Performance study of DOA-based indoor location positioning utilizing MIMO wireless LAN system

#Abdul Hafiizh [1], Futa Imai [1], Michiko Minami [1], Kazuki Ikeda [1], Shigeki Obote [1], Kenichi Kagoshima [1]
[1] *The College of Engineering, Ibaraki University*
4-12-1, Nakanarusawa, Hitachi, Ibaraki, 316-8511 Japan, obote@mx.ibaraki.ac.jp

Abstract

In this paper, we study and analyze a DOA-based indoor location positioning method utilizing MIMO wireless LAN system technique. In our method, we estimated wireless LAN terminal location by measured data from arrays of 3 antennas receiver of MIMO wireless LAN access point and estimated Direction Of Arrival (DOA) of a transmitted signal using MUSIC algorithm, MUSIC with spatial smoothing algorithm and maximum directivity algorithm. Then we introduce several approach techniques to improve the accuracy performance. By using these methods, we can achieve estimation within 1 meter accuracy in indoor 10X10 meter region.

1. Introduction

WLAN indoor location positioning is a research topic area that being discussed and researched around late this 10 years. Dysfunctional of GPS in indoor area and widely deployed WLAN system in indoor buildings make this research a good perspective research topic. The challenging factor is the multipath fading environment in indoor area.

There are many techniques that have been used to build WLAN indoor location positioning such as Received Signal Strength (RSS) measurement [2], Direction of Angle (DOA) estimation, Time of Arrival (TOA), Time-Different of Arrival (TDOA) and Roundtrip-Time of Flight (RTOF). However, RSS based method is strongly affected by movement of human and this method needs periodical update of database to achieve high accuracy. Time measurement based method needs broad frequency bandwidth in order to reduce error and this method also needs exact synchronization of each access point.

We are focusing on DOA estimation because it brings more promising accuracy technique. Direct propagation path has strongest power among all multipath components. Furthermore, by increasing the number of antenna elements, the performance can be improved and this system also does not need synchronization. This system allows us to use multiple antennas and receivers by exploiting MIMO WLAN access point. We also can exploit OFDM technology which is employed in IEEE 802.11a and IEEE 802.11g to overcome affect of multipath channels. In our experimental research, channel transfer matrix is being measured by using vector network analyzer.

We arranged and divided this paper into 6 chapters. First chapter is the introduction of this paper. In Chapter 2, we explain about our system setup. Chapter 3 briefly explains our research methodology. Chapter 4 discuss about location positioning method, algorithms and approaches that we took to do this experiment. Lastly, chapter 5 and 6 is about our experimental result, conclusion and future works.

2. System Setup

MIMO concepts have been develop and research for many years for both wireless and wire-line systems. Among the earliest MIMO-to-wireless communications applications came in 1984 with groundbreaking developments by Jack Winters of Bell Laboratories. This MIMO system described ways to send data from multiple users on the same frequency /time channel using multiple antennas at the transmitter and receiver.

In this paper, we are utilizing above-mentioned MIMO method wireless LAN system to estimated one location. Figure 1 shows MIMO WLAN system environment. Nowadays, MIMO products are using 2X3 antennas element. This configuration is typical design type now. That is the reason why we choose to use 3 antennas element at the receiver site.

The most important in this experiment system is to process the signal on the reception side because two or more information is transmitted at the same time and be able to distinguish the desire wave and the interference wave. At this time, because the beam is suitable for the direction of the desire wave, the directivity of MIMO wireless LAN base station can estimate the direction where the electromagnetic wave comes. From there, we can estimate position of the transmitter terminal.

For our experimental setup, we used 1X3 SIMO (Single Input Multiple Output) from one point location coordinate to array of 3 antennas receiver access point. Figure 2 shows 1X3 SIMO image diagram and i is representing number of subcarrier. SIMO is one of special case for MIMO system.

