Title	An Experimental Investigation of the MUSIC-based Wireless Position Location using LCX antenna at 5GHz band
Author(s)	Kosuke Shirai; Takeshi Higashino ; Minoru Okada
Citation	2019 19th International Symposium on Communications and Information Technologies (ISCIT)
Issue Date	2019-11-21
Resource Version	Author
Rights	© 2019»IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.
DOI	10.1109/ISCIT.2019.8905190
URL	http://hdl.handle.net/10061/13960

2019 19th International Symposium on Communications and Information Technologies
(ISCIT)

An Experimental Investigation of the MUSIC-based Wireless Position Location using LCX antenna at 5GHz band

Kosuke Shirai, Takeshi Higashino, and Minoru Okada
Graduate School of Science and Technology, Nara Institute of Science and Technology
8916-5 Takayama, Ikoma, Nara, 630-0192 JAPAN
Email: {shirai.kosuke.sf8, higa, mokada}@is.naist.jp

***Abstract*—In recent years, a wireless system using LCX (Leaky CoXial cable) antenna has been studied as a method of locating a wireless terminal in indoor. As typical method, the IFFT (Inverse Fast Fourier Transform) of the channel frequency response is available for obtaining channel impulse response, then, local position can be estimated based on the TDOA (Time Difference Of Arrival). Although spacial resolution of positioning is limited by measured bandwidth of frequency response, the MUSIC (MUltiple SIgnal Classification) algorithm has been proposed to overcome its limitation [1], [2]. Previous study [3] employed the MUSIC algorithm in 2 by 2 LCX antenna system at 2.4 GHz band, and its precision has been evaluated experimentally. Since the LCX antenna has newly developed for 5 GHz, positioning performance at 5GHz band has evaluated in this paper. After the channel response was measured in the radio anechoic chamber, and its precision is experimentally evaluated.**

***Index Terms*—LCX, position location, MUSIC, IFFT**

I. INTRODUCTION

Services using position information of wireless communication terminals such as smartphones are in widespread use. Applications using location information are practiced not only in navigation systems but also in new services. For example, location sharing with SNS (Social Networking Service) and O2O (Online to Offline) service for distributing content when the user approaches a store etc. The value of location information is increasing, and high accuracy location information acquisition technology is required.

As the air interface used in current indoor position detection method, ZigBee, RFID (Radio Frequency IDentifier), wireless LAN (Local Area Network) are usually employed [4], [5]. These techniques require many readers and access points depending on the required coverage area. In recent years, indoor position detection using LCX (Leaky CoXial cable) antenna has been studied as a method to reduce the number of required access points. LCX is typically used for compensating the radio dead zone [6]. In [6], base station monitors frequency response between transmitting/receiving antennas of LCX, then, channel impulse response is obtained by using IFFT (Inverse Fast Fourier Transform). Target location is estimated based on radiation directivity dependency for the radio frequency. Generally, the time resolution of the IFFT is inversely proportional to measured bandwidth. For instance, it is 50 nsec when the measured bandwidth is 20 MHz of standard wireless LAN channel. Since the spatial resolution becomes 15 meter and is not enough to position location in indoor, this paper aims target error of less than 1 meter in two dimensional space. The MUSIC (MUltiple SIgnal Classification) algorithm has been proposed to enhance spatial resolution of positioning by exploiting higher resolution for detecting AOA (angle-of-arrival) in beam-forming technique [7]. In [7], the Fourier matrix with measured frequency interval was applied to steering vector for calculating pseudo spectrum so that the number of measured frequency bin in proposal equals the number of array element in conventional MUSIC. The time resolution can beyond the reciprocal of measured bandwidth. Main contribution of this paper is to employ the super-resolution algorithm to the 2 by 2 LCX antenna system and performance is investigated experimentally. In previous work [3], performance is investigated on 2 by 4 LCX antenna system at 2.4 GHz band. Since the LCX antenna has been further developed and been available for radiating 5 GHz band signal, this paper firstly reports an experimental investigation on positioning performance at 5 GHz band in 2 by 2 LCX antenna system with the MUSIC algorithm.

