Indoor Room Location Estimation

Kevin D'HOE, Geoffrey OTTOY, Philip KEERSEBILCK,
Jean-Pierre GOEMAERE, Lieven De STRYCKER
KaHo Sint-Lieven, Department of Electronics
Gebroeders Desmetstraat 1, 9000 Gent, Belgium
dramco@kahosl.be

***Abstract*—This paper will present an indoor location estimation system, especially to locate people or objects at room level. First of all a theoretical approach is given. Secondly, a practical case, using our own system, is presented. Our system is based on a wireless sensor network, using the communication standard ZigBee. Using the signpost algorithm and considering the behavior of the received signal strength (RSS) through walls, floors and ceilings, we succeeded in developing a reliable indoor room localization system.**

***Index Terms*—Location estimation, signpost algorithm, Received Signal Strength, Wireless Sensor Network, ZigBee.**

I. Introduction

Knowing the location of people, instruments or objects in general, can be of great surplus value for many applications. Some examples could be: tracking down beds in a hospital, "indoor GPS", smart remote controls which change their functionality according to the room they are in, etc.

Often these indoor applications require low-cost hardware rather than high precision. Therefore we have developed an indoor location estimation system, which uses the signal strength of a wireless communication link, especially the link between some reference nodes and a blind node.

These reference nodes have a known and fixed location and are used to determine the position of the blind node. Our application will make a prediction in which room the blind node is situated.

Using signal strength has an extra advantage. It is a parameter, which is easily available on top of the data already present in the network. This way, the positioning application can be developed independently of an existing network application without causing extra traffic overhead.

The system uses only one reference node per room. Using the ZigBee standard at 2.4 GHz, our system is a low-power system, so we only need to use a battery, powering the blind node(s). In this paper we will only discuss the principles of the location estimation system.

II. Theoretical approach

Using the RSS values, we are able to estimate the location of the blind node based on the path loss through air, walls, floors and ceilings. The path loss, which represents signal attenuation as a quantity measured in dB, is defined as the difference between the effective transmitted power and the received power.

The wireless communication standard ZigBee supports a mesh topology (Figure II-1). Every node, surrounded by other nodes, has multiple links with its neighbours. This way, the stability and reliability of the system is guaranteed.

The location of the blind node can be estimated using the signpost algorithm. With this algorithm the position of the blind node is assumed to be the position of the reference node which is received best.

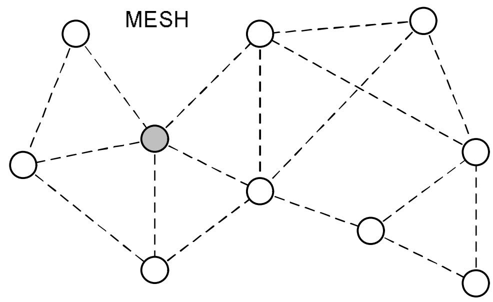

Figure II-1. ZigBee mesh topology.

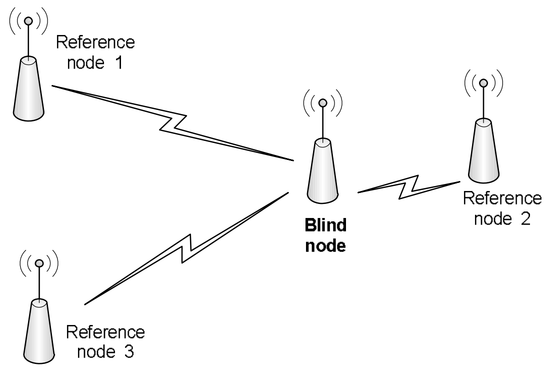

Figure II-2. Blind node connected with 3 reference nodes.

As one can see in Figure II-2 the blind node is the nearest to reference node 2. Knowing the relation between received signal strength and distance, the best wireless link will be between these two nodes.

A well known model can be used to express this relation.

$$\overline{P}(d) = X_s + P_0 - 10h_p \log \frac{d}{d_0} \qquad (1)$$

$\overline{P}(d)$ is the average received power in dBm at distance d; P_0 is the received power in dBm for a short distance d_0, most of the time d_0 is arbitrarily chosen equal to one meter; η_p is the path loss exponent, typically for indoor environments between two and four; X_σ is a Gaussian random variable with zero mean and σ^2 the variance that models the random variation of the RSS signal [1].

Due to unpredictable multipath effects, an accurate ranging in real indoor environments is often very difficult. The shape of a room and the presence of objects, with their own material properties, have an influence on how the multipath propagation affects the accuracy of the system. One of these multipath effects is fast fading. In Figure II-3 we have measured the RSS values between 2 basic RF nodes, changing the distance from one to two meter with a step of 5 cm.

