The impact of AP placement in WLAN-based Indoor Positioning System

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Abstract

In recent years, the indoor positioning systems using the existing wireless local area network and Location fingerprinting schemes are the most popular system. The accuracy of the system is the most important indicator. In this paper we present some experimental results to explore different environment parameters that impact localization error.

1. Introduction

The rapid development of pervasive computing and location-aware systems and services provides a motivation to develop techniques for estimating the location of devices. For outdoor position system, GPS performs well. But for indoor position system, it is inefficient. In recent years, the location fingerprinting technique using existing wireless local area network (WLAN) for indoor positioning as an emerging technique has been widely studied and deployed

WLAN positioning systems usually work in two phases: the offline training phase and the online location determination phase [1].

In the offline phase, the test area is decomposed into a grid. Each grid node is called Marking Position (MP). The location fingerprints are collected by performing a site-survey of the Received Signal Strength (RSS) from multiple access points (AP). The RSS is measured with enough statistics to create a database or a table of predetermined RSS values at each MP. This table is called radio map. The vector of RSS values at a grid point is called location fingerprint of that point.

In the on-line phase, a mobile station (MS) will report a sample which is the measured RSS vector from different AP to a central server; otherwise a group of AP will collect the measured RSS from a MS and send it to a server. The server uses an algorithm to estimate the MS location and reports the calculated position back to the MS or to the application requesting the position information. The most common algorithm to estimate the MS location calculates the Euclidean distance between the measured RSS vector and each fingerprint in the database [2], [3], [4], [5]. The coordinates associated to fingerprint that provide the smallest Euclidean distance is returned as the estimated position.

Previous studies in the literature mainly focus on measurements stage and then results analysis such as those in [6]. Recent developments have been emphasizing the algorithms used for estimating the location that associates the fingerprints with the location coordinates [5], [7], [8], [9], [10], [11]. To explore influencing factors, some researchers performed experimentations regarding the orientation effects [6], [12], some others applied temporal prediction model to deal with the environmental variations of the signal [1]. However, there is a lack of clear understanding of how these systems may perform in terms of accuracy and precision, how to design these systems -what is the impact of the building architecture and thus the radio propagation characteristics- and what impacts the design -what should be the spacing of the grid where location fingerprints are taken.

In order to answer the above questions, we have implemented and tested a WLAN-Based Positioning System (WPS) to evaluate its performance. The objective is to explore first results related to accuracy and localization precision.

In recent work, we have implemented Centre of Mass (CM) and Time Averaging (TA) techniques [13] in the context of WPS. Testing the new programme denoted CMTA-WPS shows that these two techniques improve WPS performance [14].

We also realized a statistical study to emphasize the influence of the WLAN configuration on the precision of a WLAN-based positioning system. Afterwards, we have defined two indicators, Specific Error Ratio (SER) and Global Error Ratio (GER), to determine the best configuration which provides the smallest localization error [15]. The results show that while varying the AP number or the MP number our statistical programme is always able to determine the best configuration under a given precision constraint. Following these conclusions, we deduced that it is possible to improve these indicators. The new indicators were called Refined Specific Error Ratio (RSER) and Refined Global Error Ratio (RGER) and will be described later in section IV.

This paper describes ongoing work where we address the impact of building architecture together with the AP placement on mobile localization. The rest of the paper is organized as follows. Section II describes our experimental environments. Section III describes and analyses the experimental results. Section IV describes two precision indicators and proposes a new way to estimate the localization error. Section V concludes the paper and proposes further work.

2. Experimental environments

This section outlines two experimental environments under different situations with different AP configurations. The first building architecture is simple; this means that the building has few obstacles. In this case, it is better to focus on the number of AP as well as their optimal placement. The second building is a typical example of offices architecture. It is more complex than the first one and has more different type of obstacles. Exploring this type of building we can study obstacles effect on MS localization. Finally, the WLAN-based positioning system CMTA-WPS is briefly described.

2.1. Building 1: a simple environment

In the first stage of experimentation, we have measured the location error in a simple environment. To evaluate the positioning system CMTA-WPS, the objective is to understand how the variation in the AP number depending on the topology of the building influences the location error. The building layout is depicted by Figure 1. The deployment covers an experimental area of approximately 80m x 40m and uses 802.11g wireless LAN infrastructure to provide coverage.

