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CAN INDOOR RSS LOCALISATION WITH 802.15.4 SENSORS BE VIABLE?

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Abstract

Indoor localisation techniques based on receive signal strength (RSS) level are commonly considered to be unreliable and inaccurate mainly because of the phenomena of multipath propagation, wireless fadings and common non-line-of-sight conditions. On the other hand, all other localisation algorithms require that the wireless devices are modified with some extra hardware, e.g. directional antennas, ultra-wideband or acoustic modules.

In this document, we present the measurements of localisation accuracy using an IEEE 802.15.4 sensor network consisting of 43 TelosB motes deployed in a university building. While we are currently during a measurement campaign, we would like to share and discuss our initial results. Our network suffers from well-known limitations typical for RSS techniques, however we identify and validate some additional methods that can increase the position estimation accuracy.

1. Introduction

While in outdoor scenarios GPS-like systems seem to be a widely accepted standard, in indoor environments the problem of localisation of a wireless device remains an open and hot topic. The phenomena of multipath radio propagation, wireless fadings and frequent NLoS conditions pose numerous difficulties in creating a reliable and accurate localisation system.

In this paper, we investigate if and how wireless sensor networks compliant with IEEE 802.15.4 standard can perform localisation tasks. Wireless sensors can be easily deployed indoor in a large number of nodes and thus are well suited to serve for the localization purpose. They are however equipped with rather simple radio transceivers and have limited processing capabilities. Here, we present initial results from a receive signal strength (RSS) measurement campaign performed with a 43-node TelosB sensor network. We propose to exploit frequency diversity in order to minimize the adverse multipath propagation effects. We analyse two localisation algorithms and compare their efficiency on the basis of the performed measurements.

2. Problem definition

The research task considered in this paper is known as a RSS-channel-model-based localisation problem without any *a priori* RSS maps [1] and can be described as follows. There is a sensor node located in a building and its position (geographical coordinates) is unknown. The sensor is transmitting a radio signal with a predefined strength. There is also a sensor network consisting of a large number of nodes. Their positions are fixed and known. They receive the transmitted signal and register its RSS level. In our measurements, the transmitting node as well as all the nodes of the network are TelosB motes. For the purpose of this paper, we call the unlocalized node as *sensor* and the nodes with known positions as *anchors*. The main goal of the localisation algorithms investigated here is to calculate the sensor position on the basis of the RSS levels measured by anchors.

At the same time we assume that there is no RSS map of the building, nor analytical neither empirical, available *a priori*. RSS maps require very detailed propagation measurements or analytical radio modelling taking into account the positions of all the walls, doors, windows and other objects reflecting or blocking radio waves. Our motivation is to discuss a system that can work without such maps. It means that the exact relation between the radio signal attenuation and the sensor-anchor distance remains unknown.

In the reported measurements, the height of the transmitting node was always the same (0.73 m above the floor level) and we assume it is known for the sensor network. Thus, our localisation problem is reduced to the 2D-space. In general, our research problem can be easily extended to 3 dimensions. However, as all the receivers are deployed more or less at the same height (2.75 m), we expect that the localisation error of the third dimension might be larger than the errors reported in this paper.

3. Transmission and reception schemes

One of our main motivations for these measurements was to look how we could mitigate the adverse phenomenon of wireless fadings. Thus, we decided to conduct the transmission on two radio channels and take advantage of frequency diversity. To avoid the same wireless fades, the channels should be separated more than the *coherence bandwidth* characterising this propagation environment [2]. The coherence bandwidth can be calculated as:

$$B_{coh} = \frac{1}{2 \cdot T_d}, \tag{1}$$

where T_d is the respective *time delay spread* [3]. Typical values of T_d for indoor radio channels are equal to 10 ns or higher [2,4]. Thus, for the worst case of 10 ns, the channels should be separated by 50 MHz or more in order to exploit their frequency diversity.

The TelosB motes can communicate on 16 radio channels numbered from 11 to 26. Their carrier frequencies are separated by 5 MHz according to the following equation:

$$f_k = 2405 + 5 \cdot (k - 11)\ \mathrm{MHz},\ k = 11,\ldots,26, \tag{2}$$

where k is the number of the radio channel. At the channel from 18 to 23, we observed some interference signals from other wireless systems working in our building. Hence, for our experiment we finally chose the border channels 11 and 26 separated by 75 MHz and easily fulfilling the abovementioned frequency diversity condition.

