Use of directional information in Wireless LAN based indoor positioning

Author:
Dempster, Andrew; Li, Binghao; Kam, Jeffrey; Lui, Jonathon

Publication details:
Proceedings of IGNSS2007

Event details:
IGNSS2007
Sydney, Australia

Publication Date:
2007

DOI:
https://doi.org/10.26190/unsworks/704

Use of Directional Information in Wireless LAN Based Indoor Positioning

Binghao Li
School of Surveying and Spatial information Systems, UNSW, Australia
Phone 93854174 Fax 93137493 Email: binghao.li@unsw.edu.au
Jeffrey Kam
Project Engineer, Hutchison Telecommunications, Australia
Email: jkfkam@gmail.com
Jonathan Lui
Associate IT Specialist, IBM, Australia
Phone 0421085158 Email: jlui@au1.ibm.com
Andrew G. Dempster
School of Surveying and Spatial information Systems, UNSW, Australia
Phone 93856890 Fax 93137493 Email: a.dempster@unsw.edu.au

ABSTRACT

Wireless LAN (WLAN) positioning has received much attention recently and location fingerprinting has been widely accepted as an effect method. In WLAN positioning, the mobile user's (MU) orientation has a significant impact on the received signal strength from an access point. Many researchers have noticed this impact and considered it when the fingerprint database is generated. In this paper, directional information is used not only to increase the positioning accuracy, but also estimate the MU's orientation. A direction-based positioning fingerprinting technique is proposed. An experiment was carried out to verify the new approach. The results show the direction based approach can successfully localize the MU and estimate the MU's direction.

KEYWORDS: WLAN, positioning, fingerprinting, direction

1. INTRODUCTION

Positioning technology is one of the key issues to be addressed for location based services. GPS is the most popular but it has shortcomings; for example, it isn't suitable for indoor environments. Other specially developed systems, such as active badge, cricket, etc. (Hightower and Borriello, 2001), have found some application. But because of their inherent problems, they can not be widely used. The existing infrastructures which are not originally designed for positioning but for other purposes such as communication have attracted more attention. Wireless LAN (WLAN) is one of them.

WLAN is becoming increasingly popular today. The area covered by WLAN signals is increasing very fast. The CBD area of a city, the university campus, the public hospital are all now well covered. WLAN positioning technology has developed rapidly (http://www.skyhookwireless.com/; http://www.ekahau.com/). The WLAN positioning techniques based on signal strength (SS) can be classified to two categories: trilateration and fingerprinting. In the trilateration technique, the principle is similar to GPS positioning. If the coordinates of the base stations (at least three) are known and the ranges from the test point to the base stations are measured, the coordinate of the test point can be estimated. As WLAN was not designed for positioning, the range can not be provided directly, and the only useful measurement is the SS. Obviously, the radio signal propagation model which is used to convert the SS to range is a prerequisite. The trilateration method has been widely used (Bahl and Padmanabhan, 2000; Wang *et al.*, 2003, Li *et al.*, 2005b). However, this technique suffers from poor accuracy. The major problem is the difficulty in producing a reliable signal propagation model. Indoor radio signal propagation is very complicated, because of signal attenuation due to distance, penetration losses through walls and floors, the effect of multipath propagation and interference (Dobkin, 2002). It is very difficult to develop a model of distance measurement based on SS. Unlike trilateration, the fingerprint technique accounts for the attenuation due to obstructions and multipath interference and will thus tend to provide more accuracy in positioning (Li *et al.*, 2006).

The fingerprinting approach has been accepted as an effective method for WLAN 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). Since the variation of the SS measured at each point is large, in order to achieve more accurate results, the probabilistic approach (Youssef *et al.*, 2003; Li *et al.*, 2006) has also been developed. However, the probabilistic approach requires more time to generate the SS distribution. Furthermore, this increases the database size and the computational burden. In this paper, for simplicity, only the deterministic method is discussed.