For the analysis need, we selected 8 reference points (RP) where several measurements have been made. The RP are distributed on the whole area as shown in Figure 1.

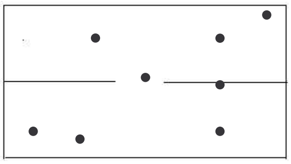

Figure 1. Building 1 layout

Note that the few obstacles result in a complex environment for signal propagation. In other words, a WLAN composed of a small AP number, for instance less than four AP, cannot provide enough coverage for good location accuracy.

According to our previous work [13], we started from a 4-AP WLAN. We tested the positioning system by varying the AP number and their locations. We did several series of measurements under different WLAN configurations inside the building. For shortness consideration, we will restrict the results description. Rather, we will only focus on three scenarios: two 4-AP WLAN configurations and one 5-AP WLAN configuration.

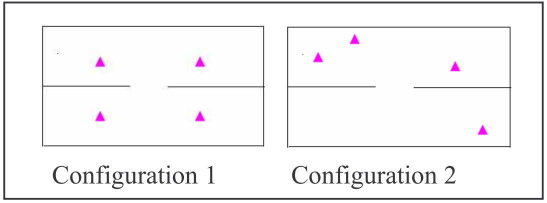

Figure 2. Building 1: first scenario 4-AP WLAN configurations

In the first case, we selected the same number of AP (see Figure. 2) but the selected AP sites (placements) are different. As shown in Figure 2, AP in configuration 1 are placed symmetrically in the building, whereas they are scattered and unsymmetrical in configuration 2.

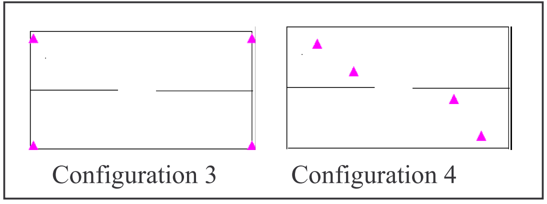

Figure 3. Building 1: second scenario 4-AP WLAN configurations

In the second case, we also select 4 AP. In configuration 3, AP are symmetrically placed in the building corners, whereas, in the configuration 4, they are scattered in a different way compared with configuration 2. Nevertheless, the average power of these RP in symmetrical placement is lower than unsymmetrical placement.

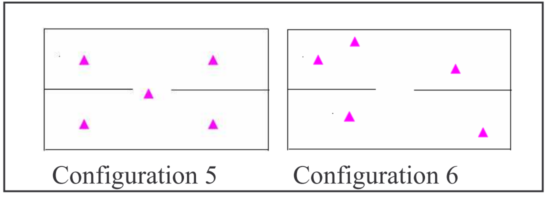

Figure 4. Building 1: third scenario 5-AP WLAN configurations

In the third case, we added another AP to configuration 1 and 2 (see figure 2). In the configuration 5, the fifth AP was placed in the building centre resulting in a symmetrical configuration whereas in configuration 6, the fifth AP is placed in the left bottom corner as depicted by figure 4.

2.2. Building 2: a complex environment

In the second stage of experimentation, we considered a more regular building (see Figure. 5) which is an office building having an experimental area of approximately 80m x 40m. It consists of seven rooms and a corridor. The deployment uses 802.11g wireless LAN infrastructure to provide coverage. It should be noted that both experiments are based on the same surfaces. Although, for this building there are more obstacles such as load-bearing walls, bulkheads and doors that may affect the wave propagation.

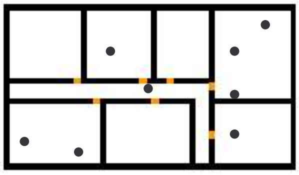

Figure 5. Building 2 layout

Despite the different number of obstacles, we used the same RP in the building 2 as shown in figure 5 since the two buildings cover the same surface.