In order to avoid the problem of sensor-anchors synchronisation, the transmitting sensor was programmed to send data during 20 ms using the channel 11, then to switch to the channel 26 and also use it during 20 ms. Then, the transmitter was returning to the channel 11, continuing the switching process. On the other hand, the anchors were listening to the channel 11 during 40 ms, then switching to the channel 26 for another 40 ms, and so on. Thus, we guaranteed that for each 40 ms of listening to a channel (11 or 26), exactly 50% of this time period was effectively realised during the transmission on the same frequency, without any extra synchronisation. This, however, came with a price of losing another 50% of time for idle listening.

4. Localisation algorithms

Using TelosB hardware, we are able to measure the RSS level. As a second step, we need an algorithm in order to transform the sets of RSS values into the transmitter coordinates. We considered two solutions: the lateration and weighted mean algorithms.

The lateration algorithm is one of the most common methods of calculating the sensor position when the distances from the sensor to a group of anchors are known [5]. Having *k* anchors, we can write down a system of *k* equations:

$$\begin{gathered} (X - x_1)^2 + (Y - y_1)^2 + (Z - z_1)^2 = {d_1}^2 \\ \vdots \\ (X - x_k)^2 + (Y - y_k)^2 + (Z - z_k)^2 = {d_k}^2 \end{gathered} \tag{3}$$

where (x_i, y_i, z_i) are the *i*-th anchor coordinates and (X, Y, Z) are sensor coordinates. In all our measurements $Z = 0.73\,\mathrm{m}$ and we assume that this value is known. Determining the (X, Y) pair is the main goal of the algorithm.

However, in our scenario the distances d_i are also unknown. We have measured only the RSS levels for each sensor-anchor path. Each RSS level can be transformed into a distance value only if a path loss propagation model is known. When we have no information about the propagation environment (the positions of walls and other obstacles blocking or reflecting radio waves) the following relationship is frequently assumed:

$$PL\,[\mathrm{dB}] = A + B \cdot \log_{10} f + 10 \cdot n \cdot \log_{10} d\,, \tag{4}$$

where PL is the average radio channel path loss, *f* is the carrier frequency and *d* is the distance between the transmitter and the receiver. The parameters *A*, *B* and *n* depend on the model, but *B* is usually between 20 and 25 and *n* (so called channel exponential coefficient) is widely accepted to be between 2 and 6. For some models, there is also one or more threshold distances defined. Parameters *A*, *B* and *n* can change depending if the distance is below or above a certain threshold. A large group of propagation models falling into this category includes the free space loss, 2-path model and numerous models based on measurements [2,6].

In our system we use two radio channels with carrier frequency of 2405 and 2480 MHz. Even in the worst case (*B* = 25), the path loss for these two channels does not differ widely: it is about 0.33 dB. The TelosB hardware registers the RSS level with 1 dB resolution, so we neglected the influence of the frequency on the channel attenuation and used a simplified channel path loss model:

$$PL\,[\mathrm{dB}] = A^{'} + 10 \cdot n \cdot \log_{10} d\,. \tag{5}$$

When the path loss is measured (measuring the RSS level and knowing the sensor transmission power), the sensor-anchor distance can be calculated as:

$$d = 10^{\frac{PL - A^{'}}{10 \cdot n}}\,. \tag{6}$$

Substituting *d* in (3) with (6), we obtain:

$$\begin{gathered} (X - x_1)^2 + (Y - y_1)^2 + (Z - z_1)^2 = 10^{\frac{PL_1 - A^{'}}{5 \cdot n}} \\ \vdots \\ (X - x_k)^2 + (Y - y_k)^2 + (Z - z_k)^2 = 10^{\frac{PL_k - A^{'}}{5 \cdot n}} \end{gathered} \tag{7}$$

Let us assume for a moment that the channel coefficient *n* is known. Also, let us substitute $L = 10^{\frac{-A^{'}}{5 \cdot n}}$:

$$\begin{aligned}(X-x_1)^2+(Y-y_1)^2+(Z-z_1)^2 &= 10^{\frac{PL_1}{5\cdot n}}\cdot L\\ &\vdots\\ (X-x_k)^2+(Y-y_k)^2+(Z-z_k)^2 &= 10^{\frac{PL_k}{5\cdot n}}\cdot L\end{aligned}\tag{8}$$