Many researchers have noticed the impact of the mobile user's (MU) orientation. Orientation here denotes the direction the receiver's antenna is pointing. When the user changes orientation, the received SS can change significantly (Ladd *et al.*, 2002; Li *et al.*, 2005a). Xiang et al. (2004) treat different orientations at one location as different logical positions in a positioning system. Obviously, the direction information is helpful to estimate the MU's location. Is it also possible to utilize this information to estimate the MU's direction? How good will the direction estimate could be? To answer these questions, further investigation was carried out and is reported here. This paper introduces a direction based technique for WLAN positioning. An experiment to verify the proposed approach is discussed and the results are analysed.

2. THE FINGERPRINTING TECHNIQUE

Location fingerprinting consists of two stages: 'training' and 'positioning'.

In the training phase, a fingerprint database is created. To generate the database, reference points (RP) must be carefully selected. Firstly, the whole area of interest must be covered. Secondly the RPs should be evenly spread in the area and the RPs' position can be easily determined. Lastly, the number of the RPs should balance the consideration of the accuracy and the labour burden to create the database (Li et al., 2005a). Locating a MU at one RP location, the SSs of all the access points (AP) are measured. The vector of SS for that RP, i.e. the "fingerprint", is determined by these measurements and the vector is recorded in the database. This process is repeated until all RPs are visited.

In the positioning phase the MU measures the SS at a place where it requires its position. An appropriate algorithm is used to compare the measurements with the data in the database. The outcome is the likeliest location of the MU. The whole process is illustrated in Figure. 1.

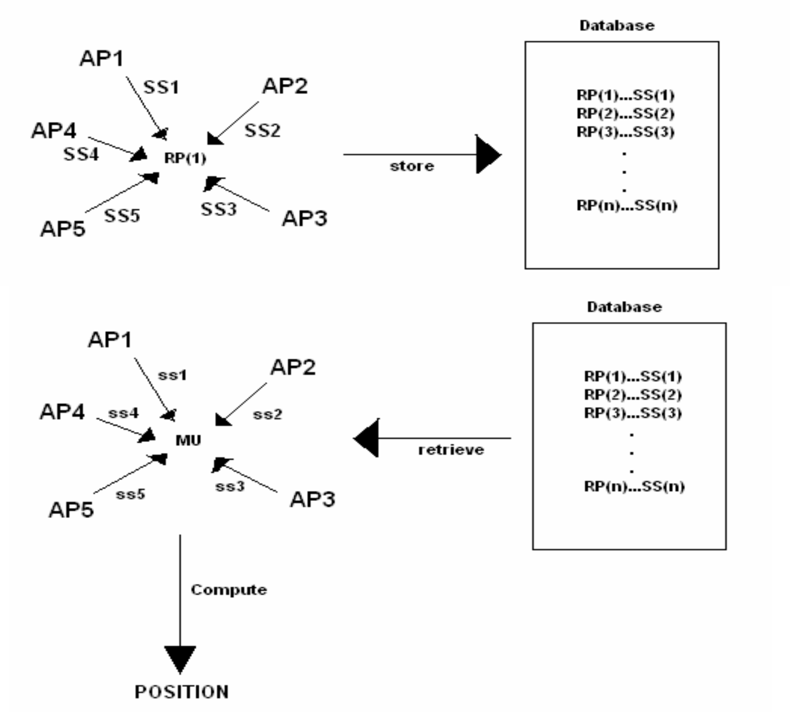


Figure 1. Training and positioning phases of fingerprinting technology

Several different algorithms could be used to locate a user. The most basic chosen for this research is the 'nearest neighbour' (NN) algorithm (Bahl and Padmanabhan, 2000) due to its simplicity and the reasonable accuracy it provides. For NN, the distance (in signal space) between the observed set of SS measurements [ss_1, ss_2, ss_3…ss_n] and the SS measurements in the database [SS_1, SS_2, SS_3…SS_n] is computed. The generalized distance between the two vectors is

