GNSS Aided Non-Line-of-Sight Radio Localization via Dual Polarized Arrays

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Abstract

This work presents a radio based localization approach that is capable of accurately positioning radio emitters even when no direct line-of-sight signal is available. A dual polarized array is employed along with the space alternating generalized expectation maximization (SAGE) algorithm. To lighten the computational load and improve the accuracy of the proposed method, Global Navigation Satellite Systems (GNSS) positioning is used to initialize and limit the search area of SAGE. A set of numerical simulations is presented, highlighting the performance of the proposed method.

Keywords

Antenna Arrays, Dual Polarization, GNSS, Localization, Signal Processing

1. Introduction

The ever growing demand for fast and low latency mobile communications have brought to the forefront technologies such as massive multiple-input multiple-output (MIMO) and millimeter wave (mmWave). Being the driving factors behind modern wireless communication standards such as 5G, these technologies can be used to enable other future applications, in special application which require precise and low latency positioning. Autonomous vehicles, vehicular networks and platooning are an example of such applications [1].

In order to obtain a position estimate radio-based localization estimate parameters from a received signal. Such parameters range from signal strength (RSS) to direction of arrival (DOA) and time difference of arrival (TDOA). After these parameters are estimated a localization estimate for the transmitter can be obtained.

Traditional radio-based localization methods rely on estimating parameters of the line-of-sight (LOS) component of a received signal. The performance of these approaches is heavily degraded in case strong non-line-of-sight (NLOS) components are present [2]. Alternative approaches that take advantage of NLOS components' information to improve the accuracy of the positioning or obtain a localization estimation even when no LOS component is present 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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This work presents a geometric localization approach that leverages a dual-polarization antenna array for positioning even under NLOS only conditions (blocked LOS component). The method presented relies employs DOA, TDOA, and the reflection angle estimates of several NLOS components to accurately position a radio transmitter. Furthermore, in order to improve the accuracy and reduce the computational load of the space alternating generalized expectation maximization (SAGE) algorithm, employed to acquire the parameter estimates, a position provided by a GNSS receiver on the transmitter is used to initialize the algorithm. The proposed method requires that the orientation of both transmitter and receiver antennas are known.

2. 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

$$\kappa_h = \frac{E_{h,r}}{E_{h,i}} \tag{1}$$

$$\kappa_v = \frac{E_{v,r}}{E_{v,i}}, \tag{2}$$

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]

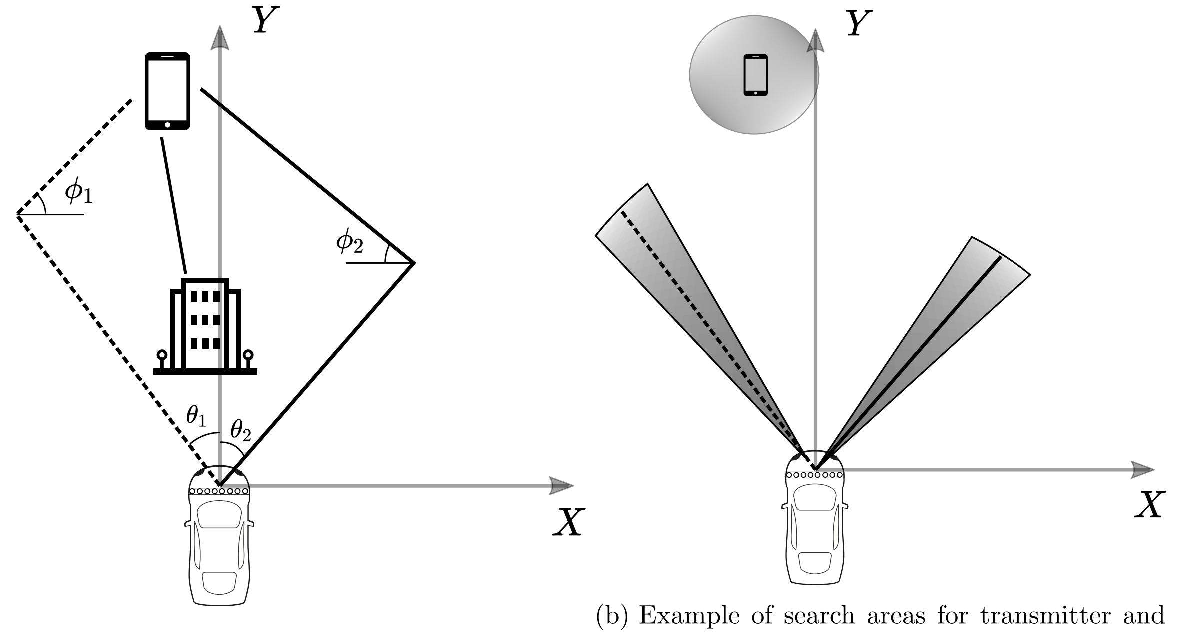
$$\kappa_h = \frac{\frac{\mu_p}{\mu_r}{\eta_r}^2 \cos\phi - \eta_p\sqrt{\eta_r^2 - \eta_p^2 \sin\phi^2}}{\frac{\mu_p}{\mu_r}{\eta_r}^2 \cos\phi + \eta_p\sqrt{\eta_r^2 - \eta_p^2 \sin\phi^2}} \tag{3}$$

