In-door Wireless Positioning Technology

Shiann-Tsong Sheu[1], Meng-Shin Li[2], Yi-Hsueh Tsai[3] and Po-Min Lin[4]

[1,2,4] *Dept. Communication Engineering, National Central University, Taoyuan , Taiwan*

[3] *Dept. Emerging Smart Technology Institute, Institute for Information Industry, Taipei, Taiwan*

[1] *stsheu@ce.ncu.edu.tw,* [2] *975203034@cc.ncu.edu.tw,* [3] *lucas@iii.org.tw,* [4] *985203050@cc.ncu.edu.tw*

Abstract**—With the flourishing development and improvement of technology, the satellite-based location technique has become the well-known navigation system, the accuracy of satellite-based positioning result significantly degrades when the receiver is located in the non-line-of-sight urban area or inside the building. To overcome the problem, the widely deployed IEEE 802.11 wireless local area network (WLAN) is naturally considered as an alternative positioning solution. Unfortunately, the WLAN-based positioning technologies usually cannot derive accurate result. As a solution, this paper proposes a long-term indoor positioning solution to obtain more precise location for the applications such as invaluable equipment property monitoring, fixed wireless sensing and so on. Based on a large amount of measurement results, the proposed methodology is able to solve the issue of time-variant signal strengths. Simulation results show that the proposed method is able to control the accuracy of tens of centimeters.**

Keywords* —*Fingerprint, Indoor Positioning, Location Estimation, LoS, NLoS, Signal Stregth, Signature, Wi-Fi

I. INTRODUCTION

The fluent development of location based service (LBS) requires the accurate location technique which is relying on satellites to acquire the position and the mobile communication to access the geographic information system (GIS). These services could be applied to the applications of material, aviation and navigation. However, GPS is unable to work well in some areas, such as indoor or basement, because of line-of-sight (LoS) limitation for positioning.

In the non-line-of-Sight (NLoS) environment, positioning techniques with cellular networks [1]–[3], wireless network [4]–[7], infrared rays [8], ultrasonic [9], RFID [8], and Bluetooth [10][11] play the major role to improve the indoor location estimation, especially in the dense urban area. The position estimation methods of wireless location techniques [12][13] are classified into four categories : Received Signal Strength (RSS), Time of Arrival (ToA), Time Differences of Arrival (TDoA) and Angle of Arrival (AoA). The latest three of them (i.e., ToA, TDoA and AoA methods) can be easily jammed by movable obstacles, and lead to the inaccurate location. In paper [14], a location-awareness system named RADAR is designed for indoor positioning estimation. This method uses a WiFi-equipped handset device to collect the received signal strength and then stores the information into the database of the location server. Afterward, it estimates the position of handset device at the location server by matching the pattern of the means of signal strengths.

CHINACOM 2010, August 25-27, Beijing, China

DOI 10.4108/chinacom.2010.117

According to existing WLAN location technique [15]–[17], many environmental factors, such as temperature, pressure, humidity, interference, and thermal noise, might significantly degrade the accuracy of the estimated location. In order words, if the access point (AP) is continuously scanned by a device at a fixed point, the measured received signal strength (RSS) indicators would vary with time. As a result, the indoor real-time location estimation is always inaccurate due to the time-variant phenomena. Previous studies of WLAN location techniques focused on how fast the location can be acquired, thus, these methods only used a small amount of the signal strength measurements received within a short period of time to estimate the location. Until now, it is still difficult to make great progress to refer to time-invariant measurements even though researchers already paid much more attentions on improving the accuracy of location.

In our opinions, the indoor position estimating systems can be classified into two types: real-time positioning system and non-real-time positioning system. The real-time system locates and tracks user inside the building, and then the non-real-time system focuses on the accuracy of the estimated location rather than how fast the location is acquired. In other words, the non-real-time system is allowed to use a longer period of time to estimate the coordinates of user. For instance, such system can be used for monitoring precious equipments in the cooperation or fixed wireless sensors. This paper aims to propose the solution for non-real-time positioning system.

To solve the issue caused from time-variant signal strengths, RSS measurements should be collected for a longer period of time in order to compensate the instability of the measurements. The experimental results show that the diagrams of the probability distribution functions (PDF) are approximate to normal distribution. By further examining the PDF characteristics of measurements, the environment could be identified as either LoS or NLoS environment. Despite of the LoS or NLoS environment, when the probability distribution of the collected measurements shows the characteristic of normal distribution, device could stop collecting information anymore.

