Poster: NLoS Positioning through Multipath Selection and AoA-based Localization

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***Abstract*—This paper proposes a Wireless Positioning (WP) approach for Vehicle-of-Interest (VoI) localization in Non-Line-of-Sight (NLoS) conditions. While traditional sensors like cameras, radars, and GNSS have limitations in environments with rich multipath, WP can complement these systems by leveraging Vehicle-to-Everything (V2X) communication infrastructure. Our method combines ray tracing, geometric constraints, and a virtual station-based approach to estimate the position of the VoI. The proposed approach aims to reduce the complexity of NLoS positioning by effectively handling multipath trajectories and leveraging AoA for accurate Tx localization. The methodology is still under validation, and its performance will be further assessed through simulations.**

***Index Terms*—V2X, NLoS, Wireless Positioning, Ray Tracing, Angle-of-Arrival**

I. Introduction

Accurate positioning is critical for Intelligent Transportation Systems (ITS) applications, such as autonomous vehicles (AV). On-board sensors such as cameras, radars, and LiDAR enable relative positioning, but their effectiveness is limited by detection range and resolution, especially in situations like around corners. The Global Navigation Satellite System (GNSS) has been widely used for decades to provide precise location information, but its usability and accuracy are compromised in rich multipath environments (e.g. urban canyons). Physical-layer mechanisms, such as Wireless Positioning (WP), can complement the previous methods by leveraging the Vehicle-to-Everything (V2X) wireless communication infrastructure, to estimate/verify the position of a given vehicle, refered to as Vehicle-of-Interest (VoI).

WP has mature solutions and technologies for Line-of-Sight (LoS) environments. We highlight multi-antenna systems for obtaining direction through **Angle-of-Arrival** (AoA), and **Time-of-Flight** (ToF) or ranging techniques for obtaining distance. However, in Non-Line-of-Sight (NLoS) conditions, the performance of such methods can be significantly degraded by poor signal-to-noise ratio and multipath propagation. We consider the scenario depicted in Fig. 1, where the VoI and

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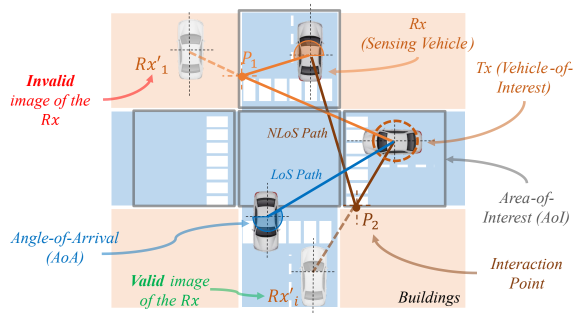

Fig. 1: Scenario: urban intersection with a Vehicle-of-Interest (VoI) Tx and a Sensing Vehicle Rx, under NLoS conditions. Position images $\mathrm{Rx}'_{\mathrm{i}}$ of the sensing vehicle are calculated using the ray tracing image method, resulting in virtual LoS paths. Invalid images are discarded based on geometric constraints, and AoA-based positioning is applied to estimate the Tx location using the valid images.

Rx can be either in LoS or NLoS conditions. We aim to develop a Cooperative Wireless Positioning (CWP) system that operates accurately and efficiently under NLoS conditions. In this work, we investigate the related literature, lay the initial architecture of such system, and identify key techniques such as ray tracing, geometric constraints, and the virtual station-based method.