II. POSITION LOCATION USING LCX ANTENNA

Fig.1 shows the structure of LCX antenna. Periodic slots are opened in the outer conductor of the coaxial cable. The

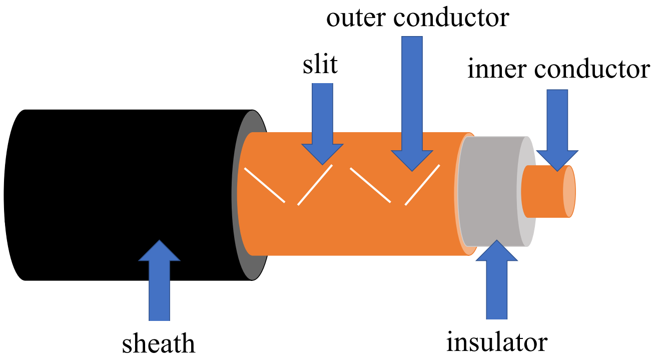

Fig. 1: Structure of LCX antenna

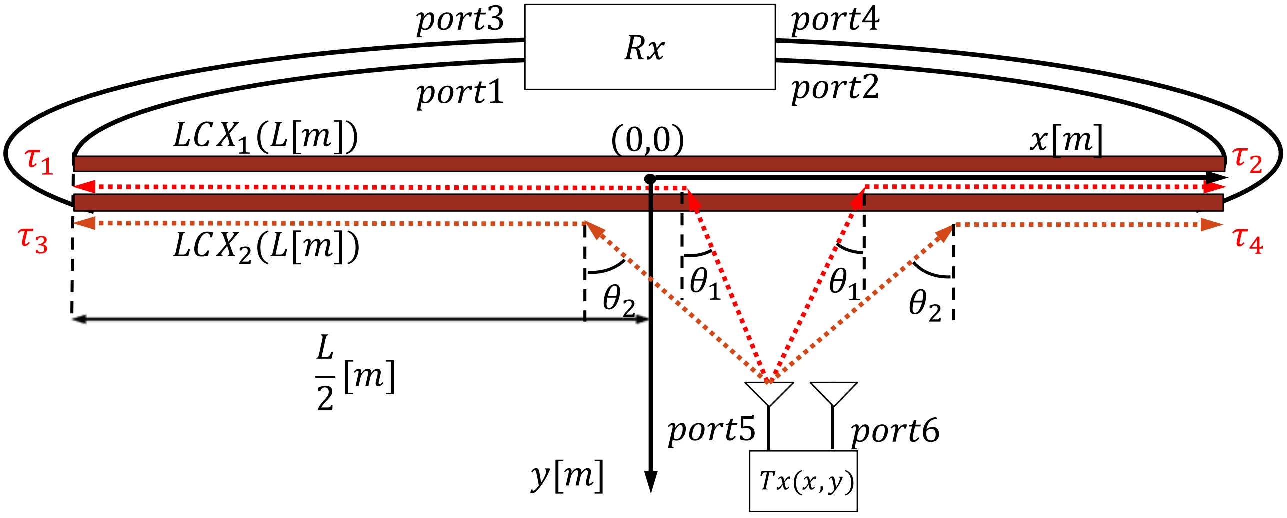

Fig. 2: Coordinate of the system

waves leaked from the slots interfere with each other and have directivity with a peak at a specific angle.

Fig.2 shows a coordinate of 2 by 4 LCX system. The LCX can be used as a Multiple-Input Multiple-Output (MIMO) antenna by attaching a receiver at both ends. In the figure, the *Tx* module has two antennas (port5 and port6), and the receiver has four antennas (port1, port2, port3, and port4), which is a 2×4 MIMO system. In this system, LCX_1 and LCX_2 with full length L [m] are arranged in parallel. Taking the middle point of LCX as the origin, take the x axis in the horizontal direction and the y axis in the vertical direction with respect to LCX. Place the *Tx* at position (x, y) and send a signal. The signal is received at LCX_1 with an incident angle θ_1 and at LCX_2 with an incident angle θ_2. The time of arrival at port1 to port4 are denoted by τ_1, τ_2, τ_3, and τ_4, respectively. When the propagation path can be geometrically approximated, τ_1 to τ_4 can be represented by the equations from (1) to (4) as,