The organization of this paper is described as follows. In section II, we survey some prior arts regarding to non-real-time wireless positioning technology. In section III, analysis of the experiments for both NLoS and LoS environments is provided, and an algorithm for identifying the environment type (i.e. NLoS or LoS) is given. The discussions of enhancing location estimation and pattern matching are described in Section IV. Section V addresses and analyzes the empirical outcomes. Finally, conclusions and suggestions for the future study are given in Section VI.

II. PRIOR ARTS

This section will discuss the prior arts regarding to outdoor locating technique (such as GPS) and indoor positioning technique (such as RADAR).

A. Global Position System - Trilateration

The Global Positioning System (GPS) is a space-based global navigation satellite system that provides reliable location and time information at anytime and anywhere where there is an unobstructed line of sight to GPS satellite. It is maintained by the United States department of defense (DOD) and is freely accessible by anyone with a GPS receiver. In recent years, it is the most important and popular navigation system in the world.

GPS receiver determines its position by precisely timing the signals sent from the satellites. Each satellite continually transmits messages which include the time stamp of transmitting the message, precise orbital information, and the general system health and rough orbits of all GPS satellites. The receiver utilizes these received messages to determine the transmission time of each message and computes the distance to each satellite. These distances along with the satellites' locations are used with the possible aid of trilateration (depending on the used algorithm) to compute the position of the receiver.

Before the receiver is located, mobile device needs to acquire the signals from at least three satellites. GPS adopts the triangulate concept, where the satellite is as the center of circle, and the distance between user and satellite is as a radius of circle. Three circles will have a cross point, which is the result of the estimated coordinates of mobile device. While using GPS to acquire indoor location, it suffers from several drawbacks: (a) the mobile device may not receive the signals from satellites in indoor space; (b) the signals from satellites will be attenuated by blocks and degenerated by multi-path effect. It is barely accurate when GPS is used in indoor environment. Hence, indoor location technique tends to use the alternatives signal measurements, such as Wi-Fi technology.

B. RADAR – Fingerprinting

Fingerprint method is used to create the location-sensitive radio map by measuring wireless signal strength in a certain area. When the fingerprint is created, a specific signature of the measurement is used to identify user's location. The authors of paper [14] proposed the fingerprint method RADAR system provide the in-building location and tracking system. There are two phases in RADAR, off-line phase and on-line phase.

During off-line phase, a radio map is created by measuring wireless signal strength of a mobile device in a certain area, and then this information is stored into the database of the location server. During on-line phase, when user desires to get his location in the room, the measured signal strength at its place is delivered to the location server. Then, the location server searches the received signal strength from the database of the server and then calculates the location. Finally, the location server replies the estimated result back to the user.

Paper [18] proposed the floor attenuation factor (FAF) propagation model. The RADAR system also showed that the wall attenuation factor (WAF) model can solve the effect of obstacles between the transmitter and the receiver.

Among methods of location estimation, the location server maintains the relationship between the signal strength and the position of user. A user delivers the measured signal strength to the location server for requesting the estimated position. Since the signal strength is time-variant, the positioning results acquired during the on-line phase will be different from the one acquired during off-line phase. The accuracy of location will be degenerated so the results may not be suited for some applications.

III. IDENTIFICATION AND ANALYSIS WITH NLOS AND LOS

In this section, the environmental analysis for both NLoS and LoS environments are shown, and a method to identify the type of environment is proposed.

A. Experimental Testbed

Our experimental environment is located at the laboratory of department communication engineering, national central university. It is a real environment regarded as a normal indoor space where the factors (such as noise, temperature and humid variation and moving obstacles) will cause attenuation and reflection of the Wi-Fi signal. During the experiment, the same method is adopted to evaluate the distributions of RF signal strengths for both LoS and NLoS environments over a long period of time, as shown in Fig. 1.

In order to measure the WiFi signals sent from AP, we use the mobile smart phone device as the test device. The mobile device is response to collect the information including SSID, BSSID, signal strength, frequency and time stamp under the sampling rate 1 sample/s.

