2012 International Conference on Indoor Positioning and Indoor Navigation, 13-15th November 2012

Direction-of-Arrival Tracking in WLAN Network Using Dual Antenna Access Points

Ji-Won Park, Jeong-Min Lim, and Tae-Kyung Sung
Department of Information and Communication Engineering
Chungnam National University
Daejeon, Korea
jwjsjk@gmail.com, likebasic@naver.com, tksaint@cnu.ac.kr

***Abstract*—This paper presents a simple direction of arrival (DOA) positioning method using dual-antenna access points. GPS signals cannot be received in the shadowed region such as indoor environment. To enable indoor navigation, other positioning systems need to be applied. Recently, WLAN access points (AP) have been deployed in most of the urban area to communicate with smart phones or notebook PCs. Therefore, many indoor positioning solutions using WLAN technology have been developed. However, positioning method based on received signal strength (RSS) has poor positioning performance, and the time-based method is hard to implement owing to strict time synchronization requirement. DOA does not require time synchronization between APs and it is fairly accurate in line of sight condition. For real-time application, fast Fourier transform (FFT) technique, and ambiguity elimination technique is used for DOA estimation. At the end of the paper, a simple experiment is presented with the wired channel, which shows the feasibility of DOA estimation in no multipath environment.**

Keywords- direction of arrival (DOA); angle of arrival (AOA); WLAN positioning

I. INTRODUCTION

The Global Positioning System (GPS) has made navigation system viable for outdoor application. However, few meter positioning accuracy and the weak signal strength property made GPS navigation unsuitable for indoor environment or in urban canyon environment. As a result, positioning techniques alternative to GPS have been studied in various fields. In indoor environment, there are many positioning systems based on different systems such as ultrasound, Infrared, and electromagnetic wave [1-3].

Since APs are deployed in most of the large buildings, WLAN technology can be used for indoor positioning. A WLAN-based positioning system has advantages over all other indoor positioning systems because communication function is a part of the existing system and can cover many buildings as possible by easily locating an AP where it is desired.

This work was supported by the Industrial Strategic Technology Development Program (10041950, Development of Mobile Safety-Inspection Systems Using High Resolution Penetration Imaging Technology for Transportation Infrastructure) funded by the Ministry of Knowledge Economy(MKE, Korea)

The basic methods that can be used for WLAN positioning are RSS, DOA estimation and time of arrival (TOA) estimation. The disadvantage of the RSS method is its inaccurate range measurements due to random deviation from the mean received signal strength caused by channel. Time based positioning method such as TOA and time difference of arrival (TDOA) requires time synchronization between each AP, which is difficult to implement [4].

The positioning performance for the method based on multi-AP is dependent of the number of AP used. The positioning accuracy is increased as the number of AP is increased. However, interference problem becomes severe when the number of AP increases. Thus, this paper presents a positioning method using DOA based on dual antenna AP. By using DOA, it can operate with single AP, and no synchronization is needed between each AP. Moreover, the system can obtain more accurate position information compared to RSS method by applying angle of arrival (AOA) method [5].

To acquire DOA information, DOA estimation should be performed to the received signal. Formerly, many methods such as maximum likelihood, MUSIC, ESPRIT has been proposed for DOA estimation [5]. However, these methods are based on complex mathematical theory, and it is difficult to implement in practice. In this paper, simple DOA estimation is presented based on FFT technique.

II. DOA ESTIMATION

A. Measurement model

DOA can be estimated by analyzing the phase difference of each antenna. To simplify the system two antenna sensors are used as in Fig. 1.

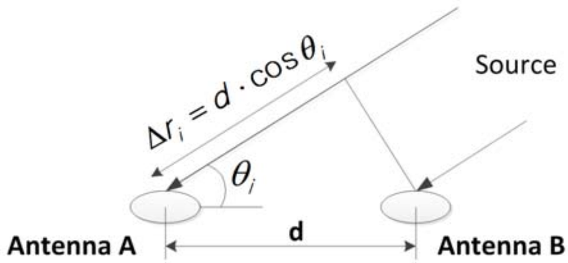

Figure 1. DOA measurement model

978-1-4673-1954-6/12/$31.00 ©2012 IEEE

It is assumed that the source is distant enough from the AP so that the wave signal is a plane wave at the receiver. This assumption is based on the fact that DOA estimation is performed only when the mobile terminal is far enough from the AP. When the mobile terminal is near the AP, RSS method can be used to identify the location which is similar to enhanced cell-ID method. Thus, plane wave is assumed at the AP array antenna further.