$$\tau_1 = \frac{1}{\mu c}\left(\frac{L}{2} - (y \tan\theta_1 + x)\right), \tag{1}$$

$$\tau_2 = \frac{1}{\mu c}\left(\frac{L}{2} - (y \tan\theta_1 - x)\right), \tag{2}$$

$$\tau_3 = \frac{1}{\mu c}\left(\frac{L}{2} - (y \tan\theta_2 + x)\right), \tag{3}$$

$$\tau_4 = \frac{1}{\mu c}\left(\frac{L}{2} - (y \tan\theta_2 - x)\right), \tag{4}$$

where c represents the speed of light, and μ represents the wavelength shortening rate of LCX. By solving these equations, x can be determined as the equation (5).

$$x = \frac{\mu c(\tau_1 - \tau_2)}{2} = \frac{\mu c(\tau_3 - \tau_4)}{2} \tag{5}$$

III. CHANNEL IMPULSE RESPONSE ESTIMATION BASED ON THE MUSIC ALGORITHM

The MUSIC algorithm is a method of high resolution frequency estimation. However, its application range extends to estimation of signal arrival direction, elucidation of scattering mechanism of electromagnetic wave, time domain estimation of electromagnetic wave device, etc. In this research, we use the MUSIC algorithm to detect the delay time of the incoming signal. The MUSIC algorithm performs high resolution estimation using the eigenvalues and eigenvectors of the correlation matrix obtained from the output signal.

When there are N sampling points in the frequency band, the relationship between the kth ($k = 1, ..., N$) output signal x_k and the input signal s_i is expressed by,

$$x_k(f) = \sum_{i=1}^{d} \boldsymbol{a}(\tau_i) s_i(f) + \boldsymbol{n}(f). \tag{6}$$

In the equation (6), d is the number of incoming signals, $\boldsymbol{n}(f)$ is a noise vector, and $\boldsymbol{a}(\tau_i)$ is a vector composed of Fourier operators, and is expressed as,

$$\boldsymbol{a}(\tau_i) = [\exp(-j2\pi f_1 \tau_i), \exp(-j2\pi f_2 \tau_i), ..., \exp(-j2\pi f_N \tau_i)]^{\mathrm{T}}. \tag{7}$$

The output signal vector $\boldsymbol{x}(f)$ is defined as,

$$\boldsymbol{x}(f) = \boldsymbol{A}\boldsymbol{s}(f) + \boldsymbol{n}(f), \tag{8}$$

where

$$\boldsymbol{x}(f) = [x_1(f), ..., x_N(f)],$$
$$\boldsymbol{A} = [\boldsymbol{a}(\tau_1), ..., \boldsymbol{a}(\tau_d)],$$
$$\boldsymbol{s}(f) = [s_1(f), ..., s_d(f)]^{\mathrm{T}}.$$

The correlation matrix of the output signal $\boldsymbol{R}_{xx}$ is expressed as the equation (9),

$$\boldsymbol{R}_{xx} = E\{\boldsymbol{x}(f)\boldsymbol{x}^H(f)\}. \tag{9}$$

In the equation (9), $E\{\}$ represents the ensemble average, and H represents the Hermitian transpose.

TABLE I: Parameter of measurement

LCX length L	$10[\mathrm{m}]$
Wavelength shortening rate μ	0.83
Maximum radiation angle θ	LCX1: -18, LCX2: -11 [deg]
Center frequency f_c	$5.230[\mathrm{GHz}]$
Frequency range	$5.1675-5.2925[\mathrm{GHz}]$
Bandwidth	$125[\mathrm{MHz}]$
Frequency resolution Δf	$312.5[\mathrm{kHz}]$
# of frequency bin	401
# of incoming signal d	1
x range(min-max: step)	$0-6.0198:25.4[\mathrm{mm}]$
y range(min-max: step)	$0.5-2.5:0.5[\mathrm{m}]$

Define $\boldsymbol{R}_{xx}$'s eigenvalues and eigenvectors as $\lambda_1,...,\lambda_N(\lambda_1 \geq ... \geq \lambda_N)$ and $\boldsymbol{e}_1,...,\boldsymbol{e}_N$. Eigenvectors can be divided in two parts, signal space $\boldsymbol{E}_S=(\boldsymbol{e}_1...\boldsymbol{e}_d)$ and noise space $\boldsymbol{E}_N=(\boldsymbol{e}_{d+1}...\boldsymbol{e}_N)$.

