DOD-based Localization Technique Using RSSI of Indoor Beacons

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***Abstract*—This paper presents direction of departure (DOD)-based localization technique suitable for indoor environment. Localization is performed by estimating direction from known multiple beacons, where each of them comprises two antennas and $180°$ hybrid. DOD estimation is performed only from received signal strength indicator (RSSI), which does not have phase information. Indoor measurement campaign has been carried out and shown that the terminal node can successfully identify its location with 0.7 m accuracy.**

Keywords*—*RSSI, localization, beacon.

I. Introduction

GNSS (Global Navigation Satellite System) is a powerful and commonly used system for localizing vehicles, etc. in outdoor environment. However, this system is not suitable for indoor localization because this uses the signals from satellites that are usually not available in indoor environment.

To resolve this problem, many attempts using indoor beacons have been undertaken previously. The ranging techniques using ultra wideband (UWB) signals can be used for localizing the nodes by estimating the distances from multiple known UWB beacons [1], [2], but a large bandwidth is required to obtain high accuracy in distance. The use of received signal strength indicator (RSSI) is alternative way to estimate the distance between the beacon and node. RSSI information is available even with the commercialized systems, such as the combination of the Bluetooth beacon and smartphone. Ideally, RSSI simply attenuates with the distance, yet it fluctuates almost randomly in indoor multipath environments. Therefore, ranging relying only on RSSI is not practical. The database of RSSI associated with the location information, which is called as *fingerprint*, is used for identify the node location [3], [4]. Although it is effective in estimating the location even in the multipath environments, the generation of the database is a fatal problem because this database cannot be used if the objects, such as furniture, moved after database creation.

Direction of departure (DOD) and direction of arrival (DOA) estimation using array antennas at multiple known locations is effective in localizing the target even with narrow-band systems [5]. Even though this technique offers quite accurate estimation in location, the phase information in the received signal is required. This means, highly accurate measurement systems, which can observe the phase difference among the array antenna elements, are needed.

The DOA estimation method without phase information has been presented by Enkoji et.al [6], where two element antennas are connected to $180°$ hybrid, and amplitude information of the sum and differential signals are translated to DOA information. Even though this study uses UWB signals, this idea can be extended to narrow band systems.

In this paper, DOD-based localization technique suitable for indoor environment is newly presented. Multiple beacons comprising two antennas connected to beacon transmitter by way of $180°$ hybrid are used. The receiver can estimate its location by observing the signals from multiple beacons, where the locations of the beacons are known. In the following, the overview of the localizing mechanism is described. Also, some experimental results are shown to demonstrate its localization performance.

II. RSSI-based DOD estimation algorithm

Figure 1 shows the proposed system model. A beacon comprises 2 antennas, $180°$ hybrid, and 2 transmitters, and at least 3 beacons are used. Now, we focus on the beacon 1, and the physical channel from beacon 1 antennas to the terminal node is defined as, $\boldsymbol{h}_1 = (h_1, h'_1)$, where the subscripts 1 and $1'$ correspond two antennas, and the elements of the channel are complex values. The correlation matrix is described as,

$$\boldsymbol{R}_1 = \boldsymbol{h}_1^H \boldsymbol{h}_1 = \begin{pmatrix} |h_1|^2 & h_1^* h'_1 \\ h_1'^* h_1 & |h'_1|^2 \end{pmatrix} = \begin{pmatrix} R_{11} & R_{12} \\ R_{21} & R_{22} \end{pmatrix}, \quad (1)$$

where $\{\cdot\}^H$ and $\{\cdot\}^*$ represent Hermitian transpose and complex conjugate operations, respectively. If the phase information of the channel is available, (1) can be directly calculated from the observed channel. However, it is assumed only amplitude information is available at the terminal node in this study. The key idea is the use of the hybrid, which provides clue to the phase information. Actually observed channel at the terminal node is described as,

$$(|h_{1\Sigma}|, |h_{1\Delta}|) = \frac{1}{\sqrt{2}}(|h_1 + h'_1|, |h_1 - h'_1|), \quad (2)$$

where Σ and Δ represent sum and differential values, respectively. On a basis of Jensen's inequality,

$$\begin{aligned} \frac{1}{2}(|h_{1\Sigma}|^2 + |h_{1\Delta}|^2) &= \frac{1}{2}(|h_1|^2 + |h'_1|^2) \\ &\geq |h_1 h'_1| = |R_{12}| \end{aligned} \quad (3)$$

is satisfied. Also,

$$\frac{1}{2}(|h_{1\Sigma}|^2 - |h_{1\Delta}|^2) = \frac{1}{2}(h_1 h_1'^* + h_1^* h'_1) = |R_{12}| \cos\alpha_1 \quad (4)$$

is satisfied, where $\alpha_1 = \angle R_{12}$. If the amplitudes of h_1 and h'_1 are assumed to be equal, α_1 is calculated by the following apprpximation as,

$$\alpha_1 \simeq \pm \cos^{-1}\left\{\frac{|h_{1\Sigma}|^2 - |h_{1\Delta}|^2}{|h_{1\Sigma}|^2 + |h_{1\Delta}|^2}\right\}. \quad (5)$$