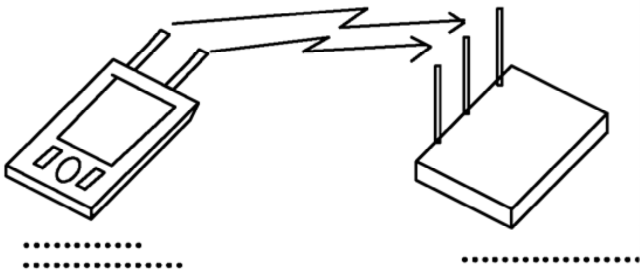

Fig. 1: MIMO WLAN system environment

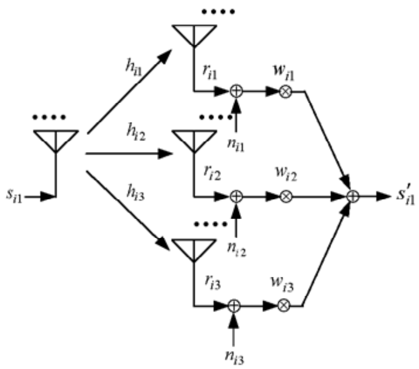

Fig. 2: 1x3 SIMO

Channel transfer matrix is defined by expression below.

$$\mathbf{H}_i = \begin{bmatrix} h_{i1} \\ h_{i2} \\ h_{i3} \end{bmatrix} \tag{1}$$

i represent number of subcarriers.

A. *System configuration in OFDM*

Orthogonal frequency division multiplexing (OFDM) is a communications technique that divides a communications channel into a number of equally spaced frequency bands. A subcarrier carrying a portion of the user information is transmitted in each band.

Each subcarrier is orthogonal (independent of each other) with every other subcarrier, differentiating OFDM from the commonly used frequency division multiplexing (FDM). Carrier centers are put on orthogonal frequencies.

For IEEE 802.11a and IEEE 802.11g, it can provide us until 64 possible subcarriers frequency slot, but only 52 data subcarriers can be used. Four of the subcarriers are pilot subcarriers that the system uses as a reference to disregard frequency or phase shifts of the signal during transmission.

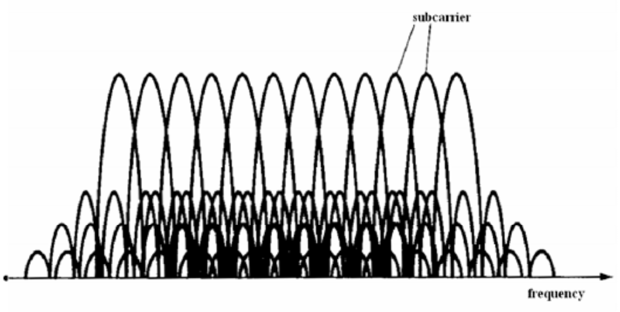

Fig. 3: OFDM modulation signal

3. Research Methodology

A. *Experimental testbed*

Our experimental testbed is 10x10(m) area, located in Ibaraki University, faculty of engineering's gym hall. The layout of the floor is shown in figure 4. We set 16 point location coordinates and 4 point coordinates for arrays of 3 antennas receiver. We name each 4 point coordinates for arrays of 3 antennas receiver as A, B, C and D. The experimental location point and arrays of 3 antennas receiver location is shown in figure 5. The basis setup is as follow.

TABLE 1: BASIS SETUP

Frequency	2.4GHz
Frequency span	20 MHz
Wavelength	12.5 cm
Antenna element interval	6.25 cm
Number of data subcarrier	19

We used one network analyzer and 4 antennas .Transmitter antenna at location estimation point is connected at port 1 of network analyzer. For array of antennas at the receiver site, to measured one receiver antenna, we connected one of the antennas to port 2 and the other two antennas were terminated by using 50 ohm load. Then we changed it one by one. We show it in figure 6. The resulting channel matrix is defined by:

$$\mathbf{H}'_i = \begin{bmatrix} h'_{i1} \\ h'_{i2} \\ h'_{i3} \end{bmatrix} \tag{2}$$

B. *Data Collection*

We collect data of 19 frequency subcarriers between 2.39GHz and 2.41GHz at 4 receiver points coordinates for each 16 location points.

