

## On outdoor positioning with Wi-Fi

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### Abstract

Though GPS is the most popular positioning system at present it does not perform well in indoor environments and metropolitan city areas. Wi-Fi positioning has received much attention due to its advantages with respect to indoor positioning and the wide spread of the Wi-Fi access points (APs). Its performance in an outdoor environment is also of interest as a Wi-Fi based positioning system can overcome the shortcomings of GPS. In this paper, the Wi-Fi positioning technologies which can be used in outdoor environments - trilateration and fingerprinting, are discussed. An experiment based on fingerprinting has been carried out in the Sydney CBD area where Wi-Fi APs are densely deployed. The test results show that the Wi-Fi positioning system based on fingerprinting works well for outdoor localization, especially when directional information is utilized.

**Key words:** Wi-Fi, Outdoor Positioning, Fingerprint

### 1. Introduction

GPS is the fully functional satellite based positioning system at present. It is widely used in many fields around the world. However it has its shortcomings such as it takes some time to get the first fix; it does not perform well indoors or in urban canyons. GPS receivers need to “see” at least 3 satellites which are relatively well distributed in the sky to calculate its 2D position. Hence in environments where the sky is blocked, positioning becomes difficult; even impossible. In indoor environments, some alternative systems, like active badge (Want et al., 1992), cricket (Priyantha et al., 2000) etc., have been developed for positioning, but they cannot be used widely due to their inherent problems. Outdoors, mobile phone networks (3GPP, 2004), television signals (Eggert and Raquet, 2004) and pseudolites (Barnes et al., 2006) can be utilized. Since 802.11 Wireless LAN (also known as Wi-Fi) technology has been widely utilized, a large number of access points (APs) have been deployed both indoors and outdoors. Wi-Fi positioning technology has attracted much attention from both researchers and

companies (Ladd et al., 2002; Youssef and Agrawala, 2005; Li et al., 2005; <http://www.ekahua.com/>).

Wi-Fi aims to provide local wireless access to fixed network architectures. Its market is growing rapidly as the flexibility, connectivity, mobility, and low cost of this technology meet the needs of consumers. A group of specifications has been ratified by the IEEE 802.11 working group. Of these, 802.11b has become the industry standard. It operates at rates up to 11 Mbps in the 2.4 GHz band, which is the only accepted Industrial, Scientific and Medical band available worldwide (Bing, 2002). The next mainstream Wi-Fi standard is 802.11g which provides optional data rates of up to 54 Mbps, operates in the same band as 802.11b, and requires backward compatibility with 802.11b devices (Geier, 2002).

Obviously, Wi-Fi is not designed or deployed for the purpose of positioning. However, the measurements of signal strength (SS) of the signal transmitted by either AP or station imply the possibility of finding the location of the mobile user (MU). In fact, several SS based techniques have been proposed for location estimation in indoor environments in which Wi-Fi is deployed (Bahl and Padmanabhan, 2000; Li et al., 2005). There are essentially two categories of such techniques. One uses a signal propagation model and information about the geometry of the building to convert SS to a distance measurement. ‘Trilateration’ can then compute the location of the MU (Li, 2006). This approach is simple to implement; however it does have difficulties in building a sufficiently good model of signal propagation that is adequate for real world applications since so many factors affect the signal propagation. The other category of Wi-Fi positioning is ‘Location Fingerprinting’. This class of technique has received more attention recently as it is able to address some of the problems related to non-line-of-sight (NLOS) and multipath propagation (Haldat, 2002). The basis of location fingerprinting is first to establish a database that contains the measurements of wireless signals at some reference points (RPs) in the area of Wi-Fi coverage. Then the location of the MU can be identified by comparing its SS measurements with the reference data (Ladd et al., 2002; Li et al., 2005). The disadvantages of this approach are the database

generation and maintenance requirements. Other methods based on different measurements rather than SS have been proposed, such as utilizing time-of-arrival (TOA), time-difference-of-arrival (TDOA), angle-of-arrival etc. The Wi-Fi positioning solution provided by WhereNet is an example. TDOA measurements are used in the position computation (<http://www.wherenet.com>). Hence WhereNet cannot use standard Wi-Fi devices.

