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Localization in a Wireless Sensor Network based on RSSI and a decision tree

Abstract*. In this paper, we propose a new localization technique in a wireless sensor network (wsn) using the Received Signal Strength Indicator (RSSI). This technique is based on a decision tree obtained from a set of empirical experiments on wireless sensors based on XBee modules. The decision tree is used to select the best three neighbour reference nodes that are involved into the estimation of the target sensor node position by applying the Cramer's Rule approach. The tests performed during this study indicate an estimated accuracy of the position around two meters after verifying the validity of our results in an actual environment. This result is acceptable, if we take into consideration the restricted number of nodes used and the application for which the technique will be deployed, this might be the localisation of personnel in high-risk areas in order to enhance their safety in the event of an occurring danger.*

*Streszczenie. W artykule zaproponowano nową metodę lokalizacji w sieci bezprzewodowej bazująca na wskaźniku mocy odbieranego sygnału. Metoda została zbadana na przykładzie sieci z modułami XBee. Bazując na drzewie węzłów sieci można określać położenie węzła czujnika stosując metodę prawa Cramera. (****Lokalizacja węzłów w sieci bezprzewodowej bazując na wskaźniku mocy odbieranego sygnału RSSI****)*

Keywords: localization, wireless sensor network, RSSI, decision tree, XBee, Cramer's Rule
Słowa kluczowe: sieć bezprzewodowa, lokalizacja węzła, XBee, prawo Cramera.

1.Introduction

Object‘s localization such as a person in a high risk working environment using wireless sensor networks (WSN), has been the focus of recent research and has gained a distinguished interest. For instance, In industry many leaders have invested in wireless measuring instruments with different degree of protection to risk areas such as IP65 and IP67. The majority of these devices are designed according to IEEE 802.15.4 norm, to allow universal communication between instruments with different brands.

Several techniques exist, to locate a target in a wireless sensor network, each of which has its own advantages and disadvantages. The simplest technique and the most energy efficient is the one based on RSSI (Received Signal Strength Indicator), which uses the measurement of transmitted power. However, its main drawback is the poor precision in estimating the position. This is due to many factors, such as the interference from other signals and the presence of objects in the path of the radio wave presenting undesirable obstacles. In our application, we select this technique as it is possible to measure the strength of signals from a sensor neighbour just by listening to messages without any added hardware. We tested this technique using communication platforms designed according to the IEEE 802.15.4 wireless protocol, forming a network of sensors. Many experiments were conducted to verify the reliability of measuring RSSI and to determine the position estimate for each type of the hardware configuration. The results are presented as a decision tree, based on which a practical application, that allows localization of one or more targets in a defined area, was implemented.

2. Related works

Many studies have been reported in the literature concerning the problem of localization in wireless sensor networks, using the RSSI. For instance, in [8] and [12], the authors performed a collaborative localization to improve the positional accuracy but their method required the participation and the coordination of several nodes. In [7] and [11] Fiis equation was used for the conversion of RSSI to distance, but the accuracy of the localization obtained was around three meters. Another indoor method based on RSSI map was implemented in [14] using an XBee platform. However, its drawback is the need for multiple samples of RSSI on site. In [3], an algorithm based on RSSI has been proposed for Indoor localization with a Zigbee platform. In [4] a similar system has been implemented with mica platforms. Another system based on ground effect and the antenna orientation with micaz platforms was developed in [6].

Our contribution in this paper consists of experimenting RSSI technique in a wireless sensor network based on XBee modules, while applying a new approach based on a decision tree for the selection of the best nodes involved in the computation of the target position using the Cramer's rule [1]. In our case, the distance between the position of a reference node and the location of the target node, is estimated from preliminary empirical gathered RSSI data using the dichotomy algorithm.

