A Combined Ray Tracing Simulation Environment for Hybrid 5G and GNSS Positioning

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Abstract

GNSS based radio frequency (RF) positioning has to cope with challenging propagation conditions, like non-line of sight (NLoS), multipath, and sparse signal availability. The introduction of the fifth-generation of mobile telecommunications technology (5G) with an improved Positioning Reference Signal (PRS) structure will be a key enabler for more reliable positioning solutions with increased availability and advanced signaling. Nevertheless, 5G-assisted positioning faces similar challenges. Therefore, to analyze the possibilities of 5G-assisted positioning, a suitable simulation environment is required. In this paper, a simulation environment based on a Ray Tracing (RT) channel model that emulates Global Navigation Satellite System (GNSS) signals is introduced, validated and extended to simulate 5G PRSs, and Sounding Reference Signals (SRSs). Additionally, the environment is applied for hybrid positioning by sensor data fusion with real-world recorded Global Positioning System (GPS) L1CA and Galileo E1BC GNSS signals under several severe conditions like strong building blockage and outdoor-indoor transition. It is shown that the simulation environment with various three-dimensional (3D)-modeled objects represents 5G signals sufficiently well when the line of sight (LoS) is visible. Additionally, the simulated 5G signals improve the GNSS positioning accuracies when combined in a hybrid positioning approach, especially under complex channel conditions, like in typical industrial environments.

Keywords

GNSS, GPS, Galileo, 5G, hybrid positioning, Ray Tracing, simulation environment

1. Introduction

The investigation and comparison of different simulation environments are relevant to evaluate different position fusion algorithms and their performance. Simulation opens up the possibility to meaningfully analyze new signal structures, specific frequency bands, chosen signal bandwidths, and different environmental conditions. This has direct influence on achievable positioning performance. Various use cases have already been analyzed using deterministic, geometric-based stochastic channel models (GSCMs) and non-geometrical stochastic

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channel models provided in [1]. The channel model parameters for GSCMs are based on exhaustive and complex measurement campaigns. For non-geometrical stochastic models, the channel is modeled stochastically with predefined parameters for the environment [2]. In this paper we focus on presentation and evaluation of a RT based simulation environment, to highlight the necessity of realistic position evaluation, with two main signal types: GNSS and sub-6GHz 5G (e.g. 5G FR1). The verification of 5G signals is based on emulated, and GNSS signals on real-world data comparing the signal-to-noise ratio (SNR) and carrier-to-noise density ratio (C/N_0) values, respectively. Finally, a simple position fusion is done using simulated 5G and recorded real-world GNSS data.

2. Problem description

Based on the overview of 5G positioning scenarios and use cases in [3], high mobility, urban area, location awareness for Internet of Things (IoT) applications in urban areas, and indoor-outdoor transition are the ones that should profit from hybridization of 5G and GNSS signals. In high mobility cases, GNSS signals will handle mobility and coverage, while 5G New Radio (NR) can improve accuracy. The opposite occurs for indoor-outdoor transition where 5G NR access points ensure signal availability indoors. For all those use cases, the challenges like GNSS satellite visibility, multipath on both 5G and GNSS signals, obscured or absent LoS components demand further analysis. To assess sensor data fusion challenges properly, it is desirable that different RF signal types undergo the same environmental conditions. Furthermore, it is necessary to fully simulate GNSS signals in a specific environment to access the data at different processing stages. Here, the use of real GNSS data should be considered if an accurate positioning reference system is available. Representative simulation should be made available as a preceding step to save time and effort otherwise invested in the field-trials preparations, costs and executions.

3. Method

Fig. 1 shows the simulation and measurement setup for real/emulated GNSS and simulated 5G data. The Leica total station is used as a reference system [4]. The GNSS measurement setup was composed of a Septentrio receiver, and a dual circularly polarized GNSS antenna (GNSSA DCP), developed by Fraunhofer IIS and distributed by TeleOrbit GmbH [5]. The Septentrio receiver logging was used to compare the emulated and measured data of some selected pseudorandom noises (PRNs) (Fig. 3a) and as a source of GNSS measurements for positioning. For emulation purposes, Sim3D is used, a GNSS signal emulator that couples a Spirent Signal Generator together with the SE-NAV RT channel model to generate realistic, environment-dependent GNSS signals [6]. The 5G emulation setup is described in [7], where Universal Software Radio Peripheral (USRP) based transmission points (TRPs) are used for 5G signal transmission. The 5G TRP deployment was reconstructed in SE-NAV together with corresponding trajectories as depicted in Fig. 2c. The perfect synchronization between the TRPs is assumed. To simulate 5G signals, their positions, the signal carrier frequency (3.75 GHz), signal bandwidth (100 MHz), transmitting power (0.032 W), and antenna pattern are the

