PERFORMANCE EVALUATION AND ERROR ANALYSIS FOR AN INDOOR LOCATION AND TRACKING SYSTEM

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Keywords: indoor location, WLAN 802.11b, positioning error

The goal of this paper is to present experimental results and conclusions concerning the accuracy of a system for positioning and tracking objects (laptops) inside an 802.11b WLAN. Our system operates by recording and processing signal strength information at multiple access points (AP) positioned to provide overlapping coverage in the area of interest. We have used the signal strengths received from the WLAN APs to build a radio map for the layout of the floor and have stored it in a database. In the on-line phase the algorithm calculates the position of the mobile user, by comparing its actual unknown position with all the reference point's positions stored in the radio map, provides the best match and display the result on the laptop screen, in XY coordinates.

1. INTRODUCTION

Indoor location sensing of people and objects is beginning to find many applications other than goods tracking and security.

Current technologies for location tracking, such as GPS or differential GPS, are not adequate for indoor applications, where the physics of radio propagation rules out the reception of GPS's weak microwave signals. So, we have used off-line radio maps for the layout of the floor to describe the power distribution of the signals emitted by APs.

Our testing environment is located on a hallway on the second floor, in a concrete building, with 20 cm thick walls and usual wood and glass doors and windows. The surface on which we have experimented has the following dimensions: 18m x 3m. The access points (ASSUS, SMC AND IPC1) are placed like the Fig. 1 shows. For collecting data from the locations marked in figure, we used a laptop with a PCMCIA Lucent Orinoco wireless card. The used driver extracts the information about SS (Signal Strength) and SNR (Signal to Noise Ratio) from the card each time a package is received. In this way we can register information regarding the radio signal function of the user's position regarding to each AP.

The on-line phase is done with the aid of an application called *LabView Tracker*, which realizes the estimation of the user's position, by comparing the received signal powers, from the APs, with the ones from the database. The off-line set of values that resembles the most with the ones from the on-line phase is chosen as the current set.

The physical point corresponding to this set of values represents, if we don't have other correction algorithms, the estimated user's position on the map.

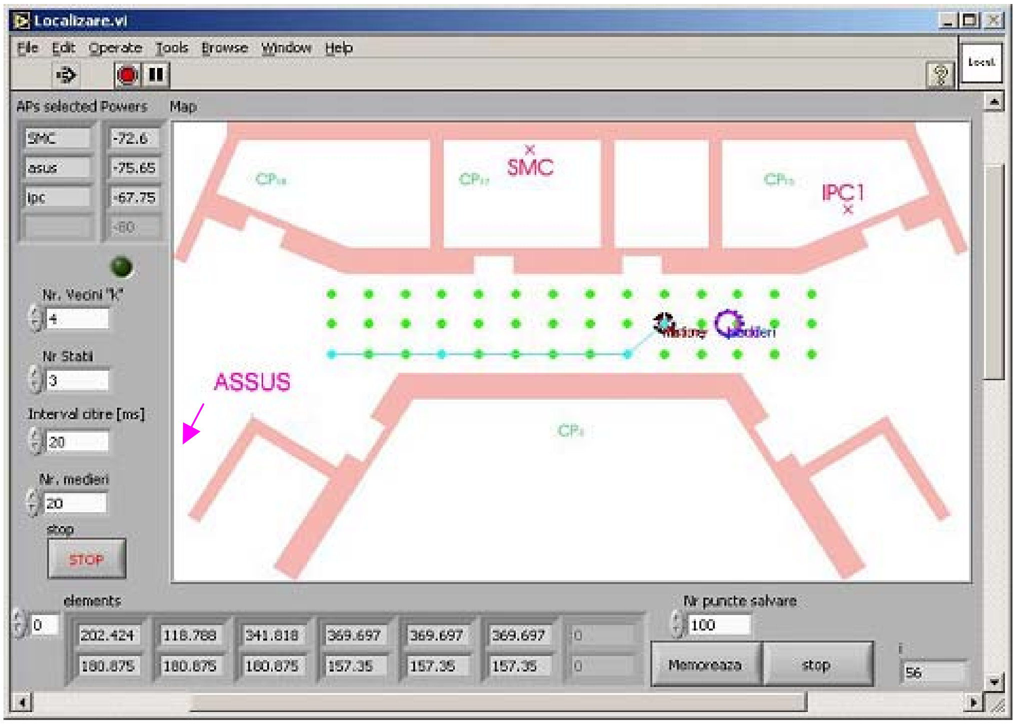

Fig. 1. The testing environment and the estimated positions of the mobile user using the average, weights and history of the last 5 positions