3. Experimental setup and the hardware platform

The application described here is performed with a network of wireless sensors, based on sensor nodes with XBee communication interfaces. XBee is in fact, a family of wireless components developed by Digi (formerly MaxStream). They implement different wireless communication protocols, including IEEE 802.15.4. There are different types of Xbee modules as it is shown in Fig.1. These are, Xbee1 with internal antenna, Xbee2 with connector UFL (MMCX) using external antenna, Xbee3 with Integrated wire antenna and Xbee4 with printed antenna.

XBee1 and XBee4 are used for applications that have size constraints. Whereas XBee2 is used when the module is enclosed in a metallic box in order to avoid the Faraday cage effect. XBee3 has less directivity than XBee1 and it is also recommended in the case of size design constraints within the application [6]. In our case, after a preliminary study we find out that XBee2 is the most appropriate to our application.

Each sensor node is placed in a well determined geographical position. The sensor of the target is composed of an XBee pro2 connected to an Arduino Uno platform [17] and a battery pack. This unit can be installed, for instance, within a safety helmet of a worker.

Antenna orientation, the presence of walls and metal objects are among many factors that affect the localisation accuracy when measuring RSSI. As consequence, the obtained distance might be unreliable. In our application we consider an outdoor localization which may reduce the effect of these factors. Experiment measurements were carried out in order to construct a decision tree which represents the evaluation of the localisation accuracy for each type of the hardware configuration, as a function of distance.

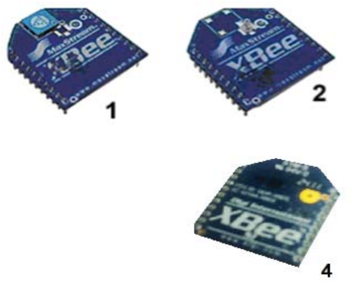

Fig.1. Different versions of the Xbee

First, we had to solve the problem of the node arrangement within the actual environment where the experiments would be conducted. Indeed, the first node was adequately mounted on a top at 2.5 m from the ground with an antenna directed perpendicularly. The second mobile sensor node, the target, is placed in a height of 1.5 m with respect to the ground as it is shown in Fig.2.

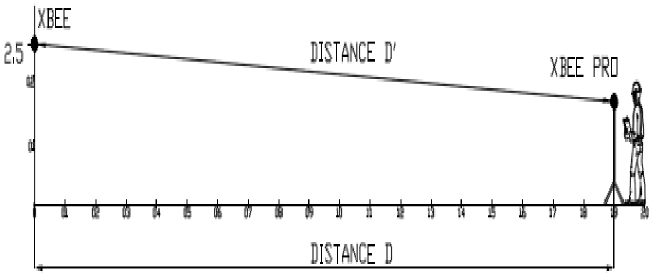

Fig.2. The position of wireless sensors

The target has a communication interface based on an XBee Pro 2 which was appropriately selected in order to receive a good radio signal. Whereas, the second node uses an XBee module with the same type of antenna.

Table1. The RSSI experimental measures versus distance

Distance D (m)	Distance D' (m)	RSSI (-dB)	RSSImoy (-dB)
01,00	01,41	39,00	37,50
02,00	02,24	36,00	37,33
03,00	03,16	37,00	36,33
04,00	04,12	36,00	36,33
05,00	05,10	36,00	37,66
06,00	06,08	41,00	39,66
07,00	07,07	42,00	43,33
08,00	08,06	47,00	44,33
09,00	09,06	44,00	45,66
10,00	10,05	46,00	45,33
11,00	11,05	46,00	46,00
12,00	12,04	46,00	46,66
13,00	13,04	48,00	46,00
14,00	14,04	44,00	45,66
15,00	15,03	45,00	46,33
16,00	16,03	50,00	47,33
17,00	17,03	47,00	50,00
18,00	18,03	53,00	51,66
19,00	19,03	55,00	53,66
20,00	20,02	53,00	54,00

4. Preliminary experimental tests

To perform correctly our experiments, we started by measuring the signal strength received by the target from the reference node in a response frame for different distances, varying from 1 meter to 20 meters by moving the target toward the reference node. The Table 1 indicates the obtained empirical values of RSSI in -dB as function of distance in meter. Each RSSI value represents the mean of three different measurements taken from the same target position.