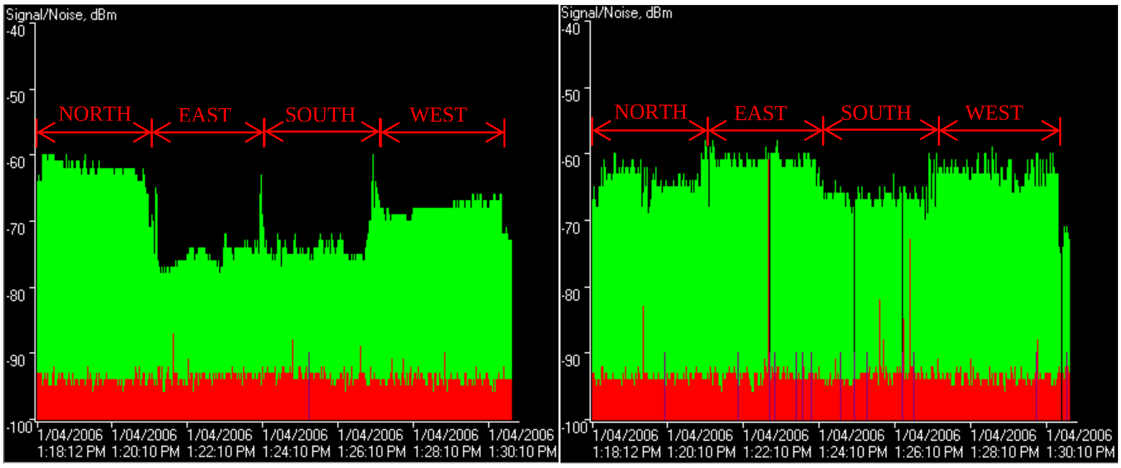
$$L_q = \left(\sum_{i=1}^{n} \left| s_i - S_i \right|^q \right)^{\frac{1}{q}}$$

The most common distance is Manhattan and Euclidean distance, L_1 and L_2 respectively. There are other algorithms that can be used, such as k-NN, k-weighted NN, smallest polygon and other probabilistic approaches (Li *et al*, 2005a; Pandya *et al.*, 2003; Li *et al.*, 2005c), but due to time constraints and the fact some are either too complicated or do not necessarily produce better results, they are not used in this paper. The improvement due to the direction-based approach is expected to apply to all positioning algorithms.

