

Multi-Space Projection Algorithm for WLAN-based Location Service

V.L.Victor Lang

National Lab of Software Development Environment
Department of Computer Science
Beihang University
Beijing, P.R.China

Z.G.Cynthia Gu

Lucent Technologies
Tower C Wangjing Science And Technology Park
No.2 Li Ze Zhong Road
Beijing, P.R.China

Abstract -WLAN-based location systems are implemented in indoor location service in recent years. These systems suffer largely from the signal disturbance under open WLAN environment, which introduces decrease in accuracy and stability of the location service. This paper presents a new algorithm, which utilizes multi-space projections of radio space on sub-level signal spaces to mitigate the influence from disturbed Wireless stations to improve accuracy and stability of the location service under complex open WLAN environment.

Keywords: Multi-Space projection, WLAN, Location service, Signal disturbance

1 Introduction

WLAN-based location systems have been presented and investigated in recent years. Compared with traditional location systems, such as Global Position System (GPS), WLAN-based location service takes the advantages of widely deployed WLAN infrastructures; therefore it needs no extra equipments. WLAN-based location systems can cooperate with other WLAN-based business services. This natural relationship helps location service to join in the growing business application and service. That is to say, there is a very big market for location service to be integrated into other business services to improve the application experience of services, such as city guidance, museum guidance, emergency call service, and staff tracking.

WLAN-based location service mainly uses statistic or pattern recognize technique in the location algorithm, such as [6] [7] [11] and [15]. These algorithms build a multi-vector signal space based on the measurement under WLAN environment in advance. The multi-vector signal space can be defined as $P\{P1, P2, P3 \dots Pn\}$, where n is the number of vectors. Each vector Px is mapped to a signal variable (e.g. RSSI, SNR) collected from a selected Access Point (AP). All the Px builds the whole multi-vector signal space.

We call the multi-vector signal space radio map or radio space. Each vector represents a signal variable space,

which is formed by the signal space of one AP. The multi-vector signal space helps us to realize the physical location. As we know, the signal space built by access point is a sphere coordinate space. But the location service needs to locate the terminal within a real physical space based on a right angle coordinate (e.g. 2-D or 3-D physical space). Therefore, location service generally requires the radio space to have enough number of signal vectors and the radio space be successfully mapped to relational physical space based on a right-angle coordinate. During the location service based on radio space, each vector of radio map will make its contribution to the physical location of terminal.

Radio signal is tend to be disturbed because of the multi-path phenomenon and attenuation happened during their transmission. This is especially serious under the crowded indoor environment. The flowing crowd and unstable environment undermines the stable signal transmission between AP and WLAN terminals. Though under most cases, this attenuation only occurs on one or a few Access Points, the result will indicate the severe error of distance measurement in the location service because one or a few vectors of radio space is seriously disturbed. It is a small probability event that all APs' signal transmissions are disturbed simultaneously by complex indoor environment. So it is possible to find an improved algorithm to mitigate the influence from the unavoidable disturbance under real WLAN environment.

In this paper, we present an improved algorithm, which utilizes the combination of multiple projections of main radio space on different sub-level radio spaces to mitigate influence from disturbed AP. It can minimize the error of distance measurement in the continuous spatial locating process. We will describe the detail of this algorithm in the following paragraphs and present the analysis of some tests done by our Weyes location system (Which is a WLAN-based location system built in our lab environment). This paper is supported by Beijing Nova Program.

2 Related Work

WLAN-based location service was widely researched by many institutes and labs. RADAR system, presented by Microsoft Research, is the first to use WLAN-based technology to realize the indoor location service [6]. Radar records the received signal strength (RSS) from different access points at the reference locations, and makes the radio map (radio space) with those reference location points. Then RADAR uses a search method named nearest neighbor(s) in signal space (NNSS) to search the radio space and pick a location point which is the nearest to the observed RSS vector in Euclid distance within radio space. NNSS-AVG is an improved algorithm for continuous space location service. It searches the radio space and gets a list of top M location points that is the most closed to the observed signal strength in radio space. Then NNSS-AVG calculates the average position from those top M location points within radio space.

