2-D Indoor Localization for Wireless Sensor Networks

5LIC0 Group 03

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***Abstract*—The growth of Internet of things (IoTs) has led to the development of Wireless Sensor Networks (WSN). IoTs are mostly associated with the acquisition of sensor node information and controlling of "things". However, the absence of location information of these sensor nodes compromises the intelligence of the IoT network, especially in an indoor environment. This paper researches the possibility and implements a method to precisely localize a mobile device inside a closed building by means of wireless sensor nodes. Using the Received Signal Strength Indicator (RSSI) and trilateration algorithm, the location of the mobile device can be approximated. This research does not contain a hardware implementation, only a simulation. Simulations are performed for the network of Contiki nodes using the Cooja environment. The greatest deviation calculated was 0.09 meters, compared to the actual location.**

***Keywords*—localization; Wireless Sensor Networks (WSN); RSSI; Kalman Filtering; ContikiOS; Cooja**

I. Introduction

In a modern world where the development of 'smart' systems are increasing rapidly, more and more electronic devices are being connected for the exchange of information. To keep expanding these type of systems, it is necessary to have devices which are able to communicate with one other wirelessly. Wireless sensors (nodes), are tiny battery powered devices which can measure, store and process parameters and then convert it into a signal which can then be picked up by a receiver. A wireless sensor network (WSN) is a network made up of such devices which can communicate information collected from monitoring environmental parameters through wireless links [1]. WSN is widely used for environmental monitoring in many different areas such as industrial, agriculture and health monitoring. Using WSN for environmental monitoring provides a real-time system with control communication with the physical world [2].

Indoor localization is becoming more and more important for multiple services as buildings increase in size. Trying to use satellite based GPS data in large buildings for precise localization can be difficult due to weak signals strengths or insufficient accuracy. Localization in an indoor environment is becoming significantly important for public safety and indoor navigation applications. Locating people in large buildings in case of an emergency could be crucial for saving their lives. Indoor localization could also be used to navigate users inside a building to reach their destination or keep track of their path. Therefore, it is of great importance to design a WSN for indoor localization with efficient and accurate localization algorithms to detect a precise location of a node in the network.

The goal of this paper is to design a WSN consisting of multiple nodes which can accurately estimate the position of a source node in an indoor environment. This will be done by using the received signal strength indicator (RSSI) to predict the distances from the anchor nodes and a trilateration algorithm will then be used to locate the source node. After designing the network, it will be implemented into Contiki through a built-in Cooja simulation.

The rest of the paper is organized as follows. Firstly, a project description is presented in section II. Then a literature survey is given in section III. Section IV presents some theoretical background and the methodology that will be implemented. Section V gives more detail about the simulation. Section VI explains how the system was implemented. Last but not least, section VII and section IX presents the simulation and measurement results and the conclusion of these results.

II. Project description

The WSN which will be implemented consists of three anchor nodes with known positions and a single source node with an unknown position, all nodes are placed in a closed room. A overview of the system architecture is depicted in Figure 1. Before estimating the position of the source node, certain measurements and calculations will take place.

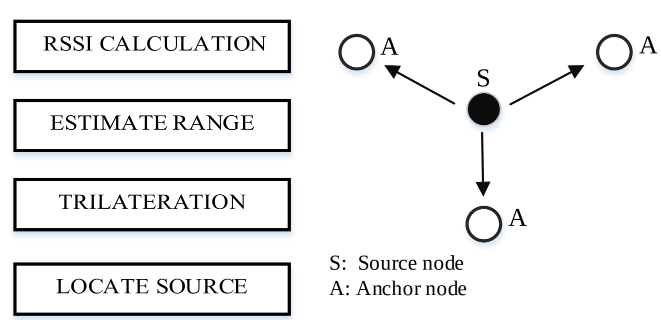

Fig. 1. Overview of the wireless sensor network

The source node will continuously sent short messages. Each anchor node will measure the RSSI value of the received signal from the source node. Using this value, the propagation loss can be calculated which can then be used to find the distances of each anchor node to the source node. In reality, the estimated distances are never perfect because the received RSSI values can always vary due to the environment the nodes are placed in. Therefore, an average RSSI value will be used for estimating the distances. After the distances are calculated, the trilateration algorithm will be applied to estimate the position of the source node with a acceptable localization error.

