Considerations for Design and Implementation of a RF Emitter Localization System with Array Antennas

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ABSTRACT

In this paper, design and implementation issues for a network-oriented RF emitter localization system with array antenna are discussed. For hardware, the problem of array mismatch and RF/IF channel mismatch are introduced and the calibration schemes for solving those problems are also provided. For software, it is explained how to overcome the drawback of conventional MUltiple Signal Identification and Classification (MUSIC) algorithm in a point of identifying the number of received signals and problems such as Data Association Problem and Ghost Node Problem in regard to multiple emitter localization are presented with some approaches for getting around those problems. Finally, for implementation, a criterion for arranging each of sensors and a requirement for alignment of array antenna' orientation are also given.

Keywords: localization, array antenna, angle-of-arrival

1. INTRODUCTION

A positioning method using radio frequency (RF) was used to identify the location of soldiers in emergency during the World War II for the first time. In the Vietnam War, a global positioning system (GPS) was introduced. Since then, GPS has been used in various commercial areas from 1990s. Although GPS is the most widely used positioning system in outdoor environments, it is limited to be used in indoor environments (Pahlavan et al. 2002, Sayed et al. 2005, Fang & Lin 2008).

Thus, it is highly important to develop indoor positioning technologies using RF (Sayed et al. 2005). Indoor positioning technologies can be utilized in various fields such as commercial, military, and public safety (Gustafsson & Gunnarsson 2005). For example, in commercial fields, demand on tracking locations of children, the elderly, and visually impaired people has increased consistently in households and hospitals. In public safety and military fields, it is necessary to have a system that can track locations of policemen, fire fighters, and soldiers who perform missions in indoor environments (Sayed et al. 2005).

Furthermore, recent location tracking technologies have been utilized in context-aware computing (Hightower & Borriello 2001) and location based services usefully. As examples of applications, asset tracking, context-aware computing, pervasive computing, wireless access security, and mobile advertisement (Yunos et al. 2003) can be found and various personal robotics applications are also included (Jensfelt 2001).

In general, positioning technologies are classified into device-oriented and network-oriented technologies. The device-oriented technology is to determine a location by receiving signals transmitted from infrastructures at a mobile device. The network-oriented technology is to determine a location by receiving signals transmitted from mobile devices at sensors in network infrastructures (Cook & Das 2004). The device-oriented technology has higher hardware requirements of mobile devices than those of the network-oriented technology. However, since the device-oriented technology can determine a location by device
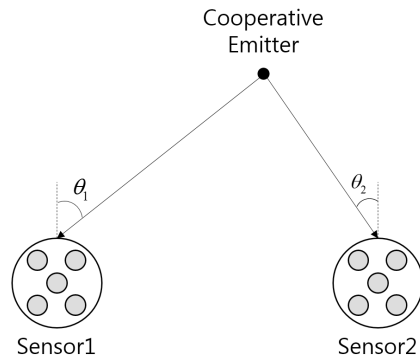
Fig. 1. Structure of network oriented localization system with array antenna.

itself rather than by infrastructures, it can have an advantage of controlling location information. GPS is one of the most well-known device-oriented location determination systems, but it is limited to be used in indoor environments. In contrast with the device-oriented technology, mobile devices at the network-oriented technology are required to create a simple and appropriate signals, which are less complex requirements that devices have in a relative sense (Stella et al. 2012).

As a technology that determines a location of emitter, Time of Arrival (TOA), Time Difference of Arrival (TDOA), Angle of Arrival (AOA), and Received Signal Strength (RSS) can be found. Patwari et al. (2005) compared four techniques of Cramer Rao Bound with regard to cooperative transmitters. However, these techniques have a weakness to determine a location of non-cooperative transmitters. This is because non-cooperative transmitters transmit various types of signals irregularly in order to avoid a detection of their own locations. Thus, determination of location of non-cooperative transmitters remains challenging (Berdanier & Wu 2013).

The location tracking technologies using RF signals have been studied consistently and some related products have been launched in market. However, few studies have been conducted on system design or implementation except for studies on algorithms. Thus, this study discusses issues that can occur while designing and implementing systems that track locations of RF emitters using sensors with array antennas based on network-orientation as shown in Fig. 1, and introduces a solution to the issues.