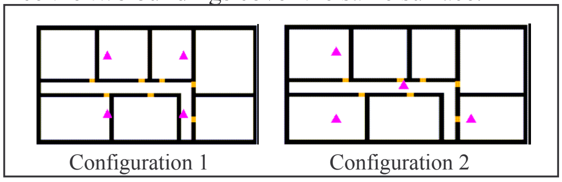

Figure 6. Building 2: first scenario 4-AP WLAN configurations

As in the first experimentation, we also varied the AP number and AP locations in order to evaluate the performance of our positioning system. We conducted several series of measurements under different WLAN configurations. Here again, we will restrict the results description and will only focus on three scenarios: two 4-AP WLAN configurations and one 5-AP WLAN configuration.

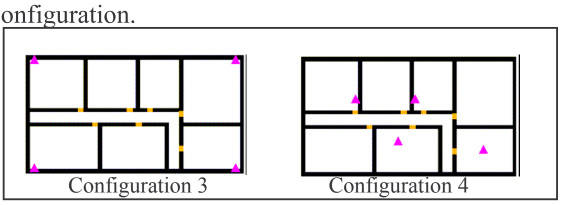

Figure 7. Building 2: second scenario 4-AP WLAN configurations

Note that, in these scenarios, AP placements of configuration 1, configuration 3, configuration 5, in building 1, respectively in building 2 are symmetrical, and AP placements of configuration 2, configuration 4, configuration 6, in building 1, respectively in building 2 are asymmetrical.

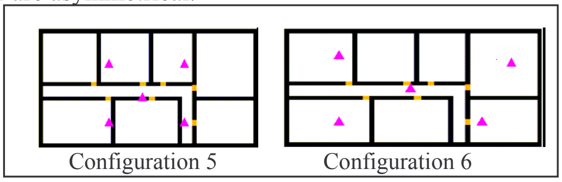

Figure 8. Building 2: third scenario 5-AP WLAN configurations

2.3. WLAN-Based Positioning System (WPS)

The implemented WLAN-Based Positioning System CMTA-WPS is a probabilistic location determination system which can perform location estimation and tracking of stationary and mobile users.

CMTA-WPS stores information about the signal strength distributions from AP in a radio map and uses probabilistic techniques to estimate the user location. CMTA-WPS uses a discrete-space estimation process that returns the radio map location having the maximum probability given a RSS vector from different AP. A continuous-space estimation process takes as input the discrete-space estimated location and one of the radio map locations, and returns a more accurate estimate of user location in the continuous space.

As described in [12][13], CMTA-WPS is based on probability distribution of the signal calculated during the training phase. Unlike other systems collecting radio map from measurements, our radio map is generated by a propagation model that takes as input the building topology and the WLAN network configuration. During the working phase, the mobile device detects a signal from each AP and uses the deployed position-determination model to calculate a real time position.

3. Studying location error using reference points

We explored two situations for position determination: stationary MS and tracking (i.e. moving MS). We run CMTA-WPS programme on both building 1 and 2, each time a unique configuration is considered. We based the analysis on location error as a criterion to evaluate CMTA-WPS. The location error is defined as the average error of all the RP.

The errors of the first experimentation inside building 1 are described in the chart of figure 9. The left graphic describes the results relating to stationary mobile; the right graphic describes those of tracking. For each graphic, the bars numbered from 1 to 6 correspond to the 6 tested configurations.

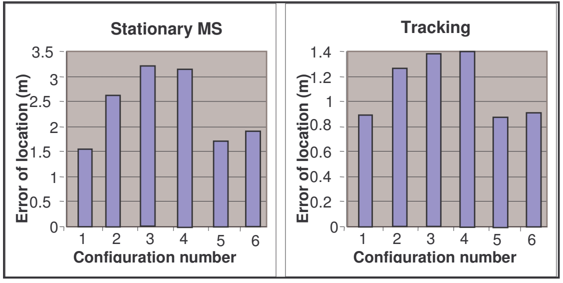

Figure 9. Location error inside building 1

As we started by building 1 where there are few obstacles, we aimed to better focus our research on the ideal AP placement and AP number. The experimentation shows that the location accuracy for tracking is better than for stationary mobile. Indeed, tracking takes advantage from prior knowledge of the building layout as well as previous positions of the mobile device.

