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Preliminary Field Results of a Dedicated 5G Positioning Network for Enhanced Hybrid Positioning †

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Abstract: Dedicated fifth-generation (5G) positioning networks are envisaged as a key technology to complement Global Navigation Satellite Systems (GNSS) in challenging situations, such as safety-critical automotive and aerial applications. These 5G networks are explicitly designed to fulfil the positioning needs in a specific environment, by using dedicated pilot signals and locating the base stations (BSs) in favorable conditions for user reception. To prove this concept, the Hybrid Overlay Positioning with 5G and GNSS (HOP-5G) testbed demonstrates the enhanced positioning capabilities resulting from the deployment of ground and aerial BSs. This paper presents a preliminary assessment of the first real-time ranging measurements obtained with a flying BS in a dedicated 5G positioning network. Under hovering and optimal conditions, field results obtained over an 80-MHz downlink bandwidth indicate a ranging precision below 1m in the 95% of cases.

Keywords: GNSS; 5G; Positioning; Flying Base Stations

1. Introduction

There is nowadays an increasing demand for precise and reliable navigation in a wide range of applications, such as in Urban Air Mobility (UAM) or autonomous vehicles. Current solutions are based on Global Navigation Satellite Systems (GNSS) for absolute positioning, navigation and timing (PNT), which are fused with relative positioning from multiple sensor technologies (e.g. inertial measurement units, cameras, radars and LiDAR, among others) for further accuracy and robustness. However, complementary navigation technologies are still expected to be necessary to fulfil the stringent reliability requirements. In this sense, fifth generation (5G) cellular technologies are very promising thanks to their key positioning features and standard support [1], including 5G new radio (NR) terrestrial and non-terrestrial networks (NTN).

5G commercial and private networks are deployed over many different use cases, i.e., from mobile broadband connectivity to Internet of Things (IoT). Still, the exploitation of 5G positioning has been mainly focused on indoor industrial use cases, such as asset tracking and industrial automation. This has been reflected on the 3rd Generation Partnership Project (3GPP) standardization, where the studies on enhanced 5G positioning has been initially focused on indoor use cases [2]. As a result, a very limited attention has been paid to the dedicated deployment of ground and aerial base stations (BSs) for enhanced 5G positioning service area in outdoor applications. Indeed, aerial BSs (ABSs),

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unmanned aerial vehicle (UAV)-mounted BSs or flying BSs have been mainly considered for communication purpose [3-4], but not for enabling enhanced positioning services, which can be especially beneficial for the increased diversity in the vertical dimension with respect to ground-fixed BSs. Thus, to prove this new opportunity, the Hybrid Overlay Positioning with 5G and GNSS (HOP-5G) testbed has been proposed as first-of-a-kind demonstrator of dedicated aerial 5G positioning networks.

The design considerations of these dedicated 5G positioning networks have been studied in [5], and their expected positioning capabilities in a representative scenario in [6]. Experimental 5G positioning results have been presented in predecessor testbeds, such as in [7-8], as well as with signals of opportunity approaches in [9-10]. To the best of authors' knowledge, the use of flying 5G BSs for positioning has not been demonstrated yet. Thus, this paper presents the first ranging results of a flying 5G BS deployed specifically for positioning purposes.

2. Dedicated 5G Positioning Network

2.1. HOP-5G High-Level Architecture

The HOP-5G testbed is based on a dedicated 5G positioning network. The key objective of this first-of-a-kind demonstrator is to assess the enhanced hybrid 5G and GNSS positioning capabilities using dedicated ground and aerial BSs. Furthermore, the HOP-5G testbed operates in real-time and in post-processing, which allows a wide range of experimentations. The main building blocks of this testbed are:

- **Ground support equipment (GSE)**: The testbed operations are performed within this building block. The GSE is used to control, command, collect data, monitor and perform post-processing functionalities within the HOP-5G testbed.
- **5G BSs**: The 5G BSs (or 5G gNBs as in the 3GPP nomenclature) can be deployed in ground or in the UAV payloads. The BSs are based on software-defined radio (SDR) synchronized with GNSS-disciplined oscillators. For each BS, dedicated positioning reference signals (PRS) are transmitted in specific downlink slots.
- **User Equipment (UE)**: The UE can be deployed in ground or in the UAV payload, and it is also based on SDR. In downlink operations, the UE exploits a specific upgrade of OpenAirInterface (OAI) to obtain 5G real-time ranging measurements. In addition, a COTS GNSS receiver is used to collect the raw observables and position estimates. Then, a positioning engine performs the UE position estimation also in real-time, by combining either or both GNSS and 5G time of arrival (ToA) in a weighted least squares (WLS) or extended Kalman filter (EKF).