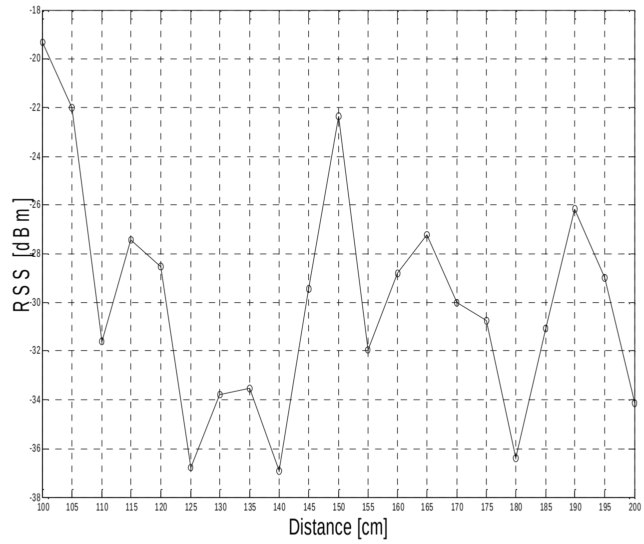

Figure II-3. Fast fading effect.

As one can see in Figure II-3, signal strength changes at a high rate. Over a distance of a few centimetres a variation of more than 10dB can occur. Using these measurements, it’s impossible to estimate a reliable and accurate position of the blind node.

Nevertheless, the signpost algorithm is still useful. Consider the situation represented in Figure II-4. If the path loss through walls introduces a sufficient decrease of signal strength in comparison with possible fast fading, the algorithm will function correctly.

In this case the link with the highest RSS value will lead us to the nearest reference node. Each reference node is associated with a room. So we can predict in which room the blind node is situated.

In Table I some figures are given of the most common construction materials at 2.4 GHz [6].

TABLE I: TYPICAL PATH LOSS IN COMMON BUILDING MATERIAL @ 2.4 GHZ

Description	*Path Loss [dB]*
Glass Window (non tinted)	2
Wooden Door	3
Cubicles	3-5
Dry Wall	4
Marble	5
Brick Wall	8
Concrete Wall	10-15

In the case of Figure II-4 one can see that the link between reference node 1 and the blind node will be stronger than any other link with the blind node.

The practical implementation of our system is given in the next paragraph.

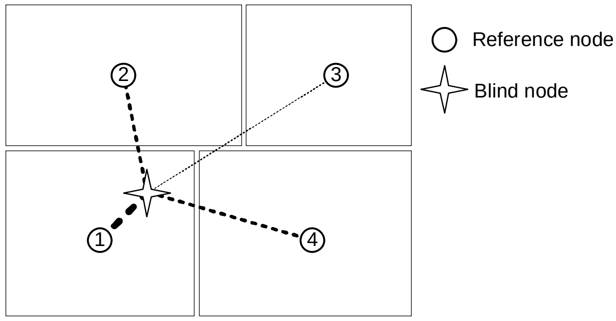

Figure II-4. Room configuration

III. EXPERIMENTAL SETUP

The experimental setup is represented in

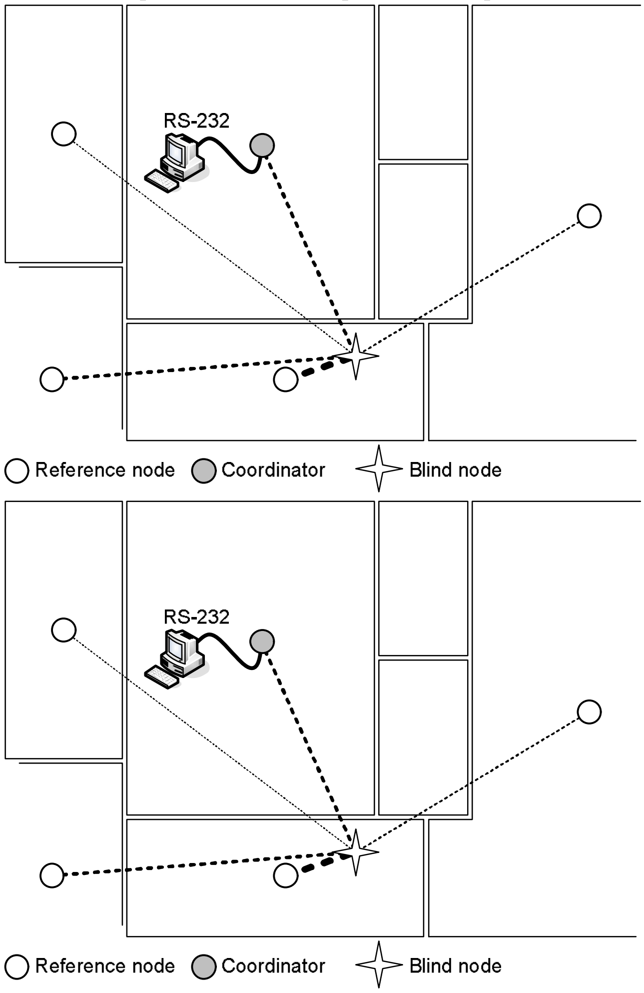

Figure III-1. In each room we want to monitor, a reference node is placed – the coordinator also functions as a reference node. These nodes are situated at a central position in the room.