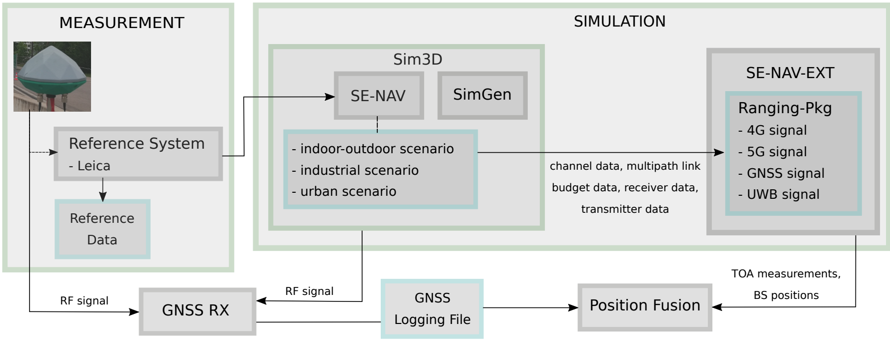
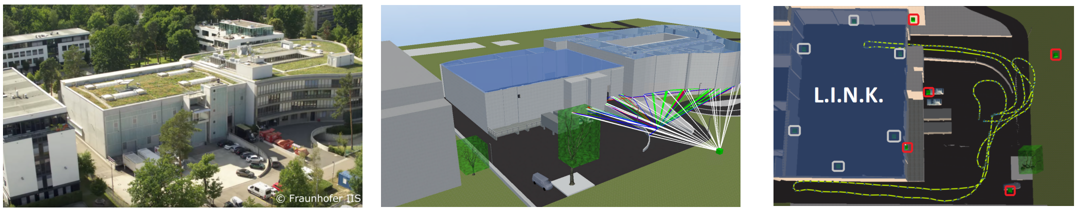


Figure 1: Measurement and simulation setup



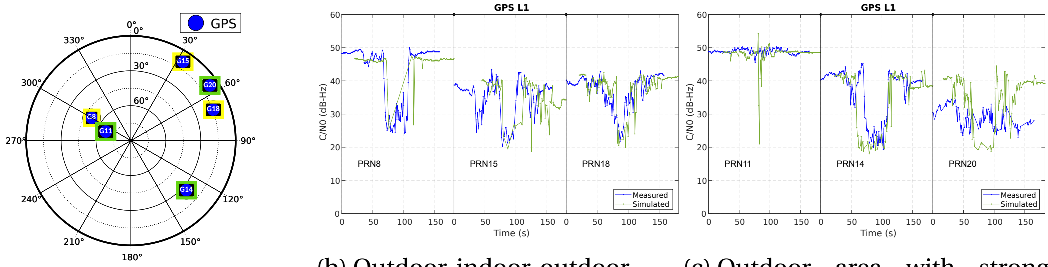
(a) Fraunhofer IIS building (b) Modeled IIS building (c) 5G TRPs deployment

Figure 2: Real and modeled IIS building with L.I.N.K. test and application center in Nuremberg

most important settings that determine the ray properties and received signal power. The transmitter antenna model is defined as 120-degree opening angle antenna. The basis for the simulation is the 3D-model of the Fraunhofer IIS building. Figs. 2a and 2b show real and rebuilt building, respectively. The goal was to have a proper simulation environment of the backyard since the tests were performed in front of the L.I.N.K. test and application center, between two buildings and indoors (Fig. 2c). The simulated building shows a roof made of glass only for the visibility of the indoor area. The used RT channel model [6] provides the option to specify the material permittivity, conductivity, and thickness which define the properties of reflected, dispersed, and transmitted rays (Fig. 2b). For signal propagation: a maximum of 2 reflections and 2 transmissions with enabled diffractions were simulated. Rays with more then 2 reflections or transmissions are neglected. Fig. 2c visualizes those LoS, reflected, diffracted and transmitted ray paths in white, red, blue and green, respectively. Since SE-NAV is a pure channel model, added software (SW) extensions enable proper signaling for the fusion of different measurements. The developed ranging package includes various signal generators for signals like 5G and GNSS. Scene-dependent ranging signals are generated based on the extracted RT channel properties.