Then, we can think of (8) as a system of equations with 3 unknown independent quantities: *X*, *Y* and *L*. It can be linearized by subtracting first equation from *k*-1 others:

$$\begin{aligned}2(x_1-x_2)\cdot X+{x_2}^2-{x_1}^2+2(y_1-y_2)\cdot Y+{y_2}^2-{y_1}^2+2(z_1-z_2)\cdot Z+{z_2}^2-{z_1}^2 &= (10^{\frac{PL_2}{5\cdot n}}-10^{\frac{PL_1}{5\cdot n}})\cdot L\\ &\vdots\\ 2(x_1-x_k)\cdot X+{x_k}^2-{x_1}^2+2(y_1-y_k)\cdot Y+{y_k}^2-{y_1}^2+2(z_1-z_k)\cdot Z+{z_k}^2-{z_1}^2 &= (10^{\frac{PL_k}{5\cdot n}}-10^{\frac{PL_1}{5\cdot n}})\cdot L\end{aligned}\tag{9}$$

As the first equation, we always choose the one related to the anchor registering the highest RSS level. The rationale behind this decision is that this anchor is probably located very close to the sensor and its RSS level is statistically more reliable than others.

The system of *k*-1 linear equations with 3 unknowns can be easily solved with the standard least-square approach [5], if only *k*-1 ≥ 3. Thus, in order to calculate the sensor position, there should be at least 4 anchors that correctly registered RSS values. It should be noted that the value of *L* (as well as *A'*) is not important for the final result.

Additionally, we propose to multiply the equations in (9) (both left and right sides of equations) by weighting coefficients w_i. A weighting coefficient for the *i*-th equation (related to the *i*-th anchor) is equal to:

$$w_i = RSS_i \cdot s_i\,, \tag{10}$$

where RSS_i is the RSS level received by *i*-th anchor and s_i is the number of its correctly measured probes. The weighting coefficients increase the importance of anchors registering more probes and higher RSS levels what results in better localisation accuracy.

Still, as the radio propagation model is not given *a priori*, the channel coefficient *n* cannot be treated as a known parameter. Concluding from the indoor measurements for NLoS scenarios [6] and theoretical derivations of 2-path model, we expect that *n* is close to 4 also in our case. In section 6, we present measurement results showing that the localisation accuracy weakly depends on *n*, as long as $n \in < 2.5, 4 >$.

The second considered solution how to calculate the sensor coordinates was the weighted mean algorithm. This is very simple technique: the sensor positions is estimated as a weighted mean of anchors coordinates. As weighting coefficients we use the values from (10).

5. Measurement scenario

All the measurements were performed on the second floor of Albacete Research Institute of Informatics. The TelosB network (anchors) had been installed in the building before our tests for the purpose of measuring the ambient parameters (temperature, energy usage, etc.) and testing other WSN protocols and algorithms [7]. Nothing has been changed in its configuration from that time. The network consisted of 43 TelosB motes [8] deployed in the labs on the floor of area of 46 × 15 m^2 (Fig. 1). They were programmed to listen to the radio signal and measure its RSS level. The receivers were switching between channels 11 and 26, as described in the section above.