Each reference node has an unique MAC address. This MAC address is used by the localization software to link the reference nodes to a room.

For each blind node, the coordinator sends the RSS values and according MAC addresses from the reference nodes to a computer. The localization software running on this computer analyses the data and displays the estimated room.

In Figure III-1 only the relevant links are shown i.e. the links between the blind node and the reference nodes. The line width is an indication for the received signal strength.

RSS values are updated every second. This has some repercussions on the life-time of the batteries. When there is no need to track down moving objects, a larger update-interval can be chosen.

The nodes itself are CC2420 [7] based ZigBee modules.

As mentioned in paragraph II the signpost algorithm is used to determine the room where the blind node is situated.

The flowchart in Figure III-2 outlines the operation of the algorithm.

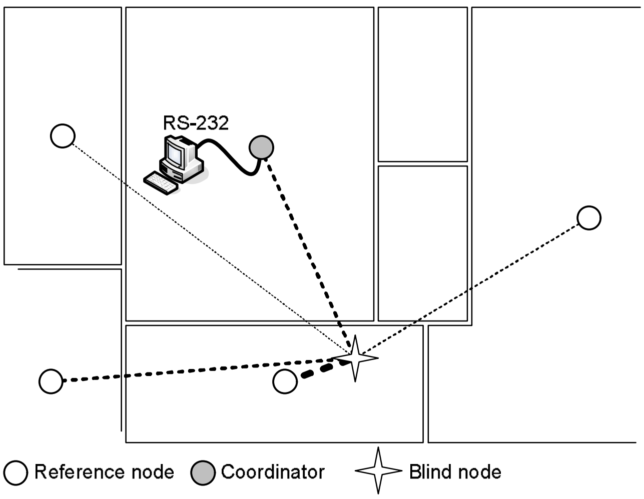

Figure III-1. Experimental Setup.

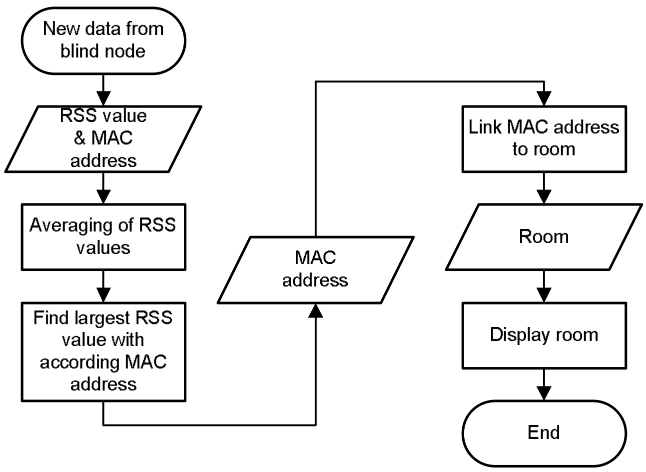

Figure III-2. Algorithm flowchart.

One can see that an averaging operation is performed before further analysis of the RSS values. This operation can filter out extreme peaks in the received signal strength which could shortly lead to an erroneous room indication.

In Figure III-3 the received signal strength over time is represented between two static nodes. In Figure III-4 the effect of an averaging filter is shown. One can see that sudden peaks are averaged out.

The filter used here is in fact a simple recursive digital filter. The filter's transfer function is described by the equation (2):

$$\hat{x}_t = a \cdot x_t + (1-a) \cdot \hat{x}_{t-1} \tag{2}$$

Where:

$\hat{x}_t$ is the averaged value at time t

x_t is the measured value at time t

And $0 < a < 1$

The parameter a should be chosen sufficiently small to average out the peaks. On the other hand, when a is chosen to small, the system will possibly react to slow when the blind node's position is changing.

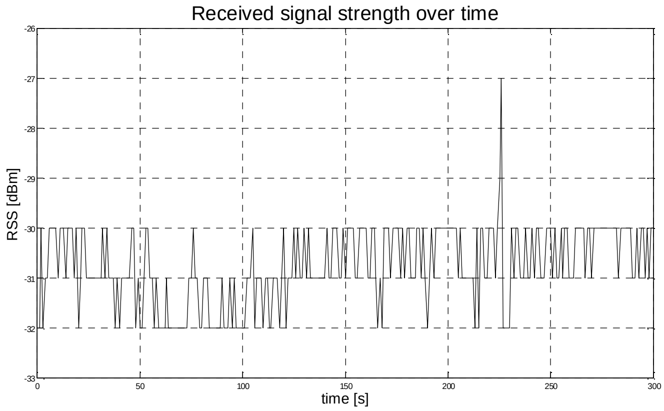

Figure III-3. Signal strength over time between to static nodes.