2. THE SYSTEM'S PERFORMANCE EVALUATION AND THE ERROR ANALYSIS

To evaluate the system's performance, we have done some experiments; we've used two 802.11b APs and have measured the received signal power in 15 reference points. Also, we have used the error in distance *e* to quantize how well the system works and to check the accuracy. We have defined the location estimation error, *e,* as the linear distance between the position (x,y) computed by the system and the real user coordinates, (x_0, y_0) given by the following formula:

$$e = \sqrt{(x - x_0)^2 + (y - y_0)^2}$$

We've made several measurement tests (60 for every reference point) and have modified some parameters, which can determine the location identification. These experiments were repeated many times to avoid statistic errors.

During the experimental tests, we have studied the effect of the chosen number of neighbors of the estimated point, the influence of the environment, the effect of the number of the APs selected to contribute at the location's determination and also the effect of modifying the distance between reference points from the radio map.

To illustrate the influence of the above parameters we have used the cumulative distribution function (CDF) of the positioning error.

2.1 The effect of the chosen number of neighbors

One of the main conditions for a proper functioning of the algorithm is a good choice of the number *k* of reference neighbor points that have to participate at the coordinates averaging. We give values for *k* from 2 to 5, computing then the coordinates of the user. The obtained results are given in the Fig. 2.

As we can see, for $k = 4$ we obtain the best localization. Increasing this value to 5 does not give a better accuracy, but increases the time for computation and the complexity of the algorithm. For this reason, for the next experiments, we set the value of k to 4.

From a statistical point of view, we may say that in 50% of the cases the distance error is almost 1 meter and the maximum error is somewhere around 2 meters (for 100% of the studied cases).

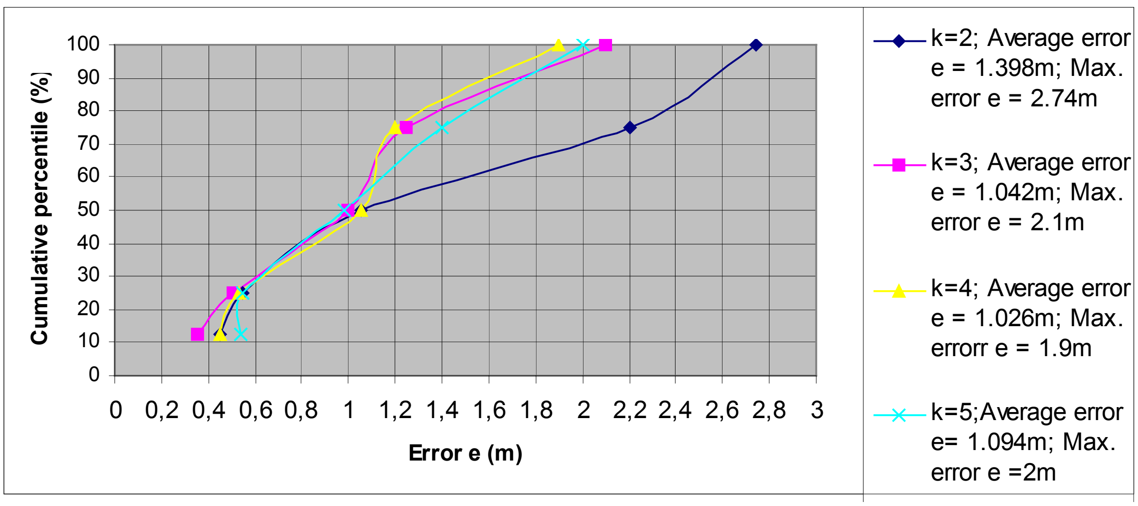

Fig. 2. CDF of the positioning error when the parameter *k* (the neighbors number of the first estimated reference point) is variable

2.2 The influence of the environment

To see the behavior of the algorithm under different medium conditions, we took the measurements at different day moments: in the morning, when the environment is subjected to radio interferences by the people from the area and in the evening, without people crossing the area. In the Fig. 3 we can observe the obtained errors after signal processing.