2. RF EMITTER LOCALIZATION SYSTEM WITH ARRAY ANTENNA

2.1 AOA Algorithm

In this section, the general principle of AOA estimation

Table 1. Comparison of angle estimation methods.

Technique	Advantages	Drawbacks
Capon	- High resolution	- Limited performance due to noise power of antenna
MUSIC	- Intermediate resolution	- Performance lower than that of ESPRIT algorithm - Sensitive to incident signal gains and phase error - Sensitive to synchronized multi-path errors
ESPRIT	- High resolution - Robust to non-precision array antennas	- Much computation - Limitation of antenna layout - Require many snap shots
ML	- Optimized only in environments where white noise and preferred signals are applied	- Much computation - Require many snap shots

is explained and characteristics of AOA estimates are analyzed. The AOA estimation technique can be classified into spectrum estimation and parameter estimation techniques. As the spectrum estimation technique, Capon Minimum Variance and MUltiple Signal Identification and Classification (MUSIC) can be found. The typical parameter estimation techniques are Estimation of Signal Parameter via Rotational Invariance Technique (ESPRIT) and Maximum Likelihood (ML). The advantages and drawbacks of each technique are listed in Table 1 and among them, MUSIC and ESPRIT are two of the best performance techniques compared to complexity (Ramos et al. 1999). However, ESPRIT can only be applied to linear array antenna so currently MUSIC has been most widely used. Thus, this study estimates an angle of arrival using the MUSIC.

The mathematical model that expresses the MUSIC technique is as follows: When M signals are incident to an array antenna with L elements, input signal $\tilde{\mathbf{x}}(t)$ can be expressed as shown in Eq. (1).

$$\mathbf{x}(t) = \sum_{i=1}^{M} \mathbf{A}(\theta_i, \phi_i) s_i(t) + \mathbf{n}(t)$$
$$= \begin{bmatrix} \alpha_1(\theta_1,\phi_1) & \cdots & \alpha_1(\theta_M,\phi_M) \\ \vdots & \ddots & \vdots \\ \alpha_L(\theta_1,\phi_1) & \cdots & \alpha_L(\theta_M,\phi_M) \end{bmatrix} \begin{bmatrix} s_1(t) \\ \vdots \\ s_M(t) \end{bmatrix} + \begin{bmatrix} n_1(t) \\ \vdots \\ n_L(t) \end{bmatrix}$$
$$= \mathbf{A}(t)\mathbf{s}(t) + \mathbf{n}(t) \tag{1}$$

where $s_i(t)$ refers to the i-th signal vector and $\mathbf{A}(\theta_i, \phi_i)$ refers to a direction vector according to the i-th signal elevation angle θ_i and azimuth ϕ_i, and $\mathbf{n}(t)$ refers to a noise vector, which is assumed to have normal distribution. Covariance matrix of the input signal can be calculated via Eq. (2) and $(\cdot)^H$ refers to the Hermitian of the matrix.

$$\begin{aligned}
\mathbf{R}(t) &= E\left[\mathbf{x}(t)\mathbf{x}(t)^H\right] \\
&= \mathbf{A}E\left[\mathbf{s}(t)\mathbf{s}(t)^H\right]\mathbf{A}^H + E\left[\mathbf{n}(t)\mathbf{n}(t)^H\right] \\
&= \mathbf{A}\mathbf{S}\mathbf{A}^H + \sigma^2\mathbf{I}
\end{aligned} \tag{2}$$

where $\mathbf{S}$ is a covariance matrix of the signal and σ^2 is a noise covariance.

If Eq. (2) is arranged with respect to discrete time, it gives Eq. (3).

$$\begin{aligned}
\hat{\mathbf{R}}(t) &= \frac{1}{K}\sum_{k=1}^{K}\mathbf{x}(k)\mathbf{x}(k)^H \\
&= \frac{1}{K}\sum_{k=1}^{K}\mathbf{A}\mathbf{s}(k)\mathbf{s}(k)^H\mathbf{A}^H + \frac{1}{K}\sum_{k=1}^{K}\mathbf{n}(t)\mathbf{n}(t)^H \\
&= \mathbf{A}\hat{\mathbf{S}}\mathbf{A}^H + \hat{\sigma}^2\mathbf{I}
\end{aligned} \tag{3}$$

where if the $\mathbf{A}\hat{\mathbf{S}}\mathbf{A}^H$ matrix rank M is smaller than the number L of elements of array antenna, $\mathbf{A}\hat{\mathbf{S}}\mathbf{A}^H$ minimum Eigen value becomes 0 and it has L-M multiplicities. If it is expressed as an equation, it can produce a matrix of Eigen-decomposition as shown in Eq. (4) (Strang 1980).