A pseudo spectrum $P(\tau)$ is generated using the noise space $\boldsymbol{E}_N$ and the Fourier operator $\boldsymbol{a}(\tau)$ such as the equation (10).

$$P(\tau)=\frac{\boldsymbol{a}^H(\tau)\boldsymbol{a}(\tau)}{\boldsymbol{a}^H(\tau)\boldsymbol{E}_N\boldsymbol{E}_N^H\boldsymbol{a}(\tau)} \tag{10}$$

When this $P(\tau)$ takes a peak, τ is a desired delay time. The MUSIC algorithm can freely set the time resolution of the pseudo spectrum regardless of the measured bandwidth.

IV. MEASUREMENT AND PERFORMANCE

The frequency response of the channel was measured in the anechoic chamber. The set up measurement is shown in Fig.3. The specification is shown in Table I. The location of the terminal was estimated using measured frequency response. The parameter in analysis is shown in Table II.

TABLE II: Parameter in analysis

Fig. #	Fig.4, 5	Fig.6, 7
Center frequency f_c	$5.230[\mathrm{GHz}]$	
Bandwidth B	$20[\mathrm{MHz}]$	
Frequency range(min-max)	$5.22-5.24[\mathrm{GHz}]$	
Frequency span Δf	$312.5[\mathrm{kHz}]$	
Speed of light c	$3.0\times10^8[\mathrm{m/s}]$	
Wavelength reduction rate μ	0.83	
Maximum radiation angle θ	LCX1: -18, LCX2: -11 [deg]	
MUSIC's time resolution Δt	$1[\mathrm{nsec}]$	$1,10,40,50[\mathrm{nsec}]$
SNR	-	$20[\mathrm{dB}]$
x range	$2540[\mathrm{mm}]$	$0-5029.2:25.4[\mathrm{mm}]$
y	$2[\mathrm{m}]$	