There are several Wi-Fi positioning systems developed such as 'RADAR' from Microsoft Research (Bahl and Padmanabhan, 2000); 'Horus' from University of Maryland, USA (Youssef and Agrawala, 2005); 'ipos' of IMST GmbH, Kamp-Lintfort, Germany (<http://www.centrum21.de/>) and 'WPS' from the University of New South Wales, Australia (Wang et al., 2003). Commercial versions of Wi-Fi positioning systems are very rare. The best-known system is the 'Ekahau Positioning Engine (EPE)', offered by Ekahau Inc. (<http://www.ekahau.com/products/positioningengine/>). 'Pango' is a similar system which is part of innerwireless now (<http://www.innerwireless.com/vision-over.asp>). All these systems are basically focused on indoor positioning. Skyhook Wireless has developed a metro-area positioning system which can be used for outdoor positioning (<http://www.skyhookwireless.com>). While many reports about Wi-Fi positioning in indoor environments are available, its performance outdoors is also of interest. In the following section, the possible outdoor positioning technologies using Wi-Fi are discussed. Then an outdoor test based on fingerprinting is introduced in section 3 and 4. In section 5, the results are reported. Finally, concluding remarks are given.

## 2. Outdoor Positioning Technologies Using Wi-Fi

In an outdoor environment, both trilateration and fingerprinting can be utilized. Furthermore, other positioning systems could also be valid, such as GPS. Hence the integration of Wi-Fi and GPS (or other systems) is also a choice.

### 2.1 Trilateration

The trilateration approach is relatively simple. Three base stations (or more) with known coordinates are required (refer to Figure 1). If the distance  $R$  from the base station to a MU can be measured, a circle with radius  $R$  can be drawn. Circles intersect at one point which is the MU's position. The coordinate of the MU can then be easily calculated. Generally, trilateration is used if the TOA measurement (which can be easily converted to distance) can be obtained, for example in mobile phone positioning. However, the measurements available in Wi-Fi are SS rather than the distance. Hence, the SS should be converted to distance first. So, the trilateration approach consists of two steps: the first step, using a

signal propagation model to convert SS to AP-MU separation distance; the second step, least-squares or other methods (such as a geometric method) can be used to compute the location. The first step is the key of this approach.

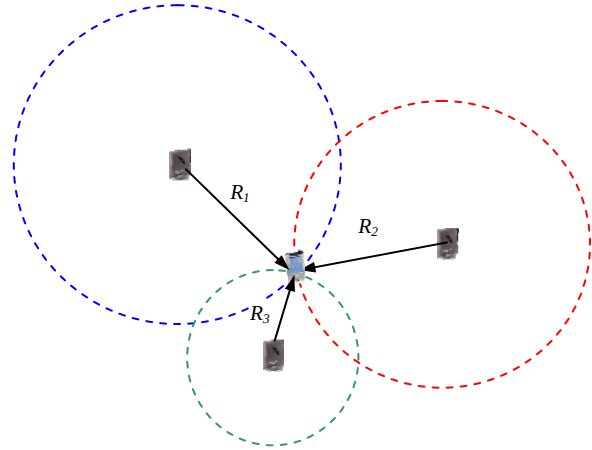


Fig. 1 Trilateration approach using Wi-Fi

Since the environments vary significantly from place to place, if the detail of the environment cannot be obtained easily, the simplest way to find the relationship of SS and AP-MU separation distance is by collecting some SS data at some points with the known coordinates. This means an extra procedure, called a learning procedure, has to be added to the trilateration approach (actually, the learning procedure is almost inevitable no matter what approach is used). The application of this approach in indoor environments has been investigated (Bahl and Padmanabhan, 2000; Li et al., 2005). Skyhook claims their system uses 'triangulation' (more accurately 'trilateration') to determine the MU's position in outdoor (<http://www.skyhookwireless.com/whoware/faq.php>).

There are two types of errors associated with this approach: signal propagation model error and NLOS error (for details refer to Li et al. (2004)). Those two errors are not trivial. Hence the estimate of the MU's position may be very inaccurate. However, if the NLOS contaminated measurement can be detected and removed and the propagation model can be well chosen, the trilateration approach may be a good choice.