As shown in Fig. 1, the DOA angle can be given by

$$\theta = \cos^{-1}\left(\frac{\Delta r}{d}\right) \quad (1)$$

where, the space between each array antenna is d, and the distance difference of arrival between the array antenna is Δr. In (1), d is fixed and known when the AP is manufactured, while Δr is variable according to the source location and needs to be measured from each antenna sensor. Since Δr is directly related to phase difference of each received signal, θ can be estimated by using the FFT technique [6].

B. DOA Estimation Based on FFT

The basic idea of DOA estimation technique is to estimate the phase differences at various frequency components of Fourier spectra between a pair of antenna sensors. If the signal received at the antenna 1 and antenna 2 in Fig. 1 is defined as $r_1(t)$ and $r_2(t)$ respectively, the Fourier transformation of each signal can be given as

$$R_1(f) = \int_0^T r_1(t)e^{-j2\pi ft}dt$$

$$R_2(f) = \int_0^T r_2(t)e^{-j2\pi ft}dt \quad (2)$$

where, T is the total length of the signal that is being used for estimation. The cross correlation between two signal can then be related by

$$G_{12} = R_1^*(f)R_2(f) \quad (3)$$

where, * is the complex conjugate. Equation (3) is a correlation of $r_1(t)$ and $r_2(t)$ in frequency domain, and can be expressed in form of magnitude and phase as

$$G_{12}(f) = \left|G_{12}(f)\right|e^{-j\phi(f)} \quad (4)$$

where, $\phi(f)$ is the phase of $G_{12}(f)$. The slope of $\phi(f)$ is directly related to the time difference of arrival between the array antenna. If all the spectral component of the signal experience a same time difference at the array antenna, then $\phi(f)$ can be modeled as a linear function of f in the frequency domain as

$$\phi(f) = a \cdot f + b\,. \quad (5)$$

where, a is the slope due to time difference at the array antenna, b is the bias induced by phase ambiguity. When the linear function $\phi(f)$ has no bias and crosses the origin, $\phi(f)$ can be given as

$$\phi(f) = \frac{2\pi f}{c} \cdot d \cdot \cos[\theta(f)]. \quad (6)$$

where, c is the speed of light. Equation (6) can be rewrite in form of $\theta(f)$ as

$$\theta(f) = \cos^{-1}\left[\phi(f)/\left(\frac{2\pi fd}{c}\right)\right]. \quad (7)$$

The mean value of incident angles can be solved by averaging the $\theta(f)$ for all frequency components in the signal band.

To apply (7) to the system, $\phi(f)$ should be crossing the origin and should be a linear function over the frequency in the signal band. However, the phase angle measurement will range within one angular frequency period, which is $0 \le \phi(f) < 2\pi$ or $-\pi \le \phi(f) < \pi$. This induces a phase ambiguity in the $\phi(f)$ for value outside the one angular frequency period. Since $\phi(f)$ has no unique value for f, it might even have a discontinuous point. Thus, line fitting process is needed to make $\phi(f)$ a unique function of f that cross the origin before applying (7).

The line fitting process is composed of phase difference analysis step and bias compensation step. The phase difference analysis step eliminates the discontinuous point in $\phi(f)$ by comparing the slope in the frequency domain. The phase difference analysis starts from the lower frequency sample to the higher frequency sample. When there is any abrupt slope change in the particular frequency, it corrects the sample by adding or subtracting $2\pi k$ to $\phi(f)$, where k is an integer number that minimizes the slope change. The shape of the corrected $\phi'(f)$ will become a linear function after the analysis process is finished. In the bias compensation step, $2\pi m$ is added or subtracted to the $\phi'(f)$ where m is an integer number that moves the $\phi'(f)$ to the position where it crosses the origin.