Analyzing these results we concluded, that there is no substantial accuracy difference, between the measurements taken under these two environment conditions. This shows that the method of the radio reference points is a good choice for the identification of the position, because it overcomes almost all interferences.

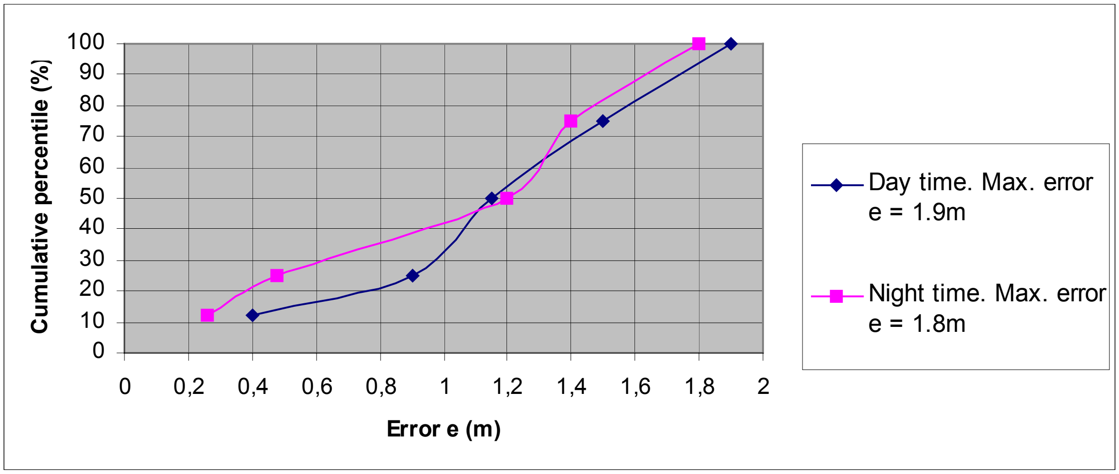

Fig. 3. CDF of the positioning error for environmental different conditions

2.3 The effect of the number of radio access points selected for positioning

One of the problems in using radio frequencies to localize objects is the inconsistency of the received signal power. This is due to the environment, but also to the devices. In most cases, the environment factors have the greatest impact on accuracy and on the maximum detection distance (furnishings and people movements also included). Another cause for the reduction of accuracy is receiving signals on different channels than the direct one, between emitter and receiver (NLOS – Non Line Of Sight). Even if NLOS does not block the transmission, like in the case of infrared radiation, this process creates the multi-path problem and interferences occur in the received signals.

To improve the precision we may increase the number of radio APs, hence increasing input data quantity. In this manner the positioning system may have better results. First we used two access points, and then we added another one. From the

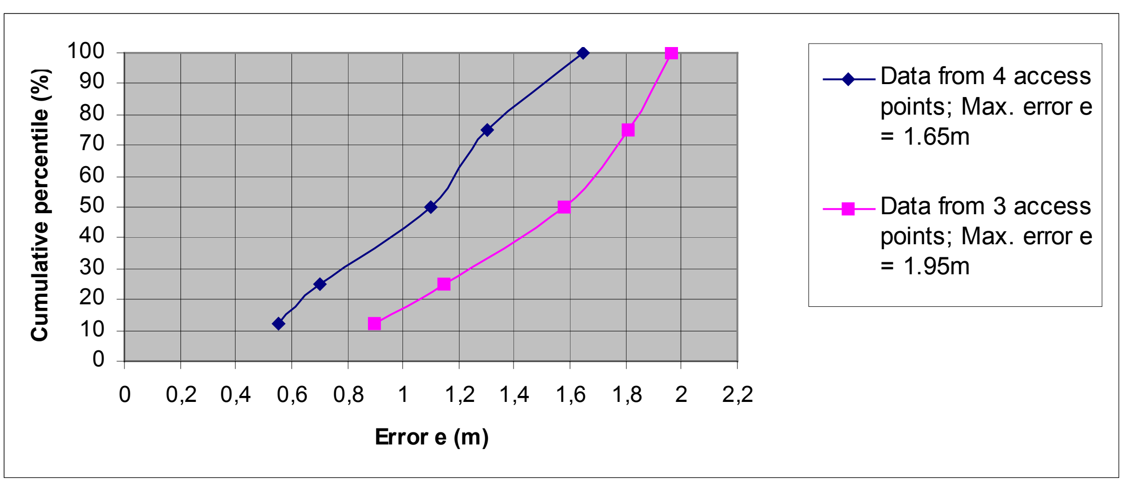

Fig. 4. CDF of the positioning error for a variable number of radio access points