C. *Data Processing*

We had chosen MUSIC algorithm, maximum directivity algorithm and MUSIC with spatial smoothing algorithm to process all the data that have been collected to find the DOA estimation for each location points. We explain about this matter in chapter 4.

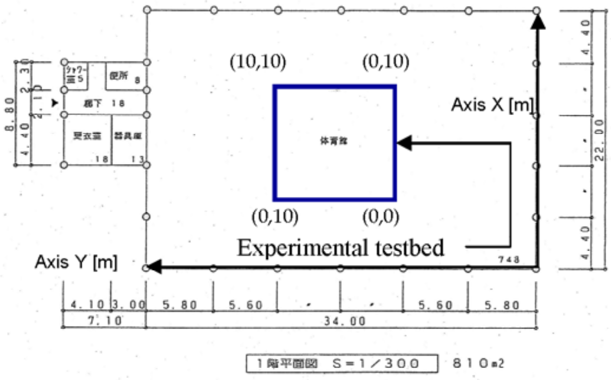

Fig. 4: Gym Hall geometry

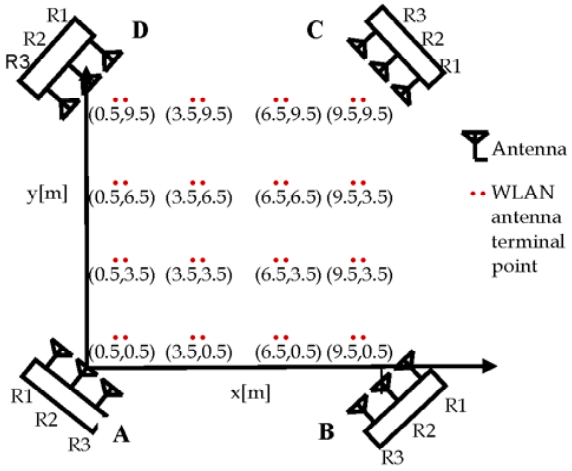

Fig. 5: Experiment location coordinates

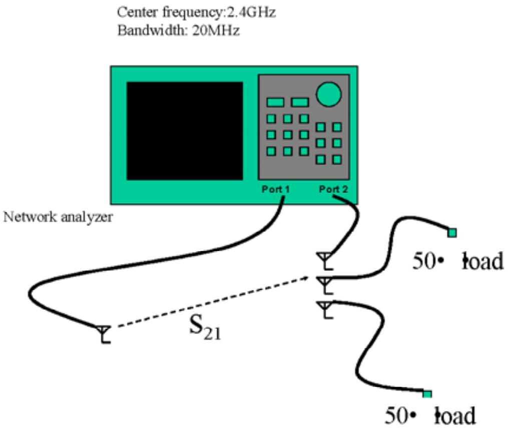

Fig. 6: Network analyzer setup

D. *Average of DOA estimation from data sub-carriers*

We did a simulation to configure numbers of data subcarrier significant to be used as in our experimental research [3]. From simulation result in figure 7, we found out that 19 subcarriers are suitable enough to be used. Using more than that is not appropriate because it produces only little gap of different result.

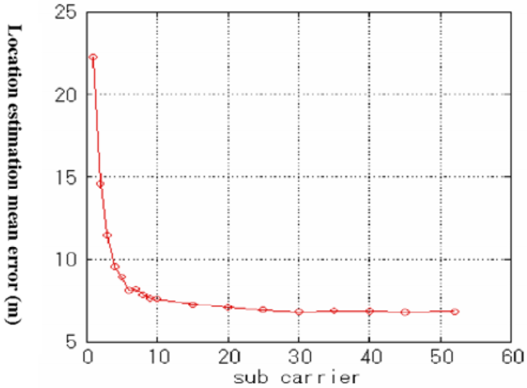

Fig. 7: Simulation result of location estimation error for 52 data subcarrier

We measured 19 data subcarriers for each location coordinates, and find DOA estimation for each data subcarriers. Then we average all of it. Theoretically this technique should improve the performance and decrease the effect of multipath fading and noise on the result. θ_i is DOA estimation in each subcarrier.