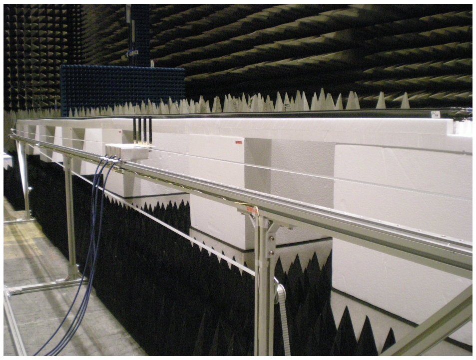

Fig. 3: Experimental setup in the anechoic chamber

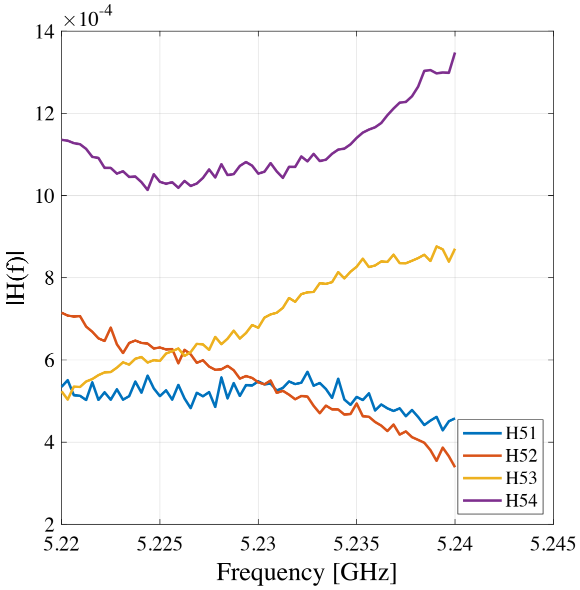

Fig. 4: Sample result of frequency response

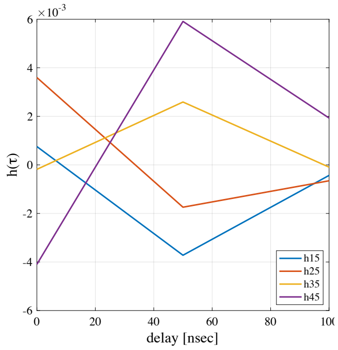

Fig. 5: IFFT

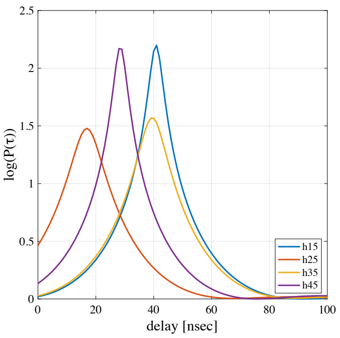

Fig. 6: MUSIC

First, impulse response was obtained from the measured channel response by using IFFT and pseudo response was obtained by using the MUSIC. The channel response of the band used for analysis is shown in Fig.4. 64 frequency points were used for calculating pseudo response, it is equivalent that 64 antenna elements are used for estimating AOA in conventional MUSIC. Calculation results are shown in Fig.5, 6. The bandwidth used for estimation is $20[\mathrm{MHz}]$. The time resolution of IFFT is determined by the reciprocal of measured bandwidth, that was $50[\mathrm{nsec}]$ and the MUSIC algorithm was set as $1[\mathrm{nsec}]$. The coordinate of the terminal is $(x,y)=(2.54,2)$. Although the time response was obtained from the same frequency response, the difference in the method showed a big difference in the waveform. It can be said that it is easier to specify the time resolution and it is easier to calculate the peak value more accurately if the MUSIC algorithm is used. Next, the x coordinate of the terminal was estimated by substituting the time τ for taking a peak in this time response into the equation (5). In this simulation, white Gaussian noise was added so that the SNR (Signal-to-Noise power Ratio) was $20[\mathrm{dB}]$. The x coordinate was estimated every $25.4[\mathrm{mm}]$ from 0 to $5029.2[\mathrm{mm}]$. The y coordinate was fixed at $2[\mathrm{m}]$. The time resolution Δt of the MUSIC algorithm was changed to $1,\ 10,\ 40,\ 50[\mathrm{nsec}]$ for performance comparison. The time resolution of IFFT was $50[\mathrm{nsec}]$.

Fig.7 shows relationship between x coordinate and estimation error when the MUSIC algorithm as $\Delta t = 1[\mathrm{nsec}]$ and IFFT is used. In addition, the lines which becomes the error $\pm 1[\mathrm{m}]$ are displayed together. In Fig.7, the error increases in both methods in the vicinity of 0 to $2[\mathrm{m}]$ of x. This is due to the large influence of the observation error. From equation (9), it is necessary to take an ensemble average to improve the accuracy of the correlation matrix. However, since these estimations use measurement data that has been made only once, it is considered that the accuracy has partially dropped. Comparing the two results, it can be seen that the estimation accuracy is improved when the MUSIC algorithm is used compared to IFFT. It can be seen that even with the estimation using the same frequency band, the MUSIC algorithm, which can freely determine the time resolution, can achieve more accurate estimation than the IFFT in which the time resolution is limited by the bandwidth.

The absolute error of CDF is shown in Fig.8. The relationship between the time resolution of the MUSIC algorithm and the absolute error can be found from Fig.8. When the time resolution of the MUSIC algorithm is $10[\mathrm{nsec}]$ or less, about 90% is less than $1[\mathrm{m}]$ error, when the time resolution is $50[\mathrm{nsec}]$ or IFFT, the error is less than $1[\mathrm{m}]$ remains less than 20%. As the time resolution of the MUSIC algorithm increases, the waveform shown in Fig.6 becomes rough, making it difficult to accurately find peaks, leading large error.