A second observation is that the best results are obtained with 4 AP for stationary mobile or tracking particularly when the AP are placed symmetrically. So, adding a new AP does not always improve the accuracy. It depends on the position of the added AP. We can also conclude that the placement of the added AP was not chosen judiciously and, as a matter of fact, the central position of the AP generates more perturbation than improvement.

Symmetric configurations are better than asymmetric configurations except the configuration 3 in figure 3. In this case, we can observe that the average signal power of the RP is very low as shown in table 1.

The experimentation in building 2 reveals very different results as described in the chart of figure 10. Unlike the previous experimentation, the accuracy of the stationary MS is always better. Since tracking is based on prior knowledge, bad performance may come from errors accumulation at each previous position.

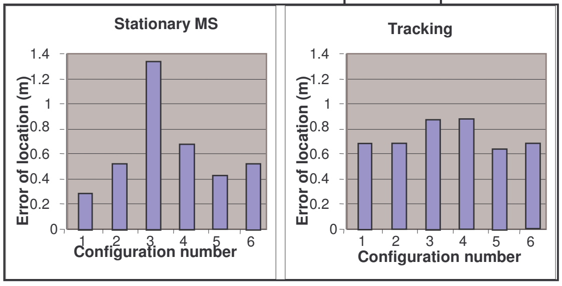

Figure 10. Location error inside building 2

More generally, the best results are obtained with a 4-AP WLAN and configuration 1 for stationary mobile and with a 5-AP WLAN and configuration 4 for tracking. In these configurations, the AP are placed symmetrically in the building. Here again, the configuration 3 in figure 7 is still the worst performance in stationary MS and tracking although it is the symmetrical configuration. That is also due to the low average signal power.

Since building 2 has many obstacles, the wave propagation is disturbed. Therefore, it is most unlikely to have RP with the same maximum probability for a given RSS vector.

Besides above observed findings, we are interested in the relationship between the average signal power of the RP and the average location error.

Table 1 provides the average signal power in milliwatt of these RP for different configurations in both buildings. High values of the average signal power reflect high RSS values and reciprocal. Since RSS values are very low in case of configuration 3 in both buildings, the location error is very high.

Table 1. Average signal power

Configuration	Building 1 (mW)	Building 2 (mW)
1	26.43×10^{-6}	27.71×10^{-6}
2	1.45×10^{-6}	20.34×10^{-6}
3	0.64×10^{-6}	0.53×10^{-6}
4	1.15×10^{-6}	6.79×10^{-6}
5	20.34×10^{-6}	21.36×10^{-6}
6	18.69×10^{-6}	20.96×10^{-6}

Synthesizing figure 9, figure 10 and table 1, it is possible to reliably establish a relationship between the average signal power of the RP and the average location error. The location error of stationary MS decreases while the average signal power increases. On the other hand, for tracking, the prior knowledge of previous positions is an important parameter which may influence the location error. This is why the relationship is not reliable in some experimentation.

Another indicator to assess this relationship is the RP proximity of the deployed AP and the location error. Indeed the average signal power is higher when RP are closer to AP.

4. Studying location error using refined precision indicators

In the previous section we chose only 8 RP in the experimentation area, so this may result in early conclusions which are valid in some area parts. In this section, we explore our refined precision indicators to estimate the location error in the global area.

4.1. Refined Precision Indicators

The calculation of precision indicators is based on the set of the predefined marking positions of the experimentation area. For SER and GER indicators, the error estimation is based on the number of marking position (MP) having the same maximum probability for a given RSS. The estimation error for the refined indicators is the distance between the MP having the same maximum probability.

4.1.1. Refined specific error ratio. We calculate the refined specific error ratio (RSER) in two steps.

First, we define μ as the local error of each MP k as follows:

If $n = 1$ so $\mu(k) = 0$;

Otherwise

$$\mu(k) = \frac{1}{(n(n-1))} \sum_{i} \sum_{j \neq i} dist(i, j)$$

where

i, j: The sequence number of the MP having the same maximum probability *P (li│O)* at the position *k*.

n: The number of MP having the maximum probability *P (li│O)* at the position *k*.

dist (i, j): The Euclidean distance between the MP *i* and the MP *j*.

