THE EVALUATION OF MAXIMUM LIKELIHOOD ESTIMATOR USED FOR LOCATION IN WPAN

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ABSTRACT

This paper will initially present the state-of-the-art in the field of location and tracking in WPAN. There will be described the channel model, range measurement methods and most common location algorithms. In the second part of this paper, there will be presented the evaluation of a Texas instruments commercial implementation of Maximum likelihood estimator.

1. INTRODUCTION

During last decades the fast growth in wireless communication and electronic science generally has enabled the development of microsensors that can interface with surroundings cordless. Since the price of these devices is decreasing, huge number of them can be deployed to cover large area for monitoring the environment, air, water or soil. The key feature for these sensors is their automatic location ability. During last years many effort has been concerned on development of local positioning systems (LPS). The LPS consist of reference nodes (RN) and blindfolded nodes (BN). RN knows their actual position, which can be set up by administrator at the installation of network or acquired by supreme positioning system (for example GPS in outdoor installations). BN calculates its location from measurements of ranges of RNs or RNs and other BNs.

To locate the device, there must be solved sequent tasks. As first, the technology principle and communicating protocol must be chosen. These days, most common used are the RF technologies, like RF identification (RFID), ZigBee (ZB) [4] or Wi-Fi. Then there must exist RNs with prior knowledge of their location, independent on used LPS. The third step is to obtain the estimated ranges of neighbouring RNs. The range estimation measurements can be based on different physical variables: received signal strength (RSS), time of arrival (TOA) or angle of arrival (AOA). Next we need to involve locating algorithm (LA) to acquire the all needed coordinates of BNs. There have been proposed many LAs: Triangulation - usually used least-mean squares approach when over-defined condition [6, 7], Maximum likelihood Estimation (MLE) [1-3], Signpost - Nearest neighbour method, Signal fingerprinting.

2. STATE OF THE ART

2.1. Problem Definition

There are two types of coordinates, estimated BN (the quantity of BN is n) and known RN (the quantity of RN is m) coordinates; we can mark them $\overline{\overline{\theta}}$. In two-dimensional (2-D) case it has $2(n+m)$ terms and two components $\overline{\overline{\theta}} = \left[\overline{\theta_X}, \overline{\theta_Y}\right]$, (2.1).

$$\overline{\theta_X} = \left[x_1, \ldots, x_n, x_{n+1}, \ldots, x_{n+m}\right], \overline{\theta_Y} = \left[y_1, \ldots, y_n, y_{n+1}, \ldots, y_{n+m}\right] \tag{2.1}$$

Coordinates 1 to n are a priori unknown positions of BN and $n+1$ to $n+m$ present positions of RN. The measured range between nodes i and j we can mark $X_{i,j}$. The coordinates will be enlarged with z-axis component in three-dimensional (3-D) case. The distance between nodes i and j (in 2-D) could be obtained with use of triangulation (2.2).

$$d_{i,j} = \sqrt{\left(x_i - x_j\right)^2 + \left(y_i - y_j\right)^2} \tag{2.2}$$

2.2. Channel model

The (indoor) wireless radio propagation channel is a complicated, random and time-varying environment [5]. There are described three types of variations in this channel:

- Small-scale variations (fast fading): Since the channel structure does not change markedly, impulse responses in the same small area are changing only very small. These variations are caused by multipath character of the channel.
- Mid-scale variations (slow fading): They are mainly caused by shadowing and terrain contours and may exhibit great differences; the distance between nodes is equal.
- Large-scale variations (path loss): The increasing distance between nodes is dramatically changing and measured parameters. RSS LAs are based on this fact.

2.3. Range Measurement Methods

TOA

TOA is the measured time which the RF signal needs to cover the distance between nodes. The main origins of errors are additive noise and multipath signals and the accuracy of measurement is greatly affected by the receiver's ability to detect line-of-sight signal.

AOA

The AOA method is reporting the angle, not the distance of neighbours. The simple example of AOA "location technology" could be mentioned the biological hearing.