$$\mathbf{A}\hat{\mathbf{S}}\mathbf{A}^H = \mathbf{V}\begin{bmatrix}\Lambda_M & 0 \\ 0 & 0\end{bmatrix}\mathbf{V}^H \tag{4}$$

where $\mathbf{V}=[v_1\ v_2\ ...\ v_L]$ is an orthogonal Eigen vector and Λ_M refers to Eigen values that are not 0. Using Eq. (4), it gives Eq. (5) by re-arranging Eq. (3).

$$\hat{\mathbf{R}}(t) = \mathbf{V}\begin{bmatrix}\Lambda_M & 0 \\ 0 & 0\end{bmatrix}\mathbf{V}^H + \sigma^2\mathbf{V}\mathbf{V}^H = \mathbf{V}\Lambda\mathbf{V}^H \tag{5}$$

Here, it satisfies $\Lambda = \begin{bmatrix}\Lambda_M + \sigma^2\mathbf{I} & 0 \\ 0 & \sigma^2\mathbf{I}\end{bmatrix}$.

Eq. (5) indicates that a subspace is divided into signal and noise and Eq. (6) refers to Eigen value that expresses the subspace of the signal and Eq. (7) refers to Eigen value that expresses a subspace of noise. Thus, the number of signals can be estimated as L Eigen values from which Eigen values that satisfy Eq. (7) are subtracted.

$$\lambda_i > \sigma^2,\ i = 1, ..., M \tag{6}$$
$$\lambda_i = \sigma^2,\ i = M+1, ..., L \tag{7}$$

As explained in the above, MUSIC makes use of orthogonal characteristics ($\mathbf{V}_n^H\mathbf{A}=0$) of signal's directional vector $\tilde{A}$ and Eigen vector $\mathbf{V}_n=[v_{M+1}\ v_{M+2}\ ...\ v_L]$ that corresponds to noise among the Eigen vectors of signals inputted into array antennas. Thus, the output power $P_{MUSIC}(\theta, \phi)$ in the MUSIC is calculated via Eq. (8).

$$P_{MUSIC}(\theta_i, \phi_i) = \frac{1}{\alpha^H(\theta_i, \phi_i)\mathbf{V}_n\mathbf{V}_n^H\alpha(\theta_i, \phi_i)} \tag{8}$$

An angle of arrival with respect to M signals is determined by searching the output power $P_{MUSIC}(\theta_i, \phi_i)$ in Eq. (8), which is the objective function with regard to (θ_i, ϕ_i), and finding the AOA that makes the maximum power spectrum of each signal. Here, an elevation angle is searched from 0° to 90° and azimuth is searched from 0° to 360°. An interval of search is determined considering the performance goal and computational capability of the system.

2.2 Localization Algorithm

Among the AOA measurement values, a relationship between azimuth and signal source locations can be given as Eq. (9).

$$\phi_i = \tan^{-1}\left(\frac{y-y_i}{x-x_i}\right) + n_i^\phi \tag{9}$$

Here, n_i^ϕ refers to a measurement noise of azimuth. Eq. (9) can be expanded to Eq. (10).

$$\begin{aligned}
\frac{\sin(\phi_i - n_i^\phi)}{\cos(\phi_i - n_i^\phi)} &= \frac{y-y_i}{x-x_i} \\
\frac{\sin\phi_i\cos n_i^\phi - \cos\phi_i\sin n_i^\phi}{\cos\phi_i\cos n_i^\phi + \sin\phi_i\sin n_i^\phi} &= \frac{y-y_i}{x-x_i}
\end{aligned} \tag{10}$$

If it is approximated to $\sin n_i^\phi \cong n_i^\phi$ and $\cos n_i^\phi \cong 1$, Eq. (10) can be represented as Eq. (11) (Du & Lee 2004, Broumandan et al. 2008).

