WLAN indoor positioning based on Euclidian distance and interpolation (isobars)

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1. Introduction

Navigation is an important feature of mobile information systems and a key ability of autonomous mobile robots. The task of navigation can be divided into positioning and path planning. The aim of positioning is estimating the position of a mobile robot or a user with a mobile handheld computer in its environment, given a map of the environment and local sensorial data.

Nowadays mobile robots and increasingly mobile devices like mobile phones or mobile handhelds often are equipped with IEEE 802.11 WLAN adapters, in order to communicate with computers or other mobile devices. Furthermore, many buildings are already equipped with an IEEE 802.11 WLAN infrastructure, as a popular and inexpensive technology. Most WLAN adapters are able to measure the signal strengths of received packets as part of their standard operation. The signal strengths of received packets vary noticeably by changing the position [1]. If a reliable positioning system could be developed using this technology, position estimation of mobile devices can be improved by cheap technology. Many mobile applications would benefit from being able to use WLAN for communication as well as positioning. In some mobile applications, WLAN positioning can be combined with other sensors to improve the robustness of position estimation.

2. State of the art

Different techniques exist for estimating the position of a mobile device in a wireless network. Generally, the main techniques can be described as follows ([5], [6]):

- Cell-of-Origin:
  This technique is easy to realize and determines the access point (AP) to which the mobile device is currently connected. Due to the known position of the AP and

its range a relatively exact position can be determined. Since all mobile devices know the MAC hardware address of the AP which they are connected to, this technique can be used in every WLAN infrastructure.

- Received Signal Strengths:
  This technique allows the estimation of the position of a mobile device using the received signal strength values from several APs in its range. Several different methods for calculating the mobile devices position exist. Most techniques use fingerprinting methods, i.e. comparing a measured set of signal strength values with a previously within a calibration phase measured set of signal strength values at known positions. The problem is finding a suitable similarity measure for comparing these signal strength value tuples.
- Time-based:
  These techniques are more accurate than techniques based on received signal strengths or cell-of-origin. The position is determined according to the time of arrival of received signals from several access points. A disadvantage is the need for a precise clock for synchronization within the mobile device. These techniques require a more expensive wireless network infrastructure usually not present in existing installations.

3. Methodology

3.1. Fingerprinting and Euclidian distance

One approach for localizing the mobile device is based on the use of received signal strengths values of several WLAN access points.

$$O_{ci} = (SS_{ci1}, SS_{ci2}, SS_{ci3}, \ldots, SS_{cin-2}, SS_{cin-3}, SS_{cin}); \; i = 1, \ldots k \qquad (1)$$

$$O_m = (SS_{m1}, SS_{m2}, SS_{m3}, \ldots, SS_{mn-2}, SS_{mn-3}, SS_{mn}) \qquad (2)$$

$$d = ((SS_{ci1} - SS_{m1})^2 + (SS_{ci2} - SS_{m2})^2 + \ldots + (SS_{cin} - SS_{mn})^2)^{1/2} \qquad (3)$$

O_{ci} : Observation within calibration phase at point i.
SS_{cij} : Signal strength value received from access point j at point i within calibration phase
O_m : Observation within positioning phase
SS_{mj} : Signal strength value received from access point j within positioning phase
n : number of access points
k : number of calibration points

The proposed method is divided in two phases. During an initial calibration phase a radio map of received signal strengths values of several access points is developed. Measurements are carried out at a number of points with known coordinates. One observation consists of received signal strength values of several access points (1).

During the second phase, the positioning phase, again received signal strength values of several access points are recorded (2). Afterwards these observations are compared with those values stored previously in the calibration phase.

There has to be a measure allowing the comparison of observations of the calibration and the positioning phase (comparing fingerprints). One measure of similarity which may be used is the Euclidian distance (3).

After calculating d for all calibration points there will at least one point with minimal d. Then one approach is declaring this point to be the estimated position. The accuracy of this method depends beside other factors on the resolution of the underlying grid of calibration points.

3.2. Fingerprinting and lines of constant signal strength (isobars)

Again, this method is based on previously recorded signal strength values (see 3.1 Fingerprinting and Euclidian distance). A network of triangles using Delaunay-Triangulation is developed. The nodes are represented by the calibration points.

