Hybrid Method for Localization Using WLAN

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Abstract:

There are essentially two categories of signal strength (SS) based techniques for positioning using WLAN (Wireless LAN): 'Trilateration' and 'Location Fingerprint'. The prerequisite of the trilateration method is using a signal propagation model to convert SS to a transmitter-receiver (T-R) separated distance measurement. Utilizing the general empirical model can only obtain a very inaccurate distance of T-R, so a more accurate model is required. The RF signal propagation is very complicated, especially in the indoor environment. However, locally, such as within a small room, the propagation model is better behaved. The proposed hybrid method has two stages. In the first stage, it uses the fingerprinting method with a fast training phase to obtain an estimate of the MU (mobile user) position—indicate which room the MU is. In the second stage, trilateration is used to compute the MU location more accurately. The result shows the proposed method is better than the simple trilateration method based on general propagation mode, but worse than the fingerprinting method with a medium training phase.

Introduction

Location-based Service (LBS) has been predicted to be a huge market in the coming future. One of the key issues of the Location-based Service (LBS) is the positioning technology. Quite a few systems have been developed to determine a user's location under certain scenarios. GPS has proved to be the most popular positioning system; however, it is not suitable for some specific environments, such as indoors. Some specially developed systems, like active badge, cricket, active bat etc., can be used in the indoor environment (Hightower and Borriello, 2001). Nevertheless, compared with deploying additional infrastructure for positioning, using existing infrastructures (used for communication or other purposes) is preferred for cost reasons. Many researchers put their efforts into using existing wireless signal systems to determine location such as cellular phone systems (Silventoinen and Rantalainen, 1996; Caffery and Stuber, 1998) or the television system (Rabinowitz and Spilker, 2005). But the most common system used for indoor positioning is WLAN.

WLAN is aimed to provide local wireless access to fixed network architectures. The IEEE 802.11 working group published 802.11b in 1999, and 802.11g later. WLAN is becoming increasingly popular today, especially in indoor and public areas. Most of the WLAN products are based on 802.11b, and operating in the 2.4GHz band which is unlicensed and can be used for data transmissions if a number of rules are followed. 2.4 GHz band is the only accepted ISM (Industrial, Scientific and Medical) band available worldwide (Bing, 2002).

WLAN can be used not only for communication, but also for positioning. Many signal strength (SS) based techniques have been proposed for location estimation in WLAN environments. There are essentially two categories of such techniques. One uses a signal propagation model and the information about the geometry of the building to convert SS to a distance measurement. Trilateration then can compute the location of the mobile user (MU) (Wang et al., 2003; Bahl and Padmanabhan, 2000). The other category is 'Location

Fingerprinting' (a database correlation method) (Ladd et al., 2002; Prasithsangaree et al., 2002; Youssef et al., 2003).

The trilateration approach is simple to implement. Three base stations (or more) with known coordinates are prerequisite (refer Figure 1). If the distance r from the base station to a test point can be measured, a circle with an r radius can be drawn. Circles intersect at one point that is the test point. The coordinate of the test point can be easily calculated. However difficulties of this approach to obtain the distance measurement from the SS are hard to overcome. Indoor radio signal propagation is very complicated, because of signal attenuation due to distance, penetration losses through walls and floors, and the effect of multipath propagation (Dobkin, 2002; Hashemi, 1993). Interference from other signals is also a problem. In the 2.4 GHz frequency band, microwave ovens, Bluetooth devices, etc., can be sources of interference. Furthermore, the orientation of the receiver's antenna, and the location and movement people inside the building, can affect the SS significantly (Ladd, 2002). It is extremely difficult to build a sufficiently good general model of signal propagation that coincides with the real world situation.

The 'Location Fingerprinting' consists of two phases, 'training' and 'positioning' (Bahl and Padmanabhan, 2000; Ladd et al., 2002). In the training phase, a database that contains the measurements of wireless signals (that is, the SS) at some RPs (reference point) in the area of WLAN coverage is established. During the positioning phase, the location of MU can be identified by comparing its SS measurements with the reference data. To achieve a good estimation of user location, the more RPs, the better. And since the measured SS is affected by so many factors, the variation of the RSS at each point can be as large as 10dB to 15dB. The more measurements obtained at each point the better. However, more RPs and more measurements mean that the training phase is a significant task in terms of labour and time. The database generation and maintenance requirements are the disadvantages of this approach.