$$\theta_s = \sum_{i=1}^{19} \theta_i \Big/ 19 \qquad (3)$$

4. LOCATION ESTIMATION METHOD

At least 2 DOA estimation and maximum 4 DOA estimation is used to locate a location coordinate. For each location coordinate we transmitted signals and collected data at 4 arrays of antennas receiver at our experimental bed. The method is shown clearly in figure 8.

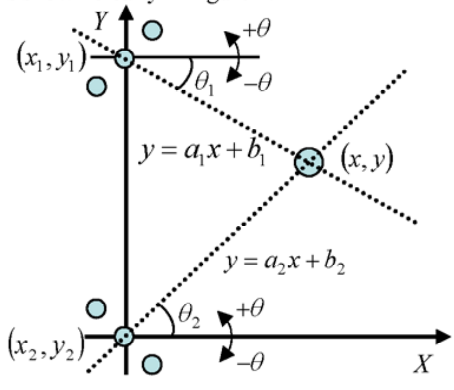

Fig. 8: Location positioning method

From the 2 DOA estimation at (x_1,y_1), (x_2,y_2) we estimate (x,y) location coordinate using expressions below .

$$
\begin{aligned}
&a_1 = \tan(\theta_1) \quad b_1 = -a_1 \cdot x_1 + y_1 \\
&a_2 = \tan(\theta_2) \quad b_2 = -a_2 \cdot x_2 + y_2 \\
&y = a_1 x + b_1 \\
&y = a_2 x + b_2 \\
&x = \frac{b_2 - b_1}{a_1 - a_2}
\end{aligned}
\tag{4}
$$

A. MUSIC Algorithm

To estimate the DOA of a wave from the signals received at the array, MUSIC algorithm is often used [1]. The MUSIC algorithm is based on exploiting the eigenstructure of the input spatial covariance matrix and provides high resolution. The covariance matrix is given by

$$\mathbf{R}_{\mathbf{hh}i} = \mathbf{H}'_i \mathbf{H}'^H_i \tag{5}$$

where superscript H means conjugate transpose. DOA is estimated by using eigenvector corresponding to the third eigenvalue.

B. Maximum Directivity Algorithm

This is a technique of which the DOA is estimated by referring it to the peak of the signal propagation directivity. The peak of directivity is searched by the next expression in equally spaced linear array of K element. d represent element of interval.

$$|D(\theta,i)|^2 = \left| \sum_{k=1}^{K=3} h_{ik} \cdot \exp\left[-j\frac{2\pi}{\lambda} d(k-1)\sin\theta \right] \right|^2 \tag{6}$$

It is assumed that the direction where the reception sensitivity in the highest peak is where the direction of the signal wave has come. This algorithm has much less computational complexity than MUSIC algorithm.

C. MUSIC with spatial smoothing

Two or more array antennas of the same composition might be able to be extracted from one array antenna. This extracted array is called a sub-array. For instance, two sub-arrays can be extracted for equal intervals linear array of three elements antenna with the first sub-array from first element and the second element and the second sub-array from second element and the third element (Figure 9). The improvement of the characteristic can be attempted by calculating in each sub-array under the multipath environment, and levelling the correlation matrix when MUSIC is applied.