Given a measured signal strength value of one access point we can select triangles whose nodes show signal strength values higher and lower than the measured value. Linear interpolation between node values within the triangle delivers a more detailed radio map consisting of a surface of interpolated signal strength values over the triangle. Moreover, it is possible to calculate an interpolated line of constant signal strength (isobar) within the triangle and in the whole area of triangulation (figure 1). Given two signal strength values of different access points we are now able to select triangles whose interpolation surfaces include the according isobar. If there is an intersection of both isobars, we can calculate the intersection point within the triangle.

Triangulations with coarse grids

Depending on the size of the triangles a differentiated approach is recommended. In the case of triangles of larger size we use weighted means of points of intersection (see formula (4)). The weighted mean represents the estimated position $\overline{p}$.

$$\overline{p} = \frac{\sum_{i=1}^{n} w_i p_i}{\sum_{i=1}^{n} w_i} \quad \text{mit} \qquad p_i \in R^2 \qquad (4)$$

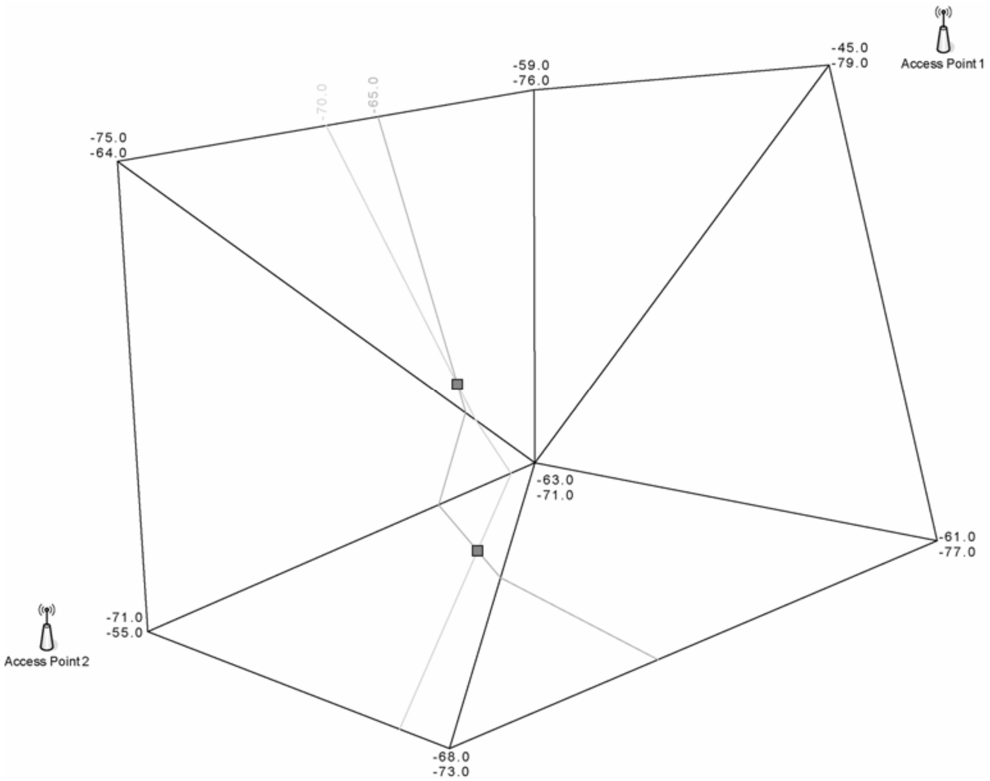

Figure **1**: Merged radio map for access point 1 and 2

Measurements have shown that measuring positions closer to access points are more reliable than those in larger distance. Hence, the weights w_i are formed according to difference of the signal strength values of two isobars which have a point of intersection and a minimum signal strength value s_{min}.

$$w_i = (s_1 - s_{\min})^2 + (s_2 - s_{\min})^2 \text{ mit } \quad s_{\min} = -100dBm \qquad (5)$$

Triangulations with fine grids

With smaller sized triangles the balance point of the triangle itself is used as an estimated position. The according approach is as follows. We select triangles including as much isobars of measured single strength values of access points as possible. Within this list of selected triangles we establish a ranking based on the number of intersection points of two isobars at a time. The balance point of the "best" triangle, i.e. the triangle with a largest number of intersection points, is considered to be the estimated point.