In order to improve the trilateration approach, a hybrid method is proposed. This method is based on the fact that although the RF signal propagation is very complicated in the indoor environment, but locally, such as in a room, the propagation model is better behaved. The hybrid method has two stages. In the first stage, it uses the simple fingerprinting method with a fast training phase (that means there are only few RPs and the database is very small) to obtain an estimate of the MU position—indicate which room the MU is. In the second stage, an accurate empirical model of the signal propagation can be found and the T-R distance can be estimated. Then trilateration is used to compute the MU location more accurately.

Indoor propagation model

The propagation of radio waves is characterized by several factors: (a) free space loss. (b) Attenuated by the objects on the propagation path, such as walls, windows, and floors of building. (c) The signal is scattered and can interfere with itself.

The basic propagation model is based on free space propagation. The signal strength received by an ideal receiving antenna from an ideal transmitting antenna over a free-space distance *d* can be expressed as:

$$P_r = P_t \frac{1}{4\pi d^2} G_r G_t \left(\frac{\lambda^2}{4\pi} \right) \tag{1}$$

Where P_r and P_t are the received and transmitted power respectively, G_r and G_t are the directivity of the receiving and transmitting antenna respectively, and _ is the wavelength. The wavelength term is often folded into the term in distance for convenience, but it is actually a statement about antenna size. It reveals that free space propagation is not wavelength-dependent (Dobkin, 2002). Many models have been created by other researchers can possibly be used in the case of 802.11b.

The free space loss is defined as:

$$L = \frac{P_t}{P_r} \tag{2}$$

When G_t=G_r=1, the free space loss can be expressed as:

$$L = \left(\frac{4\pi d}{\lambda}\right)^2 \tag{3}$$

Using decibels to express the loss and using 2.45GHz (the center frequency of 2.4GHz band) as the signal frequency for 802.11b APs, the equation can be simplified to:

$$L(dB) = 40.23 + 20 \times \log(d) \tag{4}$$

Literatures show that inside a building, the attenuation due to different materials varies largely. For example, the wood/synthetic material used by the partitions can attenuate the signal slightly, while the concrete wall decreases the signal strength significantly. Thickness also increases the loss. Different frequencies used to communicate between the transmitter and the receiver will be subject to different attenuation levels (Rappaport, 1996; Bing, 2000; Seidel et al., 1992). The general values of the attenuation with respect to different obstacles are hard to determine. Carrying out the experiment to measure these values is inevitable.

While a great deal of research has gone into the characterization of signal scattering, a simple and common way to cope with the effect of scattering is to change the exponent on the distance factor (see (5)). The path loss exponent is also varying depend on the environment. For example, when a signal is propagating along a corridor, the wave guiding effect might make the exponent lower than 2 (the value of exponent in the case of free space), while when the environment is a complex office building, the exponent could be larger than 4 (Seidel and Rappaport, 1992). Experiment is still the best way to get the accurate value. However, there are still some difficulties when using the exponent to model the effect of scattering since the exponent tends to increase with range in an environment with a lot of scattering.

When all the three factors (Free Space Loss, Attenuation and Scattering) are considered, the loss is:

$$L = d^n \left(\frac{4\pi}{\lambda}\right)^2 + L_a \tag{5}$$

where L_a is the attenuation caused by obstacles.
Expressed in decibels:

$$L(dB) = 40.23 + 10 \times n \times \log(d) + L_a(dB) \tag{6}$$

This is the common expression of the empirical model. Similar expressions can be found in (Motley and Keenan, 1988; Seidel and Rappaport, 1992; Ghassemzadeh, 2002).

Since the accurate propagation models for the prediction of the path loss between fixed base station antennas (e.g. WLAN APs) is so important for the planning of wireless communication networks in indoor scenarios, a lot of research has been done. Except the empirical propagation models, other methods like the ray-optical model (Valenzuela, 1993; Hoppe et al., 2003), the dominant path model (Wölfle et al., 2005), and multi channel coupling (Liebendorfer and Dersch, 1997) have been developed. These methods can to some extent more accurately describe the propagation details of the RF signal. However, they require the details of the environment, in other words, a database with all the information about the building are needed. And the computation burden is relatively high. And these methods are not very helpful to compute the T-R distance if the SS is known.