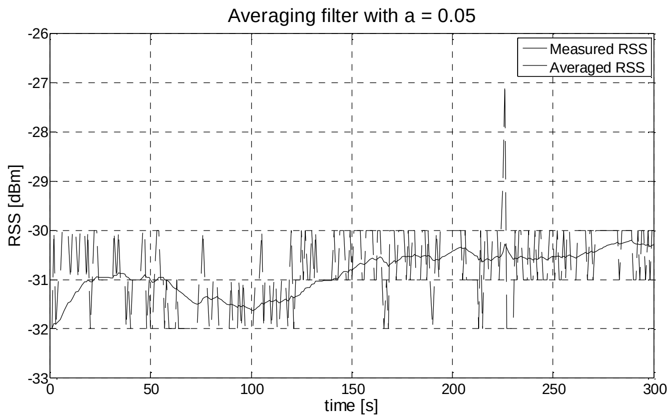

Figure III-4. Averaged signal strength between two static nodes.

IV. RESULTS

The system's performance is remarkably well in comparison to its simplicity, though sometimes erroneous room indication occurs when the blind node is located in the vicinity of a wall. At this point the fading effect needs to be considered.

Figure IV-1 gives a better view of the problem. The distances between the blind node and the reference nodes are comparable. The total path loss for the link with the left reference node is given by:

$$L_{total\_left} = L_d + L_w + L_{f\_left} \tag{3}$$

Where L_d is the path loss introduced by the distance between the nodes; L_w the loss caused by the wall and L_{f_left} a change in signal strength caused by multipath effects.

For the right link a similar formula can be used. Only L_w is dropped.

$$L_{total\_right} = L_d + L_{f\_right} \tag{4}$$

Since the distances between the two reference nodes and the blind node are comparable, L_d will be the same for (3) and (4).

Due to the unpredictable character of the indoor multipath effects or when L_w is insufficiently large e.g. when signals pass through glass (Table I) or a combination of these two cases, the following might occur:

$$L_{f\_right} > L_w + L_{f\_left} \qquad (5)$$

So it follows that:

$$RSS_{right} < RSS_{left} \qquad (6)$$

Consequently the blind node will be incorrectly assumed to be in the left room.

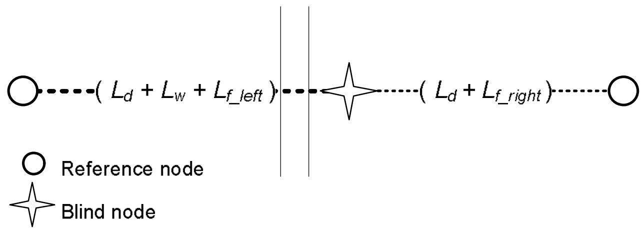

Figure IV-1. Example of a problematical case blind node in the vicinity of a wall.

V. FUTURE WORK

Using a structural description of the floor plan (for instance in XML), some incorrect localizations could be avoided. An example: the blind node is incorrectly assumed to have moved from room A to room B, because it is e.g. close to a wall (discussed in paragraph IV). In the case that it is physically impossible to get from room A to room B, the algorithm can use the structural description to detect this impossible move.

A second improvement of the system could be to decrease the number of reference nodes. Now, a reference node is needed in every room that needs to be monitored. Again, the structural description could be used to provide more information (e.g. number of walls, materials used, etc.) to perform a kind of pattern recognition, so that less reference nodes are needed. Also an indication should be given when the blind node is assumed to be in a room that is not being monitored.

Another way to reduce fluctuations of the path loss caused by fast fading, L_f in (3) and (4), is using antenna diversity. This technique is already used in laptops.

The application can easily be extended to a location estimation system which can monitor rooms spread over multiple floors in a building. These rooms separated by ceiling and floors can be approached in the same way as rooms separated by walls.

Finally, since ZigBee is developed as a standard for wireless sensor networks. Some sensors e.g. accelerometers or gyroscopes, could be coupled to the blind node to provide extra information such as speed or acceleration. This should ease tracking down a moving node.

VI. CONCLUSION

The system studied in this paper has a good performance at room-level localization and tracking of objects. It could be integrated at low cost, even on top of an already existing application, as long as MAC addresses and RSS values are available.

The algorithm uses the attenuation of radio signals caused by walls, ceilings and floors in an efficient way to estimate the blind node's position.

The simplicity of the algorithm is an advantage, though some improvements could be made.

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