The location server is a laptop computer installed with Microsoft Windows Server 2003 and MySQL Database for storing signal strengths. The mobile smart phone installed with Android operating system [19] is running Java-based management program for reporting measured Wi-Fi signal and acquiring estimated location. The mobile smart phone is placed on a designated position over a long period of time, and is used to measure the signal strengths under both LoS and NLoS environments. By using the Software development kit, the signal strength of Wi-Fi can be easily extracted and calculated. It can tell different sources of the signals in a location with multiple APs, and record the distinct signal strength individually. As mentioned in the previously paragraph, in order to know the relationship between the position and the signal strength, we have to pre-collect a plenty of measured signal strength at every designated

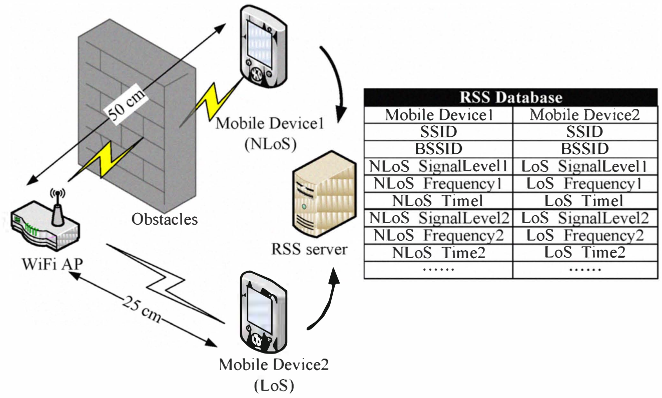


Fig. 1 NLoS and LoS experimental environments

location. By analyzing the long-term signature of the stored signal strengths in database, the variations of those probability distributions can be studied and investigated. The experimental results for both LoS and NLoS environments show that the signal strength is changed apparently if the signal is attenuated by obstacles.

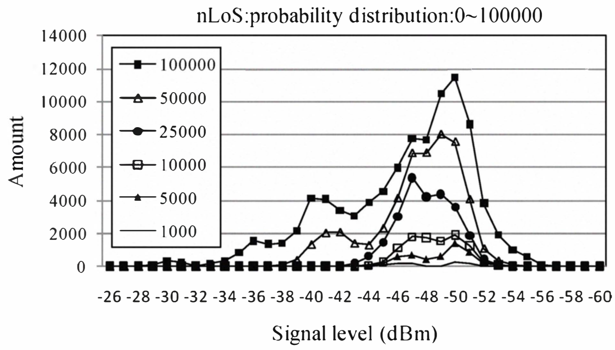
B. Identification with NLoS and LoS and Post-processing Signal Strength Data

For both NLoS and LoS environments, we gather statistics of signal strengths from the database in the location server and analyze the PDF of the signal strength measurements according to paper [20].

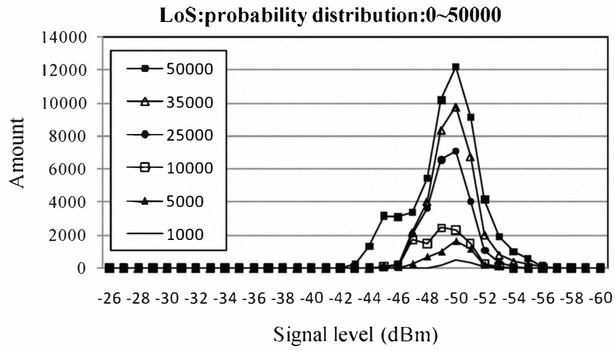
Under NLoS situation, over one hundred thousand values of the signal strengths are collected by a fixed mobile smart phone, and the corresponding probability density functions of the signal strength measurements are shown in Fig. 2(a). Since the signal strength measurements are time-variant and also affected by environmental factors, it is difficult to figure out the signature from its probability distribution diagram. If the location of the device is derived by using a small amount of measurements, the accuracy of the positioning result should be unacceptable, especially there is obstacle located between the AP and the mobile device. On the other hand, the probability distribution of a large amount of signal strength measurements is actually similar to a normal distribution and this outcome shows that the accurate location technique could be acquired. In other words, if the measurements are accumulated over a long period of time, the probability distribution diagram of the signal strength measurements will eventually converge to normal distribution with a specific signature and become time-invariant.

Fig. 2(b) shows the PDF of signal strengths derived in LoS environment. Similarly, we also found that the more measurements we accumulated, the degree of time-invariant will become higher. It is evident that the PDF of signal strengths in LoS environment looks much like a normal distribution even though the number of samples is small. In fact, as the device collects fifty thousand measurements, the PDF of collected measurements is already very similar to the normal distribution.