The hybrid method and experiment

The experimental test bed is located in the fourth floor of Electrical Engineering building in UNSW. The layout of the test bed is shown in Figure 2. The test bed has dimensions of 17.5m by 23m. The test area is the upper part of the test bed with the dimension of 11m by 23m. It has 7 rooms and a part of the corridor. Five WX-1590 SparkLAN 11Mbps WLAN Wireless Multi-Mode APs were installed at the locations (pentagram symbols) indicated in Figure 2. The APs are essentially base stations transmitting signals for positioning. The MU is a Compaq iPAQ 3970 installed with the Pocket PC 2002 operating system. The network card used in this test is the Lucent Technology Wi-Fi Orinoco Wireless Golden Card, which can exchange information with the APs. The SS information (in units of dBm) of the received signal can be extracted and logged. Figure 3 displays the AP, wireless card and PDA used for these tests.

Tests were carried out in the test bed. More than one hundred locations were chosen randomly and the SSs of 5 APs at each location were recorded. To find the relationship of SS and distance from the AP, the figures of the SS versus distance were plotted. Figure 4 gives two examples. It is very clear that locally (say in a room) the SS behaved better than when taking a wide area into account. The corridor is an exception. AP2 was set up on the left side of the corridor. The received SS of AP2 behaves very well along the corridor (similar to free space propagation), however the SSs of other 4 APs were different (Figure 4 shows that). The reason is the paths of the other 4 APs' signals change a lot depending on where in the corridor measurements are taken. The corridor was divided into 3 small parts to solve that problem (refer Figure 2, the dash line in the corridor). If the part of the corridor the MU is in can be foreknown (e.g. using fingerprinting), the signal propagation model can be chosen more accurately. It also means the ranges from the APs can be derived from the SS more accurately.

In this paper, the empirical propagation model is used to estimate the SS. There are often 2 types of obstructions – concrete walls and soft partitions - between the AP and MU when the terminals are on the same floor. Since the thickness and quality of the concrete walls and soft partitions are various, they have to be classed to sub-categories. Table 1 gives the attenuation factors (AF) of difference obstacles. AFs are decided by experiments. The SS can be measured in units of dBm, the power estimate model can be expressed as:

$$P(d)[dBm] = P(d_0)[dBm] - 10 \times n \times \log(\frac{d}{d_0}) - L_a$$
$$L_a = \begin{cases} \sum_{i=1}^{n} L_i (When \sum_{i=1}^{n} L_i \le L_{\max}) \\ L_{\max} (otherwise) \end{cases} \quad (7)$$

where P is the received power in units of dBm, d_0 is the distance between the transmitter and SS reference point. L is the attenuation caused by the obstacles. n can has different values in different environments, it is 2 in free space. In the hybrid method, there is an other way to get the L_a. During the first stage, after the SS measurements of RP are collected, the L_a can be derived using (7). This way is more efficient than the previous one. But the error should be carefully considered since only very few RPs are chosen. The $P(d_0)$ can either be obtained from the hardware specifications provide by the manufactory or derived empirically. The transmit power is not exactly the same even when the same type of APs are used. For example, the datasheet shows the transmit power of the APs used for this experiment is 18±1.5 dBm (WX-1590L datasheet). So the empirical method is preferred. The d_0 can be chosen arbitrarily, but in this experiment, it was fixed as 2.5 m for the convenience. In order to take the orientation into account and reduce the affection of the fast fading, at each reference point, the user faced east first, then the orientation was changed to north, west and south consequently, the SS values were logged. A total of 12 measurements were made at each point. Table 2 gives the reference SS at d_0 of each AP. Figure 5 shows a scatter plot of the measured SS versus predicted SS for all measurement locations. The diagonal straight line shows where measured and predicted SS are identical. The result shows the model works very well. Meanwhile, a general model of all the locations was derived from all the measurements utilizing curve fitting.

$$P(d)[dBm] = 34.299 \times \log(d) + 33.313 \quad (8)$$

Figure 6 depicts the measured and predicted SS based on (8). One can see the result is much worse.