Horus system is another WLAN-based location system [11], which also uses RSS as the base reference value to build radio map. Each point on the radio map of Horus system does not record the single array of RSS but the probability of location based on each observed RSS value of each access point. Then, the radio space of Horus records the cluster of probability for each access points covering the area. When Horus provides location service online, it uses the probability model to calculate the multi-locations' probability, and then uses the Center of Mass algorithm to calculate the real coordinate. In Center of Mass algorithm, the real location of a WLAN client is calculated according to the probability of multiple locations on the radio map. The larger the probability of the location is, the nearer the mobile station is to the location. So, Horus system presents an estimate of the location in a continuous space, and takes the probability of location into location service.

Although compared with WLAN-based location systems built on the radio space and location algorithm, such as RADAR, Horus and other WLAN-based location systems improves their algorithms to reach better accuracy, all these systems still confront some common problems. The disturbance to the signal transmission in complex indoor environment is the main problem among them. It directly causes the unstable of signal value from access points and contributes to the error of distance measurement in location service.

Radio space is a multi-vector one. Radar system requires the number of AP(s) be larger than or equal to 4 to generate each vector. So the number of vector of Radar's radio space should be no less than 4. Horus system also requires adequate number of AP to build a usable radio space. In fact, under many real WLAN environments, the number of AP is more than enough but general location

systems only use part of them. Those access points redundant to general location systems are necessary for the multi-space projection algorithm presented by this paper. The additional access points can be used in weakening the disturbance of environment. That is what this paper will talk about in the following sections.

3 Multi-Space Projection Location Algorithm

In the multi-vector radio space, every vector indicates a signal variable collected from an individual AP. The number of vector of radio space will influence the precision of location service. According to the result from our testbed, the number of vectors should be no less than four on each point. The additional available vectors of a radio space can improve the accuracy of location service, however when the number of vectors exceeds six, the improvement of the accuracy is not very notable. So under the real WLAN environment, the number of vectors for radio space must be within a reasonable range. The additional vectors of a radio space are not necessary for location service under this situation.

The error of distance measurement in location system is mainly resulted from the disturbance of signal of a curtain AP or AP(s). Moving bodies and objects within WLAN environment frequently disturb the transmission of signal from one or more AP at many time stamps. The Multi-vector projection algorithm is realized under the above situations to resolve disturbance on signal space.

The radio space is defined as a group $P\{L(X, Y), R\{R1, R2, \dots, Rn\}\}$, where n is the number of vectors and the number of visible APs. $L(X, Y)$ record the physical location coordinated to the point in radio space, and $R\{Ri\}$ ($i=1, \dots, n$) represents the multi-vector radio space. In our test system, we select the received signal strength (RSS) as the reference vector for radio space, and vector Ri ($1 < i < n$) records the value of RSS from APi.

We introduce a sub-level radio space which is defined as a group $P_{sub}\{L(X, Y), R_{sub}\{R1, R2, \dots, Rm\}\}$ where $1 < m < n$. $R_{sub}\{Rj\}$ ($j=1..m$), and $R_{sub}\{Rj\} \in R\{Ri\}$. The sublevel radio space is different from the main radio space in the number of vector. Each main radio space can be divided into C_n^m number of different sublevel radio spaces P_{subk} ($1 \leq k \leq C_n^m$).

Each sub-level radio space P_{subk} can be used as normal radio space to do locating work. We need to collect a group of vector value $r\{r1, \dots, rm\}$, and only those ri which belong to the vectors within that sub-level radio space can be adopted in the location process to calculate the physical coordinate of evaluated location point. We define those location points as the projection from points in the main radio space to the sub-level radio space. For example, we can use the NNSS algorithm of Radar system [6] in

locating process on the sub-level radio space. The Center of Mass algorithm of Horus system [11] can also be used if we change the structure of radio space to fit for the requirement of Hours.

The evaluated location point from each sub-level radio space is defined as $Et(x, y)$, $1 \leq t \leq C_n^m$, which is the projection of the location point $E(x, y)$ in the main radio space on each radio space.

The multi-space projection (MSP) algorithm is realized in the following steps.

$D(Et(x, y))$ is the distance in the sublevel radio space P_{subk} between the evaluation location point and the real location point. It is simplified as $D(t)$ ($1 \leq t \leq C_n^m$).