### 2.2 Fingerprinting

The word 'fingerprint' here denotes the location-sensitive parameters of measured radio signals: in the case of Wi-Fi this is SS. Similar to human fingerprints, the fingerprint of a specific place can be used to identify the location. The key idea of the fingerprinting approach is to map location-sensitive parameters of measured radio signals in areas of interest.

Location fingerprinting has two phases: ‘training’ and ‘positioning’ (Li et al., 2005). The objective of the training phase is to build a fingerprint database. In order to generate the database, RPs must first be carefully selected. Generally, the data acquired are the SSs measured by the MU. Locating a MU at one RP, the received SSs of all the APs are measured. From such measurements the characteristic features of that RP are determined, and are then recorded in the database. This process is repeated at another RP, and so forth until all RPs are visited. In the positioning phase, the MU measures the SS at a place where it requires its position. The measurements are compared with the data in the database using an appropriate search/matching algorithm. The outcome is the likeliest location of the MU. The whole process is illustrated in Figure 2.

The fingerprinting approach has been accepted as an effective method for Wi-Fi positioning, despite having some disadvantages. There are in fact two ways to estimate the unknown location. The simpler is the deterministic method (Bahl and Padmanabhan, 2000; Saha et al., 2003; Li et al., 2006). The average SS, which is taken over several measurements, of each Wi-Fi AP measured at each RP is used to create the fingerprint database. Since the variation of the SS measured at each point is large, in order to achieve more accurate results, the probabilistic approach (Roos et al., 2002; Li et al.,

2006) has also been developed. Unfortunately, the distribution of the SS is non-Gaussian. Even worse, it varies at different locations, and at the same location when the orientation of the antenna changes (Ladd et al., 2002; Li et al., 2007). Hence many measurements are necessary, and this takes more time to generate the SS distribution at each RP. Furthermore, this increases the database size and the computational burden. However, the establishment of the location fingerprint database is an essential prerequisite. To achieve a good estimate of user location, the more RPs, or in other words, the smaller the granularity, the better. And since the measured SS is affected by so many factors, the variation of the received SS at each point can be as large as 10dB to 15dB. Therefore, 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.

Many researchers have noticed the impact of the MU’s orientation - the direction in which the receiver’s antenna is pointing. When the user changes orientation, the received SS can change significantly (Ladd et al., 2002; Li et al., 2005). Xiang et al. (2004) and Li et al. (2007) investigated the methods using directional information to improve the positioning accuracy and estimate the MU’s direction in an indoor environment.