Table1. Attenuation factors of difference obstacles

Different Obstacle	AF (dB)
Very Thick Concrete Wall	12.6
Thick Concrete Wall	9.5
Concrete Wall	5.5
Soft Partition	0.8

Table2. Reference SS at d_0 of each AP

	Reference SS (dBm) at d_0=2.5m
AP1	-44.2
AP2	-46.7
AP3	-45.1
AP4	-44.9
AP5	-43.7

Since choosing the correct propagation model is based on the prior information indicating which room the MU is in, a simple fingerprinting method was applied first. Totally, 14 RPs were chosen (the crosses in Figure 2 are RPs). A small database of these fingerprints was created (including the mean SS of each AP and the coordinate of the RP). Then the nearest neighbour (NN) algorithm was applied. NN is the basic algorithm used in database correlation method for positioning (Bahl and Padmanabhan, 2000). The signal distance between the measured SS vector [s1 s2 … sn] and the SS vector in the database [S1 S2 … Sn] is computed first. The generalised distance between two vectors is:

$$D_q = \left(\sum_{i=1}^{n} \left| s_i - S_i \right|^q \right)^{\frac{1}{q}} \tag{9}$$

Manhattan distance and Euclidean distance are D_1 and D_2 respectively (Cormen, 1990). Experiments show increasing q does not necessarily improve the accuracy of location estimation. The nearest neighbour is the point with the shortest signal distance. The Euclidean distance that is the most common used distance (but not necessarily to be the optimal one) is used in this paper (Li *et al.*, 2005). The RPs are linked to the room they are in, so the nearest neigbour can indicate which room the MU is in. In this experiment, 97% test points could be correctly estimated which room (or part of corridor) it is in.

After the parameters related to the specific environment are decided, the propagation model can be derived. This time, the inverse of the model is needed:

$$d = d_0 \times 10^{\frac{P(d_0) - P(d) - L_a}{10n}} \tag{10}$$

The SS the MU acquired were used to compute the T-R distance. Figure 7 shows a scatter plot of measured and predicted distance from APs. Although the empirical model works well (refer Figure 5), when T-R distance increases, the error also increases because 1dB in signal level represents a larger distance.

Then the trilateration can be used to calculate the location of MU. There are in total 30 test points (see Figure 2, the squares are test points). Displacements of the estimates from the true position are shown in Figure 8, where the squares are the true position of the test points and the stars are the estimated position. Table 3 lists the results using the hybrid method and the general model. The result based on a fingerprinting with medium training phase (33 RPs in total rather than 14 RPs in hybrid method) is also listed for comparison. It shows that the hybrid method performed much better than the method based on general model. However, it is slightly worse than the fingerprinting method.

Table3. Comparing the result using different methods

	Hybrid method	General model	Fingerprinting (NN)
Mean distance error (m)	1.83	4.62	1.78
Standard deviation (m)	0.97	3.50	1.14

Concluding remarks

In this paper, a hybrid method for localization using WLAN based on 802.11b standard is discussed. An experiment shows the result is much better than utilizing the trilateration method based on the general signal propagation model. Generally, the difficulty of the trilateratin method using SS is how to convert SS to T-R distance accurately. However, the complex indoor environment makes this task very hard. Even though the hybrid method used here has improved the accuracy of the model a lot, the results still no better than the fingerprinting method. It is hard to improve the empirical model, but not very difficult to promote the fingerprinting method, such as increase the RPs, using better algorithms rather than the basic NN one. More work will be done in that field in future research.

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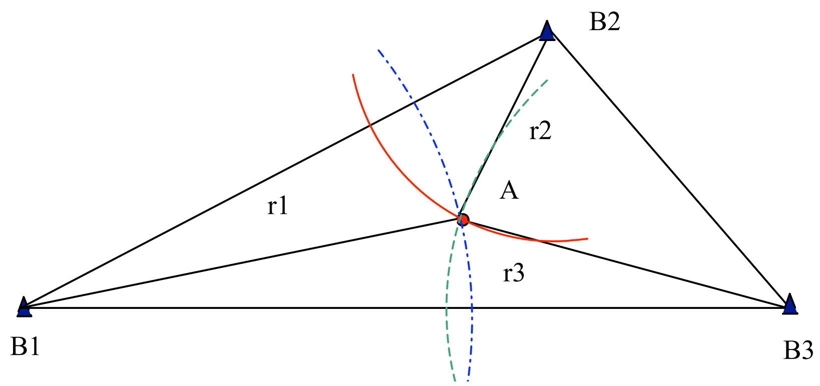