The characteristic of observed statistics shows that the accuracy of user location in the indoor space would be



(a) PDF derived from NLoS case



(b) PDF derived from LoS case

Fig. 2 PDF of signal strengths

TABLE I Statistics of Signal Strengths in NLoS environment (in dBm)

Amount	1000	5000	10000	25000	50000	100000
Mean	-48.34	-48.90	-48.51	-47.99	-47.31	-46.37
Variance	4.921	4.327	3.549	3.705	9.670	22.37
Mode	-50	-50	-50	-47	-49	-50
Max	-43	-38	-37	-37	-36	-28
Min	-53	-54	-54	-54	-55	-59
Mid	-48	-46	-45.5	-45.5	-45.5	-43.5
Mids	-48.25	-47	-45.25	-45.75	-45.5	-44.5

TABLE II Statistics of Signal Strengths in LoS environment (in dBm)

Amount	1000	5000	10000	25000	35000	50000
Mean	-50.23	-49.70	-49.05	-49.45	-49.76	-49.31
Variance	0.73	1.85	2.31	1.96	2.41	5.41
Mode	-50	-50	-49	-50	-50	-50
Max	-48	-45	-45	-45	-45	-42
Min	-55	-55	-55	-55	-57	-59
Mid	-51.5	-50	-50	-50	-51	-50.5
Mids	-51.5	-49.25	-49.25	-49.75	-50.75	-50.25

significantly improved by simply referring to a lot of signal strength measurements, regardless of LoS or NLoS environment.

The analyses of observed signal strengths under NLoS case and LoS case are shown in Tables I and II. There are seven different characteristics among collected signal strengths. It shows the values and ranges of Mean and Variance are somehow proportional to the number of measurements. In general, the maximal signal strength (Max) and minimal signal strength (Min) indicate the best signal strength without any interference and the worst signal strength with lots of interference respectively. The mode value (Mode) is the most number of the signal strength appearing in the samples.

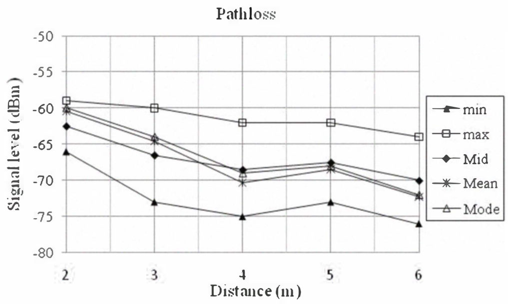


Fig. 3 Comparison of path loss for five characteristics

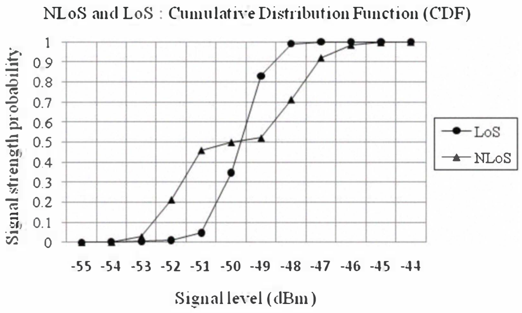


Fig. 4 CDFs of signal strengths in NLoS and LoS environments

Furthermore, Mid value is calculated by averaging the Max and Min, and Mids value is calculated by averaging the Mid value of the first half and the Mid value of the second half of the signal strengths.

If one uses such signal strength characteristics to compute the distance between the mobile device and the AP, it is difficult to find out the relationship. However, as the Mode values shown in Tables I and II, we found that Mode value is more stable than the others characteristic values. The value is about -50 dBm in both cases. However, from our observations, the Mode values derived at two different locations may have the same value. It implies that such characteristic signal strength is not sufficient for identifying a certain location. According to Fig. 3, we further observe the relation between the signal strength and distance. Intuitively, the signal strength is contra proportional to the distance.

Moreover, there is no obvious contrast among Mean, Mode and Mids values. So, we use the Mid value as the characteristic signal strength to estimate the location of device. In addition, we can only store the maximal and minimal signal strength instead of a large amount of signal strength measurements at each location.

Recall the Fig. 2 shows that the PDF of signal strengths under the NLoS environment has two peak values and the one under the LoS environment has single peak value only. After transforming the measurement results into cumulative distribution function (CDF), we can easily check whether the PDF of signal strengths shows the feature of time-invariant. As shown in Fig. 5, the curve of CDF under LoS environment smoothly and gradually climbs up to the top, which implies that there is single peak value. On the contrary, the curve of CDF under NLoS environment stops climbing at the center which is the valley between two peak values.