$$\begin{aligned}
0 \cong -(x-x_i)\sin\phi_i + (y-y_i)\cos\phi_i \\
+ \sqrt{(x-x_i)^2 + (y-y_i)^2}\,n_i^\phi
\end{aligned} \tag{11}$$

Thus, the measurement equation can be obtained as Eq. (12) and a horizontal location can be estimated using least square technique via Eq. (12).

$$\begin{aligned}
-x_i\sin\phi_i + y_i\cos\phi_i = -x\sin\phi_i + y\cos\phi_i \\
+ \sqrt{(x-x_i)^2 + (y-y_i)^2}\,n_i^\phi
\end{aligned} \tag{12}$$

Furthermore, a relationship of location between elevation angle and signal source can be given as Eq. (13).

$$\theta_i = \tan^{-1}\left(\frac{z-z_i}{\sqrt{(x-x_i)^2 + (y-y_i)^2}}\right) + n_i^\theta \tag{13}$$

Here, n_i^ϕ refers to a measurement noise of elevation angle. Eq. (13) can be expanded to Eq. (14).

$$\tan\left(\theta_i - n_i^\theta\right) = \frac{z - z_i}{\sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2}}$$

$$\frac{\sin\theta_i \cos n_i^\theta - \cos\theta_i \sin n_i^\theta}{\cos\theta_i \cos n_i^\theta + \sin\theta_i \sin n_i^\theta} = \frac{z - z_i}{\sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2}} \quad (14)$$

It is approximated into $\sin n_i^\theta \cong n_i^\theta$ and $\cos n_i^\theta \cong 1$ thereby obtaining Eq. (15).

$$-\sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2}\,\sin\theta_i - n_i^\theta \cos\theta_i$$
$$= \left(z - z_i\right)\cos\theta_i + \left(z - z_i\right)n_i^\theta \sin\theta_i \quad (15)$$

Eq. (15) can be represented as Eq. (16) using $\cos\theta_i = \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2} \Big/ \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(z - z_i\right)^2}$ and $\cos\phi_i = \left(x - x_i\right) \Big/ \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2}$ (Peng & Sichitiu 2006, Lim et al. 2012).

$$0 \cong -\left(x - x_i\right)\frac{\sin\theta_i}{\cos\phi_i} + \left(z - z_i\right)\cos\theta_i$$
$$+ \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(z - z_i\right)^2}\,n_i^\theta \quad (16)$$

Finally, a location can be estimated using a least square technique via the measurement equation arranged to Eq. (17).

$$-x_i \frac{\sin\theta_i}{\cos\phi_i} + z_i \cos\theta_i = -x \frac{\sin\theta_i}{\cos\phi_i} + z \cos\theta_i$$
$$+ \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(z - z_i\right)^2}\,n_i^\theta \quad (17)$$

As shown in Eq. (17), a three-dimensional location can be obtained by either estimating the vertical location after horizontal location is estimated or combining Eqs. (12, 17) at once.

The TDOA technique has a non-linear type of measurement equation in contrast with the AOA technique. It is linearized using the Taylor's Series Expansion at an arbitrary location and estimates a location with an iterative form. Thus, AOA measurement equation should be changed to an iterative form as shown in Eqs. (18) and (19) to perform the composite positioning of TDOA and AOA.

$$-\left(x_i - x_0\right)\sin\phi_i + \left(y_i - y_0\right)\cos\phi_i$$
$$= -\left(x - x_0\right)\sin\phi_i + \left(y - y_0\right)\cos\phi_i$$
$$+ \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2}\,n_i^\phi \quad (18)$$

$$-\left(x_i - x_0\right)\frac{\sin\theta_i}{\cos\phi_i} + \left(z_i - z_0\right)\cos\theta_i$$
$$= -\left(x - x_0\right)\frac{\sin\theta_i}{\cos\phi_i} + \left(z - z_0\right)\cos\theta_i$$
$$+ \sqrt{\left(x - x_i\right)^2 + \left(y - y_i\right)^2 + \left(z - z_i\right)^2}\,n_i^\theta \quad (19)$$

where (x_0, y_0, z_0) is an initial location, which can be obtained using only the AOA technique or direct solution method based on the TDOA. The measurement matrix is shown in Eq. (20).