$Min(D(t))$ is the minimum value of $\{D(t)\}$ ($1 \leq t \leq C_n^m$).

Q is defined as a gene for filter $Et(x, y)$ during location process, and

$$Q \geq 1.$$

$Final\{Et(x, y)\}$ is a group of $Et(x, y)$.

For each $Ei(x, y)$ belongs to $Final\{Et(x, y)\}$,

$$D(i) \leq Min(D(t)) * Q.$$

There are two methods to calculate the final physical coordination. The first is called MSP-AVG, it simply calculates the average physical coordination of $Final\{Et(x, y)\}$.

MSP-AVG:

$$E(x^*, y^*) = Average(Final\{Et(x, y)\})$$

The other is called MSP-POSS. It defines $P(i)$ as the possibility of the $Ei(x, y)$ derived from the sub-level radio space P_{subi} .

MSP-POSS:

$$E(x^*, y^*) = \sum (P(i) * Ei(x, y)) \quad (1 \leq i \leq C_n^m, Ei(x, y) \in Final\{Et(x, y)\})$$

There are many methods to calculate $P(i)$, for example: $P(i) = 1 - (D(i) / \sum(D(t)))$ ($1 \leq i, t \leq C_n^m, Et(x, y) \in Final\{Et(x, y)\}$)

Under open WLAN environment, when one AP is disturbed by environment elements, the related vector in the main radio space will be infected too. As the result, the

error of distance measurement is introduced by this infection when we evaluate the location of a client in the main radio space.

For those radio space P_{subi} which do not include the infected vector, if we use the sub-level radio spaces for location process, the error of distance measurement can be avoided in the evaluation of $Ei(x, y)$, $D(i)$ is smaller and the point is more closed to the real location point. For those sub-level radio spaces which include the infected vector, the error of distance measurement still exists on the coordinate of evaluated location points $Et(x, y)$, $D(i)$ is bigger and the point is farther from the real location point. So a gene Q can help location process to fill out those $Et(x, y)$ which are largely far away from the real location point, and get the group $Final\{Et(x, y)\}$, which is used in the final process.

In comparison, MSP-AVG is simpler and less computing consuming. MSP-POSS implements the possibility model to gain higher accuracy.

In the next section, we will analysis the performance of MSP, and compare it with results from other location algorithms.

4 Comparing Test and Analysis

This section presents a performance comparison test between MSP and NNSS-AVG. Both of them were realized on our WLAN-based location system. The tested bed was built on the 5th floor of YiFu science building, the location of the national lab of computer science school. As showed in figure 2, there are totally 7 access points (Netgear WG302) on the floor. The WLAN clients were X86 based laptops supporting centrino.

On each physical location, WLAN clients could see all the seven access points and collect their signals. Firstly, we selected 91 points as the reference points in the main radio space, and collected RSS from AP(s) on each reference points. The RSS from one or more AP(s) formed one vector in the main radio space.

After the main radio space was built, we realized an improved NNSS-AVG algorithm (NNSS-AVG+) on our Weyes location system. The algorithm was improved from the original NNSS-AVG of RADAR. The original NNSS-AVG algorithm of RADAR chooses the fix number of nearest reference points to calculate the average coordination as the final evaluated location points. The NNSS-AVG+ also do the average operation but the fix number of nearest reference points are replaced by the dynamic number of reference points whose Euclid distances from real location points are less than or equal to $Q * Min(D(t))$ ($Q \geq 1$).

We also realized the MSP algorithm using same radio space. During the test of MSP, we realized the simpler one - MSP-AVG, and tried some different settings of m and Q to find their contribution to the performance.

During our test, Q was a fix gene both worked for both the improved NNSS-AVG and MSP-AVG.

Both NNSS-AVG+ and MSP-AVG support continued space location. So during the test, we freely selected 20 positions on the floor, and on each position we tested for 5 times. Each time we collected 10×7 signal values and evaluated the different coordinates of evaluated location points with NNSS-AVG+ and MSP-AVG algorithm. The error of distance measurement is defined as the distance between the real position and the evaluated position. The result is displayed as in figure 1. The above test was made between 9:00 AM and 11:00 AM, which is busy hours in our lab environment.