4. Measurements

Two different series of measurements have been carried out within two different environments :

- Measurements with a notebook on a floor within an office building of Fachhochschule Dortmund (see figure 2) and
- Measurements with a personal digital assistant (pda) within a museum (RWE-Museum 'Strom und Leben', Herne) (figure 3).

One observation of single strength values per second was received and recorded. Recorded single strength values vary with time within a certain range. Over ten seconds values were received and the median value was taken as representative for the whole time period. Since the distribution of received signal strength values over time is not Gaussian [3], we choose the median and not the mean value.

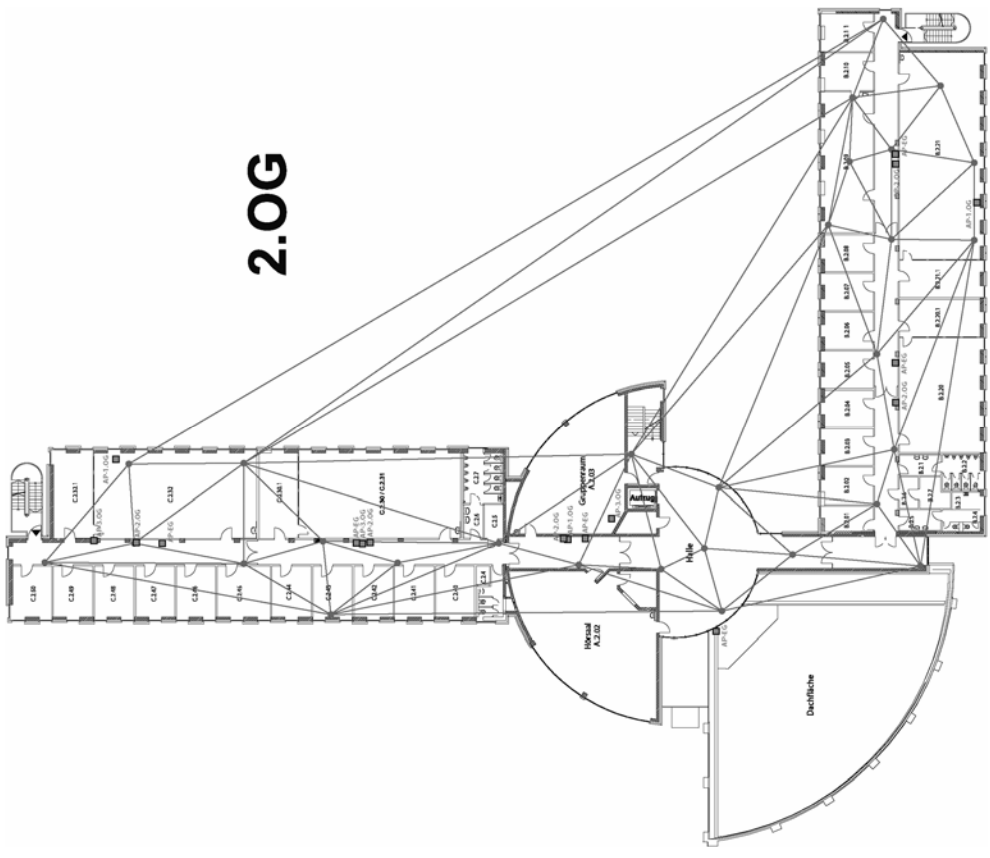

Figure 2: Test bed 'office building floor' with triangulation

4.1. Test bed 'office building floor'

At Fachhochschule Dortmund we tested our algorithm during measurements on an office floor of the building of the Computing/Business departments.

This test bed is characterized by a coarse grid consisting of triangles of larger size. We used the existing WLAN-infrastructure (see figure 2). Triangles are set up by a Delaunay triangulation using calibration points as nodes of the triangles ([4], [2]).

Figure 2 shows some unsuitable triangles, e.g. triangles covering an area outside of the building. Thereby triangles and points of intersection had to be eliminated from the calculation of the estimated position.

The elimination of points of intersection was performed using an acceptance circle. As centre of this circle the balance point of a most 'suitable' triangle was assumed. For each triangle we calculated s, the sum of the Euclidian distance of the signal strength values of the triangles three nodes. The triangle with minimal s was assumed to be the 'best' triangle. The largest edge of this triangle was taken as radius of the circle. All intersection points outside of the acceptance circle were excluded from the weighted mean calculation.