$$\begin{bmatrix} -\left(x_1 - x_0\right)\sin\phi_1 + \left(y_1 - y_0\right)\cos\phi_1 \\ \vdots \\ -\left(x_N - x_0\right)\sin\phi_N + \left(y_N - y_0\right)\cos\phi_N \\ -\left(x_1 - x_0\right)\frac{\sin\theta_1}{\cos\phi_1} + \left(z_1 - z_0\right)\cos\theta_1 \\ \vdots \\ -\left(x_N - x_0\right)\frac{\sin\theta_N}{\cos\phi_N} + \left(z_N - z_0\right)\cos\theta_N \end{bmatrix} = \begin{bmatrix} -\sin\phi_1 & \cos\phi_1 & 0 \\ \vdots & \vdots & \vdots \\ -\sin\phi_N & \cos\phi_N & 0 \\ -\frac{\sin\theta_1}{\cos\phi_1} & 0 & \cos\theta_1 \\ \vdots & \vdots & \vdots \\ -\frac{\sin\theta_N}{\cos\phi_N} & 0 & \cos\theta_N \end{bmatrix} \begin{bmatrix} x - x_0 \\ y - y_0 \\ z - z_0 \end{bmatrix} \quad (20)$$

where N is the number of sensors.

3. DESIGN AND IMPLEMENTATION ISSUES

3.1 Calibration of Antenna Mismatch

Since the number of elements and type in array antenna are directly related to performance objectives of a system, they should be considered during the system design. When the number of elements in array antenna is N with regard to narrow-band signals, AOA measurement values can be acquired up to N-1 signals (Chen et al. 2010). Comparing configurations of array antenna, performance of uniform circular array (UCA) is known to be better than that of uniform linear array (ULA) (Shen & Win 2010, Tan 2010).

In order to obtain accurate AOA measurement values, ideal array antennas are needed but errors are present due to mismatch of amplitude and phase and inaccuracy of mutual coupling and antenna element location (Tan 2010). Thus, accurate AOA measurement values can be acquired when these errors are calibrated during the system implementation. There are several calibration methods. In general, transmitters are arranged at generally known positions and amplitude and phase responses of array antennas are measured and calibrated (Cherntanomwong et al. 2005, Tan 2010).

3.2 Calibration of Channel Mismatch

When an AOA is estimated using array antennas, phase response of the RF front-end of each antenna elements in array antenna should be synchronized. To achieve
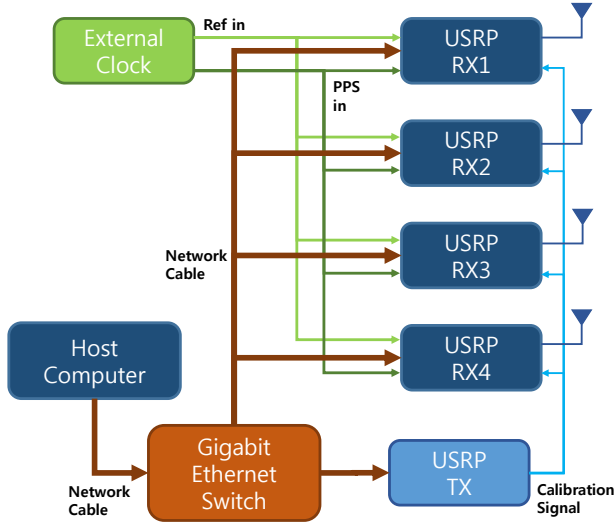
Fig. 2. Array test bench setup comprised of four antennas and NI USRP boards.

Fig. 3. Steps involved in MUSIC, Root-MUSIC and gold-MUSIC.

this, a common clock is used during signal demodulation but phase delay occurred at filters may vary so it is not sufficient. Thus, as shown in Fig. 2, a method that measures a phase difference occurred at the output of each channel after known signals of the same phase thereby calibrating the difference has been widely used (National Instruments 2016).

3.3 AOA Algorithm

Eigen values acquired using general MUSIC algorithms do not satisfy Eq. (7) but show the characteristics as shown in Eq. (21).

$$\lambda_i \approx \sigma^2, \, i = M+1, \ldots, L \qquad (21)$$

Therefore, it is difficult to estimate the number (M) of input signals. To solve this problem, a number of statistical approaches have been proposed. Typically, Akaike Information theoretic Criteria (AIC) and Minimum Description Length criteria (MDL) proposed by Wax & Kailath (1985) and predicted Eigen-Threshold (ET) approach proposed by Chen et al. (1991) can be found. However, these methods have been known to show poor performance over the colored noise environment (Tan 2010).

