x_{(m-1)1}^2-x_{m1}^2-2(x_{(m-1)1}-x_{m1})x_{a1}\\ &+x_{(m-1)2}^2-x_{m2}^2-2(x_{(m-1)2}-x_{m2})x_{a2}\\ &\qquad+\ldots\\ &+x_{(m-1)p}^2-x_{mp}^2-2(x_{(m-1)p}-x_{mp})x_{ap}=\hat{d}_{(m-1)a}^2-\hat{d}_{ma}^2\end{aligned}\tag{6}$$

A system of linear equation in the form $Ax = b$ is obtained by reordering the terms, where:

$$A=\begin{bmatrix}2(x_{11}-x_{m1}) & \cdots & 2(x_{1p}-x_{mp})\\ \vdots & \vdots & \vdots\\ 2(x_{(m-1)1}-x_{m1}) & \cdots & 2(x_{(m-1)p}-x_{mp})\end{bmatrix}\tag{7}$$

$$b=\begin{bmatrix}x_{11}^2-x_{m1}^2+\cdots+x_{1p}^2-x_{mp}^2+\hat{d}_{ma}^2-\hat{d}_{1a}^2\\ \vdots\\ x_{(m-1)1}^2-x_{m1}^2+\cdots+x_{(m-1)p}^2-x_{mp}^2+\hat{d}_{ma}^2-\hat{d}_{(m-1)a}^2\end{bmatrix}\tag{8}$$

As we have errors in the estimated distance, we cannot find an exact solution to this system of equations.

The nearest solution (in the least-squares approach) of the exact solution is obtained by minimizing $(Ax - b)^T(Ax - b)$.

Therefore $\hat{x}_a=\arg\min_x(Ax-b)^T(Ax-b)=(A^TA)^{-1}A^Tb.$

So $\hat{x}_a=\begin{bmatrix}\hat{x}_{a1}\\ \hat{x}_{a2}\\ \vdots\\ \hat{x}_{ap}\end{bmatrix}$ the estimated position of the node a.

The process can be repeated with any unknown network nodes. We thus obtain the positions of all nodes in the network.

3.0 MATERIALS AND METHODS

We have conducted practical experiments to see whether RSSI can be used as a tool in the localization algorithms regardless to the hypothetical assumptions that have been revolving around RSSI. For this, we made a series of measuring of the signal strength received by a receiver sensor for different distances and in the same outdoor environment (soccer field Figure 4) in order to derive the formula of the distance shown in (2).

Figure 4 The experience outdoor environment

Three steps are necessary to validate the equation:

- Evolution of the RSSI in function of the distance.
- Linearization and interpolation of the measured values of RSSI.
- Validation of the equation (2).

Different mathematical models are deduced for different power and frequency.

The development kit we used is CC2530ZDK from Texas Instrument which integrates 802.15.4 radio (CC2530) with a built-in 2.4GHz antenna.

The two sensors (transmitter and receiver Figure 5) are placed in a straight line and line of sight with the following configuration:

Number of packet sent: 1000 packets;

The Packet transfer speed: 100 packets/s;

The possible transmission powers: -3 dBm, 0 dBm, 04 dBm;

Selected Channels: C11(2405 Mhz), C18(2440 MHz), C26(2480 Mhz) ;

The displayed RSSI value = the average RSSI values of the last 32 packets.

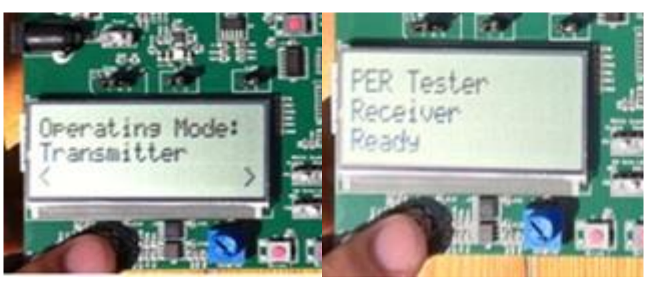


Figure 5 Transmitter and reciver mode

4.0 EXPERIMENT RESULT AND DISCUSSION

The good quality of transmission in a wireless sensor network is generally based on the choice of the power and frequency on the one hand and adaptation to the transmission support on the other hand. The node localization algorithm can be divided into two phases, the distance measure and the localization computation. This paper begins by studying the influence of frequency and power of transmission in order to develop a mathematical model of RSSI applied later in the Trilateration algorithm, which minimizes the localization error.

