Non-Line-of-Sight Based Radio Localization With Dual-Polarization Antenna Arrays

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***Abstract*—This work presents an approach for radio-based localization in non-line-of-sight (NLOS) environments by leveraging a dual-polarization antenna array. By estimating the polarization of the received signal, it is possible to estimate the angle of reflection of a NLOS signal. An estimate of the position of the transmitter concerning the receiver can be obtained based on a joint estimation of the reflection angle of several NLOS signals together with their respective directions of arrival (DOAs) and time differences of arrival (TDOAs). A set of numerical simulations is used to assess the performance of the proposed method.**

***Index Terms*—Localization, Dual-Polarization, Angle of Arrival, Time of Arrival, Non-Line-of-Sight**

I. Introduction

Radio-based localization has received increased research interest again in recent years with enabling technologies such as massive multiple-input multiple-output (MIMO) and millimeter wave (mmWave) being driving technologies of modern wireless communication standards such as 5G. Furthermore, future technologies such as autonomous vehicular networks and platooning also require precise localization [1].

Radio-based localization systems rely on estimating parameters such as received signal strength (RSS), direction of arrival (DOA), time difference of arrival (TDOA) of a transmitted signal, and translating such information into a localization estimate for the transmitter.

Most localization methods rely on estimating parameters of the line-of-sight (LOS) component of transmitted signals. Such approaches have their performances heavily degraded under the presence of strong non-line-of-sight (NLOS) components [2]. Approaches that aim to use NLOS components' information in order to obtain improved location estimates, or obtain a localization estimation even in the absence of a LOS component have also been proposed [3]. The application of dual-polarization antenna arrays has been discussed for global navigation satellite systems (GNSS) signals in order to improve localization performance in case of strong NLOS components [4].

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In this work, we propose a geometric location estimation approach that employs a dual-polarization antenna array for positioning under NLOS only conditions (blocked LOS component). The proposed method relies on estimating DOA, TDOA, and the reflection angle of several NLOS components. This information then can be translated into a location estimate for the transmitter as long as the orientation of both transmitter and receiver antennas are known.

II. Signal Model

This work assumes a polarized electromagnetic transmitter that is transmitting a broadband signal and a dual-polarization antenna array receiver composed of M antenna elements, and we consider N impinging wavefronts. The polarized wavefront of the nth path is propagating in direction $\vec{\boldsymbol{d}}_n$. Assuming a signal path that impinges onto a reflective surface with angle ϕ the horizontal and vertical components of the polarized wave are reflected with relative amplitude and phase given by

$$\kappa_h = \frac{E_{h,r}}{E_{h,i}} \quad (1)$$

$$\kappa_v = \frac{E_{v,r}}{E_{v,i}}, \quad (2)$$

where $E_{h,i}$ and $E_{v,i}$ refer to the complex amplitudes of the incident electric field and $E_{h,r}$ and $E_{v,r}$ refer to the complex amplitudes of the reflected electric field. For a smooth, plane surface, κ_h and κ_v can be written as [4]

$$\kappa_h = \frac{\frac{\mu_p}{\mu_r}{\eta_r}^2\cos\phi - \eta_p\sqrt{\eta_r^2 - \eta_p^2\sin\phi^2}}{\frac{\mu_p}{\mu_r}{\eta_r}^2\cos\phi + \eta_p\sqrt{\eta_r^2 - \eta_p^2\sin\phi^2}} \quad (3)$$

$$\kappa_v = \frac{\eta_p\cos\phi - \frac{\mu_p}{\mu_r}\sqrt{\eta_r^2 - \eta_p^2\sin\phi^2}}{\eta_p\cos\phi + \frac{\mu_p}{\mu_r}\sqrt{\eta_r^2 - \eta_p^2\sin\phi^2}} \quad (4)$$

where η_p and η_r are given by $\sqrt{\frac{\epsilon_p\mu_p}{\epsilon_0\mu_0}}$ and $\sqrt{\frac{\epsilon_r\mu_r}{\epsilon_0\mu_0}}$, respectively. Here, ϵ_p, ϵ_r, and ϵ_0 are the permittivity of the propagation medium, reflection medium, and vacuum, respectively. μ_p, μ_r, and μ_0 are the permeability of the propagating medium, reflection mediums, and vacuum, respectively.

The received multi-carrier signal´s space-frequency response of the kth subcarrier received by antenna m with polarization z at time snapshot t can be written as

$$x_{m,z,k}[t] = \sum_{l=1}^{L} \kappa_{l,z} s_{l,k} e^{jw(x_m \cos\theta_l + y_m \sin\theta_l)} \cdot e^{j2\pi k \Delta_f \tau_l} + n_{m,z,k}[t], \quad (5)$$

where $s_{l,k}$ is the complex symbol transmitted at the kth subcarrier of the lth signal, where $l = 1, 2, \dots, L$, x_m and y_m are the coordinates of the position of the mth antenna element, where $m = 1, 2, \dots, M$, w is the wavenumber, θ_l is the azimuth of the lth signal with respect to the orientation of the antenna array, Δ_f is the subcarrier spacing, and τ_l is the time of flight of the lth signal.

The signal can be re-written in matrix form as

$$\mathbf{X}[t] = \mathbf{K}[t] \diamond \mathbf{A}[t]\mathbf{S}[t] + \mathbf{N}[t] \quad (6)$$

with $\mathbf{K} \in \mathbb{C}^{2\times L}$, $\mathbf{A} \in \mathbb{C}^{M\times L}$, $\mathbf{S} \in \mathbb{C}^{L\times K}$, $\mathbf{N} \in \mathbb{C}^{2M\times K}$, and $\mathbf{X} \in \mathbb{C}^{2M\times K}$.