Even if the number of input signals can be known accurately, it is still difficult to perform location estimation of multiple signals. To estimate a location of transmitter, AOA measurement values at each sensor should be combined but it is not known that each measurement value is transmitted which transmitter. This problem was firstly
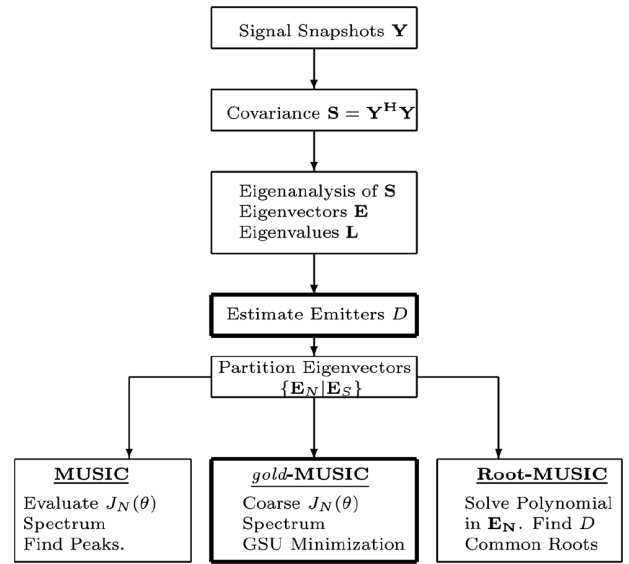
recognized in 1964 and now it is known as Data Association Problem (Sittler 1964) or Ghost Node Problem (Reed 2009). The solution to this problem is to use a brute force approach or line of bearing (LoB) intersection clustering-based approach. The brute force approach estimates the locations of all transmitters with respect to combination of AOA measurement values and the number of all cases and predicts the AOA again from the estimated locations thereby finding the final location of transmitter by searching the minimum location of residual between measured and predicted values. This method can be applicable when the number of transmitters and sensors is small because of much computation. The LoB intersection clustering based approach is based on K-means algorithm and it is a sub-optimal technique of the brute force approach. However, it has as advantage of less computation than brute force method (Makhoul et al. 1985, Proakis 2001).

MUSIC algorithms have been improved to enhance resolution and reduce computation. Among the improved algorithms, root-MUSIC is an algorithm based on the square root of the polynomial, which provides high resolution but has a limitation that it can only be applied to linear array antennas (Rubsamen & Gershman 2008). gold-MUSIC employs an iterative method based on gold-section univariate (GSU) minimization thereby obtaining accurate measured values with regard to a wide range of signal to noise ratio (SNR) (Rangarao & Venkatanarasimhan 2013). Thus, appropriate algorithm should be selected according to application fields and processing procedure of each algorithm is summarized in Fig. 3. There are other algorithms such as one that is applied to multi-path
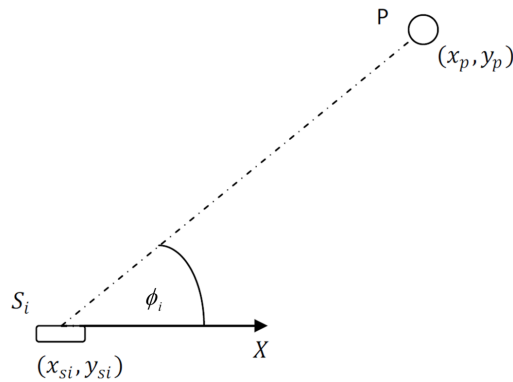
Fig. 4. AOA measurement from a sensor.

environment such as indoor space or urban areas (Seow & Tan 2008, Gentile et al. 2013, Wielandt 2015) and filtering or smoothing method (Wielandt et al. 2014) should also be considered.