4. Evaluation

First we verify the 3D-model based on GPS measurements. The building model shown in Fig. 2c has the same orientation as the skyplot in Fig. 3a. Figs. 3b and 3c show the evaluations



(a) 3b: yellow, 3c: green

(b) Outdoor-indoor-outdoor transitions

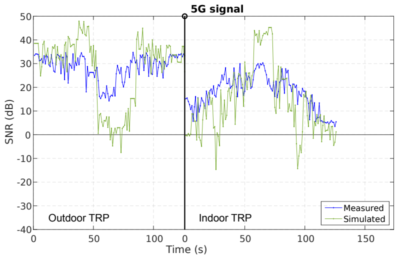
(c) Outdoor area with strong blockage

Figure 3: Skyplot and C/N_0 comparison for GPS L1CA

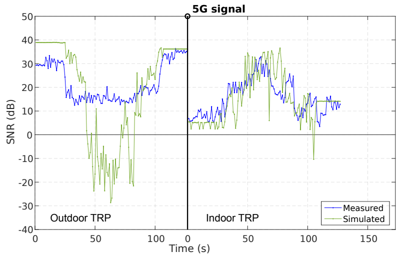
for satellites in Fig. 3a. The receiver is indoor and between two buildings for short time in the middle. The Fig. 3b identifies two modeling issues: Missing objects and vegetation on the east side of the building, and the height of the hall entrance gate. This affects PRNs 15 and 18 on the east side, as well as PRN 20 in Fig. 3c. The PRN 11, high elevation satellite is shortly blocked in the middle at the turning point, resulting in a significant C/N_0 drop in the simulated data. This is due to uneven terrain between the two buildings which was not modeled. The results show that the 3D-model in its current version agrees with reality in essential aspects covering relevant propagation conditions for GNSS signals. Second, the 5G FR1 representation is evaluated. The SNR in the Fig. 4 decreases in multipath-rich conditions, for both emulated and simulated data. The underestimation of lower SNRs impacts statistical evaluations in Table 1. The SNRs standard deviation ranges between 5.5 and 8.5 dB for LoS. This is sufficiently accurate since RT channel models show a standard deviation below 8 dB [8]. To compare the positioning performance GNSS and simulated data is used with mostly LoS. Results in Fig. 5a indicate a visible shift between measured and simulated position solution with two-dimensional (2D)-error mean of 18.1 m and a standard deviation of 1.62 m. The atmospheric effects are modeled, resulting in a systematic mean error bias. Finally, the simulated 5G FR1 PRS signals are fused using weighted least squares method with measured GNSS signals in Fig. 5b. The measured observations are GPS L1CA and Galileo E1BC pseudoranges, and 5G PRS time of arrival (ToA) values. Here, we use measurements from the TRPs from which the LoSs are present and distinguish two areas: outdoor-indoor-outdoor transitions (left) and outdoor area with strong blockage (right). We compute 5G FR1 position solution for channel data collected: (1) for all TRPs at once and (2) through individual runs for each TRP. The ToA set from (2) is used for sensor data fusion with GNSS. The 5G positioning outperforms both GNSS and hybrid position solution when indoors. In the outdoor case with severe blockage, the 5G signals slightly enhance the GNSS solution because the useful TRPs do not significantly improve the geometrical Dilution of Precision (DOP).

5. Conclusion

We have shown that the presented simulation environment is representative for GNSS and 5G FR1 signals under LoS conditions. Additionally, possible modifications for the 3D-model



(a) Outdoor-indoor-outdoor transitions

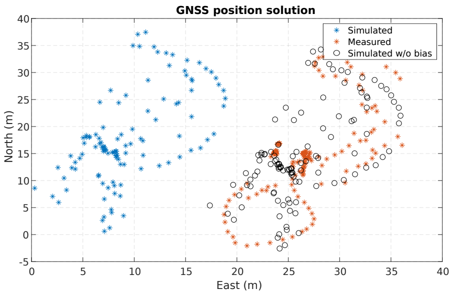


(b) Outdoor area with a strong blockage

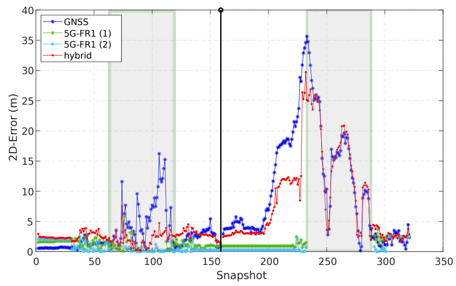
Figure 4: Measured and simulated SNR values for 5G TRPs deployed as in Fig. 2c

Table 1
Difference between emulated and simulated 5G SNR values ΔX_{LoS} and ΔX_{NLoS} for LoS and NLoS cases respectively where μ and σ denote sample mean and variance

Scenario	$\mu(\Delta X_{LoS})$	$\sigma(\Delta X_{LoS})$	$\mu(\Delta X_{NLoS})$	$\sigma(\Delta X_{NLoS})$
outdoor-indoor transition	2.49 dB	8.42 dB	-6.63 dB	11.26 dB
outdoor with strong blockage	8.41 dB	5.74 dB	-2.02 dB	12.66 dB



(a) 2D GNSS position solution comparison



(b) Fused 2D position solution

Figure 5: 2D position solution

improvement are given. Especially, the 5G NLoS case is strongly dependent on the material properties and requires additional study. Brief hybrid positioning results for 5G and GNSS have been shown. With this simulation environment advanced hybrid positioning solutions will be developed.

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