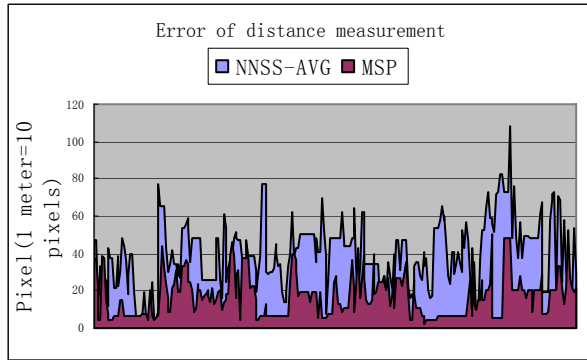


Figure 1. The cumulative distribution map for the error of distance measurement resulted from NNSS-AVG+ and MSP-AVG.

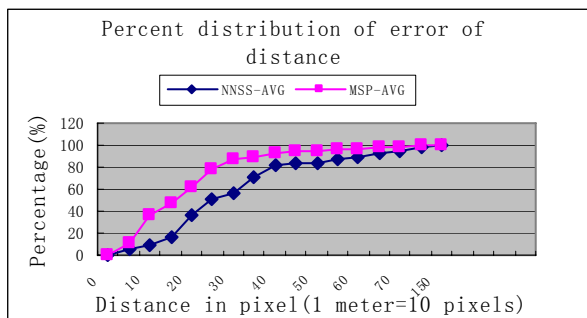


Figure 2. The percent distribution map for the error of distance measurement resulted from NNSS-AVG+ and MSP-AVG.

In order to test the performance of MSP under the infection, we simulated another advanced disturbance test. In the disturbance test, stochastic AP or AP(s) were selected to create an artificial disturbance by controlling the transmission power of stochastically selected AP to 50% of full power. The result of the test when only one

AP was stochastically selected to work under transmission power, and when two APs were stochastically selected to work under controlled transmission power was shown in figure 3.

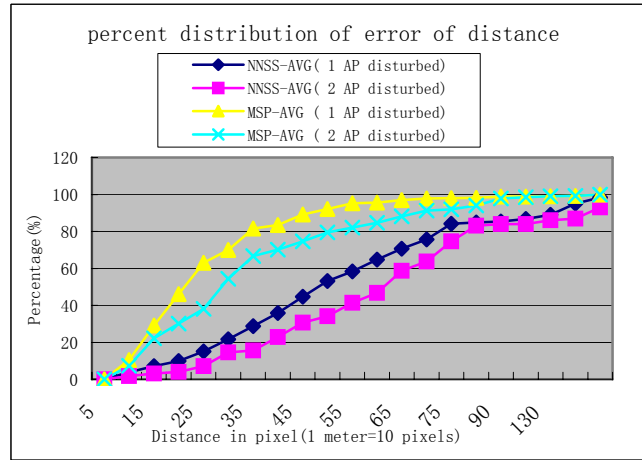


Figure 3. The percent distribution map for the error of distance measurement resulted from different situations during simulated test.

From above tests, we can find that during the real office environment, MSP-AVG can gain about 20% increment to NNSS-AVG+ when the error of distance measurement is less than or equal to 4 meters (equal to 40 pixels) (when $Q=1.25, n=7, m=5$). During the simulated disturbance test, under the situation that only one AP is selected to simulate infection (when $Q=1.25, n=7, m=5$), MSP-AVG can gain a larger increase than NNSS-AVG+ when the error of distance measurement is less than or equal to 7.5 meters (Figure 3). The increase is also obvious under the situation that two AP(s) were selected to simulate infection at the same time (when $Q=1.25, n=7, m=5$) (Figure 3).

Additional tests for the performance of different settings of m and Q show that, when m is less than or equal to 4, the performance of MSP-AVG is worse than or close to that of NNSS-AVG+. When Q is increased, the evaluated positions from location system tend to concentrate to a much smaller area and the error of distance measurement is much more closed to a fix number. But when Q is larger than 2, this infection is largely weakened.