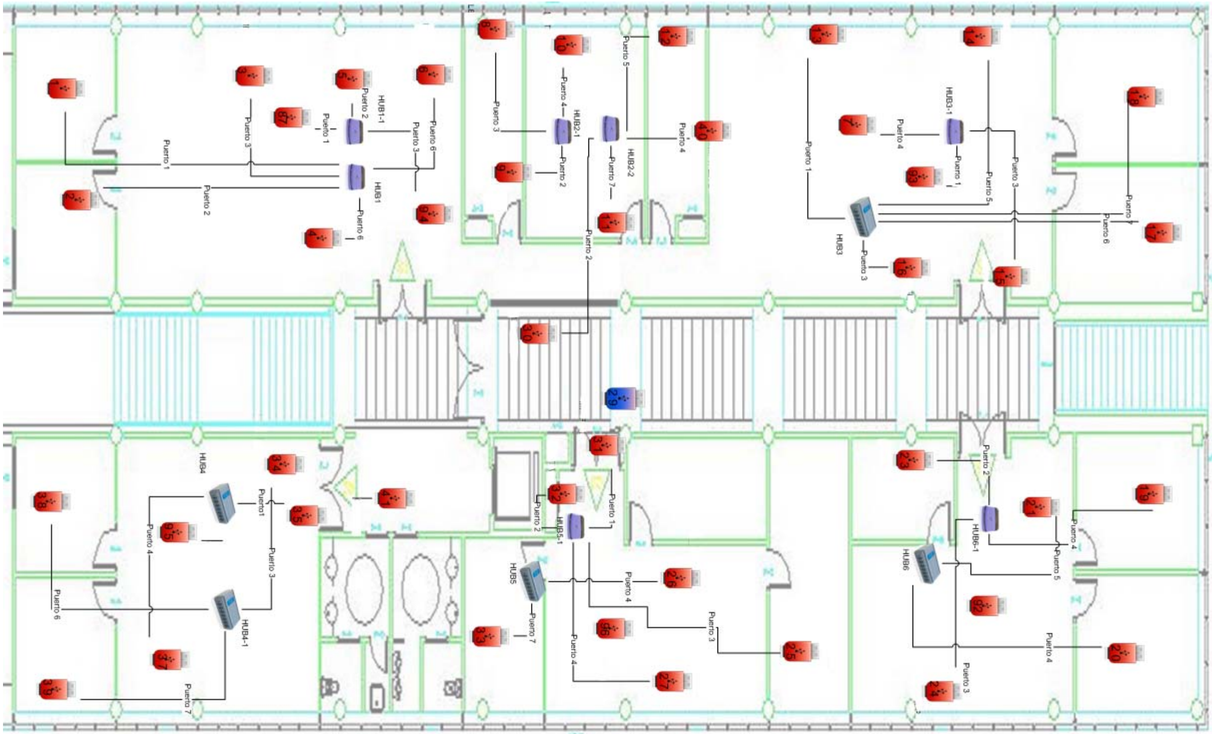

Fig. 1. The plan of the floor with the TelosB sensor network deployed.

Except of the deployed network, we used a single TelosB sensor, whose position we wanted to calculate with the aid of the localisation system. This sensor was continuously transmitting data: packets with a fixed length of 127 bytes, which is the largest possible packet size according to the IEEE 802.15.4 standard. The packets were transmitted switching between the channels 11 and 26, once per 20 miliseconds. The transmitted power was set to 1 mW (0 dBm).

The transmitting sensor was placed in turn at 103 different locations. For each sensor location, the anchors measured RSS levels during 1 second: the probes were gathered once per 2 ms, thus 500 probes were obtained each time. However, because of the lack of sensor-anchors synchronisation (see section above) and time intervals appearing between the transmitted packets, the number of correct probes were much smaller. The probes with RSS level lower than –85 dBm were rejected as being incorrect.

For each of 103 measurements, each anchor registered 8 different parameters: the number of correctly measured probes, minimum, average and maximum RSS values for the channel 11, as well as the same 4 parameters for the channel 26.

6. Results

The values registered by anchors could be used as input data for a localisation algorithm. We could use minimum, average or maximum RSS for the channel 11 or 26. We could also compare the respective channel 11 and 26 values and choose one of them. We tested two simple criteria: choosing the higher or lower value of two channels. Thus, we had 4 different approaches: choosing the RSS value of the channel 11, 26, higher or lower of them. For each approach we could use minimum, average or maximum RSS values. So finally, we had 12 parameters that could be used with both lateration or weighted mean algorithms. We calculated the root-mean-square-error of the estimated sensor position for both localisation algorithms in each of these 12 cases and compared the respective results in Tab. 1 and 2.

	channel 11	channel 26	lower of both	higher of both
minimum values	9.42 m	6.98 m	8.87 m	7.32 m
average values	7.60 m	4.97 m	6.17 m	6.23 m
maximum values	9.59 m	6.51 m	7.01 m	8.21 m

Table 1. The root-mean-square-error of the lateration localisation algorithm.

	channel 11	channel 26	lower of both	higher of both
minimum values	7.15 m	4.12 m	5.67 m	5.83 m
average values	7.02 m	4.29 m	**2.98 m**	7.42 m
maximum values	6.01 m	4.41 m	3.87 m	5.95 m

Table 2. The root-mean-square-error of the weighted mean algorithm.

The results in Tab. 1 are given for the channel exponential coefficient $n = 4$. An analysis what is the influence of n on the localisation accuracy is presented in Fig. 2. There, two best cases from Tab. 1 (marked in blue) are considered. In the first one, the average RSS values of the channel 26 are taken into account. In the second one, the algorithm takes the lower value of the average RSS levels of two channels.