4.2. Test bed 'museum'

As test environment was chosen the museum of 'Strom und Leben' in Herne. Figure 3 illustrates the area of measurement within the museum. This area consists of one large exhibition hall of size 30m x 10m.

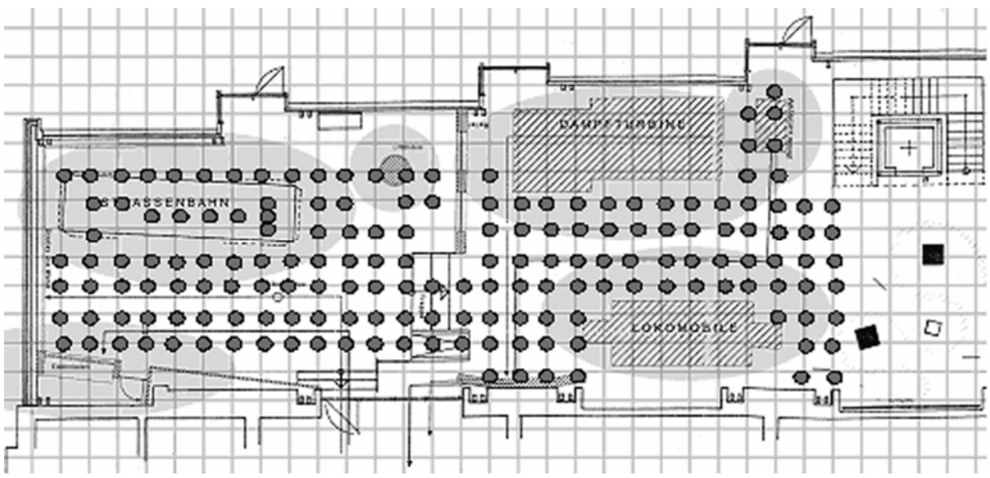

Figure 3: Exhibition hall of museum with calibration points

Within the room we find several points of interest, i.e. large objects like a tram, a gas turbine of a locomobile. This test bed is characterized by a finer grid of triangles of smaller size and leg length of 1m. The WLAN system is set up within in the exhibition hall. The system consists of 4 access points which are placed at the corners beneath the ceiling (see figure 7).

The area where people are able to move was covered with a 1m x 1m grid of calibration points (see figure 3). For each calibration point signal strength values of 4 access points were recorded. One observation consists of a quadruple of 4 signal strength values.

In order to calculate isobars of the recorded observations we have to set up a set of triangles, which are not overlapping each other and with grid nodes representing nodes of the triangles. Such a set of triangles we can achieve by using Delaunay triangulation ([4], [2]).

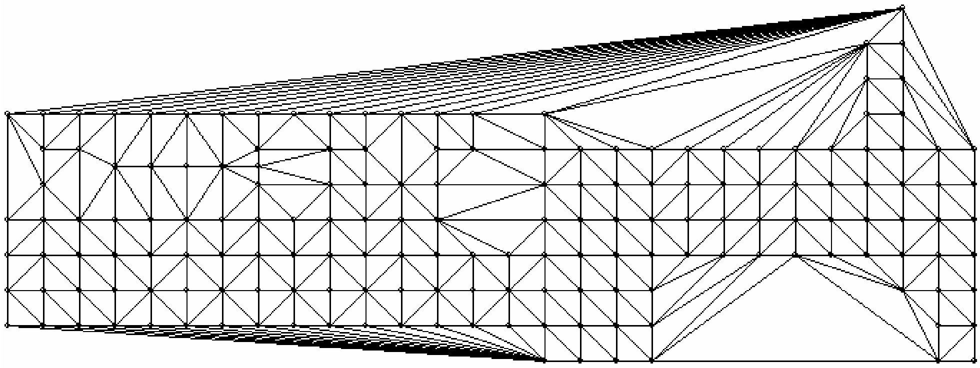

Figure 4: Set of triangles achieved by Delaunay triangulation

Similar to the case of 4.1 some triangles are not acceptable, because they cover areas with large exhibition objects or areas people are not able to enter. Such triangles would contain invalid interpolation data, so they have to be removed from the triangulation.