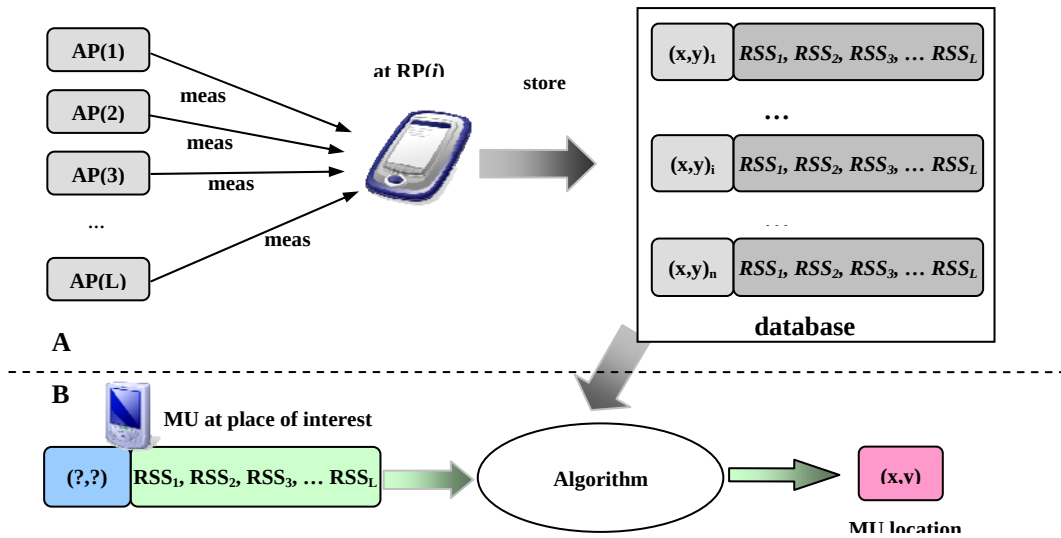


Fig. 2 Two phases of fingerprinting approach, A) training B) positioning

### 2.3 Wi-Fi plus GPS (Other Sensors)

Outdoors, the probability of receiving a line-of-sight signal from at least one GPS satellite is quite high. It is possible to integrate Wi-Fi and GPS to estimate the MU’s position. However, as mentioned previously, Wi-Fi cannot provide the TOA measurement. Using a model

can convert SS to AP-MU distance, but this distance is very inaccurate. The fingerprinting approach cannot provide range measurements. So, how to integrate Wi-Fi and GPS is an interesting problem to be investigated. Integration of Wi-Fi with other sensors is also of great interest.

### 3. Test bed and Equipment

To investigate the performance of Wi-Fi positioning in an outdoor environment, the Sydney CBD was chosen to carry out the test. This area is well serviced with Wi-Fi signals. The test area has a dimension of about 500m by 800m. More than 1300 APs can be detected in this area.

Some of them are deployed by telecommunication companies such as Telstra as part of their fixed infrastructure. Some APs are established by private users for personal use. The chosen area has a typical urban setup with tall buildings and towers blocking the sky. Figure 3 shows the test area.



Fig. 3 Sydney CBD area where test was conducted ([www.airviewonline.com.au](http://www.airviewonline.com.au))

During the experiment researchers used a Compaq iPAQ 3970 personal digital assistant (PDA) running the Pocket PC 2002 operating system (<http://www.compaq.com>). A Wireless card from Lucent Technology Wi-Fi Orinoco Wireless Golden Card (<http://www.orinocowireless.com>) has also been used. For comparison purpose, a Garmin eTrex GPS receiver has been utilized to collect GPS data (Figure 4).



Fig. 4 Equipment used in the test (Wi-Fi card, PDA and GPS receiver)

The software used to collect and preliminarily process SS data is NetStumbler and a pruned version for the PDA called MiniStumbler (<http://www.netstumbler.com>). Screenshots of the user interface are shown in Figure 5.

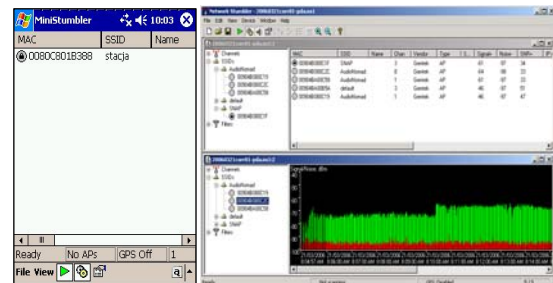


Fig. 5 Software used to collect data, MiniStumbler (for PDA); software used to preliminarily process the data, NetStumbler (for PC)

### 4. Methodology and Data Collection

As introduced in section 2, the trilateration approach is the simplest to use in outdoor positioning. However, apart from the difficulties which have been discussed previously, there is another issue that must be considered seriously – the coordinate of the APs. It is not easy to obtain this information. The reality is the operators of these fixed infrastructures won't give the coordinates free (or if they do not want this information to be public at all) while the owners of the private APs do not even know the coordinates. To detect these APs (mainly the APs in fixed infrastructure) and measure their coordinates becomes the preliminary requirement for use of the trilateration



approach. Skyhook's major contribution is to collect this information and their data are in confidence. So, the simple approach becomes hard to carry out. Furthermore, it is very unlikely to obtain better results than using another method. Hence the trilateration approach was not considered for this test.