In order to allow error correction for the obtained measurements, we compute the RSSImoy, the mean value based on the interpolation using RSSI neighbouring values for each target position given in Table 1, and according to the equation 1.

$$RSSI_{moy,n}=(RSSI_{n-1}+RSSI_{n}+RSSI_{n+1})/3 \tag{1}$$

where $RSSI_{moy,n}$ gives RSSI with correction for the point n, $RSSI_{n-1}$ represents the previous value of RSSI without correction, $RSSI_n$ the value of RSSI without correction for the point n and $RSSI_{n+1}$ the next value of RSSI without correction.

In order to adequately evaluate the experimental results, we defined a new parameter that we called, PRSSI, representing the evolution of the RSSI, function of distance. PRSSI describes how the RSSI changes, for two successive values, as a function of the corresponding change in the distance. PRSSI is given by equation 2 and it is expressed in dB per meter.

$$PRSSI=\frac{RSSI2-RSSI1}{\text{Distance2}-\text{Distance1}}(-dB/meter) \tag{2}$$

In Fig.3, we have represented the RSSI variations function of the distance before and after the correction based on the interpolation as stated above. From Fig.3, we can deduce different distance intervals according to the values of PRSSI. Indeed, the interval [1-4] m shows an attenuation of RSSI from 39 to 36 due mainly to interferences. In the case of the]4-8] m, we notice rapid evolution of RSSI from 36 to 47 with an average of 2.5 dB / m. Whereas the interval]8-14] m presents slight evolution of RSSI from 45 to 46 with an average of 0.5 dB / m. Finally, the interval]14-20] m presents rapid evolution of RSSI from 36 to 47 with an average of 2 dB by meter.

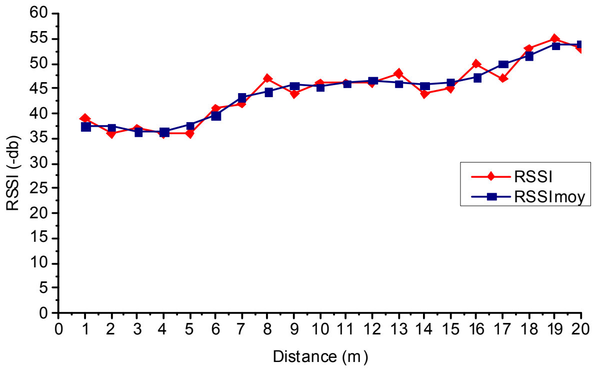

Fig.3. The RSSI variation versus the distance, with and without correction

Table 2. Evaluation of RSSI quality as a function of PRSSI

PRSSI	quality	Vote (point/m)
PRSSI < 0.5	bad	0
0.5 ≤ PRSSI < 1	average	1
1 ≤ PRSSI < 1.5	good	2
1.5 ≤ PRSSI ≤ 2	very good	3
2 < PRSSI	excellent	4

The results obtained from the previous test, and the use of the PRSSI parameter, helped us in evaluating the quality of RSSI of each neighbour node, by proposing a vote. The vote value was set according to the conditions given in Table 2. This vote will be used as a metrics to classify the quality of RSSI into five different categories according to the accuracy of the measured RSSI value. The quality varies from bad to excellent if the vote is respectively equal to 0 or 4.

3.1 Creation of the decision tree

To enhance the localization accuracy, we have considered the information in Table 2 in order to derive the decision tree, which was used to automatically select the best three sensor nodes participating in the determination of the position of the target node according to the obtained votes. The decision tree represented in Fig.4 shows the vote number allocated to the XBee2 module according to the distance interval.