The measured RSSI values from the nodes of sensors deployed over a distance which varies from 0 to 100 m are represented in Figure 6.

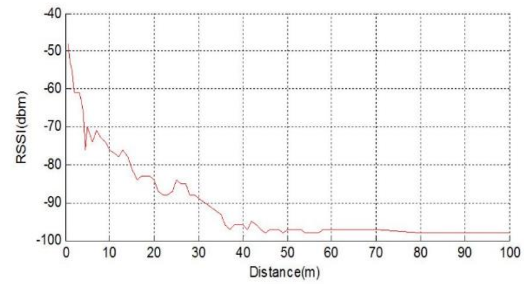


Figure 6 RSSI in function of distance (f = 2440 MHz, Po = -3 dBm)

We plotted the curve of RSSI = f(-log(d)) as it is shown in Figure 7.

We repeat the same experiment for different frequencies (f_1 = 2405 MHz, f_2 = 2440 MHz, f_3 = 2480 MHz) and different power (po1 = -3 dBm, po2 = 0 dBm, po3 = 4 dBm), the results are illustrated in Table 2.

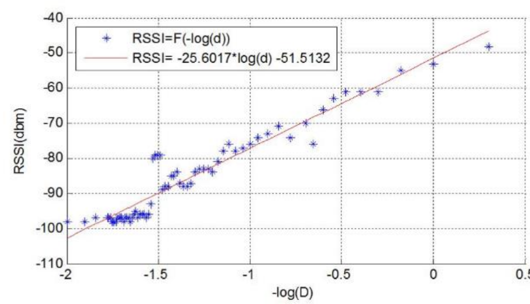


Figure 7 Linearization and interpolation of the measured values of RSSI (f = 2440 MHz, Po = -3 dBm), and the linearization and interpolation of measured values of RSSI allows deducing a model which corresponds to (2).

As it can be seen, the distance axis can be divided into two ranges according to the error and we can exploit the attenuation formula for each range. The formula of the first range (< 60 m) will give a better precision in distance estimation. For the formula of second (> 60 m) we cannot estimate the distance because of the stability of measured RSSI values.

Table 1 The obtained coefficient according to the different configuration of frequency and power

Frequency (MHz)	Power (dBm)	Distance (m)	*A*	*k*
2405	-3	> 60	RSSI constant	
		0 to 60	25.7770	-45.0991
	0	> 60	RSSI constant	
		0 to 60	25.9235	-43.1266
	4	> 60	RSSI constant	
		0 to 60	26.1713	-39.1317
2440	-3	> 60	RSSI constant	
		0 to 60	25.9879	-51.1516
	0	> 60	RSSI constant	
		0 to 60	24.8992	-51.4099
	4	> 60	RSSI constant	
		0 to 60	25.3006	-47.0641
2480	-3	> 40	RSSI constant	
		0 to 40	23.0327	-54.5814
	0	> 40	RSSI constant	
		0 to 40	23.7042	-50.7069
	4	> 40	RSSI constant	
		0 to 40	23.0730	-45.8645

By using the formula of the first range as it shows in (9), for example in the Trilateration and Multilateration algorithm we can see that the error of localization can be changed according to the frequency and the power Figure 8 and 9 and the error decrease when the powers increase.

$$d = 10^{[(-51.1516 - RSSI)/25.9879]} \tag{9}$$

Table 2 Sensor position

	Sensor 1 (x_1, y_1)	Sensor 2 (x_1, y_1)	Sensor 3 (x_1, y_1)	Unknown Sensor 4 (x_1, y_1)
x	0	0	60	18
y	0	30	0	15

But in some cases we cannot locate the unknown sensor because there will be no intersection between the circles of the sensor Figure 10. The Table 3, shows the result of the different experiences.