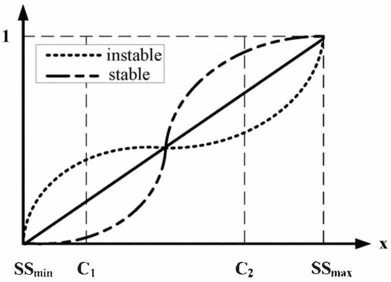


Fig. 5 Explain the resolution for identifying LoS and NLoS

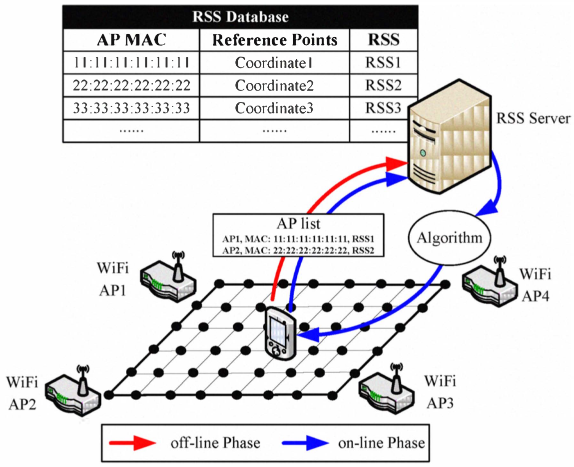


Fig. 6 An illustration of in-door location experimental environment

To determine the variation of signal strength is stable or not, we propose a simple mathematical formulation, namely Obstacle Attenuation Discrimination (OAD), which depends on a small amount of signal strength information. The function of OAD model is listed as follows:

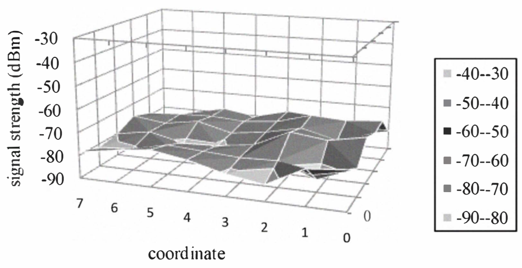
$$f(x)=\begin{cases}\dfrac{1}{SS_{\max}-SS_{\min}}\times x\le P_x(x<C_1)\ \&\ \dfrac{1}{SS_{\max}-SS_{\min}}\times x>P_x(x>C_2), instable\\ \dfrac{1}{SS_{\max}-SS_{\min}}\times x\ge P_x(x<C_1)\ \&\ \dfrac{1}{SS_{\max}-SS_{\min}}\times x<P_x(x>C_2), stable\end{cases}$$

where $SS_{\min}$ and $SS_{\max}$ respectively indicate the minimal and maximal signal strengths, C_1 and C_2 respectively denote the fore part and the back part of probability distributions and P_x denotes the random variable x. Based on this OAD function, we can roughly identify the indoor environment is LoS type or NLoS type.

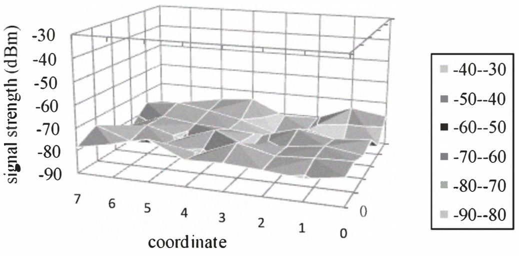
Moreover, we can just observe few signal strength measurements to find out whether there is obstacle located between the AP and the mobile device. As the sequence of observed signal strengths is time-invariant, it is no longer to collect more information because more measurements have a little chance to affect the characteristic of the accumulated measurement results. Then, we retrieve the minimal, the maximal and the middle values from those signal strength measurements to determine the location of the mobile device.

IV. LOCATION ESTIMATION AND PATTERN MATCHING

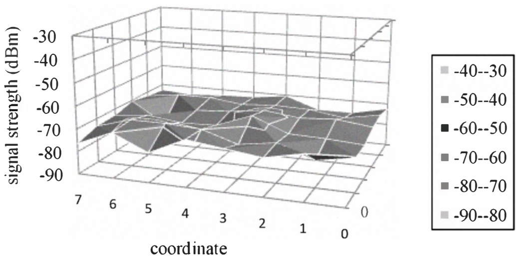
Fig. 6 illustrates that the experimental indoor space under the LoS scenario. The space is divided into 35 grids and the length between two adjacent cross points is 20 centimeters.