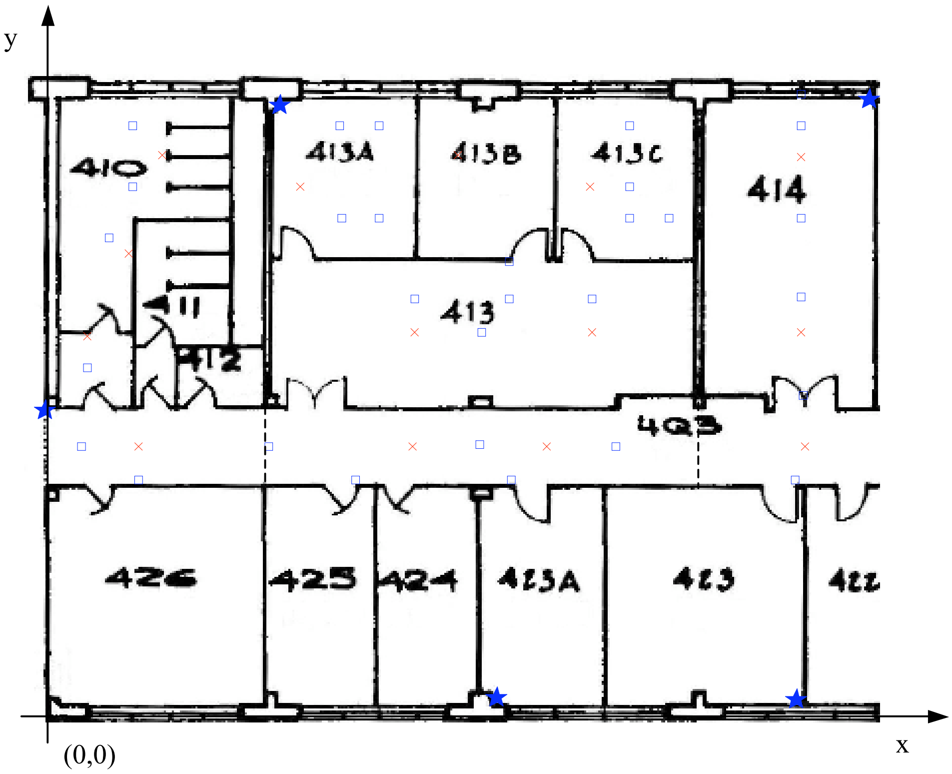


Fig. 2 Experimental test bed

Fig. 3 AP, Wireless card and PDA

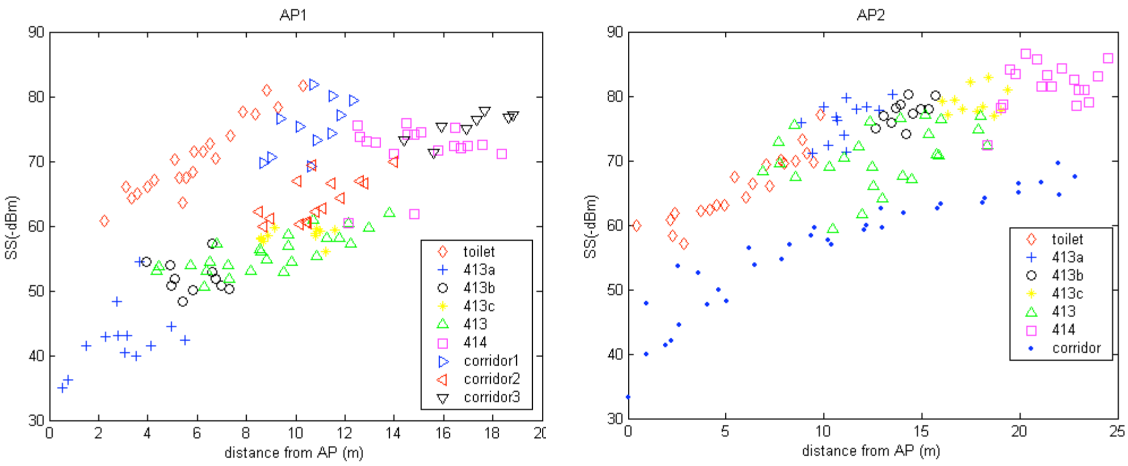