3.4 Arrangement of Each Sensors

Since the arrangement of sensors (array antennas) is closely related to system performance, a relationship between them should be identified first prior to arranging them. As shown in Fig. 4, when the i-th sensor and arbitrary transmitter are located at $S_i = [x_{si} \ y_{si}]^T$ and $p = [x_p \ y_p]^T$, covariance of location estimation error can be expressed as defined in Eq. (22) using the Cramer-Rao inequality.

$$E[(\hat{p} - p)(\hat{p} - p)^T] \geq I^{-1}(p) = C(p) \qquad (22)$$

where I refers to Fisher information matrix. When the characteristic of AOA measurement values about N sensors is $\hat{z} \sim N(z(p), R_z)$, Fisher information matrix can be expressed as shown in Eq. (23).

$$I(p) = \nabla_p z(p)^T R_z^{-1} \nabla_p z(p) \qquad (23)$$

A relationship equation between azimuth and transmitter location among the AOA measurement values is defined in Eq. (9) and for $n_i^\Phi \sim N(0, \sigma_\phi^2)$, Fisher information matrix from Eq. (23) can be obtained using Eq. (24) (Herath & Pathirana 2013).

$$I_\phi(p) = \frac{1}{\sigma_\phi^2} \sum_{i=1}^{N} \frac{1}{r_i^2} \begin{bmatrix} \sin^2\phi_i & -\sin\phi_i\cos\phi_i \\ -\sin\phi_i\cos\phi_i & \cos^2\phi_i \end{bmatrix} \qquad (24)$$

Here, it satisfies $r_i = \|p - S_i\|$.

As shown in Eq. (24), performance of the AOA-based location tracking system depends on AOA measurement noise, the number of sensors, a distance between sensor and transmitter, and AOA. Here, unless a transmitter is present
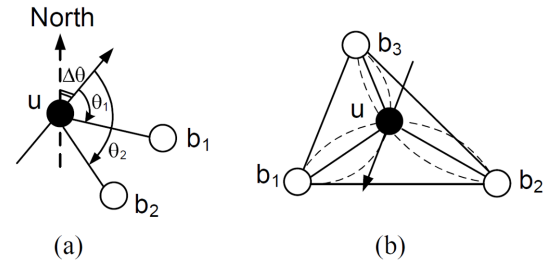
Fig. 5. Triangulation in AOA localization: (a) Localization with orientation information; (b) Localization without orientation information.

at a fixed location, the Fisher information matrix cannot be calculated so it is assumed that a transmitter is located within a given region. By this assumption, a system can be designed in order to satisfy statistical characteristics within the region. The AOA measurement noise can be predicted theoretically from statistical models (Astely & Ottersten 1999, Pedersen et al. 2000, Spencer et al. 2000, Abdi et al. 2002, Andersen & Pedersen 2002). Once the achievable AOA measurement noise is determined, the number of sensors and arrangement can be determined (Lim et al. 2012).

3.5 Alignment of Each Antennas (Measuring Orientation)

The AOA estimated in the algorithm is a relative AOA of signals with regard to the orientation where sensors (array antennas) are installed. Therefore, absolute AOA should be calculated to predict a location of transmitter from the AOA. That is, all sensors should be aligned in specific directions (e.g., true north) or orientation where each sensor is installed should be measured (Peng & Sichitiu 2006). That is, absolute AOAs $\theta_1 + \Delta\theta$ and $\theta_2 + \Delta\theta$ with regard to true north can be calculated by adding sensor's installation orientation $\Delta\theta$ when AOAs of received signals are θ_1 and θ_2 at transmitters b_1 and b_2 as shown in Fig. 5a.

Even when the installation orientation of sensor is not known, AOA can be measured to estimate a location (Peng & Sichitiu 2006) but it can only be applicable to estimate a location of receivers when there are three or more transmitters at already-known locations as shown in Fig. 5b. That is, it cannot be applied to estimate a location of transmitter when sensors are arranged in known locations.

4. CONCLUSIONS

This study summarized issues that can occur while designing and implementing systems that estimated locations of RF emitters using sensors with array antennas based on network-orientation including a solution to the issues. This study explained array antenna error and RF/

IF channel error in terms of hardware and introduced a method to calibrate the error as a solution. From the aspect of software, AIC, MDL, and ET techniques were introduced to explain the problem of typical MUSIC algorithm and solve the problem from the viewpoint of identification of the number of received signals and data association problem or ghost node problem that can occur during the determination of a number of emitters were introduced as well as their solution method. Finally, a relationship between sensor array and performance was presented mathematically to implement the system and the need of orientation alignment of array antennas of each sensor was summarized.

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