$$
\begin{aligned}
&\mathbf{R}_{\mathbf{hh}i12} = \mathbf{H}'_{i12} \mathbf{H}'^{\,H}_{i12} \\
&\mathbf{R}_{\mathbf{hh}i23} = \mathbf{H}'_{i23} \mathbf{H}'^{\,H}_{i23} \\
&\mathbf{R}_{\mathbf{hh}i} = (\mathbf{R}_{\mathbf{hh}i12} + \mathbf{R}_{\mathbf{hh}i23})/2 \\
&\mathbf{H}'_{i12} = \begin{bmatrix} h'_{i1} \\ h'_{i2} \end{bmatrix} \\
&\mathbf{H}'_{i23} = \begin{bmatrix} h'_{i2} \\ h'_{i3} \end{bmatrix}
\end{aligned}
\tag{7}
$$

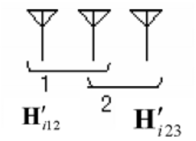

Fig. 9: 2 sub-arrays antenna extracted from one equal interval linear array antenna

5. EXPERIMENTAL RESULT

Flow chart in figure 10 explaining our working steps to get the estimated result in table 2.

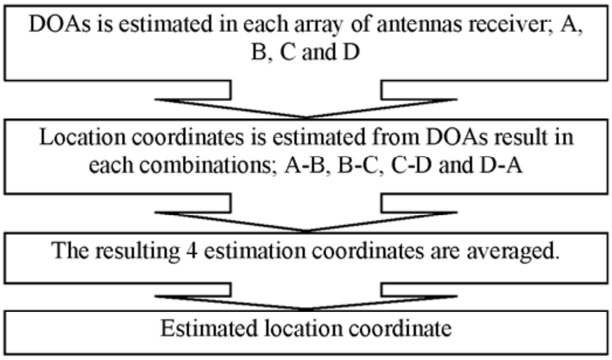

Fig. 10: Flow chart of location estimation steps

TABLE 2: ACCURACY PERFORMANCE RESULT

	1 data subcarrier (2.4 GHz) accuracy (m)	7 data freq. subcarriers mean accuracy(m)	19 data freq. subcarriers mean accuracy(m)
MUSIC	10.5	3.25	3.48
Maximum directivity	2.61	1.75	1.72
MUSIC with Spatial smoothing	3.01	1.21	1.31

From the result of table 2, clearly it stated that maximum directivity algorithm and MUSIC with spatial smoothing algorithm perform well than MUSIC algorithm. DOA estimation of MUSIC algorithm did not perform well.

Figure 11~14 show results of MUSIC algorithm and MUSIC with spatial smoothing.

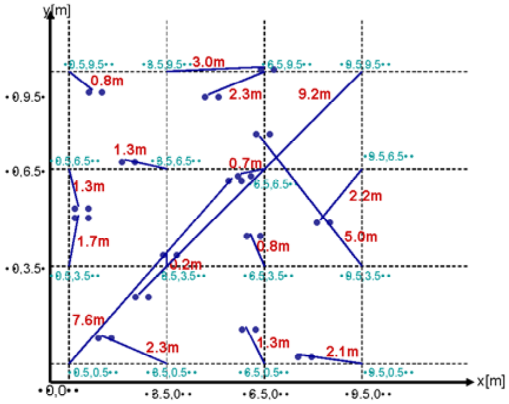

Fig. 11: Accuracy for each location coordinates using maximum directivity algorithm from 1 data subcarrier (2.4GHz). Mean accuracy is 2.61 meter.

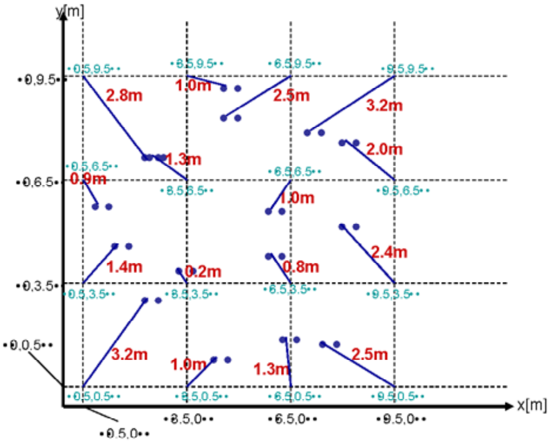

Fig. 12: Accuracy for each location coordinates using maximum directivity algorithm from 19 data subcarriers. Mean accuracy is 1.72 meter.