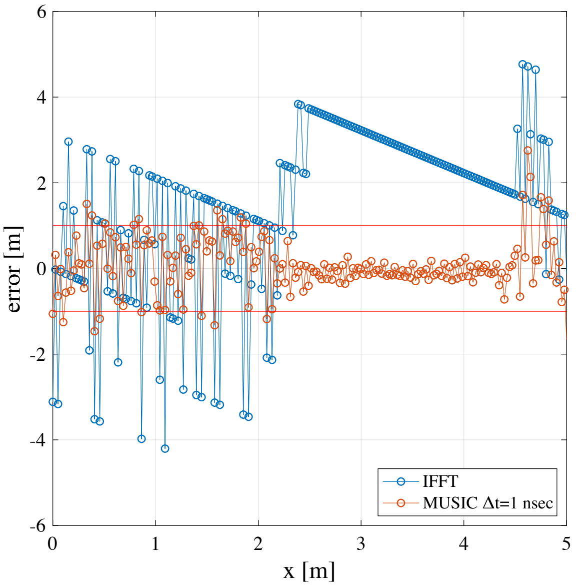

Fig. 7: Relationship between x-axis and error

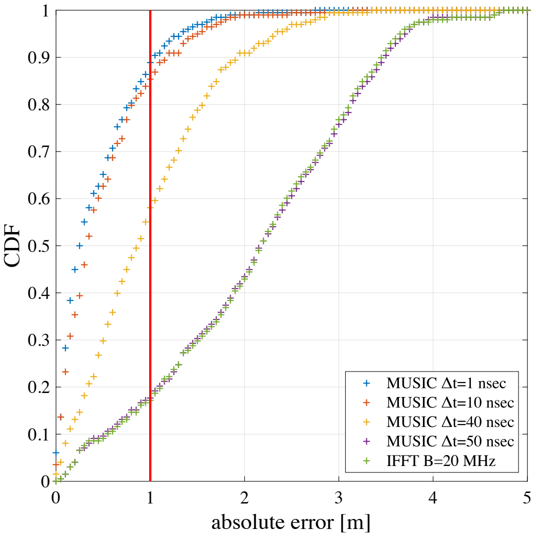

Fig. 8: CDF performance in absolute error

V. CONCLUSION

In this paper, The error performance in positioning using the MUSIC algorithm has been investigated experimentally in the 2 by 4 LCX antenna system at 5GHz. In the MUSIC algorithm, 90% of the estimation result is less than error of $1[\mathrm{m}]$ when the time resolution is set as $10[\mathrm{nsec}]$. In the IFFT, since the time resolution depends on the bandwidth, the estimation accuracy is degraded in the narrowband transmission, and in the transmission with the bandwidth of $20[\mathrm{MHz}]$, the estimation result is less than $1[\mathrm{m}]$ only in 20% of the estimation result. From the above, it is clear from the CDF comparison that the result using the MUSIC algorithm is superior to the IFFT.

REFERENCES

[1] Ralph O. SCHMIDT, “Multiple Emitter Location and Signal Parameter Estimation,” IEEE Transactions on antennas and propagation, Vol. AP-34, No.3, March 1986.
[2] Josep Vidal, Montse Nájar, and René Játiva, “High resolution time-of-arrival detection for wireless positioning systems,” Vehicular Technology Conference, 1988, IEEE 38th, February 2002.
[3] Shuhei Oki, Takeshi Higashino and Minoru Okada, “Proposal of LCX-assisted Wireless Positioning using Modified Subspace Method,” 2013 IEEE International Conference on Electronics Technology and Industrial Development, 23 Oct. 2013.
[4] Samer S. Saab, and Zahi S. Nakad, “A Standalone RFID Indoor Positioning System Using Passive Tags,” IEEE Transactions on industrial electronics, vol.58, no.5, pp.1961-1970, May 2011.
[5] Hao Ni, Guangliang Ren, and Yilin Chang, “A TDOA Location Scheme in OFDM Based WMANs,” IEEE Transactions on consumer electronics, vol.54, no.3, pp.1017-1021, August 2008.
[6] Kenji Inomata, Takashi Hirai, and Yoshio Yamaguchi, “Two-Dimentional Target Location Estimation Technique Using Leaky Coaxial Cables,” IEICE Trans. commun., vol. E91-B, No.3 March 2008.
[7] Xinrong Li, and Kaveh Pahlavan, “Super-Resolution TOA Estimation With Diversity for Indoor Geolocation,” IEEE Trans. wireless communication, vol.3, No.1, pp.224-234, January 2004.