RSS

The large-scale variation in power path-loss over distance $d_{i,j}$ between nodes i and j is observing inverse-exponential pattern, in dBm (2.3).

$$P_{i,j}(dBm) = P_0(dBm) - 10n_p \log\frac{d_{i,j}}{d_0} \tag{2.3}$$

Where n_p is path-loss exponent, typically between 2 and 4 [3], for more detailed determination see [5]. P_0 is received power at short reference distance d_0. From (2.3) we can obtain the relationship (2.4) between measured power $\widetilde{P}_{i,j}$ and estimated range $\widetilde{d}_{i,j}$.

$$\widetilde{d}_{i,j} = d_0 10^{\frac{P_0 - \widetilde{P}_{i,j}}{10n}} \qquad (2.4)$$

Since wireless radio propagation channel is a complicated environment, the logical way of describing such an environment is by statistical models. In the literature (e.g. [2], [5]), there is used a log-normal (Gaussian if expressed in decibels) distribution for modelling the range measurement errors and can be described with formula (2.5).

$$f\left(\widetilde{P}_{i,j}(dBm) = p \mid \overline{\overline{\theta}}\right) = N\left(P_{i,j}(dBm); \sigma_{dB}^2\right) \qquad (2.5)$$

The probability of received power $\widetilde{P}_{i,j}(dBm)$ has Gaussian probability density function (PDF) with mean $P_{i,j}(dBm)$ and dispersion σ_{dB}^2 (the standard deviation σ_{dB} is in literature described as relatively constant with distance and typically between 4 and 12 [3]).

2.4. LOCATION ALGORITHMS

From the range measurement method (presented in previous paragraph) obtains the LA estimated set of ranges $X(i) = \{X_{i,1}, \ldots X_{i,k}\}$, where k is the number of nodes with which our investigated node i has the range observation.

Signal Fingerprinting

The database of signal fingerprints is collected during the off-line training phase at numerous places, first. There is chosen the closest matching database item by the LA during on-line, working phase and reported as the node location.

Signpost - Nearest Neighbour Method

This method assigns the location of nearest RN to our investigated node. The accuracy is determined with the number of RNs.

Triangulation

Triangulation is the most mathematically natural approach coming out from Euclidian math. If the solution is over-determined (there are more then 3 RNs), there can be used many optimization methods, i.e. LMS [7].

Maximum Likelihood Estimation

MLE [1-3] is coming out from the maximization of the probability of location solution based on the statistical character of propagation channel (2.6).

$$[x_1, \ldots, x_n; y_1, \ldots, y_n] = \underset{[x_1, \ldots, x_n; y_1, \ldots, y_n]}{\arg\max} \left[L\left([x_1, \ldots, x_{n+m}; y_1, \ldots, y_{n+m}]\right)\right] \qquad (2.6)$$

Where $L([x_1, \ldots, x_n; y_1, \ldots, y_n])$ is the likelihood of certain location solution. As mentioned before, we use the log-normal statistical model for measurements of RSS in wireless propagation channel and the likelihood function from equation (2.6) is described in (2.7), where ΔP is the normalization factor.

$$L([x_1,\dots,x_n;y_1,\dots,y_n]) = \prod_{i=1}^{n+m} \prod_{j\in H(i)} \left(\exp\left(-\frac{1}{2}\left(\frac{P_{i,j} - \widetilde{P}_{i,j}}{\sigma_{dB}} \right)^2 \right) \Delta P \right) \tag{2.7}$$

We can plug equations (2.2) and (2.4) to (2.7), then take the negative logarithm, skip the constant elements and find the minimum (2.8) [2].

$$[x_1,\dots,x_n;y_1,\dots,y_n] = \underset{[x_1,\dots,x_n;y_1,\dots,y_n]}{\arg\min} \left[\left(\ln \frac{\widetilde{d}_{i,j}^{\,2}}{d_{i,j}^{2}} \right)^2 \right] \tag{2.8}$$

Then it’s needed to implement some numerical method to find the minimum.

3. MLE EXPERIMENTAL EVALUATION

Microcontroller CC2431 incorporates ZigBee stack and MLE location engine [8] and together with Zigbee Development Kit from TI/Chipcon was used as platform for our tests. There were 8 marked as RNs and 2 as BNs, changing gradually positions of these two BNs. There were made five measurements at each BN position and calculated linear average, which was used to determine the absolute position error and standard deviation of measurements. There were made two arrangements of RNs (rounds), which can be seen on Figure 1. On these pictures there are also the real positions of BNs (triangles), corresponding averaged estimated position (squares) and absolute position error (dashed lines). In the first arrangement, there were used the positions of RNs as positions for the BNs, too (they should not be considered as an estimations of RN’s positions.). The layout of this figure is showing the shape of the room and the furniture (grey spots).