III. Literature survey

Indoor localization is the topic of more and more research. There have been a lot of studies already done in this field with respect to different technologies (WiFi, BlueTooth, and Zigbee for example) and implementation methods (RSSI and AoA for example) [3]. Each technology and implementation method has its advantages and disadvantages, which also depends on the application of the WSN. Apart from the technical aspect, there are also challenges with respect to cost, privacy and security, and efficiency. Since this paper studies a simulation, this will not be further elaborated but can be read in surveys such as [3].

Common technologies for indoor localization are WiFi, Bluetooth, and Zigbee. WiFi (IEEE 802.11) is a popular option due to its range. A disadvantage of using WiFi for localization is that it is rather new (and less techniques are known for localization), and that there is uncontrolled interference. Bluetooth (IEEE 802.15.1) has the advantage that many techniques can be used (AoA, RSSI for example). However, these techniques have limits on the accuracy. Zigbee (standard IEEE 802.15.4) is the most favourable option for indoor localization. However, due to its low in availability on devices it is not used often. [3]

Besides the choice of technology, there is also a choice of implementation. In other words, there are several methods to approximate the location of the desired device. The most known method is to make use of RSSI (Received Signal Strength Indicator), which is also done in this research. This method is popular because it is simple and cost efficient. A disadvantage is that its accuracy is relatively low to other models. This is due to wall reflections, multi-path fading, and obstacles within the closed room [3]. [4] uses two-ray tracing to study the influence of wall reflections. One of the results is that wall reflections have more negative impact with respect to LoS (line of sight) if a node is closer to a wall. Accuracy and precision can be improved in big open spaces, such as warehouses, by placing at least one receiving node on each wall.

Other studies, such as [5], [6], and [7], show a significant increase of performance with the use of filters. Filters can filter out wrong estimations and increase performance of node tracking, which is done in [5] for moving nodes. [7] uses the Kalman filter for RSSI, obtaining a positioning error of at most 0.5 metres. In [6], a new algorithm called the RMM (RSSI Moving Median) algorithm is proposed. It shows that the variance of the error signal is 22.62 dB. Using the Kalman filter, this variance is 50.93 dB. Even though the Kalman filter shows higher stability if there is no movement involved, the new RMM algorithm shows better performance where human presence is non-negligible and where obstacles are moving. It still remains that this algorithm must be tested in real-time systems.

In a WSN, at least three nodes are necessary to enable localization in an ideal situation. More nodes are needed in a real environment since distant measurements are not one hundred percent accurate and precise. There are several methods to accomplish localization. The one used in this research is trilateration. Studies such as [8] show successful results with respect to localization using RSSI-based trilateration. Trilateration has its downsides, however. It cannot apply localization accurately if the measurements are noisy. An improved version of trilateration is multilateration [9], which uses more than three nodes for localization. The mean location error is smaller using multilateration, compared to trilateration. However, the energy consumption is lower when using trilateration.

A different approach to localization is proposed in [10]. This research introduces shadow edges. In this study, a new algorithm is used in case that the selected locating nodes are not able to sense each other. Selected non-communicating nodes are connected using a shadow edge. Simulations of this technique show successful results in situations where trilateration fails.