The overall FFT DOA estimation system block diagram is depicted in Fig. 2. First, the source signal will be received at the array antenna with different arrival time. The mixer in the radio frequency (RF) block will demodulate the RF signal to the intermediate frequency (IF). The clock used in each array antenna system is required to be synchronized, thus minimize any clock induced errors. Second, the band-pass filter (BPF) will pass only the IF signal component.

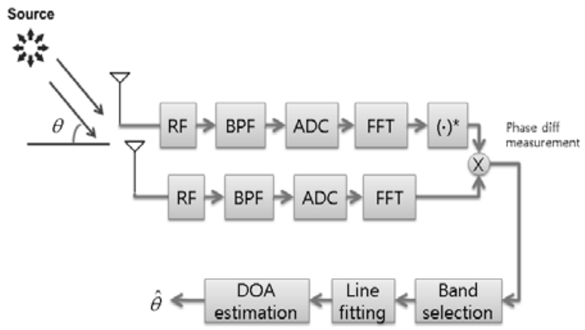

Figure 2. FFT DOA estimation block diagram

The analog to digital converter (ADC) samples the IF signal with a sampling frequency dependent on signal bandwidth and IF frequency. Third, FFT is performed for each array antenna signal and phase difference measurement is obtained by applying (3). Next, sample point selection is performed in the Band Selection block which filters out the useless data and remains only the sample that can be used for DOA estimation. With the selected sample, correction is performed in the Line fitting block that will eliminate ambiguity and bias in the sample. Finally, estimated DOA angle $\hat{\theta}$ is obtained from the DOA estimation block by averaging the $\theta(f)$ in the frequency domain.

III. Experiment Results

In this section, feasibility for DOA estimation is shown by experiment. For this purpose, Agilent vector signal generator E4438C equipment was used to generate a WLAN signal source. The 100msec length 802.11b DSSS preamble signal was used for the signal source. The receiver array antenna distance d was set as 1m. To make the experiment simple, RF stage was skipped by using a wired channel, and IF stage signal was used. Since the channel between the source and the receiver was wired, it was assumed to have little multipath. The location of the source was arranged so that the true DOA angle can be measured as 135 degrees. The IF carrier frequency was set as 100MHz, and under sampling was used by setting the sampling frequency to 125MHz. The resultant center frequency of the signal was 25MHz, and the cross-correlation result between two signals was shown as in Fig. 3 when FFT size of 1024 was used.

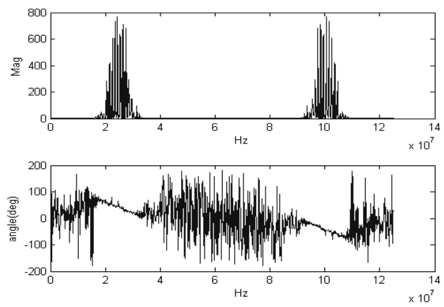

Figure 3. FFT cross correlation result in frequency domain

By proceeding with the band selection, only the sample point around 25MHz was selected from the angle phase based on the bandwidth of signal, which is 22MHz, and the other useless sample was filtered out as in Fig. 4.

The Line fitting block performs a phase difference analysis to eliminate discontinuous points for the selected sample. It then estimates the linear function model based on (5) from the phase samples. The sample points that deviate from the estimated linear model are calibrated so that $\phi(f)$ is nearly a line. The result of calibration is shown in Fig. 5.

Before proceeding to the bias compensation step in the Line fitting block, it should be noted that the phase samples have been shifted in the frequency domain due to under sampling. Thus, the frequency shift compensation must be performed prior to bias compensation. In the case of Fig. 5, the phase was shifted by 125MHz in the frequency domain from -100MHz, which is the original center frequency of the signal. Thus, all the phase sample points were shifted by -125MHz before bias compensation was applied.