error point of view, we obtained a significant decrease (Fig. 4). Adding more radio access points also influences the data processing time. For this reason, we should make a compromise between precision and system computing speed, especially when the user's tracking is done.

2.4 The effect of the position of reference points on the radio map of the floor

Normally, the position of the radio reference points and their density should influence the precision. To verify this assumption, we placed the reference points on the radio map, from meter to meter. We repeated then the measurements from 2 to 2 meters and from 3 to 3 meters.

The error decreases indeed if the number of points grows, but this decrease is not spectacular, due to the inertia of the wireless network. At a certain distance from the access point, there is a fluctuation of 2-3% from signal power. The positioning algorithm can overcome this, but affecting the precision of the measured distance.

Increasing the number of reference points also increases the complexity and the time necessary for realizing the radio map.

We can make a compromise, by placing more points near areas where our interest is high and placing few points, in areas where we don't need a precise localization.

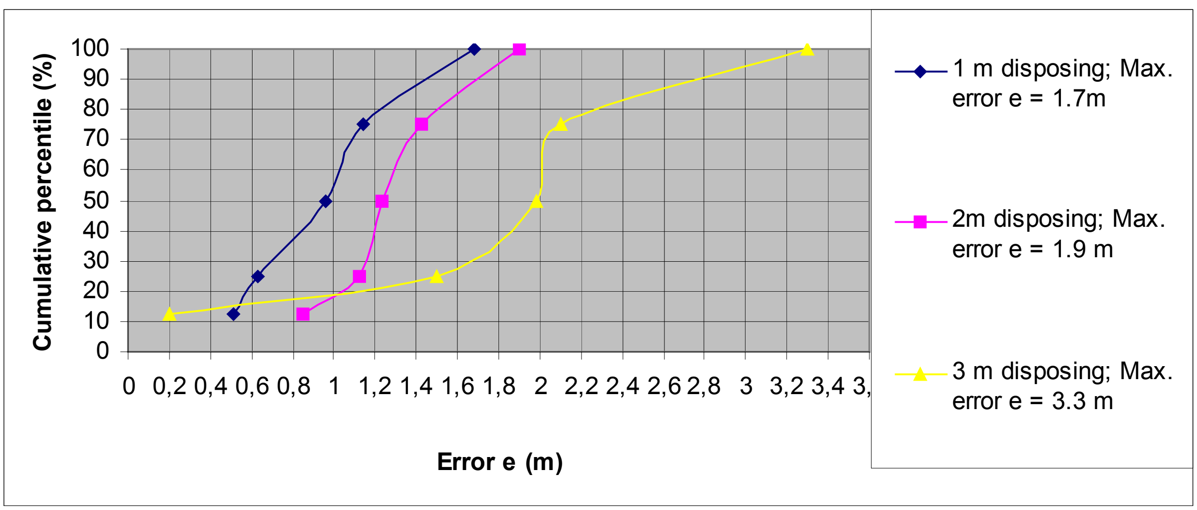

Fig. 5. CDF of the positioning error for a different disposing of the reference points from the radio map

3. CONCLUSIONS

As we can see, the best localization is obtained when the neighbors of the first estimated reference point, that participate at the coordinates averaging, equals to four. Increasing this value does not give a better accuracy, but increases the time for computation and the complexity of the algorithm.

Analyzing the results obtained when the environmental conditions are changing we can conclude that there is no substantial accuracy difference between the measurements taken under these two conditions (day time and night time).

The number of radio APs used for positioning is a very important parameter of the system, but adding more than four APs the data processing time increases and the estimated point remains "behind" the user when tracking. For this reason, we should make a compromise between precision and system computing speed.

The density of the reference points existing on the radio map of the layout of the floor should be big to have a better accuracy, but again we have to do a compromise between the positioning error and the complexity of the algorithm.

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