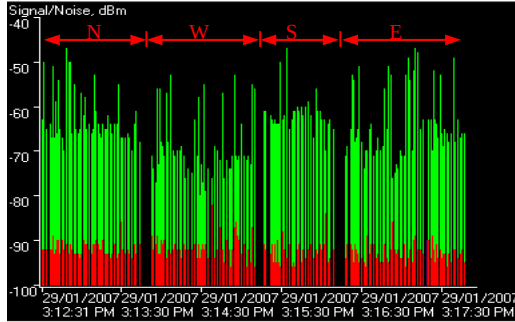


Fig. 6 The correlation between the received SS and the orientation of the MU

AP coordinates are not required in the fingerprint approach. Moreover all of the APs (both the APs as fixed infrastructure and the private users' APs) signal can be utilised for positioning as the private user's APs are unlikely to move far away inside the shop or apartment. Similar to the indoor environment, a direct correlation between the received SS and the orientation of the MU can be observed. Figure 6 gives an example. The data were collected at the south-west corner of the intersection of George Street and Martin Place. The AP is a Telstra CBD hot spot with the MAC of 0011209C1BC0. It implies that directional information may also be able to be used to improve the positioning accuracy and possibly estimate the MU's orientation. Figure 7 depicts the two

ways to generate the database: the traditional way and the way to utilize the directional information (for details refer to Li et al. (2007)).

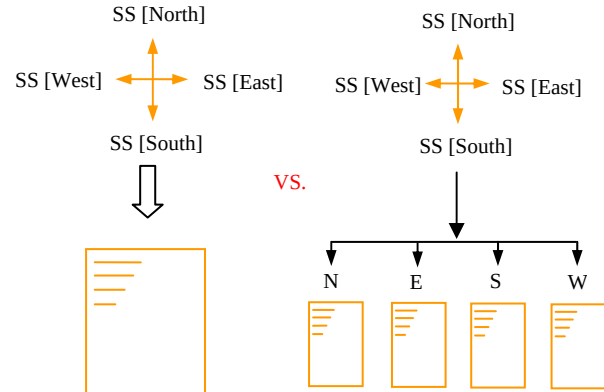


Fig. 7 Creation of traditional fingerprint database vs direction-based fingerprint database (four directions)

In total, 172 RPs and 23 test points (TPs) are evenly distributed in the test area (see Figure 8). At each RP, the data were collected as follows:

- Set the PDA, facing north.
- Open the MiniStumbler and commence data collection of RSS for around 60 seconds, log it into a file.
- Orientate the device to face east by rotating 90 degrees clockwise and collect data for around 60 seconds, and again log it into a file.

Repeat data collection procedure for the south and west orientations.



Fig. 8 The RPs and TPs in CBD area of Sydney (image from Google earth)

The data collected at 10 of the test points consists of directional information and the rest only have the data collected facing one direction. Hence there are effectively 53 TPs.

In this test, the simple deterministic method was used. The ‘Nearest Neighbour’ (NN) algorithm (Bahl and Padmanabhan, 2000; Li et al., 2005) was applied because of its simplicity and reasonable level of accuracy. The basic idea is to calculate the distance (in signal space) between the observed set of SS measurements  $[ss_1, ss_2, ss_3, \dots, ss_n]$  and the SS measurements recorded in the database  $[SS_1, SS_2, SS_3, \dots, SS_n]$ . The distance between these two vectors can be stated as

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

Manhattan ( $q = 1$ ) and Euclidean distance ( $q = 2$ ) are the most common distant measurements. The RP which can provide the smallest signal distance is the nearest neighbour. The estimate of the MU’s position is the position of the nearest neighbour.

In an indoor test, the test area is small, so the number of the APs is small and most of the time the MU can receive the signals from most of the APs, the NN works fine. However, in this outdoor test, with more than a thousand APs, we noticed that the NN could not always find the ‘true’ nearest neighbour. Figure 9 gives an example. The SSs detected at RP1, RP8 and TP1 are listed in the table. If the SS from a certain AP can not be detected, -100 dBm is nominally “recorded”. Obviously, RP1 is more likely the nearest neighbour than RP8. However, the calculated signal distance shows that RP8 is the nearest neighbour. So applying NN directly has a problem. To solve this problem, the concept of ‘candidates’ for nearest neighbour was introduced. Before NN is applied, the candidates are selected from all the RPs. The candidates are the RPs which can ‘hear’ the signal from similar APs to those that can also be heard at the specific TP. In the previous example, at TP1, AP1 to AP3 were detected; at RP1, AP1 to AP6 were detected; at RP8, AP1 and AP7 were detected. The same AP(s) which appeared at RP1 and TP1 are AP1 to AP3 while at RP8 and TP1 is AP1 only. If the similarity (the proportion of matching APs) is set to 1/3, RP1 is a candidate while RP8 is not considered. Using the candidate method has two advantages: one is that the ‘true’ nearest neighbour can be found; the other is the calculation is sped up. Since fingerprinting is a pattern matching procedure, pattern matching algorithms can be applied. Using candidates is just a simple attempt to find a reliable algorithm and more investigation is needed.