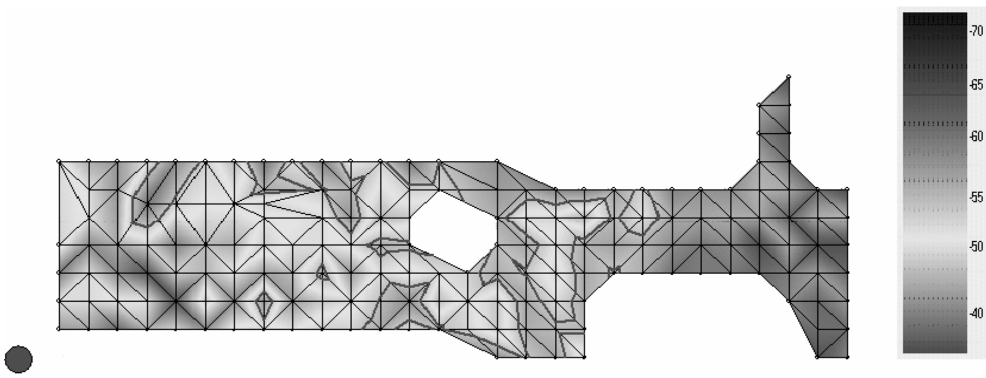

Figure 5: Radio map with lines of constant signal strength (isobars)

Figure 5 shows the interpolated radio map (signal strength values) of one access point (circle below/left) over the reduced triangulation. Moreover we show the isobar of one measured signal strength value (positioning phase) within the radio map (calibration phase).

5. Results

5.1. Test bed ' office building floor '

Within figure 6 filled circles represent calibration points. Lines with numbers show signal strength isobars with according signal strength values.

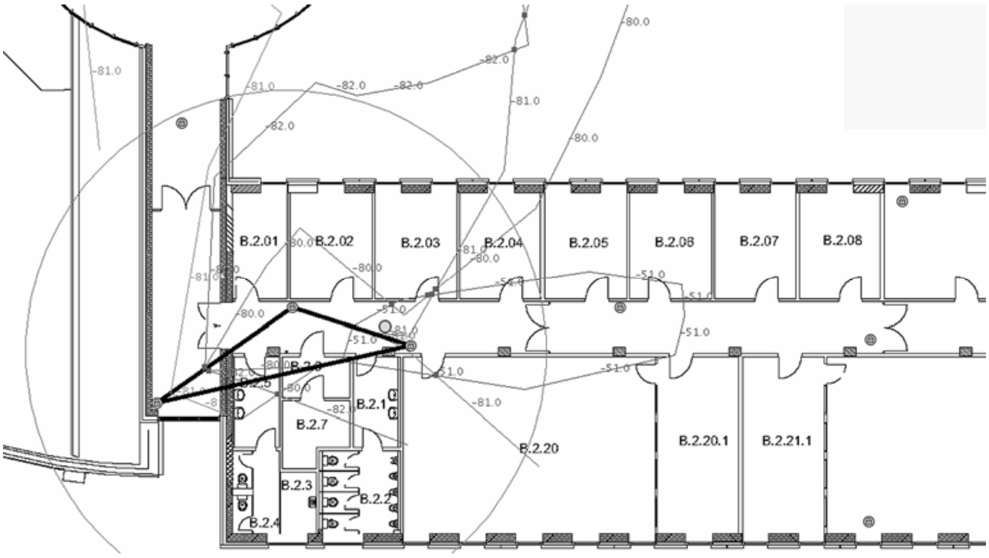

Figure 6: 'Best' triangle and acceptance circle

Using the methods described in 3.2 and 4.1 we were able to find a 'best' triangle (see figure 6) on the office floor. The circumscribed acceptance circle is shown covering the 'best' triangle. The small grey circle close to the right node of the 'best' triangle represents the measuring position.

Measurements achieved a deviation of calculated position from measuring position in a range from 1 to 5 m.

5.2. Test bed 'museum'

Calculation of deviations between measuring point and estimated point using the method of Euclidian distance showed results in the range between 3 and 5 m.

Figure 7 shows the results of one online measurement using the method of interpolated isobars. The interpolated radio map of one access point is presented. Four filled circles mark the position of 4 access points. Additionally the isobars of one observation, i.e. signal strength values of 4 access points, are drawn in the figure.