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

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

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



(a) Depiction of NLOS localization scenario

(b) Example of search areas for transmitter and reflectors

$$+\, n_{m,z,k}[t], \tag{5}$$

where $s_{l,k}$ is the complex symbol transmitted at the kth subcarrier of the lth signal, where $l = 1, 2, \ldots, L$, x_m and y_m are the coordinates of the position of the mth antenna element, where $m = 1, 2, \ldots, M$, 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.

3. Localization Method

To estimate the position of a transmitter, this work applies a dual polarized antenna array A LOS path is not required, as the present of two distinct NLOS paths is sufficient for obtaining a position estimate of a transmitter. A graphical description of the scenario considered in this work is presented in Figure 1a. The figure presents two NLOS paths impinging over an antenna array whose center serves as the origin for a two-dimensional coordinate system. The parameters show in the figure are the angle of arrival θ, and angle of reflection ϕ of the two different paths.

The parameters τ_l, θ_l, and ϕ_l of the lth signal are related to the position of the transmitter t_l and reflector r_l according to

$$\theta_l = \frac{\Pi}{2} - \arctan\left(\frac{y_{r_l}}{x_{r_l}}\right) \tag{6}$$

$$\phi_l = \left|\frac{y_{t_l} - y_{r_l}}{x_{t_l} - x_{r_l}}\right| + (\Pi - |\theta_l|) \tag{7}$$

Equations (6) and (7) highlight the direct relationship that exists between the position of the transmitter and reflectors and the incidence and reflection angles. Therefore the position of the transmitter and reflectors can be calculated by obtaining as estimate of all received θ_l and ϕ_l and following the geometric relationship shown in [5]

This work extends the work in [5] by employing the space alternating generalized expectation maximization (SAGE) algorithm [6] to directly solve the multidimensional problem over the transmitter and reflector positions. Directly searching over the position will yield a more robust estimation, by eliminating nonlinear error relationships that arise when a position is estimated geometrically with respected to angles of arrival and reflection.

However, directly searching over the possible positions greatly increases the computational load required to obtain a position estimate for the transmitter. In order to mitigate this problem, two steps are proposed.

The first step consists of using a position estimate provided by the transmitter itself. This work considers that this estimate is obtained by a GNSS system. The estimate can than be sent to the receiver in order to minimize the search area with respect to the transmitter location. The average horizontal position accuracy of a GPS receiver in a smartphone in urban environments ranges from 7 to 13 meters [7]. Whiles this accuracy may be insufficient for safety of life applications, such as autonomous vehicles, it is sufficient to greatly reduce to computational complexity of the proposed method.

To reduce the search area with respect to the reflector locations an initial angle of arrival estimate can be used. This estimate can be obtained by applying SAGE itself over only one of the polarization's of the received signal, preferably the one with a higher signal to noise ratio (SNR). Once the DOA estimates have been obtained it is possible to restrict the search area to a given region around the line created by the DOA line crossing the receiving antenna array. The area around the DOA line can be defined by defining a tolerance or sensitivity parameter α such that the search area is contained within the lines that cross the center of the receiving array with angles $\theta_l + \alpha$ and $\theta_l - \alpha$. Figure 1b presents an example of the search areas for the transmitter and for the possible reflectors.

4. Numerical Simulations

Figure 2 presents the results for a set of numerical simulations performed to access the performance of the proposed method, refereed to as direct positioning, in comparison to the method proposed in [5], refereed to as geometric positioning. For this set of simulations, a transmitter is placed 30 meters in front of the receiver at coordinates $(0, 30)$. Three reflectors are placed at coordinates $(-30, 20)$, $(25, 10)$, and $(15, 16)$. For this set of simulations it is assumed that no LOS signal reaches the receiving antenna array. The antenna array is composed of $M = 10$ dual-polarized antenna elements, and $T = 100$ snapshots are used to estimate the position of the transmitter. The permittivity and permeability of the reflectors are assumed to be known in this case.

The results show that the method proposed in this paper outperforms the one presented [5], especially at low SNRs. Furthermore, the accuracy of the proposed method is superior to that of a commercial GPS receiver present in a modern smartphone, making it a more suitable method for safety of life applications.