IV. Methodology

A. RSSI

RSSI is a hardware-based Link Quality Estimator (LQE). The basic functionality of RSSI is to provide a measure of signal power at the receiver node. It can be used as simple form of Link Quality Indicator (LQI) but also, more importantly in this research, for estimating the range between sender and receiver. An RSSI-based approach does not require extra hardware, making it relatively simple to implement in an already existing sensor node. Friis transmission formula is used to relate free space path loss, antenna gains and wavelength to the transmitted and received signal power. Friis transmission formula is gien by

$$P_{Rx} = \frac{P_{xT} G_{Tx} G_{Rx} \lambda^2}{(4\pi R)^2}, \tag{1}$$

where P_{Rx} is the received power, P_{Tx} the transmitted power, G_{Tx} and G_{Rx} the gain of the transmitter and receiver, respectively, and R is the distance between the receiver and the transmitter in meters. The equation can be rewritten such that R becomes a function of P_{Rx}, with the constants P_{Tx}, λ and G_{Tx}, G_{Rx}.

In extension to Friis free space model, a log distance path loss model is used to predict propagation losses in situations other than only free space. The path loss is given by

$$PL = -10n \log_{10} \frac{d}{d_0} + PL_0, \tag{2}$$

where PL is the path loss, n the path loss exponent, and d_0 the reference distance to calculate PL at further distances d. Different environments can be accounted for, by varying the path loss exponent n. Typical value for n in an indoor scenario is 1.6 - 1.8, whereas for free space a value of $n = 2$ is used. In reality and especially indoor environments, however, accuracy of this method is varying strongly due to the unpredictable way of radio propagation in these scenarios. Multi-path effects generate amplifications or attestations in the signal, causing large errors in the range estimation. To account for this, Kalman filtering such as discussed in [7] can be applied. The filtering formula is given by

$$\begin{aligned} x_{k|k-1} &= x_{k-1|k-1} + u_k \\ P_{k|k-1} &= P_{k-1|k-1} + Q. \end{aligned} \tag{3}$$

In (3), the state prediction equations are shown, where the first equation describes the current status of predictive value x, depending on its previous value. By initially assuming a constant RSSI signal, control input vector u_k can be set to 0. The second line in (3) describes the co-variance of x in which Q is the system noise.

$$\begin{aligned} x_{k|k} &= x_{k|k-1} + K_k(Z_k - HX_{k|k+1}) \\ K_k &= \frac{P_{k|k-1}H^T}{HP_{k|k-1}H^T + R} \\ P_{k|k} &= (1 - K_kH)P_{k|k-1} \end{aligned} \tag{4}$$

The set of equations in (4) describe the status update of the filter, where Z_k is the measured value at moment k and R is the measurement noise. H is a parameter of the measurement system and K_k is the Kalman filter gain that can be adjusted.

B. Localization

For this research, an RSSI-based trilateration technique is used as localization algorithm. Trilateration calculates the location of a point in space, using its distances to other known points. With a minimum of three nodes, it can be solved as a geometrical problem. An illustrated two dimensional example of the trilateration algorithm can be seen in Figure 2. The coordinates of the circles' centers are known, representing locations of the fixed anchor nodes. The radius of each circle is determined by the obtained RSSI of that specific node. The source node is then located on the intersection of the three circles. These coordinates can be calculated by using the equations in (5), where x and y are coordinates and r_n is the radius of anchor node n.

$$(x - x_1)^2 + (y - y_1)^2 = r_1^2 \tag{5}$$
$$(x - x_2)^2 + (y - y_1)^2 = r_2^2 \tag{6}$$
$$(x - x_3)^2 + (y - y_1)^2 = r_3^2 \tag{7}$$

Substitution of equations in (5) results in a solvable system of two equations with two unknowns, which can be found in (8).