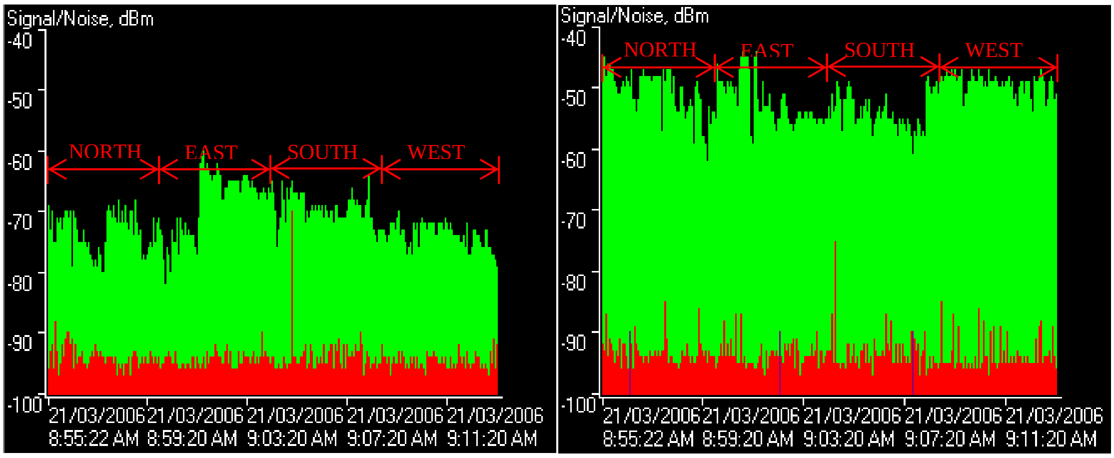
3. METHODOLOGY OF THE DIRECTION BASED APPROACH

To develop the direction-based approach, SS data were collected at some points of interest in an office environment. As expected, one can see clearly a direct correlation between the received SS and the orientation of the MU. Figure 2 gives two examples of the test. Each example shows the SS received from two different APs respectively. The example data were collected at two different points in similar environments at different times. The turning from one direction to the next was timed "manually", i.e. by a person observing a time piece, so exact boundaries do not exist between directions. It can be seen that the SS varied significantly depending on the orientation of the user in Figure 2 (a). The difference can be up to 15dB. However, in Figure 2 (b), the correlation is not that significant. It should be noticed that the data of the first example was logged in a weekend (Saturday, 1:18PM-1:30PM), while that of the second example were collected in a weekday (Tuesday 8:55AM-9:11AM). During the weekend, there was not much human activity in the area while on the weekday a lot of human movement was noted. This both makes the directions less obviously separated, but also increases the SS variation when direction was held constant. Obviously, human activity impacts the signal propagation seriously.

Nevertheless, there was a direct correlation between the received SS and the orientation of the MU observed at most of the points where data was collected. This indicates that it is feasible to develop a fingerprint database comprised not only of positional information but directional information as well. This also implies that positioning would be possible on a direction basis rather than just on location.



a)



b)

Figure 2. The correlation between the received SS and the orientation of the MU. a) Significant correlation (data collected during a weekend), b) Less significant correlation (data collected on a week day)

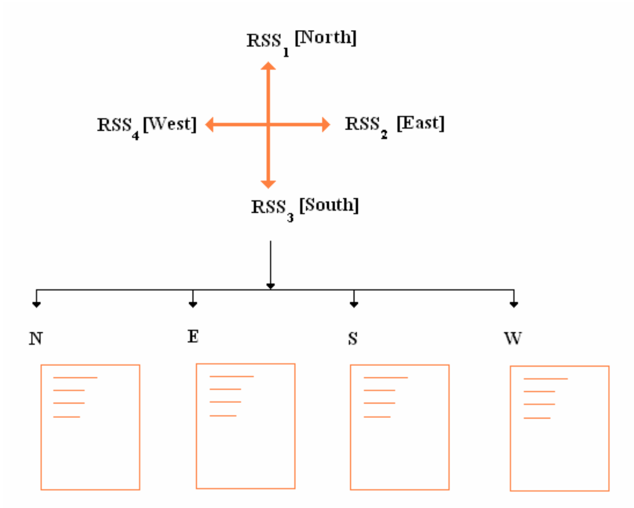


Figure 3. Creation of direction based fingerprint database (four-direction)

The traditional approach (refer to Figure 1) consists of taking SS measurements in four directions at each reference point and then consolidating these measurements into a single representative average for that reference point (Li *et al.*, 2005a). This results in the formation of only one database, which cannot be used to determine user orientation. The new approach aims to retain the implied directional information contained by each SS measurement. To achieve this, instead of creating a fingerprint that consists of only a single averaged SS measurement, the four directional readings per RP will be maintained as separate readings to result in a fingerprint consisting of four individual SS measurements. Each of these four measurements will relate to the SS at a RP when orientated in four orthogonal directions illustrated in Figure 3 and will result in the formation of four separate databases relating to the directions of North, East, South and West. Ultimately this approach will need four times as much data to be stored in these databases, but could introduce new capabilities for directional analysis and possibly increase the accuracy for positioning. The variance in the directional fingerprints is lower than that in the traditional approach indicates that the direction-based approach can perform better than the traditional approach.

4. EXPERIMENT

4.1 Test bed and Equipments

The experimental test bed was located on the 4th floor of Electrical Engineering Building at the University of New South Wales. The layout of the test bed is indicated in Figure 4. The test bed has an area of 36m by 17.5m and contains various rooms including a kitchen, a laboratory, office rooms, the main foyer, a toilet as well as a long corridor. As the absolute coordinates (say latitude, longitude) or a coordinate system relative to the whole floor do not mean much in the indoor environment, the local Cartesian coordinate system is applied independently for each small test area, that is each room will have its own naming format, e.g. corridor (3,1) or SNAP (2,0). Five WX-1590 SparkLAN 11 Mbps WLAN wireless multi-mode APs (http://www.sparklan.com) were used. These are shown as dots in the test bed map. The crosses are RPs while the circles are the test points. There are in total 88 RPs, and 20 test points.