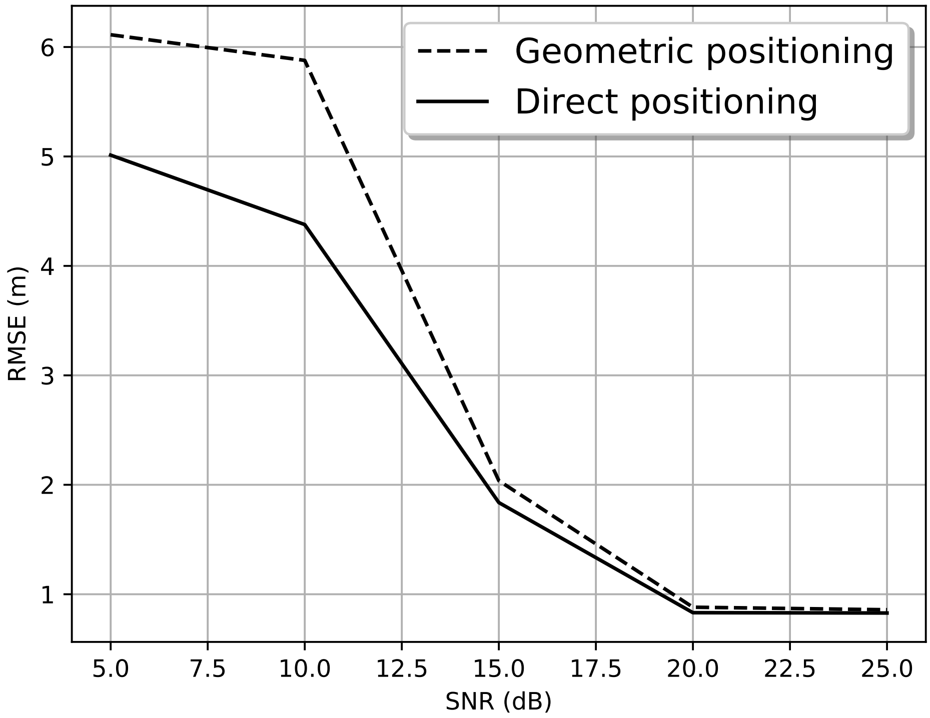


Figure 2: Localization performance of the proposed method

5. Conclusion

This work presented a radio localization method based on a dual polarization antenna array. The proposed approach utilizes a GNSS based position to reduce the search area of a SAGE based search in order to directly estimate the position of the receiver. When compared to a geometric based positioning approach the accuracy obtained by the proposed method is vastly superior at low SNRs as it avoids errors caused by highly nonlinear relationships between parameters such as angle of arrival and angle of reflection with the position of the transmitter. Future research should focus on estimating the permittivity and permeability of the reflectors. This would allow for a more flexible implementation of the proposed algorithm as it would be able to respond to changes in the physical parameters of the material around the receiver that might be caused by phenomena such as rain or rust.

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References

[1] H. Wymeersch, B. Peng, W. P. Tay, H. C. So, D. Yang, A survey on 5G massive MIMO localization, Digital Signal Processing 94 (2019) 21–28. doi:10.1016/J.DSP.2019.05.005.

[2] J. A. Del Peral-Rosado, R. Raulefs, J. A. López-Salcedo, G. Seco-Granados, Survey of Cellular Mobile Radio Localization Methods: From 1G to 5G, IEEE Communications Surveys and Tutorials 20 (2018) 1124–1148. doi:10.1109/COMST.2017.2785181.

[3] C. K. Seow, S. Y. Tan, Non-Line-of-Sight localization in multipath environments, IEEE Transactions on Mobile Computing 7 (2008) 647–660. doi:10.1109/TMC.2007.70780.

[4] F. Fohlmeister, A. Iliopoulos, M. Sgammini, F. Antreich, J. A. Nossek, Dual polarization beamforming algorithm for multipath mitigation in GNSS, Signal Processing (2017). doi:10.1016/j.sigpro.2017.03.012.

[5] M. Marinho, F. Antreich, A. Vinel, F. Tufvesson, M. A. Yaqoob, Non-Line-of-Sight Based Radio Localization With Dual-Polarization Antenna Arrays, in: WSA 2020; 24th International ITG Workshop on Smart Antennas, 2020.

[6] B. H. Fleury, M. Tschudin, R. Heddergott, D. Dahlhaus, K. I. Pedersen, Channel parameter estimation in mobile radio environments using the SAGE algorithm, IEEE Journal on Selected Areas in Communications 17 (1999) 434–450. doi:10.1109/49.753729.

[7] K. Merry, P. Bettinger, Smartphone gps accuracy study in an urban environment, PloS one 14 (2019).