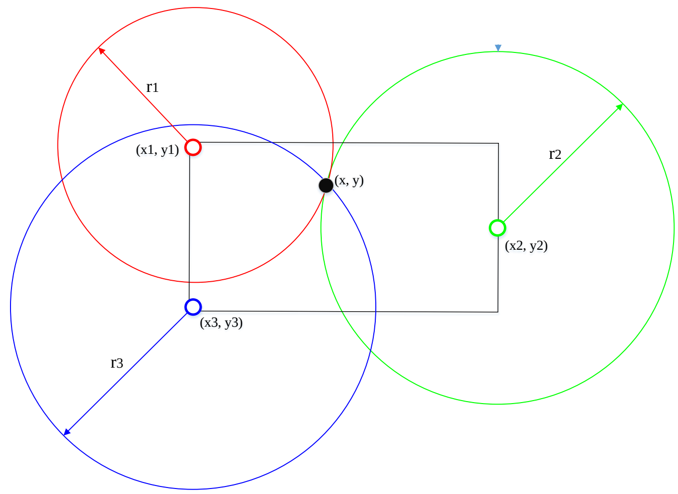

Fig. 2. Example of trilateration applied to a source node with three anchor nodes.

$$Ax + By = C \tag{8}$$
$$Dx + Ey = F \tag{9}$$

V. Simulation

The project is developed on the Contiki operating system [11] with Rime network stack, which is a custom lightweight networking protocol designed for low-power wireless networks [12]. Carrier-sense multiple access (CSMA) protocol is adopted as the MAC layer with ContikiMAC [13] as the RDC layer and the framer used is 802.15.4. Finally, cc2420 is used as the radio layer. Cooja simulation supports several types of motes including Z1, TelosB and Tmote Sky [14]. In our simulation Tmote Sky motes are used as anchor and mobile nodes and are placed in the Cooja environment. The anchor motes run an application developed in C with ContikiOS and are programmed as receive type nodes and the mobile node as broadcast node. Both these type of nodes run on the same firmware. During the simulation, the four motes are selected and placed in the locations defined in the location file shown in Table I and Table II. The mobile node broadcasts its signal changing its position every ten seconds and the RSSI values captured by the anchor nodes are stored for further computation in MATLAB.

VI. Implementation

A. Cooja

In the Cooja environment, four skymote nodes with an adapted version of the Rime stack were used. The broadcasting source node sends with timed interval and does not expect any acknowledgements back. Re-transmissions are of no use in this research since not the data but the strength of any received message is the required input for the localization algorithm. Three anchor nodes are continuously listening to the channel, and storing the RSSI value. For this research, the RSSI data

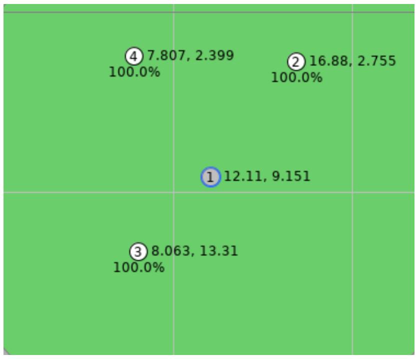

Fig. 3. Cooja simulation consisting of a single source node [ID: 1] and 3 anchor nodes[ID: 2, 3, 4] and their locations.

was exported and used in an offline localization algorithm in MATLAB.

The nodes with a range of $15m$ were placed such that they represented the corners of a large $(9m \times 10m)$ room, represented in 3. Important to notice is Cooja utilizes a different type of radio wave propagation model. Where as Section IV proposes a logarithmic equation for realistic scenarios, the simulator uses a linear model of which the equation can be found in (10).

$$RSSI = SS_{STRONG} + distFactor \times (SS_{WEAK} - SS_{STRONG}) \tag{10}$$

In this equation, SS_{STRONG} and SS_{WEAK} are constants and $distFactor$ is the ratio between actual distance and the transmission range.

B. Mobility

Once four nodes were implemented in Cooja and the source and anchor nodes could send and receive signals, adding mobility functionality to the source node was considered. A mobility plugin can be implemented onto Cooja. When it is enabled, it gives the opportunity to move nodes over time when the simulation is running. Once the Cooja extension plugin was built, the source node was programmed to change position over time while still staying in-between the anchor nodes. Table Table I shows the positions for which the source node was programmed to move over time. This gives the opportunity to run a localization simulation for a node with mobility.