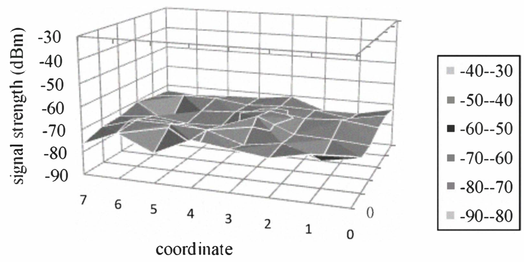
(a) AP1



(b) AP2



(c) AP3



(d) AP4

Fig. 7 Comparison of 3D space of signal strength distribution

Four APs are placed in each corner of the map to offer signals for device to measure. By using the mobile device, the site survey is performed at each of 48 cross point and each point is represented as a coordinate (x,y). Mobile device receives information from the WLAN APs and then it uploads the collected information to the database in the location server as mentioned before.

The location server adopts both Nearest Neighbor localization (NN) [14] and Rule-base localization method [21] to determine the possible location of the mobile device according to the input measurements and the stored information in the database.

With the NN localization method, the location server compares the input middle signal strength and that stored in

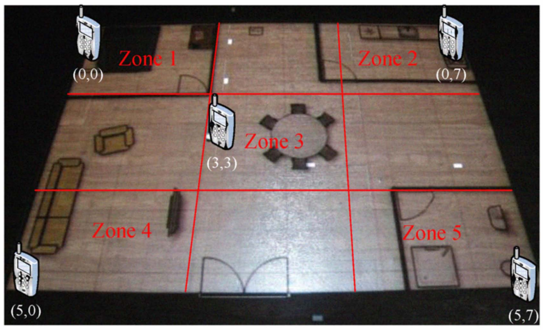
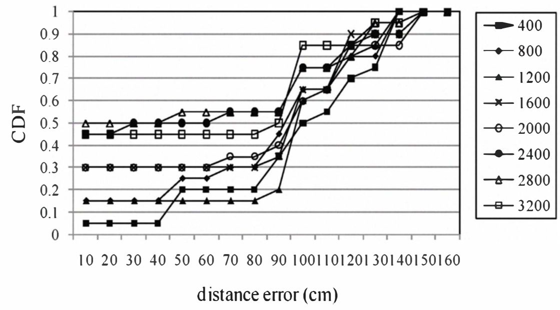
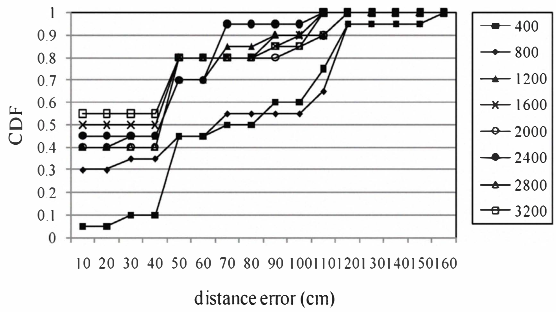


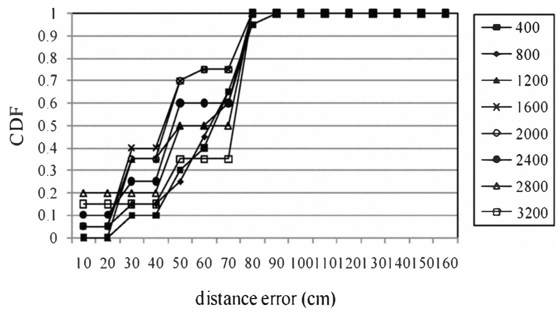
Fig. 8 Experimental indoor space



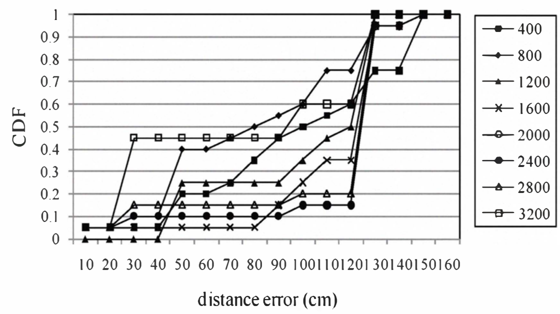
(a) At the (0,0)



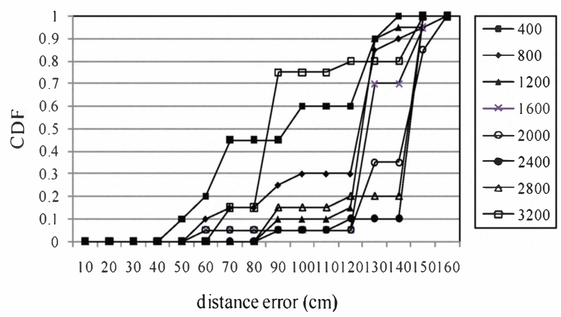
(b) At the (0,7)