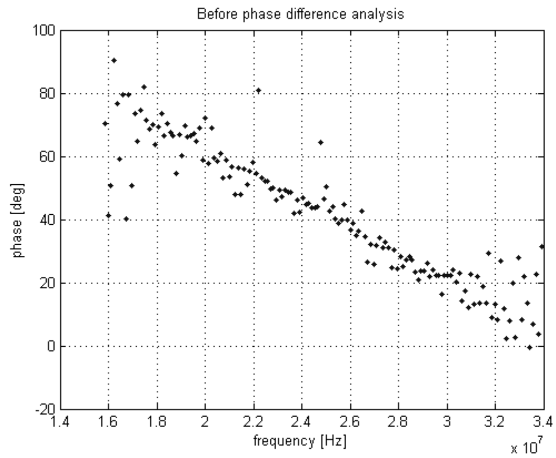

Figure 4. Phase sample points after Band selection

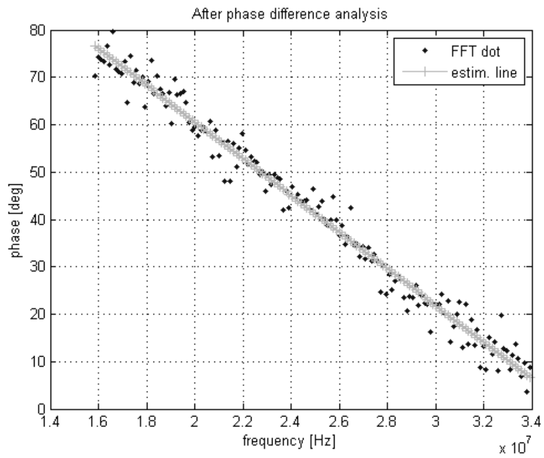

Figure 5. Phase sample points after Linear fitting

Finally, DOA angle was obtained for each frequency using (7) as shown in Fig. 6. By averaging $\theta(f)$ for all the frequency, $\hat{\theta}$ was estimated as 134.38 degree with an error of 0.7 degree.

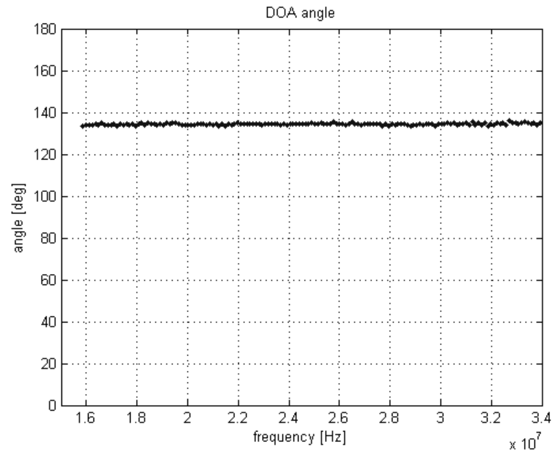

Figure 6. DOA angle for each frequency component

IV. CONCLUSION

In this paper, a simple DOA estimation for WLAN system was shown using a dual antenna AP. The FFT correlation method was used in estimating the DOA angle and simple adding and subtracting method was used to compensate for the phase ambiguity. From the experiment of DOA estimation, the estimation error appeared to be less than 1 degree when there was no multipath. Further study is needed for DOA estimation in multipath environment.

ACKNOWLEDGMENT

The authors would like to thank Lim for continuously aiding the repetitive experiment, and Professor Sung who gave insight and right advice regarding the research.

REFERENCES

[1] M. Hazas, and A. Ward "A Novel Broadband Ultrasonic Location System," Proc. Int. Conf. on Ubiquitous Computing. pp. 264-280, 2002.

[2] R. Want, A. Hopper, V. Falcao, and J. Gibbons "The Active Badge Location System," ACM Trans. Information Systems, pp. 91-102, Jan. 1992.

[3] Y. Wang, X. Jia, H.K. Lee, and G.Y Li, "An indoor wireless positioning system based on WLAN infrastructure," 6th Int. Symp. on Satellite Navigation Technology Including Mobile Positioning & Location Services, Melbourne, Australia, pp. 22-25 July , 2003.

[4] I. Jami, M. Ali, and R. F. Ormondroyd: "Comparison of methods of locating and tracking cellular mobiles," IEE Colloquium on Novel Methods of Location and Tracking of Cellular Mobiles and their System Application, vol. 99/046, pp1/1-6/1, 1999.

[5] C. Sathish, Advances in Direction-of-Arrival Estimation, AETECH HOUSE, 2006.

[6] R. Mardiana, and Z. Kawasaka, "Broadband radio interferometers utilizing sequential triggering technique for locating fast electromagnetic sources emitted from lightning," IEEE Trans. Instrum. Meas., vol. 49, pp.376, 2000.