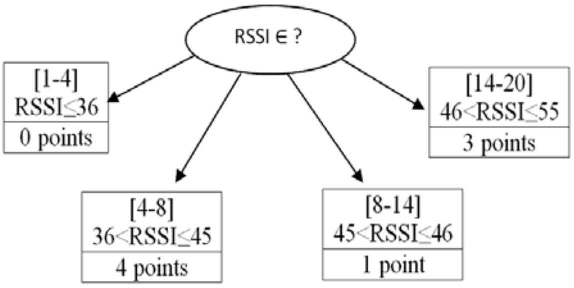

Fig.4.The decision tree for the choice of the best three neighbours

```
// declarations
 start, end, val, mid : Integers
Xbee: Table [0...20] ranked integers
found: Booléen
//initialisation
 start ← 0
 end ← 20
found← false
// search loop
 Repeat
      mid ← integer part ( start + ((end-start) / 2) )
If Xbee [mid] = val then
             found ← true
     Else
             If val > Xbee [mid] Then
                          start ← mid+1
             Else
                          end ← mid-1
             EndIf
      EndIf
     While found=false AND start ≤ end
             // display results
             If found Then
                      Display "RSSI ", val, " the distance: ", mid
             Else
                   d=val * end/ Xbee [end]
                   Display "RSSI ", val , " the distance:" ,d
             EndIf
```

3.2 Conversion of RSSI to a distance

The most common used method to convert the RSSI to a distance is to use the mathematical equation given in 3.

$$(3)\quad RSSI=-(10\ n\ \log_{10} d+A)$$

where n is the signal propagation constant, d is the distance from the sender and A is the received signal strength at one meter distance. But the disadvantage of this method is the computation overhead, and the bad accuracy obtained in using the inverse of the logarithm function. In our case, we have adopted the dichotomy algorithm based on the obtained empirical results shown in Table 1. The summarized program given below allows searching Table 1 for a corresponding distance value, given a RSSI value.

3.3 Cramer's rule approach

Cramer's rule [1] [12] has been widely applied in several localization applications. It is based on the concept of the linear equation systems, where the number of equations is equal to the number of variables, and the transformation of the linear equations into the matrix form. Fig.5 shows the structure and components used by Cramer's rule based on three reference nodes.

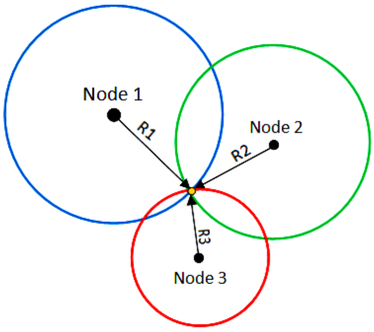

Fig.5. Cramer's rule [1]

We used (x_i, y_i) as the coordinates of the referencing node i, (x_u, y_u) as the coordinates of the target object, and ***R*** R_i as the distance between the node i and the object. From the circle equation given in 4, and doing all mathematical transformations as in [1], we get equations 5,6 and 7 from which we can obtain the coordinates defining the position of the target node as it is indicated in equation 8.

$$(4)\quad (x_i - x_u)^2 + (y_i - y_u)^2 = R_i^2 \qquad i = 1,2,3$$

$$(5)\quad \det(A) = \begin{vmatrix} (x_3 - x_1)*2 & (y_3 - y_1)*2 \\ (x_3 - x_2)*2 & (y_3 - y_2)*2 \end{vmatrix}$$

$$(6)\quad \det(A_1) = \begin{vmatrix} (R_1^2 - R_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) & (y_3 - y_1)*2 \\ (R_2^2 - R_3^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) & (y_3 - y_2)*2 \end{vmatrix}$$

$$(7)\quad \det(A_2) = \begin{vmatrix} (x_3 - x_1)*2 & (R_1^2 - R_3^2) - (x_1^2 - x_3^2) - (y_1^2 - y_3^2) \\ (x_3 - x_2)*2 & (R_2^2 - R_3^2) - (x_2^2 - x_3^2) - (y_2^2 - y_3^2) \end{vmatrix}$$

$$(8)\qquad x_u = \frac{\det(A_1)}{\det(A)} \ \text{and}\ y_u = \frac{\det(A_2)}{\det(A)}$$

4. Tests and results

Several tests were performed in order to evaluate the localization accuracy of the proposed technique. We considered a practical situation where the Xbee modules were deployed in known locations at the same 1.80 m height level of the target. Whereas, the position of the target was calculated by selecting the best three neighbours among four reference nodes using the decision tree shown in Fig.4. After receiving the data packet by the target, we extracted the RSSI of each neighbour node and then we converted it into distance using the dichotomy method based on the results given in Table1.