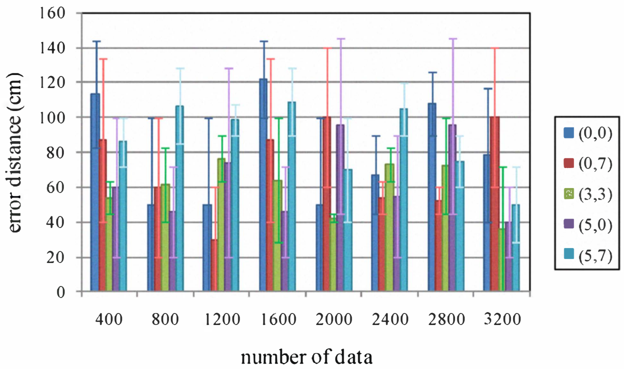
(c) At the (3,3)



(d) At the (5,0)



(e) At the (5,7)



(f) Distance error performance

Fig. 9 Comparison of distance error of five positions using NN method

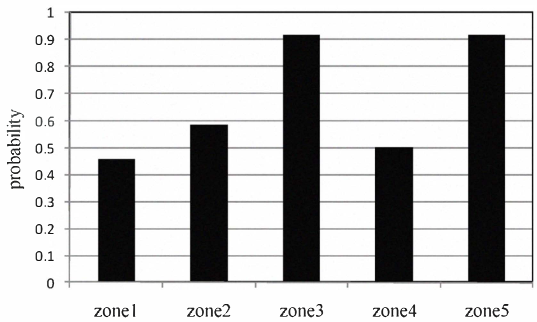


Fig. 10 Comparison of accuracy performance for five zones by Rule-based localization method

the database. The nearest neighbor localization method searches the middle value which has the smallest difference with the input middle value. If such middle signal strength is time-variant, this method may provide inaccurate location information. Contrarily, the Rule-base localization method utilizes the cross-relationships as the signatures to reduce the mistake. This method needs to create rules before performing positioning. Usually, a map is divided into several zones. If the middle signal strength matches the rules of a zone, the location server will select this zone as the location of mobile device.

V. Performance Evaluation

To evaluate the performance of proposed scheme, we compare the performance of the NN localization method and Rule-based localization method.

The radio map of signal strength measurements is shown in Fig. 7. It shows the messy space-signal distribution for each of four APs, which is not as smooth as we expected. However, we still try to use the middle value signature to locate the mobile device over a long period of time.

As shown in Fig. 8 , five coordinates in radio map ((0,0), (0,7), (5,0), (5,7) and (3,3)) are used as tested locations. Notably, the location estimation at the central location (3,3) has the best result, where the worst distance error of is 80 centimeters. As shown in Figure 9, the location estimation at the central point using the radio map is more accuracy than the result at the other grids.

As shown in Fig. 10, the space is divided into nine zones, and the mobile device is placed in each of five zones for testing. The experimental results are given in Fig. 10 and the best estimated results occur at zone 3 and zone 5 with 90 percent accuracy. In summary, the overall performance derived by the Rule-based method outperforms the one using NN method. The results also show that the central zone or grid is able to obtain more accurate location estimation than the corners.

VI. Conclusion

This paper proposed a long-term indoor positioning scheme for non-real-time positioning and tracking applications. The accurately estimated location could be derived by proposed scheme only when a large amount of measured signal strengths are accumulated at a certain location. To find out the required number of measurements, an interesting method is introduced to identify the type of environment. The number of measurements required for non-line-of-sight environment is obviously higher than that of line-of-sight environment due to the instable signal strengths. The systematic analysis of signal strength measurements for both non-line-of-sight and line-of-sight environments for a long-term period is given. As the number of measurements reaches a threshold, the corresponding PDF will display the characteristic of normal distribution, which is very useful for designing an indoor positioning system. The empirical method indeed shows the improvement on the indoor positioning accuracy with tens of centimeters distance error.

References

[1] Caffery, J., Jr., and Stuber, G.L., "Subscriber location in CDMA cellular networks," IEEE Transactions on Vehicular Technology, vol. 47, pp. 406–416, May 1998.

[2] Kamil A. Grajski and Ellen Kirk, "Towards a Mobile Multimedia Age – Location-Based Services: A Case Study," Wireless Personal Communications, vol. 26, pp.105–116, September 2003.