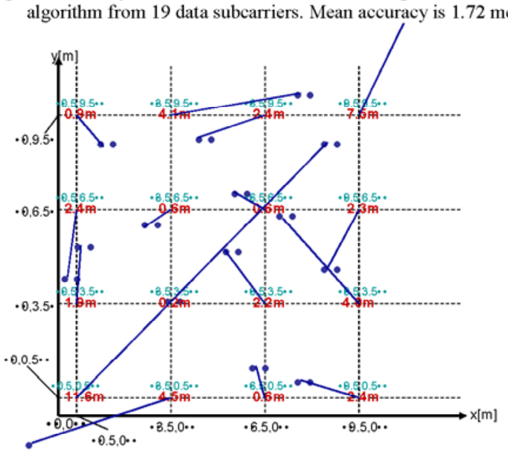

Fig. 13: Accuracy for each location coordinates using MUSIC with spatial smoothing algorithm from 1 data subcarrier. Mean accuracy is 3.01 meter.

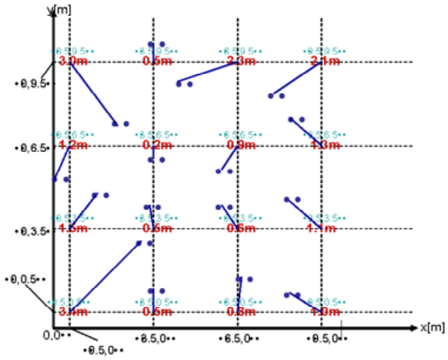

Fig. 14: Accuracy for each location coordinates using MUSIC with spatial smoothing algorithm from 19 data subcarriers. Mean accuracy is 1.31 meter.

The important fact is the result shows that by using more than one data frequency, we can improve accuracy performance of the system. Furthermore, we proposed two methods in order to improve the performance of MUSIC with special smoothing algorithm result.

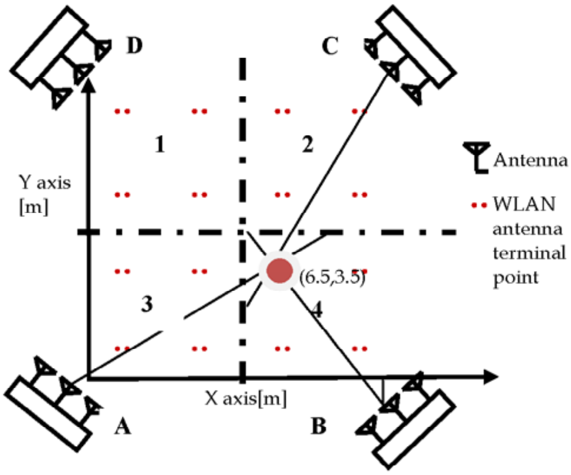

Fig. 15: 4 divided area

First, we divided the experimental testbed and location coordinates into four areas which each area is near to arrays of antennas location receivers. For more clearly we showed it in figure 15. We name each divided area with no. 1, 2, 3 and 4. For example, if the points coordinate lies in area 4, we average location estimation from array antennas B-C and array antennas A-B. The reason to our approach is because receivers close to transmitter will receive high power of line of sight (LOS) rays and it helps to give good DOA estimation.

Second, from the data result in figure 16, it shows that for all 19 data subcarriers DOA estimation, there are 15 point frequency subcarrier shown near result to true DOA and 4 points are quite opposite of true DOA and if we average all the data, it will give high error DOA estimation.

This is because MUSIC is strongly affected by multipath component and causing opposite estimation of true DOA. To solve that problem we introduce majority vote algorithm. We judge a sign of DOA at each subcarrier and discard the minority in case of applying average operation. This is our second approach method.