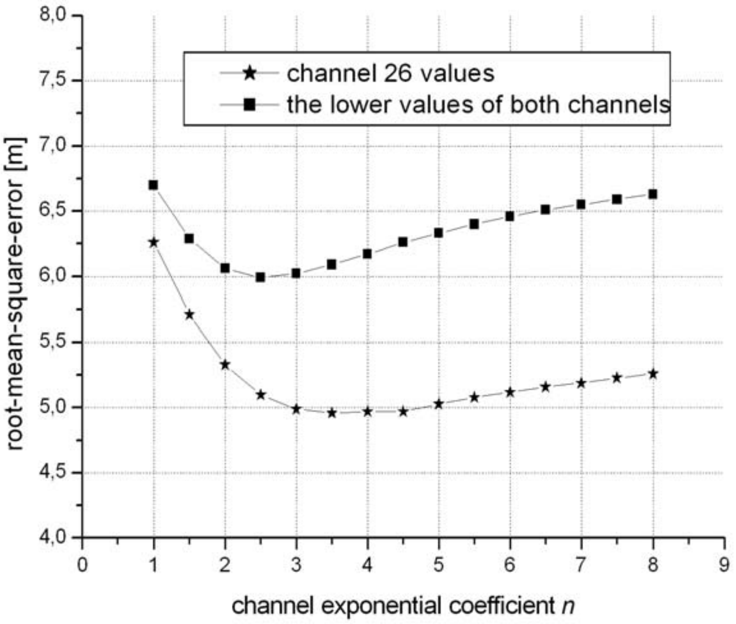

Fig. 2. The root-mean-square-error as a function of the channel exponential coefficient.

Additionally, we gathered all the RSS values registered by the network during the whole measurement campaign and prepared two figures showing the path loss as a function of the distance. In Fig. 3, the average path loss for the channel 11 (2405 MHz) and the channel 26 (2480 MHz) is shown.

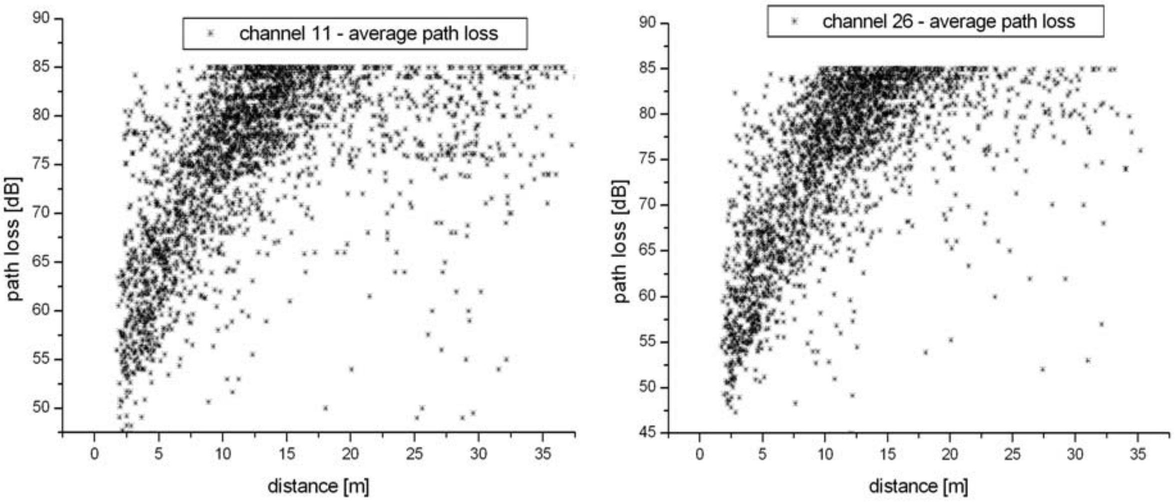

Fig. 3. The path loss as a function of the sensor-anchor distance for the channel 11 (on the left) and the channel 26 (on the right).

7. Results analysis and conclusions

Taking into account the building size, the localisation accuracy of the lateration algorithm is not satisfactory. In order to be considered as a reliable technique, lateration requires accurate sensor-anchor distances. However, as shown in Fig. Xxx, there is no clear dependence between RSS values and distance and consequently it is very hard to thoroughly estimate a distance on the basis of a RSS value. The analysed lateration algorithm is rather robust for erroneously chosen coefficient *n*, but in general its localisation error is quite large.

On the other hand, the weighted mean technique results in better accuracy of about 3 meters, which is comparable with other indoor localisation schemes reported in literature, even with the techniques with *a priori* RSS maps [1]. Using the frequency diversity seems to be a promising solution for the indoor localisation, as it allowed to reduce the root-mean-square-error by about 30 %. Surprisingly, the accuracy in the channel 11 was always worse than in the channel 26. This issue requires some further investigations.

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