[3] SnapTrack Inc., "Location Technologies for GSM, GPRS, and UMTS Network," White Paper of Snap Track Inc., U.S.A., 2003.

[4] P. Castro, P. Chiu, T. Kremenek and R.R. Muntz, "A Probabilistic Room Location Service for Wireless Networked Environments," in Proceedings of the 3rd International Conference on Ubiquitous Computing, pp.18–34, January 2001.

[5] J-J. Pan, Q. Yang and S-J. Pan, "Online Co-Localization in Indoor Wireless Networks by Dimension Reduction," in Proceedings of AAAI Conference On Artificial Intelligence, vol. 2, pp.1102–1107, 2007.

[6] A-M. Ladd, K-E. Bekris, A. Rudys, G. Marceau, L-E. Kavraki, and D-S. Wallach, "Robotics-Based Location Sensing Using Wireless

Ethernet," in Proceedings of the 8th ACM International Conference on Mobile Computing and Networking, pp.227–238, 2002.

[7] J. Letchner, D. Fox, and A. LaMarca, "Large-Scale Localization from Wireless Signal Strength," in Proceedings of in Proceedings of AAAI Conference On Artificial Intelligence, vol. 1, pp.15–20, 2005.

[8] M. Fleck, M. Frid, T. Kindberg, E. O'Brien-Strain, R. Rajani and M. Spasojevic, "Remember: A Tool for Capturing Museum Visits," in Proceedings of International Conference on Ubiquitous Computing, pp. 48–55, September 2002.

[9] B. Brown, I. McColl, M. Chalmers, A. Galani, C. Randell and A. Steed, "Lessons from the Lighthouse: Collaboration in a Shared Mixed Reality System," in Proceedings of ACM, pp. 577–585, April 2003.

[10] A. Madhavapeddy, and A. Tse, "A Study of Bluetooth Propagation Using Accurate Indoor Location Mapping," in Proceedings of International Conference on Ubiquitous Computing, vol. 3660, pp. 105–122, August 2005.

[11] C-Y. Chang, K-P. Shih, C-H. Hsu and H-C. Chen "Location-aware Multicasting Protocol for Bluetooth Location Networks," Information Sciences, vol. 177, pp. 3161–3177, 2007.

[12] R. Roberts, "IEEE P802.15 Wireless Personal Area Networks: Ranging Subcommittee Final Report," Ranging Subcommittee of TG4a, 2004

[13] K. W. Cheung, H. C. So, W.-K. Ma, and Y. T. Chan, "A Constrained Least Squares Approach to Mobile Positioning: Algorithms and Optimality," EURASIP Journal on Applied Signal Processing, vol. 2006, pp. 1–23, 2006.

[14] P. Bahl and V. N. Padmanabhan, "RADAR: An In-Building RF-BASED User Location and Tracking System," in Proceedings of INFOCOM, vol. 2, pp. 775–784, April 2000.

[15] P. Castro, P. Chiu, T. Kremenek, and R.R. Muntz, "A Probabilistic Room Location Service for Wireless Networked Environments," in Proceedings of International Conference on Ubiquitous Computing, vol. 2201, pp.18–34, 2001.

[16] A-M. Ladd, K-E. Bekris, A. Rudys, G. Marceau, L-E. Kavraki, and D-S. Wallach, "Robotics-Based Location Sensing uses Wireless Ethernet," in Proceedings of ACM International Conference on Mobile Computing and Networking, pp.227–238, 2002.

[17] J. Letchner, D. Fox, and A. LaMarca, "Large-Scale Localization from Wireless Signal Strength," in Proceedings of AAAI Conference On Artificial Intelligence, vol. 1, pp. 15–20, 2005.

[18] S. Y. Seidel and T. S. Rapport, "914 MHz path loss prediction Model for Indoor Wireless Communications in Multi-floored buildings," IEEE Transactions on Antennas and Propagation, vol. 40, pp. 207–217, February 1992.

[19] "Android developers". Available: http://developer.android.com/sdk/index.html

[20] S. T. Sheu, M. S. Li and Y. H. Tsai, "In-Door Long-Term Positioning Technology," in Proceedings of CSCIST, July 2010.

[21] Qiuxia Chen, Dik-Lun Lee and Wang-Chien Lee, "Rule-Based WiFi Localization Methods," in Proceedings of International Conference on Embedded and Ubiquitous Computing, vol. 1, pp. 252–258, January 2009.