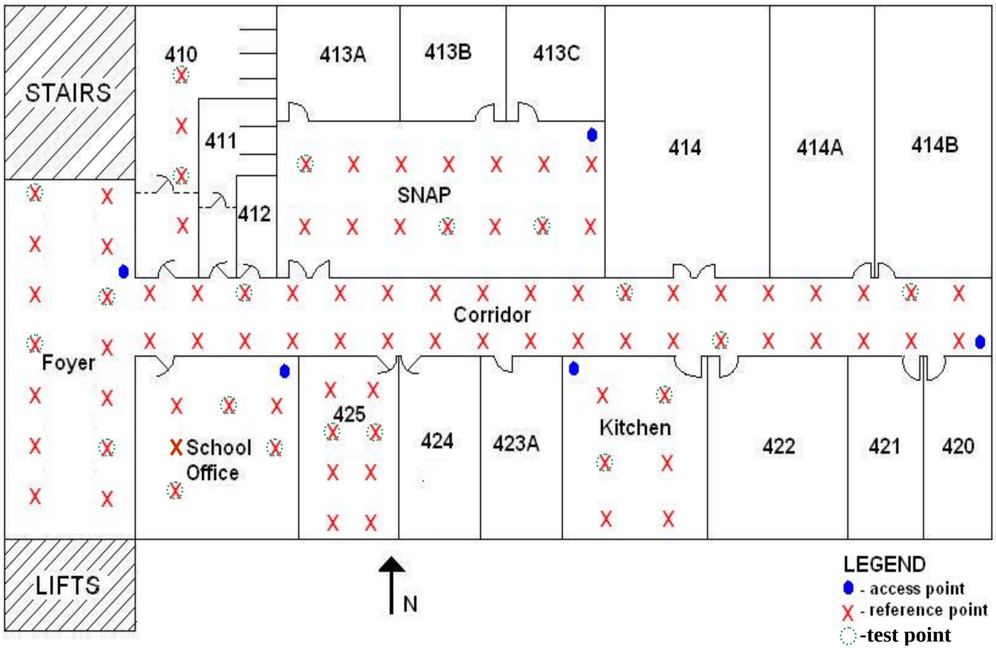


Figure 4. Experimental test bed

Two devices are used to perform data collection. The first is a Compaq iPAQ 3970 personal digital assistant (PDA) running Pocket PC 2002 operating system (http://www.compaq.com). A wireless card is also used which is the Lucent Technology Wi-Fi Orinoco Wireless Golden Card (http://www.orinocowireless.com). The other equipment used is an Acer Travelmate 291L laptop computer running Windows XP Professional Service Pack 1. The laptop uses Intel's Pentium M processor technology, which, in conjunction with the Intel 915 Express Chipset Family and the Intel PRO/Wireless Network connection (2200BG on this laptop), forms the Centrino platform. With the Intel PRO/Wireless connection technology, a wireless adaptor is integrated inside the chipset. Figure 5 displays the equipments used.

Figure 5. Equipments used in the experiment

The software used to collect SS data is NetStumbler and a trimmed down version for the PDA, MiniStumbler (http://www.netstumbler.com/). Screenshots of the user interface for these two programs are shown in Figure 6. NetStumbler and MiniStumbler are tools that facilitate the detection of WLANs. Both programs operate by sending requests to any listening AP in the vicinity. In return, all APs within range send back a packet to the program with its own service set identifier. It should be noted that these programs do not offer connection to the networks but rather detection only.