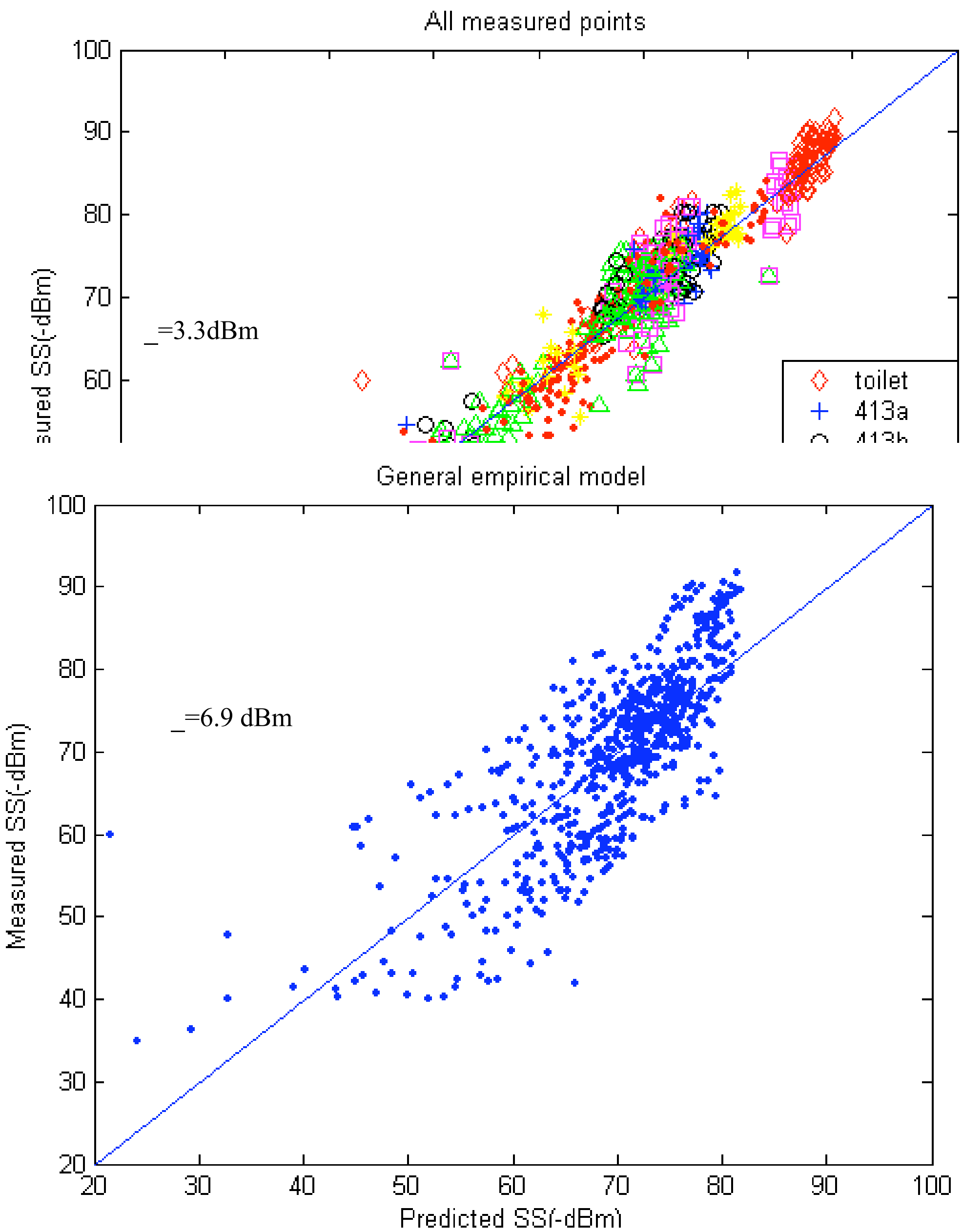


Fig. 4 SS as a function of T-R separated distance from the empirical data (a)AP1 (b)AP2