|     | AP1 | AP2  | AP3  | AP4  | AP5  | AP6  | AP7  |
|-----|-----|------|------|------|------|------|------|
| RP1 | -60 | -60  | -60  | -60  | -60  | -60  | -100 |
| RP8 | -90 | -100 | -100 | -100 | -100 | -100 | -85  |
| TP1 | -70 | -70  | -70  | -100 | -100 | -100 | -100 |

|                                                                  |   |                              |
|------------------------------------------------------------------|---|------------------------------|
| Signal distance (Manhattan)<br>TP1 to RP1: 150<br>TP1 to RP8: 95 | → | RP8 is the nearest neighbour |
|------------------------------------------------------------------|---|------------------------------|

Fig. 9 An example of finding the wrong nearest neighbour

## 5. Test Results and Analysis

The test results are analyzed and reported in this section.

### 5.1 Using GPS only for positioning

The test area has a typical urban setting and the number of visible satellites are limited by tall buildings, towers etc. GPS needs at least 3 satellites to calculate a position (2D) and this requirement is not met in most of the TPs. Figure 10 shows the number of visible satellites from all the TPs. Thus this indicates the situation if GPS was used to calculate position.

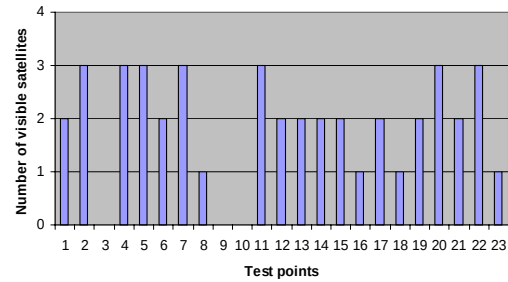


Fig. 10 Number of visible satellites from TPs

It is clearly noticeable that four or more satellites are not visible from any of the TPs. 3 satellites are visible from 7 TPs (about 30% of all the TPs) and even fewer satellites are visible from the rest of the TPs. No satellites were visible at 3 of the TPs. Obviously, at most of the TPs the number of visible satellites is not sufficient and thus a position could not be calculated. Furthermore, in the TPs where position can be calculated with 3 visible satellites (using a fixed altitude, for instance), the geometric distribution of the satellites is bad, i.e. the dilution of positioning (DOP) values are quite large (Kaplan, 1996). The consequence is that the error is quite high. Another disadvantage is that the time to calculate the first position fix is not short. Therefore, some other techniques of positioning are required to achieve satisfactory level of accuracy and speed.

## 5.2 Positioning based on the traditional database

As discussed in section 4, the proportion of matching APs is important to estimate the MU's position. If the proportion is too small, the problem described in section 4 may still exist; while if the proportion is too large, the 'true' nearest neighbour can be wrongly eliminated. Data were processed matching one fourth of APs, then one third and half of the APs. After choosing the candidates, the NN algorithm was applied. Figure 11 compares the results. The best result is found matching half of all the APs. These results are quite preliminary and further investigation is needed.

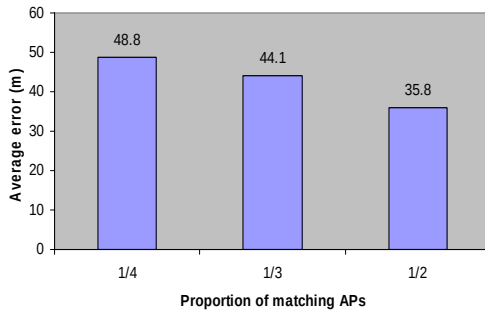


Fig. 11 Number of visible satellites from TPs

## 5.3 Using directional information

Table 1 summarises the results of using both traditional database and the directional database for each TP. It is clear that using the directional fingerprint database can provide more accurate estimates of position. The average error drops from 35.8m (traditional approach) to 23.5m (direction-based approach). The position estimates of all the test points except TP36 are better (or at least the same) using the directional SS information. However, estimating the MU's direction is difficult. In this test, only about 30% of the orientation estimates are correct (slight better than random). Further investigation is required.