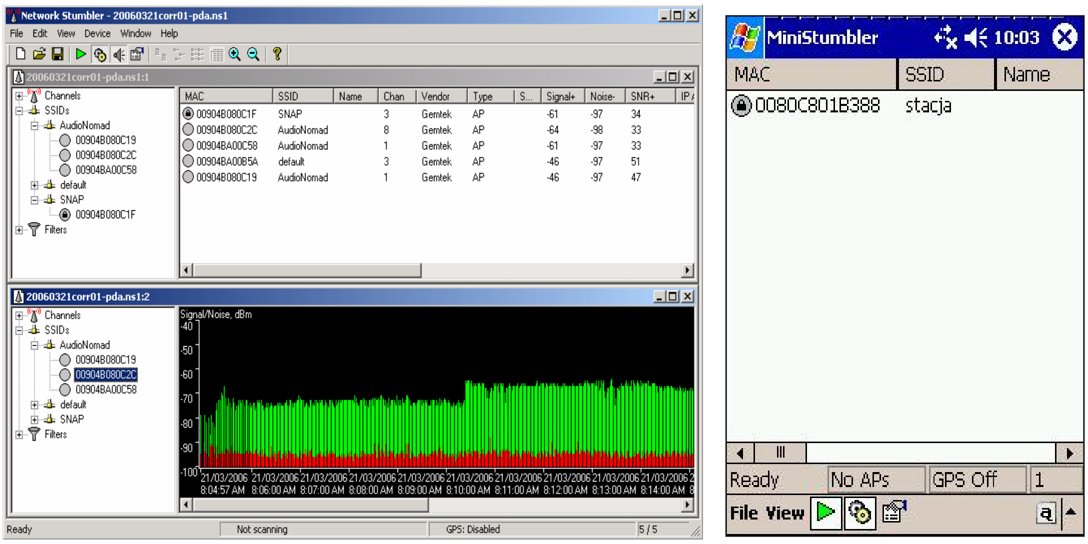


Figure 6. The software used to collect data, NetStumbler (for PC) and Ministubler (for PDA)

4.2 Data collection

First of all, the fingerprint databases should be created. In order to apply the directional information, four extensive fingerprint databases each comprised of 88 vector entries should be generated. The four databases represent the directions North, East, South and West respectively. Within each database, a vector entry ('fingerprint') will consist of 5 measurements representing the received SS measured from each AP (5 in total) at that RP. This database will be used as the basis for the positioning phase.

The method reference data collection is as follows:

a) At a predetermined RP position the SS capturing device (laptop/PDA) facing North
b) Open NetStumbler/MiniStumbler and commence data collection of received signal strength for around 180 seconds, record the start and end time.
c) Orientate the device to face east by rotating 90 degrees clockwise and collect data for around 180 seconds, record the start and end time
d) Repeat data collection procedure for south and west orientation
e) Save data, advance to next point and repeat from step a

Once the training phase is complete, the collected data is stored to form the four directional fingerprint databases. For comparison, a fingerprint database which does not consider the orientation is also generated at the same time (using all the data collected in four directions). The content of the database is shown in Figure 7.

NORTH direction

location	device	access point	no. of readings	mean signal strength (dbM)	standard deviation
corridor (0,0)	laptop	corridor	210	-61.43	2.31
corridor (0,0)	laptop	foyer	210	-47.3	4.47
corridor (0,0)	laptop	kitchen	210	-54.8	3.14
corridor (0,0)	laptop	school office	210	-43.57	4.96
corridor (0,0)	laptop	SNAP	210	-54.35	2.41
corridor (0,1)	pda	corridor	164	-73.77	1.28
corridor (0,1)	pda	foyer	140	-58.49	2.14
corridor (0,1)	pda	kitchen	68	-74.89	2.75
corridor (0,1)	pda	school office	159	-50.25	2.76
corridor (0,1)	pda	SNAP	117	-67.92	1.79

Figure 7. Contents of the database

After the fingerprint database is created, the data from the test points are collected. The method of the test points' data collection is similar to that of the RPs. However, it would be unrealistic to let the MU who wants to know its position to remain stationary for several seconds facing North, and so on for East, South and West in order to determine location and position. Hence, the SS at each test point is logged over a small period of time (5 seconds) and only faces one direction (say North). The average of the SS is used to search/match the fingerprint database.

4.3 Test results and analysis

To simplify the positioning phase the simple algorithm NN is used. The traditional approach and the direction-based approach are applied independently and the results are compared in Table 1. Given that the test points are co-located with the reference points, this is less a "positioning" test and more a test of how well matched the databases are to measurements made at the reference points. Since the direction-based approach utilizes the direction information, not only the MU's position, but also the MU's orientation can be estimated. That means the direction based approach should have the advantage of giving more useful information to the user.