5 Conclusion and Future Work

This paper presents a multi-space projection (MSP) algorithm, which has the advantage in decreasing the environment influence to the signal transmission of APs. MSP separates the main radio space to several sub-level radio spaces, and tries to evaluate the location point with sub-level radio spaces that is less infected. The comparison test between NNSS-AVG+ and MSP-AVG indicated the advantage of MSP-AVG under the disturbed WLAN environment.

MSP algorithm requires additional access points to separate disturbed access points from radio space, so it needs more infrastructure equipments than other location algorithms. Fortunately, WLAN environment is very popular and easily deployed under many office environments. All of those WLAN equipments can be utilized as the infrastructure support of MSP. For example, on the floor of our lab, there are totally 11 access points, deployed by different offices. Seven of them were selected to serve for location service.

MSP requires much more computing resource than other algorithms during location process. Under our testbed, MSP-AVG algorithm required 1000% time more resource than NNSS-AVG+. But it still had a very quick response and met the requirement of location service.

Different kinds of disturbance to the WLAN exist in the real indoor environment. Our future work includes the improvement of MSP on accuracy of MSP and less cost of computing resource. Other kinds of disturbance existed in real open WLAN environments are also researched by in our works, for example, realizing the adaptability of location system to the difference of WLAN equipments in Weyes system.

6 References

- [1] ANSI/IEEE, Std 802.11, 1999 Edition
- [2] R. Want, A. Hopper, V. Falcao, J. Gibbons., "The Active Badge Location System," ACM Transactions on Information Systems, Vol. 40, No. 1, pp.91-102, January 1992
- [3] T. W. Christ, P. A. Godwin, "A Prison Guard Duress Alarm Location System", Proc. IEEE International Carnahan Conference on Security Technology, October 1993
- [4] P. Enge, and P. Misra, "Scanning the Special Issue/Technology on the Global Positioning System" Proceedings of the IEEE, Special Issue on GPS, Vol. 87, No. 1, pp. 3-15, January 1999. 11
- [5] Tong Liu, Paramvir Bahl, Imrich Chlamtac, Mobility Modeling, Location Tracking, and Trajectory Prediction in Wireless ATM Networks, IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATIONS, VOL. 16, NO. 6, AUGUST 1998
- [6] Paramvir Bahl and Venkata N. Padmanabhan Microsoft Research,RADAR: An In-Building RF-based User Location and Tracking System,Infocom 2000
- [7] Castro, P., Chiu, P., Kremenek, T. and Muntz, R., A probabilistic room location service for wireless networked environments. in UbiComp 2001, (2001), 18-34.
- [8] H. Maass, "Location-Aware Mobile Applications based on Directory Services," MobiCom '97, pp. 23-33, September 1997
- [9] O'Reilly, 802.11 Wireless Networks - Definitive Guide, April 2002
- [10] O'Reilly, Rob Flickenger,Wireless Hacks, 2003
- [11] M. Youssef, A. Agrawala, and A. U. Shankar, "WLAN Location Determination via Clustering and Probability Distributions," in IEEE PerCom 2003, March 2003.
- [12] M. Youssef and A. Agrawala, "On the Optimality of WLAN Location Determination Systems," Communication Networks and Distributed Systems Modeling and Simulation Conference, January 18-24 2004.
- [13] Paramvir Bahl, Venkata N. Padmanabhan and Anand Balachandran, "A Software System for Locating Mobile Users: Design, Evaluation and Lessons", Technical Report, MSR-TR-2000-12, Feb. 2000.
- [14] Kamol Kaemarungsi, and Prashant Krishnamurthy, "Modeling of Indoor Positioning Systems Based on Location Fingerprinting ," IEEE Infocom, Hong Kong, March 2004.
- [15] S. Ganu, A.S.Krishnakumar, P.Krishnan, "Infrastructure-based Location Estimation in WLAN Networks," IEEE Wireless Communications and Networking Conference (WCNC 2004).
- [16] P. Krishnan, A.S. Krishnakumar, Wen-Hua Ju, Colin Malloes, and Sachin Ganu, "A System for LEASE: Location Estimation Assisted by Stationary Emitters for Indoor RF Wireless Networks," IEEE Infocom, Hong Kong, March 2004.