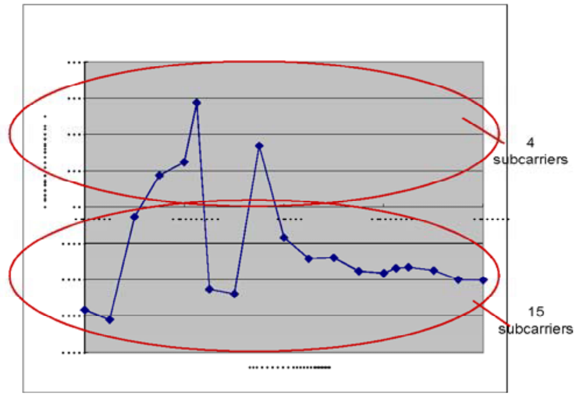

Fig. 16: DOA estimation for 19 subcarriers (true DOA is at -30 °).

In Table 3, **a** representing previous result of MUSIC with spatial smoothing algorithm (Table 2), **b** representing first approach technique and **c** representing second approach technique.

TABLE 3: IMPROVEMENT PERFORMANCE RESULT

	Mean Accuracy(m)
a	1.31
b	1.42
c	0.96
b+c	0.73

The result shows that our approaches have successfully increased accuracy performance from previous result **a**. Figure 17 shows last performance result using MUSIC with spatial smoothing.

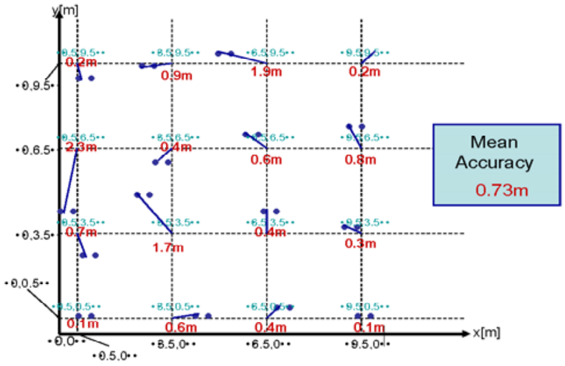

Fig. 17: Accuracy for each location coordinates using MUSIC with spatial smoothing algorithm from 19 data subcarriers after b and c approaches method techniques.

6. CONCLUSIONS AND FUTURE WORK

In this paper, we proposed, study and analyze a DOA-based indoor location positioning method utilizing MIMO Wireless LAN system. We have proven that by considering and adding more data subcarriers to estimate DOA and location positioning, will bring better result. It is an advantage for IEEE 802.11a WLAN and IEEE 802.11g WLAN. From the experimental result, we also succeed to bring output till 1 meter accuracy with our approaching techniques. Finally, we can achieve accuracy of below one tenth of width of measured area.

But we believe there are still many improvement should be done in the future. For indoor location positioning, bigger and complex experimental testbed, should also be considered. Adding more antennas element also would increase the accuracy. Study, research and producing the good DOA estimation algorithm are among the top priority that we should be looking at.

ACKNOWLEDGEMENT

Authors would like to thank Electromagnetic Wave and System Research Laboratory's members for their support, comments and help while we are doing this research.

REFERENCES

[1] R.O. Schmidt, "Multiple emitter location and signal parameter estimation, "*IEEE transactions on Antennas and Propagation*," vol. AP-34, March 1986.

[2] P. Bahl,V. N. Padmanabhan, "*RADAR: An In-Building RF based user location and tracking system*," *Proceedings of IEEE INFOCOM 2000*, Tel-Aviv, Israel, March 2000

[3] M. Yamane, S. Obote, K. Kagoshima, "Study on location method utilizing MIMO wireless LAN system," *technical report on IEICE(in Japanese) , A.P 2005-185, PP. 75-80, March 2006*

[4] B. Allen, M. Ghavani, *Adaptive Array Systems*, John Wiley and Sons, pp. 118-119, 2005