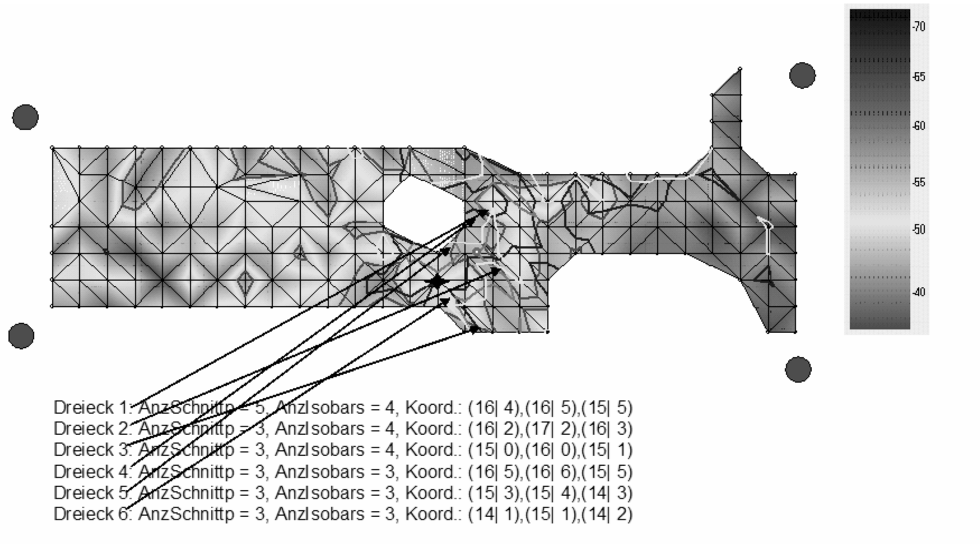

Figure 7: Radio map and ranking of triangles

Triangles were selected which include 3 or 4 isobars. In this case we found 6 triangles ranked according to the number of included intersections of isobars. The 'best' triangle shows 5 intersections. The arrows show the corresponding triangles within the triangulation. The black diamond symbol in figure 7 shows the point of measurement.

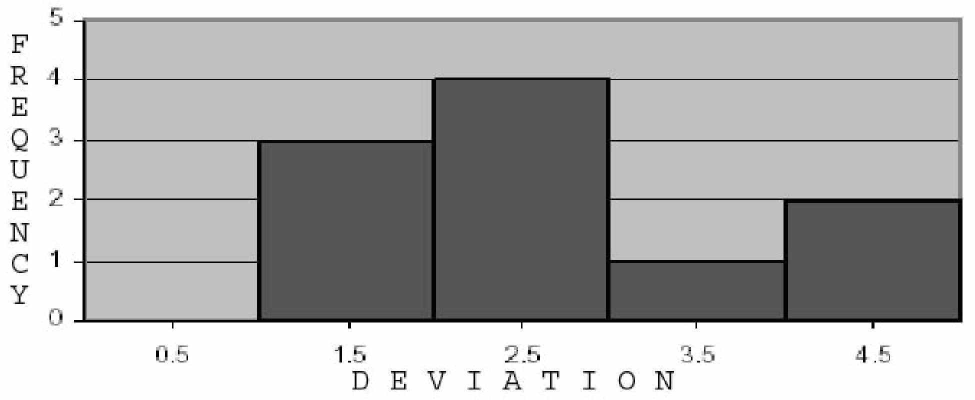

Figure 8 : Distribution of calculated deviations

Figure 8 shows an absolute frequency distribution of all calculated deviations from the point of measurement. Most calculated deviations are lying in the range of 1.5 and 2.5 m. Nevertheless, some values even increase to 4.5 m.

6. Discussion and outlook

The results show, that in both test beds under good circumstances we can achieve a deviation between measuring position and estimated position of 1.5 m. But still we have to take into account deviations up to 5 m. For general use in a mobile application both methods, Euclidian distance and method of isobars, do not seem to be accurate enough. The calculations of test bed 'office building floor' show that reducing the acceptance area and eliminating unacceptable points of intersection increases the accuracy.

One main problem seems to be the non-Gaussian distribution of received signal strength values over time. Using the median leaves a lot of fingerprinting information unused. Statistical methods using the whole distribution of measured signal strength values will potentially offer better measures of similarity between observations of the calibration phase and positioning phase [3].

7. Acknowledgement

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8. References

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