Then the diagonal components of (1) is approximated as,

$$R_{11} \simeq R_{22} \simeq |R_{12}| \simeq \frac{1}{2}(|h_{1\Sigma}|^2 + |h_{1\Delta}|^2). \quad (6)$$

Hence, the correlation matrix is approximated as,

$$\boldsymbol{R}_1 \simeq \begin{pmatrix} A & Ae^{j\alpha_1} \\ Ae^{-j\alpha_1} & A \end{pmatrix}, \quad (7)$$

where,

$$A = \frac{1}{2}(|h_{1\Sigma}|^2 + |h_{1\Delta}|^2). \quad (8)$$

This method estimates the correlation matrices that are used for estimating DOD at all Beacons. The terminal node estimates its location by calculating points, where all DOD angles are satisfied. However, the sign of $\alpha_i (i = 1, 2, \cdots)$ is indeterminate. This means two directions are estimated at each beacon, and results in several wrong solutions. To resolve this problem, this method uses at least 3 beacons. If more than 2 beacons are used, a right solution can be identified out of multiple solutions because right solution always appears in all DOD combinations among the beacons. This study therefore extends multiple signal classification (MUSIC) algorithm to the evaluation function as

$$P(\theta_1, \theta_2, \cdots) = \frac{1}{F_{1+}F_{1-} + F_{2+}F_{2-} + \cdots} \quad (9)$$

$$F_{i+} = |\boldsymbol{a}_i^H(\theta_i)\boldsymbol{u}_{ni+}|^2 \quad (10)$$

$$F_{i-} = |\boldsymbol{a}_i^H(\theta_i)\boldsymbol{u}_{ni-}|^2 \quad (11)$$

where i is beacon number, and $\boldsymbol{u}_{ni+}$ and $\boldsymbol{u}_{ni-}$ represent the noise space eigenvectors of $\boldsymbol{R}_i$ corresponding to positive and negative α_i, respectively. The value of (9) becomes maximum at the node location and false images are automatically eliminated.

III. Measurement

Figure 2 shows measurement setup and environment. 3 beacons are located closely to the wall with 1.5 m spacing. All beacons have two-element square microstrip antennas with 0.5 wavelength spacing. A microstrip antenna is also used for the terminal node. The channels between the beacon antennas and terminal node are measured by using vector network analyzer (VNA), and ideal hybrid circuit is assumed. Only the amplitude information is used for estimating the locations. Here, the operation frequency is 2.47 GHz.

Figure 3 shows the spectrum distribution obtained by (9), where ◇, □, ○ represent the locations of beacons, actual node, and estimated node, respectively. In this case, all of the false images are successfully eliminated and the function becomes maximum right at the actual location. The location error was 0.22 m. Also, the location of the terminal nodes was moved all over the location in this environment, and the median estimation error was 0.7 m. The estimation accuracy degradation due to the multiple reflections was observed when the terminal node was located closely to the wall.

IV. Conclusion

This paper has proposed an indoor localization method using DOD information calculated from RSSI. Multiple known beacons are used to identify the location of the terminal node. Measurement campaign has been carried out and shown that the location of the terminal node is successfully identified with 0.7 m accuracy even in indoor environment.

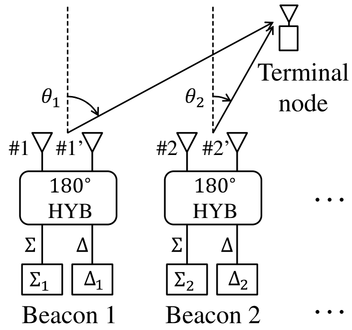

Fig. 1. Phaseless localization system.

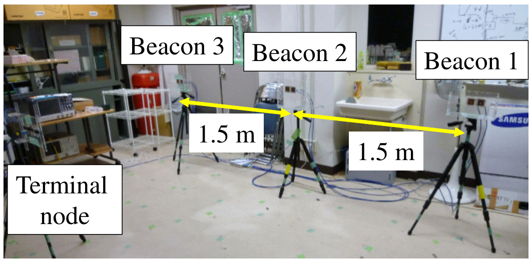

Fig. 2. Measurement setup and environment.

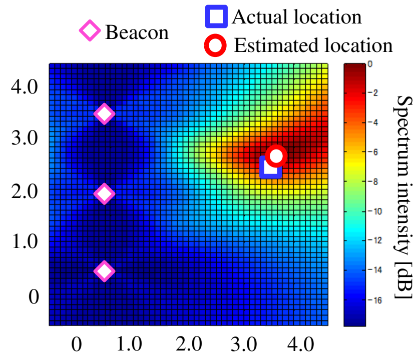

Fig. 3. Spectrum distribution of evaluation function.

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