III. Proposed Localization Method

The position of a transmitter can be triangulated in space by estimating the parameters τ_l, θ_l, and ϕ_l of at least two paths, where ϕ_l is the angle of reflection of the lth received signal. The proposed method does not require the presence of a LOS component but requires that the receiver can separate LOS and NLOS components. Figure 1 presents a graphical description of the scenario studied in this work. Two NLOS paths are arriving at an antenna array whose center serves as the origin for a two-dimensional coordinate system. The total length of the NLOS paths can be estimated once an estimate of τ_1 and τ_2 has been obtained by $r_l = c\tau_l$.

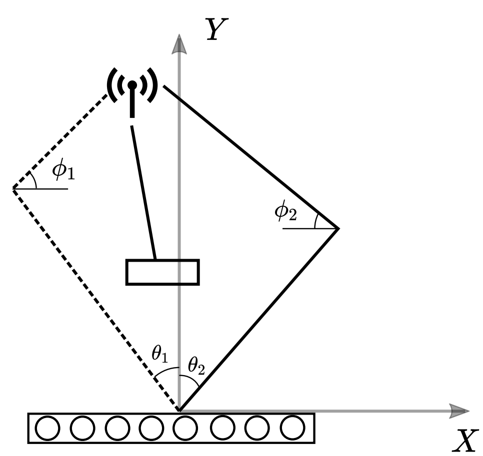

Fig. 1. Depiction of NLOS localization scenario

With a range estimate at hand, for each received path, a line segment containing all the possible positions of the transmitter can be drawn. Once at least two line segments are obtained, the transmitter position can be estimated by calculating the point where both line segments meet. Two points can be used to draw each of the needed line segments. The first point, p_l^1, can be obtained by finding the point along the line that represents the received signal at the array with angle θ_l whose distance from the center of the array is equal to r_l. The second point, p_l^2, can be obtained by finding the point along a line that passes through the center of the array and whose angle with respect to the X axis is equal to the estimated reflection angle ϕ_l and whose distance from the center of the array is equal to r_l. The line segment defined by joining these points contains all the possible locations of the transmitter for the lth path. By repeating these processes for all L paths, the position of the transmitter can be estimated by finding the point where all line segments meet. Figure 2 presents an example of the proposed localization method.

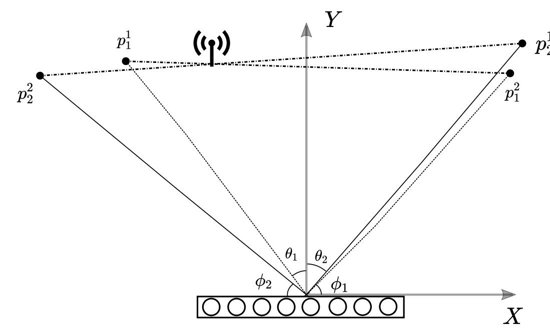

Fig. 2. Example of localization using the proposed method

IV. Numerical Simulations

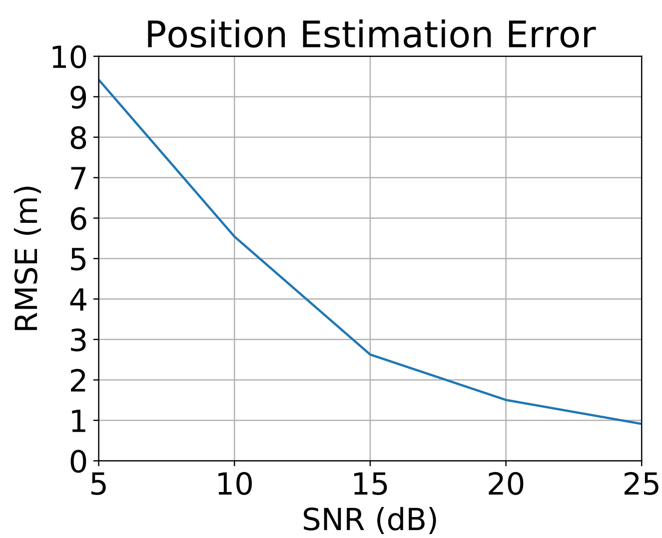

Fig. 3. Localization performance of the proposed method

Figure 3 presents preliminary results of a set of numerical simulations performed to access the performance of the proposed method. For this set of simulations, a transmitter is placed 30 meters in front of the receiver at coordinates $(0, 30)$, two reflection points are placed at coordinates $(-20, 20)$ and $(15, 10)$, and no LOS signal is received at the antenna array. The antenna array is composed of $M = 10$ dual-polarized antenna elements, and $T = 100$ snapshots are used to estimate the angles θ_l and ϕ_l as well as the time of flight τ_l. We perform a joint maximum likelihood estimation of all parameters of all NLOS signals. To solve the resulting multi-dimensional problem, we apply the space alternating generalized expectation maximization (SAGE) algorithm [5].

V. Conclusion

In this paper, we have presented a novel geometric localization method that does not require the presence of a LOS signal. By using a dual-polarized array, the reflection angle of several NLOS signals can be estimated. By employing the reflection angle estimates together with DOA estimates, it is possible to estimate the position of a transmitter in space if at least two NLOS components are received at the array. The orientation of the transmit and receive antenna (array) need to be known for the presented approach. Future work will also address the case for which the orientation of the transmit antenna is unknown.

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