Then in order to provide the percentage of error ratios, we normalized the local error μ based on statistical studies and proposed the definition of the RSER as follows:

$$RSER = \left[\frac{e^{\frac{\mu}{2}}}{e^{\frac{\mu}{2}} + 1} * \left(\frac{2\mu}{2\mu + 1} \right)^{5} \right] * 100$$

From the above formulation, we determine the relationship between the local error μ and RSER as follows:

When $\mu = 0$ meter RSER = 0%;
When $\mu = 1$ meter RSER = 8%;
When $\mu = 5$ meters RSER = 58%;
When $\mu > 11$ meters RSER > 80%.

4.1.2. Refined global error ratio. The refined global error ratio (RGER) was defined as the average of all RSER relating to each MP of the experimentation area.

$$RGER = \frac{1}{n} \sum_{i=0}^{n} RSER(i)$$

where:

n: The number of MP in the experimentation area.

4.2. Results analysis with RSER and RGER

Now we can explore the AP configurations deployed in both buildings. As mentioned above, we will focus on three scenarios: two 4-AP WLAN configurations and one 5-AP WLAN configuration.

We notice that performing RGER values according to WLAN configurations we considered is a way to choose the best configuration relative to building architecture; for instance, selecting the configuration having the minimal RGER seems to be the most convenient. Note that, to determine location error, RGER does not take into account the prior knowledge of previous positions. Thus RGER reflects only the performance estimation of stationary MS in the global experimentation area.

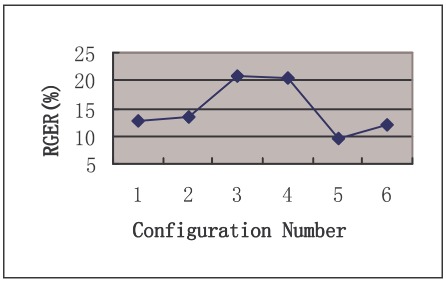

Figure 11. RGER variation in building 1

Figure 11 shows the results obtained from the experimentations in the first building. Two major observations emerge.

Firstly, in the previous section, we have concluded that adding a new AP does not always improve the accuracy. But studying the RGER, we can adjust the conclusion as follows: adding a new AP does not always improve the accuracy in some area parts but improves it globally.

Secondly, both conditions of symmetrical configuration and high average signal power give better results in the global experimentation area.

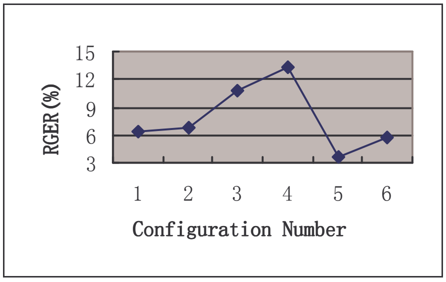

Figure 12. RGER variation in building 2

Besides the two observations mentioned above, figure 12 also reveals that the global accuracy of the closed-space (the second building) is better than open-space (the first building) with the same AP configuration. Indeed, in a closed-space environment, the probability to have RP with the same signal vector is very low.

5. Conclusion and perspective

In this paper, we have selected two buildings and conducted several experimentations using our WLAN-based indoor positioning system to give more insight of the impact of AP placement on location error. For the first building, we focused on the influence of the placement and the number of AP on location accuracy. The experimental performance shows that if we place the AP in symmetric positions distributed over the experimentation area in such a way that the average signal power is high it is likely to be the best choice for reducing location error.

For the second building, we focused on the influence of the obstacles on the location error. The stationary MS and tracking performances are entirely different. Due to the positive effects of obstacles which make RSS vectors diverse, stationary MS are located more accurately. On the contrary, for tracking, location accuracy sometimes decreases. This is caused by the cumulated errors in the previous positions of the mobile device.

Since our former studies are based on 8 selected RP, we explored refined precision indicators to extend the analysis to the whole experimentation area. We defined two indicators called RSER and RGER to estimate the location error using the same experimentation environment. Thanks to these indicators, we observed that increasing the AP number improves the global accuracy of our WLAN positioning system.

Realising these experimentations was based on different indicators (AP number, AP placement, obstacles number, average signal power, etc.) to estimate the location error. When modelling the indoor positioning problem, these indicators will be used to set the optimisation parameters.

6. References

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