Table 1 The positioning error using the directional fingerprint database vs traditional fingerprint database (units are metres)

|      | Directional database | Traditional database |      | Directional database | Traditional database |      | Directional database | Traditional database |
|------|----------------------|----------------------|------|----------------------|----------------------|------|----------------------|----------------------|
| TP1  | 14.7                 | 14.7                 | TP19 | 16.0                 | 16.0                 | TP37 | 10.0                 | 52.4                 |
| TP2  | 14.7                 | 14.7                 | TP20 | 25.7                 | 25.7                 | TP38 | 10.0                 | 10.0                 |
| TP3  | 14.7                 | 25.3                 | TP21 | 45.3                 | 97.7                 | TP39 | 10.0                 | 52.4                 |
| TP4  | 14.7                 | 51.2                 | TP22 | 16.9                 | 97.7                 | TP40 | 52.4                 | 52.4                 |
| TP5  | 25.7                 | 33.6                 | TP23 | 97.7                 | 97.7                 | TP41 | 3.4                  | 3.4                  |
| TP6  | 25.7                 | 33.6                 | TP24 | 45.3                 | 97.7                 | TP42 | 11.4                 | 11.4                 |
| TP7  | 25.7                 | 33.6                 | TP25 | 25.2                 | 25.2                 | TP43 | 30.8                 | 30.8                 |
| TP8  | 33.6                 | 33.6                 | TP26 | 25.2                 | 63.5                 | TP44 | 15.1                 | 15.1                 |
| TP9  | 29.6                 | 29.6                 | TP27 | 25.2                 | 25.2                 | TP45 | 60.9                 | 60.9                 |
| TP10 | 17.3                 | 17.3                 | TP28 | 25.2                 | 63.5                 | TP46 | 23.3                 | 50.7                 |
| TP11 | 29.6                 | 29.6                 | TP29 | 5.8                  | 76.4                 | TP47 | 5.2                  | 5.2                  |
| TP12 | 17.3                 | 17.3                 | TP30 | 5.8                  | 5.8                  | TP48 | 7.5                  | 7.5                  |
| TP13 | 27.2                 | 27.2                 | TP31 | 5.8                  | 5.8                  | TP49 | 39.0                 | 85.1                 |
| TP14 | 26.8                 | 27.2                 | TP32 | 5.8                  | 5.8                  | TP50 | 21.5                 | 35.7                 |
| TP15 | 26.8                 | 82.2                 | TP33 | 18.4                 | 18.4                 | TP51 | 32.1                 | 32.1                 |
| TP16 | 27.2                 | 27.2                 | TP34 | 18.4                 | 18.4                 | TP52 | 23.7                 | 46.9                 |
| TP17 | 16.0                 | 16.0                 | TP35 | 18.4                 | 18.4                 | TP53 | 10.9                 | 38.7                 |
| TP18 | 16.0                 | 16.0                 | TP36 | 50.7                 | 18.4                 | Mean | 23.5                 | 35.8                 |

## 6. Concluding Remarks

In this paper, the positioning technologies for outdoor positioning using Wi-Fi are discussed. An outdoor test is carried out in the Sydney CBD. In such an outdoor environment the Wi-Fi signal generally is much stronger than in indoor environments, but there are many pedestrians and cars. Hence, signal propagation is more complex. The test results show that fingerprinting works well for outdoor positioning, with errors in the tens of meters. Using the direction-based fingerprint approach can improve the performance. However, the orientation results do not show the same level of success as the indoor experiment (Li et al., 2007) and require further investigation.

As discussed through the previous sections, further works are needed for several issues, such as:

- How to decide the percentage of APs matching;
- New algorithm for outdoor positioning (pattern matching);
- The way to integrate Wi-Fi and GPS.

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