TABLE I
COORDINATES OF THE MOBILE NODE

Time[s]	X-coordinate [m]	Y-coordinate [m]
0	8.10	3.00
10	8.50	4.00
20	8.80	5.00
30	9.20	6.00
40	9.60	7.00
50	10.50	8.00
60	11.00	9.00
70	12.00	10.00
80	13.00	11.00
90	14.00	12.00

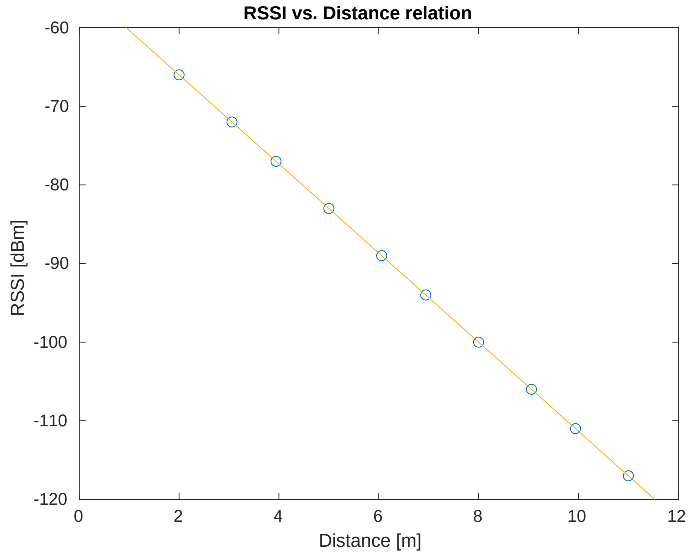

Fig. 4. Linear relation between RSSI and Distance

VII. Results

A. RSSI to distance

To calculate the distance from RSSI, equation (10) was implemented into MATLAB. The *distFactor* is given by the equation (11) where $Position_A$ and $Position_S$ are the positions of the anchor and source node respectively. The difference between these two values gives the distance between two nodes. Using the two equations, the distance based on RSSI was calculated and a graph of this relation is given in Figure 4.

$$distFactor = \frac{|Position_A - Position_S|}{TransmissionRange} \tag{11}$$

A linear relation between RSSI and distance takes place because that is how it actually is in the Cooja simulation. The simulation created on Cooja considers an ideal environment with no interference and attenuation which is why the RSSI decreases at the rate the distance increases. In the real world however this would not be the case and the measured RSSI would decrease at a greater rate as distance increases.

Since the simulation is in an ideal environment, he measured RSSI values on Cooja also always give the same value for the same distance. In the real world it would make sense to take multiple measurements for each distance and then take their average. Nevertheless, in this case only a single value of RSSI value is measured for each distance since it is always the same.

B. Distance to Location

The equation sets of (5) and (8) in Section IV were implemented in MATLAB. Together with the distances retrieved from the RSSI values, the trilateration function calculates the position of the source node, which can be seen in Figure 5. All node coordinates and measured signal strengths used for this simulation, can be found in Table II, where S represents the source node and $A1$ to $A3$ respectively anchor nodes 1, 2 and 3.

TABLE II
RSSI VALUES AND NODE COORDINATES

Nodes	RSSI [dBm]	X [m]	Y [m]
S	-	12.08	9.20
A1	-100	16.88	2.76
A2	-87	8.06	13.31
A3	-100	7.807	2.40

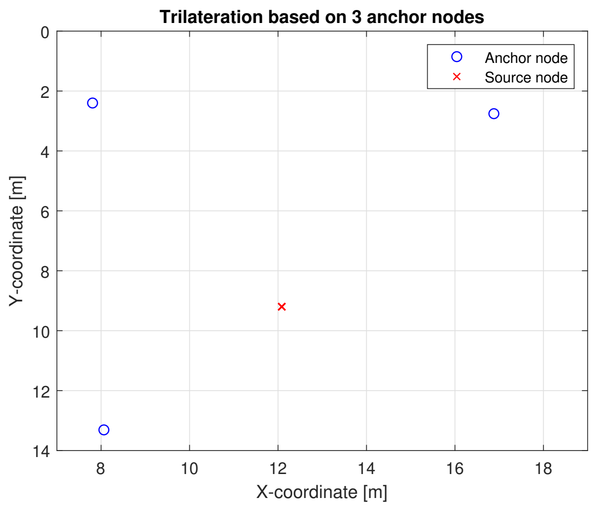

Fig. 5. Trilateration algorithm applied to a static node.