According to the results, it can be concluded also that the method of Triangulation gives better precision of the location in the case of intersection of the three circles, whereas in other cases Multilateration is more accurate.

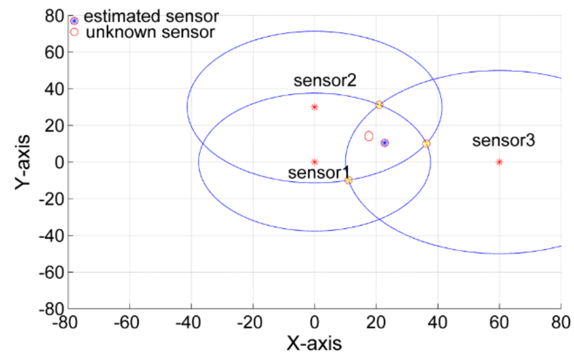


Figure 8 Estimated sensor (f = 2405 MHz, Po = 4 dBm)

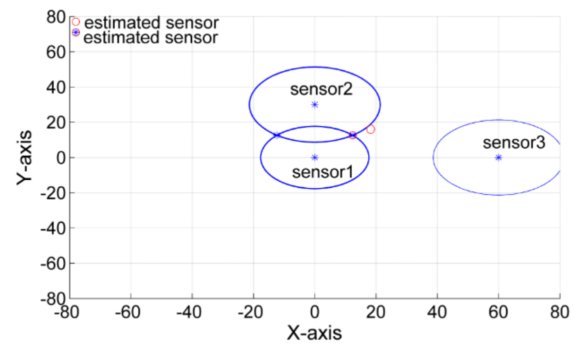


Figure 9 Estimated sensor (f = 2480 MHz, Po = -3 dBm)

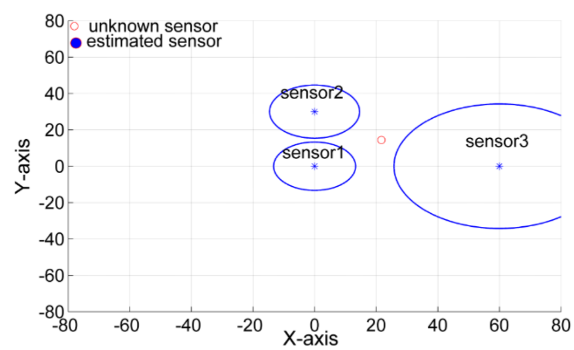


Figure 10 Estimated sensor (f = 2440 MHz, Po = 4 dBm)

5.0 CONCLUSION

From the results of theoretical study and practical experiments it was concluded that the steps followed in estimating distances are required for the study of environment and permitted to exploit a formula relationship between signal strength and distance. Also, it is extremely difficult to develop a graph between RSSI and distance which can be used as a standard reference for getting the distance value for a given RSSI value.

In the future we will try to use other algorithms of localization and compare the obtained results.

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Table 3 Localization error

Frequency (MHz)	**Power** (dBm)	**RSSI** (dBm)			**Localization Error** (m)	
		From sensor 1	From sensor 2	From sensor 3	Tri	Multi
2405	- 3	-91	-92	90	10.10	16.12
	0	-89	-88	-89	13.02	22.24
	4	-82	-80	-86	4.91	7.19
2440	- 3	-83	-86	-91	6.54	0.95
	0	-80	-86	-86	9.41	3.27
	4	-75	-76	-86	///	1.50
2480	- 3	-82	-84	-88	11.05	0.683
	0	-77	-79	-87	///	1.13
	4	-74	-80	-79	10.35	0.51

///: no intersection between the circles