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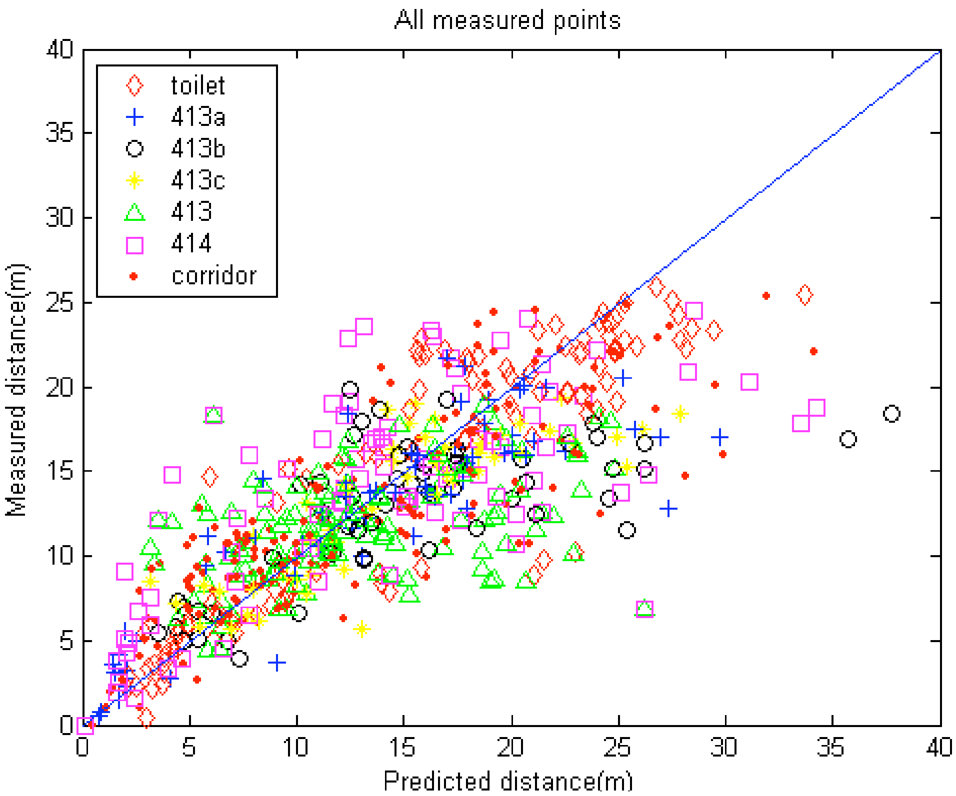

Fig. 7 Scatter plot of measured and predicted T-R distance

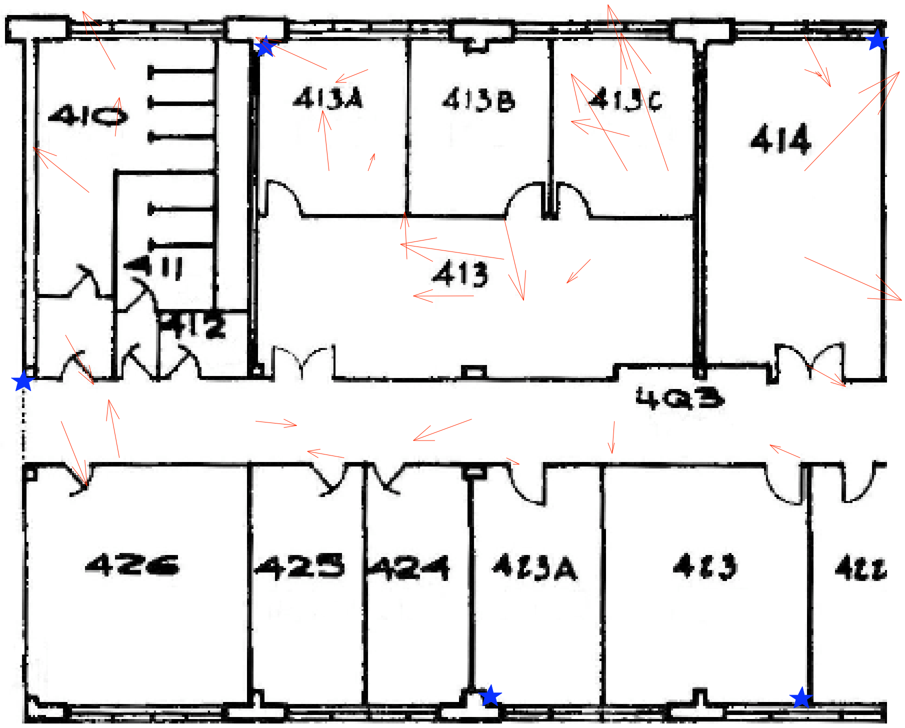

Fig. 8 Displacement error