C. Localizing a mobile node

After calculating the location of the source node for a single position, the same calculations have been made for multiple positions. Figure 6 shows the localization plot of the nodes over ten seconds. The blue circles represent the location of the anchor nodes which is given as input values. Together with the location of the anchor nodes and the RSSI value received at each anchor node, the path which the source node takes over time is represented by the red cross. The calculated coordinates for the mobile node is shown in Table III.

TABLE III
CALCULATED COORDINATES OF THE MOBILE NODE

X [m]	Y [m]
8.17	3.01
8.43	4.06
8.81	4.97
9.14	6.04
9.61	7.00
10.59	7.99
11.01	8.99
12.05	10.00
12.94	10.95
14.01	11.94

VIII. DISCUSSION

The simulation environment of Cooja is ideal. There is a linear relationship between the distance and captured RSSI values, as shown in Figure 4. However, in a real environment the relationship is non-linear which is defined in section IV. This leads to using a linear formula defined in equation (10) to calculate distance and not the non-linear formula used in real scenarios. Also, the error rates achieved are very ideal and not realistic. In order to simulate close to real environment, the model Cooja uses to calculate RSSI values needs to be changed to a non-linear model. By this, we can get better results for localization and not the unexpected results observed in the simulation. Additionally, the RSSI values captured in Cooja remain constant at a given node location at all times, thereby discounting the necessity of implementing any filters. The model in this paper used the distance values calculated from RSSI by three anchor nodes to determine the location of the source node using the trilateration algorithm. Since the simulation is not being done in a real environment, it is not fully reliable for real-life applications. It only forms a basis for research. In the future, it is necessary to implement this wireless sensor network in a real environment. This setup would have interference, multi-path fading effects, noise, and variance in captured RSSI values from a given position. This could be tackled by introducing a filter called Kalman filter to remove noise from RSSI as discussed in section IV .

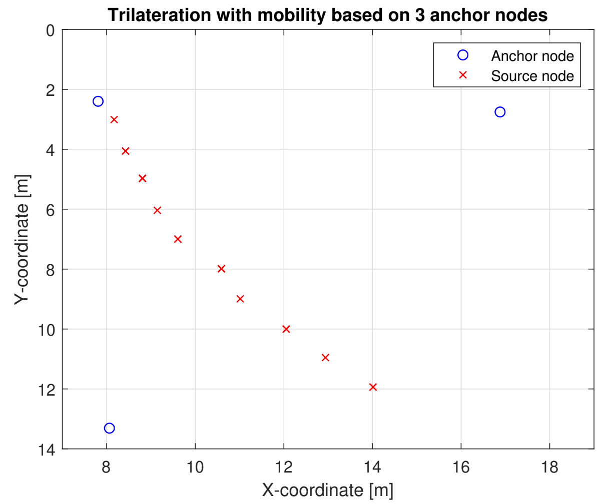

Fig. 6. Trilateration algorithm applied to a mobile node.

IX. CONCLUSIONS

In this paper, we simulated indoor localization in Contiki using Cooja. It was done by simulating a WSN consisting of three anchor nodes and one source node. The method was RSSI-based, and trilateration was used to calculate the position of the source node. The simulation was very accurate, since the greatest deviation was 0.06 meter for the Y-coordinate and 0.09 m for the X-coordinate. These inaccuracies are due to inaccurate RSSI of Cooja.
Since the simulation represents an ideal environment, it is necessary to test the set-up with real hardware. For this, a filtering method such as Kalman filtering must be applied in order to filter out wrong RSSI values.

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