II. State-of-the-Art

Typical NLoS positioning methods include: **ray tracing** [1], [2], **geometric constraints** [3], [4], **NLoS error mitigation** [5], [6], **fingerprint matching** [7], [8], and **virtual station-based methods** [9], [10]. Ray tracing simulates radio wave propagation by tracing paths in an environment, considering reflections, diffractions, and scattering. However, as the area increases, the number of trajectories grows exponentially, making it computationally expensive and impractical for large-scale scenarios. In contrast, the geometric constraints method uses the environment's geometric layout and positioning parameters, such as Angle of Arrival (AoA), Time of Arrival (ToA), and Received Signal Strength Indicator (RSSI), to estimate the target position. However, it may struggle in dynamic or complex environments where the geometric design changes frequently. The NLoS error mitigation method enhances LoS estimation by reducing the impact of NLoS signals, but it is only effective in scenarios with a mix of LoS and NLoS signals. The fingerprint matching method relies on a database of unique location fingerprints for position determination, making it more suitable for indoor or small-area applications. On the other hand, the virtual station-based method addresses NLoS by converting NLoS paths into LoS paths using multiple virtual stations, enabling the use of LoS positioning algorithms.

In previous work [11], we applied a geometry-based approach to cooperative positioning in LoS conditions. Sensing vehicles estimate AoA to a VoI, and exchange that information among themselves to estimate the VoI's position by applying regression over the projections' intersection points. To extend such strategy to NLoS, multipath situations need to be identified to ascertain the exact geometry of the situation.

III. NLoS Positioning Approach

Our NLoS positioning approach is based on the AoA estimation technique of [11], now extended to handle NLoS. We address vehicular scenarios, specifically urban intersections with high-rise buildings, where a sensing vehicle Rx and a Tx Vehicle-of-Interest (VoI) exist. For the sake of manageability, we break down the scenario into cells of 20×20m blocks, referred to as the Area-of-Interest (AoI). Both vehicles can be under LoS or NLoS conditions (i.e., being in the line of sight or not). NLoS paths occur due to reflections in fixed obstacles, such as buildings. We consider first-order reflections (i.e., a single reflection) and second-order reflections (i.e., two consecutive reflections).

Additional techniques are introduced to account for such reflections, as discussed in Sec. II. The high-level architecture of our proposed NLoS positioning approach can be broken down into two parts, explained next. Fig. 2 shows the architecture.

A. Multipath Identification and Modelling

1. Ray Tracing Method (RT): RT is used to compute the rays between each pair of Areas of Interest offline (i.e., areas where the VoI and Rx are respectively located). Then, this information can be stored in a database (DB), or used to train a neural network (NN), or some other geo-referenced ML technique, to reduce the computational cost of performing RT in real-time. We will test some RT tools like *Sionna RT* [12] in Python, or *QuaDRiGa* [13] in Matlab.
2. Power-Delay Profile filtering: power-delay profiles enable detection of multiple paths and isolate the most energetic ones. PDP needs to be investigated offline for a particular scenario, and then stored in DB or used to train NN models for quick application in the real-world.

B. Geometry-correction Techniques for VoI Positioning

After identifying relevant multipath rays, that information can be used to correct the situation geometry and apply traditional positioning methods. Correction techniques are:
1. Rx Position Imaging: position images of the sensor vehicle Rx'_1 to Rx'_i (i: number of paths) are calculated based

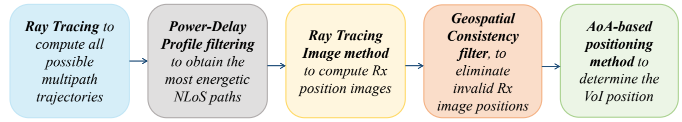

Fig. 2: NLoS positioning approach

on the selected multipath trajectories using the ray tracing image method [14]. This process generates virtual LoS paths, allowing traditional positioning methods for LoS conditions to be applied.
2. Geoespatial Consistency filter: invalid position images of the sensing vehicle (e.g., on a building or a lake) are discarded.

IV. Conclusions and Future Work

We lay the foundation for a Wireless Positioning (WP) methodology for hetero-localization under NLoS conditions. We review relevant techniques in the literature, and identify ray tracing, geometric constraints, and virtual station-based method as the most promising. Future research will focus on validating and evaluating the method through simulations. We will analyze how the number of selected NLoS trajectories and the increase in sensing vehicles affect localization precision.

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