Table 3.Representation of real and estimated target positions

Actual position			Average RSSI				Estimated distance				Position		Error
N°	**x**	**y**	**N1**	**N2**	**N3**	**N4**	**N1**	**N2**	**N3**	**N4**	**x**	**y**	
01	2,50	9,00	35,66	45,00	38,00	37,00	4,44	8,56	5,49	5,35	2,32	9,05	0,19
02	2,50	8,00	36,00	45,33	37,66	37,00	4,49	8,62	5,45	5,35	2,70	8,86	0,88
03	2,50	7,00	36,00	41,66	36,33	37,33	4,49	6,60	4,53	5,40	1,70	7,87	1,18
04	2,50	6,00	36,00	37,66	36,66	39,00	4,53	5,45	4,57	5,64	1,99	6,42	0,66
05	3,50	6,00	37,00	38,00	36,00	37,00	5,35	5,49	4,49	5,35	3,86	5,35	0,74
06	4,50	6,00	37,66	39,00	36,00	36,33	5,45	5,64	4,49	4,53	4,69	5,32	0,71
07	5,50	6,00	38,00	42,00	35,66	36,66	5,49	6,66	4,44	4,57	6,14	5,38	0,89
08	5,50	5,00	39,33	39,00	36,00	37,00	6,23	5,64	4,49	5,35	4,70	4,93	0,80
09	5,50	4,00	42,33	38,66	36,33	37,33	6,71	5,59	4,53	5,40	5,14	4,57	0,68
10	5,50	3,00	44,00	36,66	36,00	39,66	8,00	4,57	4,49	6,28	5,58	3,01	0,08
11	5,50	2,00	45,33	36,00	37,00	43,00	8,62	4,49	5,35	7,42	4,97	2,39	0,66
12	6,50	2,00	45,66	38,00	37,00	43,00	10,52	5,49	5,35	7,42	6,39	2,08	0,14
13	7,50	2,00	45,66	39,00	38,00	44,00	10,52	5,64	5,49	8,00	5,85	2,54	1,74
14	8,50	2,00	46,00	42,33	38,00	43,66	11,46	6,71	5,49	7,54	8,21	1,66	0,45

The obtained positions of the target are compared with actual positions. The position error Δx is calculated as it is illustrated in equation 9. Where (x, y) are the actual coordinates of the target and (x_u, y_u) are the estimated coordinates.

The results obtained for the range of the distance considered in this study, are summarized in Table 3.
The three neighbour nodes selected by the decision tree are marked by a gray colour in Table 3.

$$\text{(9)}\quad the\ position\ error = \sqrt{(|x - x_u|)^2 + (|y - y_u|)^2}$$

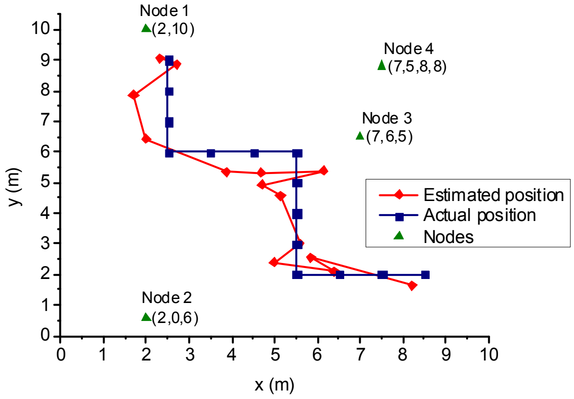

Fig.6. The position of the target using the decision tree

In Fig.6 we represent graphically the coordinates of the target according to the positions of the four reference nodes. In Fig.7 the position error is represented function of the considered position of the target. According to Fig.7, we can state that in the overall, the error position is less than one meter, for almost all target positions. However, in the case of position 3, the error is 1.18 meter and this is mainly due to the problem of measuring the RSSI by the node N 3. The worst error position 1.74 meter is noticed in the case of the position 13, which is probably caused by the interferences. We can conclude from these results that the localization accuracy can be enhanced by increasing the number of reference nodes and by selecting the appropriate positions of the reference nodes.