Table 1 gives the details of the test results utilizing both the traditional approach and the direction-based approach. Column 1 and 2 list the true coordinates and direction of the test points. Column 3 consists of the estimate based on traditional approach, while column 4 and 5 give the estimate (both coordinates and direction) applying the new approach. It is clear that the direction-based approach performs much better than the traditional approach. The advantages of the new approach can be shown in two aspects. First, the percentage of correct estimates of the MU's position is higher: 95% of the test points have been correctly positioned using the directional approach while the correct rate is only 55% using the traditional approach. The other is the direction-based approach can also provide the orientation of the MU, here with the correct rate of 85%. If the position is localised correctly, there is a 90% accuracy rate of correctly determining the direction of the user (This can be expressed using Bayes formula).

Evaluating the error cases observed in both approaches, it can be seen the only error in direction-based approach is SNAP(2,0) which is 1 unit of the grid (1.8m) away from the true coordinates. However, in the traditional approach, the location error is up to 3 units of the grid (5.4m). This behaviour occurs due to the fact that the traditional database will appear to have an exaggerated signal distance error if compared with a sample point which contains data only in one direction. This is because the traditional fingerprint has been generated taking into account error observed from each direction, North, East, South and West. However when comparing this to a sample fingerprint, whose mean and variation are better calculated in just one direction, the calculations cannot accommodate this difference and could thus position a user further from the true location.

Actual Coordinate	Actual Direction	Estimated Coordinate (Traditional approach)	Estimated Coordinate (Direction based approach)	Estimated Direction (Direction based approach)
Foyer(0,3)	**North**	***Corridor(0,0)***	Foyer(0,3)	North
Foyer(0,6)	**East**	Foyer(0,6)	Foyer(0,6)	East
Foyer(1,1)	**West**	***Foyer(1,2)***	Foyer(1,1)	West
Foyer(1,4)	**West**	Foyer(1,4)	Foyer(1,4)	West
SNAP(0,1)	**South**	***SNAP(3,1)***	SNAP(0,1)	South
SNAP(3,0)	**East**	SNAP(3,0)	***SNAP(2,0)***	***West***
SNAP(5,0)	**North**	***SNAP(6,0)***	SNAP(5,0)	North
AD(0,2)	**West**	AD(0,2)	AD(0,2)	West
AD(1,2)	**East**	AD(1,2)	AD(1,2)	East
Corridor (16,1)	**East**	***Corridor (17,1)***	Corridor (16,1)	East
Corridor (10,1)	**West**	Corridor (10,1)	Corridor (10,1)	West
Corridor (2,1)	**South**	Corridor (2,1)	Corridor (2,1)	***North***
Corridor (12,0)	**North**	Corridor (12,0)	Corridor (12,0)	North
Toilet (0,3)	**South**	Toilet (0,3)	Toilet (0,3)	***East***
Toilet (0,1)	**East**	Toilet (0,1)	Toilet (0,1)	East
School Office (0,0)	**West**	***Corridor(0,1)***	School Office (0,0)	West
School Office (1,2)	**North**	***School Office (2,1)***	School Office (1,2)	North
School Office (2,1)	**East**	***School Office (1,2)***	School Office (2,1)	East
Kitchen (0,1)	**South**	***Kitchen (0,2)***	Kitchen (0,1)	South
Kitchen (1,2)	**West**	Kitchen (1,2)	Kitchen (1,2)	West

Table 1. The test results of traditional approach and the direction based approach. Red italics indicate an incorrect estimate

5. CONCLUSIONS

In this paper a direction-based WLAN positioning system is presented. Although based on the traditional fingerprinting technique the direction-based WLAN positioning system differs in that it retains the fingerprint database in direction-specific form. The direction-based fingerprinting technique was tested and its performance was then compared against the performance of the traditional approach. The results indicate that a direction-based approach can perform better than the traditional approach. Not only can position be estimated more accurately, but the MU's orientation can also be provided. These results also demonstrate that this technique of positioning is robust and performs consistently.