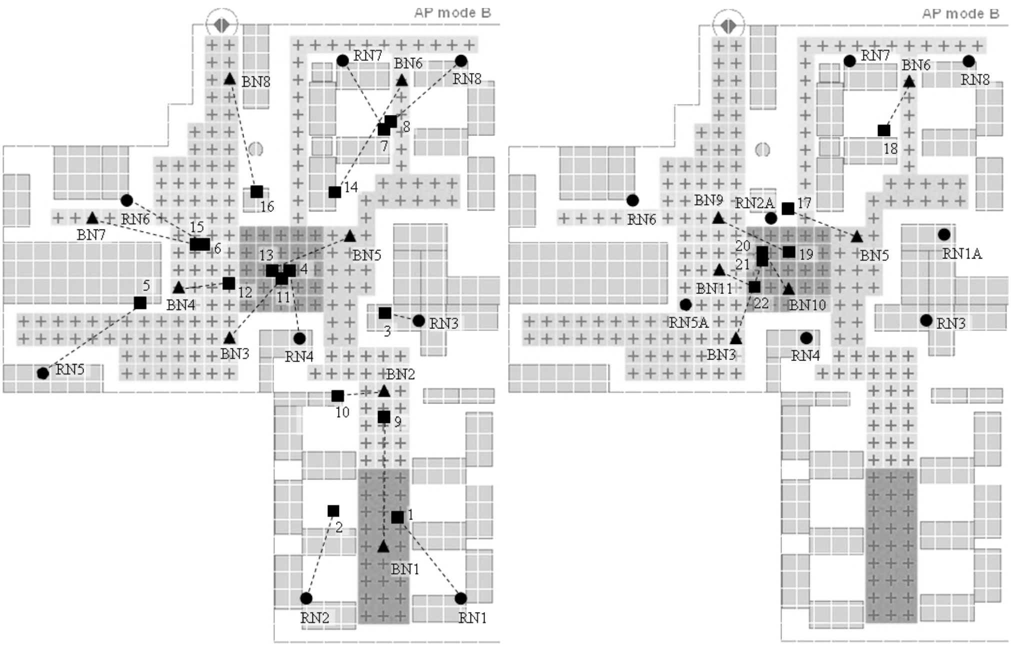

Figure 1: Layout of the experiment.

	Arran. No.1	Arran. No.2	Arran. No.3	Aver. Of all meas.
Av. abs. pos. err. [m]	2,44	2,71	1,78	2,36
Average stand. deviation [m]	0,152	0,246	0,135	0,181

Table 1: Experimental results

The whole experiment could be divided onto three parts: Arrangement 1 - part 1 (RNs arrangement 1, BN positions correspond to the positions of RNs), Arrangement 1 - part 2 (RNs arrangement 1, BN positions not correspond to the positions of RNs) and Arrangement 2 (RNs arrangement 2). According to this division, Tab. 3.1 contains the calculated average absolute position error and average standard deviation.

4. CONCLUSIONS

The field of location and tracking technologies is nowadays growing very fast. The main problem in location techniques is their precision compared to the cost spent on the technology. In this paper there was evaluated the commercial implementation of MLE location algorithm based on RSS range measurement method, which is representative of cheap, not very accurate solution.

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REFERENCES

[1] Patwari, N., O'Dea, R. J., & Wang, Y. (2001). Relative Location in Wireless Networks. *Proc. IEEEE VTC*, *2*, 1149-1153.

[2] Patwari, N., Hero III, A. O., Perkins, M., Correal, N. S., & O'Dea, R. J. (2003). Relative Location Estimation in Wireless Sensor Networks. *IEEE Trans. Signal Processing*, *51*(8), 2137-2148.

[3] Patwari, N., Ash, J. N., Kyperountas, S., Hero III, A. O., Moses, R. L., & Correal, N. S. (2005). Locating the Nodes [Cooperative localization in wireless sensor networks]. *IEEE Signal Processing Magazine*, *22*(4), 54-69.

[4] Sugano, M., Kawazoe, T., Ohta, Y., & Murata, M. (2006). Indoor Localization System Using RSSI Measurement of Wireless Sensor Network Based on ZigBee Standard. *Proc. The Sixth IASTED Int. Multi-Conf. on Wireless and Optical Communications*, 503-508.

[5] Hashemi, H. (1993). The Indoor Radio Propagation Channel. *Proceedings of the IEEE*, *81*(7), 943-968.

[6] Keunho, Y., & Daijin, K. (2007). Robust location tracking using a dual layer particle filter. *Pervasive and Mobile Computing*, *3*(3), 209-232.

[7] Savarese, C., Rabaey, J. M., & Beutel, J. (2001). Location in Distributed Ad-hoc Wireless Sensor Networks. *Proc. IEEE ICASSP '01*, *4*, 2037-2040.

[8] System-on-Chip (SoC) Solution for ZigBee/IEEE 802.15.4 Wireless Sensor Network - CC2431 - TI Product Folder. http://focus.ti.com/docs/prod/folders/print/cc2431.html