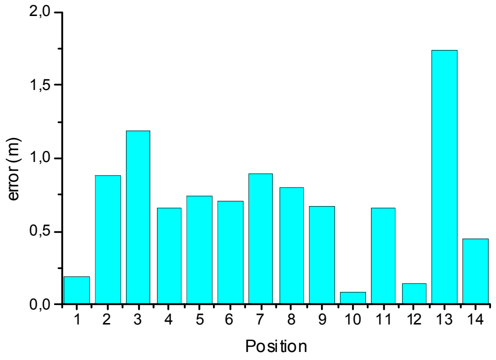

Fig.7. The position error versus distance

5.Operating mode of the proposed WSN

The wireless sensor of the target starts by the neighbourhood detection based on the command mode of the Xbee module. Then, we store the information gathered for each neighbour node in a neighbourhood table, which specifies the node ID, the address M, and the value of the RSSI. After that, we select the appropriate three nodes that are involved in the determination of the position of the target, using the decision tree, then the RSSI of each neighbour node is remotely converted and finally the obtained information will be sent to the parent station.

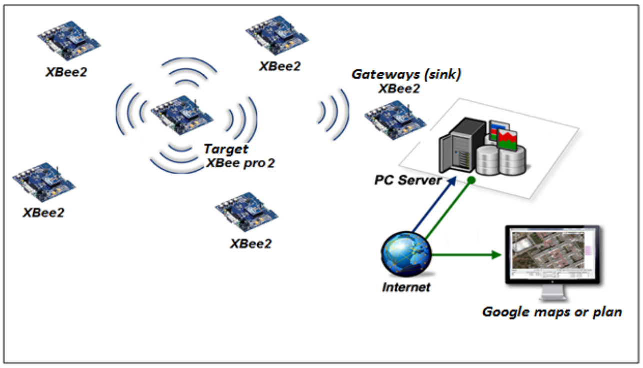

Fig.8. Block diagram of the proposed WSN

We developed a monitoring system that has been installed in a PC server connected to the Internet in the main station. This system collects information sent by the target using a sink connected via an USB port. The gathered information of neighboring nodes is stored in a MySQL database together with the coordinates of the target. Then, the positions of the sensor nodes are projected in Google maps using the Apache server that supports php5, as it is illustrated on the block diagram of the developed application in Fig.8. We have created a PHP page that uses the Google Maps API [16] for the projection of geographical coordinates in a satellite mapping. This page is available on our intranet using a web browser. The data is shown within the graphical user interface of the developed application using a component that integrates a web browser in our application.

6-Conclusion and perspectives

In this paper, we have presented a new technique to improve the accuracy of localization in a wireless sensor network using the RSSI. The obtained results based on empirical data, gathered from many experiments, indicate an accuracy less than two meters, which allows us to precisely perform the localization of objects. This result is acceptable for the localization of personnel in areas at risk. However, the operating mode of this technique depends on the number of sensor nodes and their precise locations. In addition, this method is restricted to outdoor applications.

To improve the proposed localization technique, we are working on the fusion of inertial data, acceleration and velocity, together with the position of the target using the Kalman filter, which allows us to correct the position error by estimating the next target position.

The WSN based on this technique will be deployed in the identification of accidents, such as falls using inertial sensors installed within the helmet of a worker. The occurring accidents will be automatically reported to the monitoring system located in a remote control room. Our research work continues in this direction.

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