In this experiment, the overlap of the test points with the RPs makes the test lost its generality of 'positioning'. Also, the assumption that the MU faces only one of four directions (North, East, South and West) limits the assessment of the new approach. The local Cartesian coordinate system brings some convenience to the WLAN positioning system, but some disadvantages also exist, such as the distance error can not be computed easily. The best coordinate frame to use needs further investigation. Furthermore, the NN algorithm is successful utilized in this experiment. It is apparent however, that this deterministic technique could be improved on. The probabilistic technique should be investigated based on the directional information. It can be expected possibly to outperform the deterministic technique because the lower variance in the directional fingerprints comparing to the traditional fingerprints. The solutions for the human activity problem are also required. 'Sniffers' be installed in the network or different models be used at different time are the possible solutions. There are also several critical issues to be investigated in future work. For example the effects of long term variations of the SS are not clear. If there is a significant long term SS change (due to changes in the APs or the electromagnetic environment), detecting such change automatically and overcoming the impact are the questions that still need to be answered.

REFERENCES

Bahl, P, Padmanabhan, VN (2000) RADAR: An in-building RF-based user location and tracking system, *IEEE Infocom 2000*, Tel Aviv, Israel, 26-30 March, vol. 2, pp. 775-784.

Dobkin, D (2002) Indoor propagation issues for wireless LANs, *RF Design*, Sep 1, pp. 40-46.

Hightower, J, Borriello, G (2001) Location systems for ubiquitous computing, *IEEE Computer*, 2001, 34, (8), pp. 57–66

Ladd, AM, Bekris, KE, Rudys, A, Marceau, G, Kavraki, LE, Dan, S (2002) Robotics-based location sensing using wireless Ethernet. *Eighth ACM Int. Conf. on Mobile Computing & Networking (MOBICOM)*, Atlanta, Georgia, USA, 23-28 September, pp. 227-238.

Li, B, Wang, Y, Lee, HK, Dempster, AG, Rizos, C (2005a) Method for Yielding a Database of Location Fingerprints in WLAN, *Communications, IEE Proceedings*, Vol. 152, Issue 5, October 2005, pp. 580-586.

Li, B, Dempster, AG, Barnes, J, Rizos, C, Li, D (2005b) Probabilistic algorithm to support the fingerprinting method for CDMA location, *Int. Symp. on GPS/GNSS*, Hong Kong, 8-10 December, paper 9C-05, CD-ROM procs.

Li, B, Dempster, AG, Rizos, C, Barnes, J (2005c) Hybrid method for localization using WLAN, *Spatial Sciences Conference*, Melbourne, Australia, 12-16 September, pp. 341-350, CD-ROM procs.

Li, B, Salter, J, Dempster AG, Rizos, C (2006) Indoor Positioning Techniques Based on Wireless LAN, *First IEEE International Conference on Wireless Broadband and Ultra Wideband Communications*, Sydney, Australia, 13-16 March, paper 113.

Pandya, D, Jain, R, Lupu, E, (2003) Indoor location estimation using multiple wireless technologies, *14th IEEE Int. Symp. on Personal, Indoor, & Mobile Radio Communications (PIMRC)*, Beijing, China, 7-10 September, vol. 3, pp. 2208-2212.

Xiang, Z, Song, S, Chen, J, Wang, H, Huang, J, Gao, X (2004) A wireless LAN-based indoor positioning technology, *IBM J. Res & Dev*, Vol 48 no. 5/6, September/November 2004

Youssef, M, Agrawala, A, Shankar, AU (2003) WLAN location determination via clustering and probability distributions, *IEEE Int. Conf. on Pervasive Computing & Communications (PerCom) 2003*, Fort Worth, Texas, USA, 23-26 March, pp.143-150.

Wang, Y, Jia, X, Lee, HK and Li, GY (2003) An indoor wireless positioning system based on WLAN infrastructure, *6th Int. Symp. on Satellite Navigation Technology Including Mobile Positioning & Location Services*, Melbourne, Australia, 22-25 July, CD-ROM proc., paper 54.