The baseline HOP-5G deployment is based on two ground-fixed BSs, two UAV BSs and two UEs. Further details of the HOP-5G testbed architecture can be found in [6].

2.2. Testbed Equipment

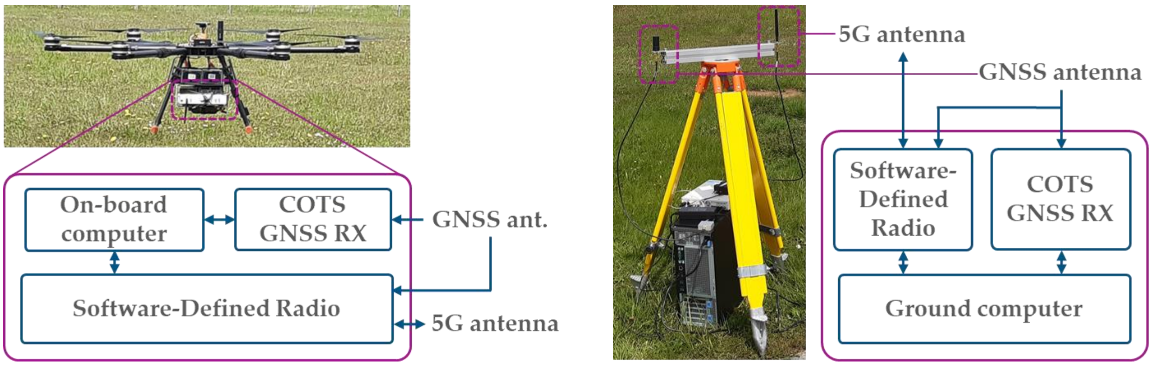
The testbed equipment is based on commercial off-the-shelf (COTS) components, while keeping a high-degree of flexibility and modularity thanks to the use of SDR and regular computer. Each node of the HOP-5G testbed shares the same high-level architecture, including both aerial and ground deployments. As it shown in Figure 1, the nodes are based on four key components:

- **Computer**: The HOP-5G software modules are installed and executed in a regular computer with Ubuntu 20.04 operating system. When installed within the UAV payload, an Intel NUC with Thunderbolt3-to-10GbE adapter is used to fulfil the size, weight and power (SWaP) constraints. When fixed on ground, a workstation or tower computer with 10GbE adapter is preferred to support very high computational performance. In both cases, a Wi-Fi module is used to establish a remote connection with the operator.
- **SDR**: The USRP X300 is considered the preferred SDR to transmit and receive 5G signals. This SDR is built with an UBX daughterboard to operate at frequency

range 1 (FR1), i.e., below 6 GHz, and with a GPS disciplined oscillator (GPSDO) to keep a tight synchronization among testbed nodes.

- **GNSS receiver**: The COTS GNSS receiver are the u-blox F9P for ground-fixed nodes and the u-blox F9R for moving aerial or ground nodes.
- **Antennas**: The two additional antennas of the node are a 5G monopole omnidirectional antenna and a GNSS helical antenna. An L-band splitter is used to connect the GNSS antenna output with the SDR and the GNSS receiver.

Thanks to the hardware and software flexibility and modularity, a node can be used as a BS or as UE with only software configuration updates. All the nodes are remotely controlled and monitored with a regular laptop, e.g. by exploiting a Wi-Fi connection.



(**a**) (**b**)

Figure 1. Example equipment of the HOP-5G testbed for UAV-mounted and ground deployments: (**a**) UAV-mounted BS or UE with the key building blocks of its payload; (**b**) Ground-fixed BS or static UE with its key building blocks.

3. Experimental Methodology

3.1. Experimental Procedure

The HOP-5G testbed is deployed in the heliport at Airbus premises, and it is used to assess the precision of the real-time downlink ranging measurements at a static UE from a flying 5G base station. The experimental procedure is based on hovering the UAV at several line-of-sight (LoS) points. As it is shown in Figure 2, each of those sequential points are classified based on the distance d to UE and the UAV height h from ground.

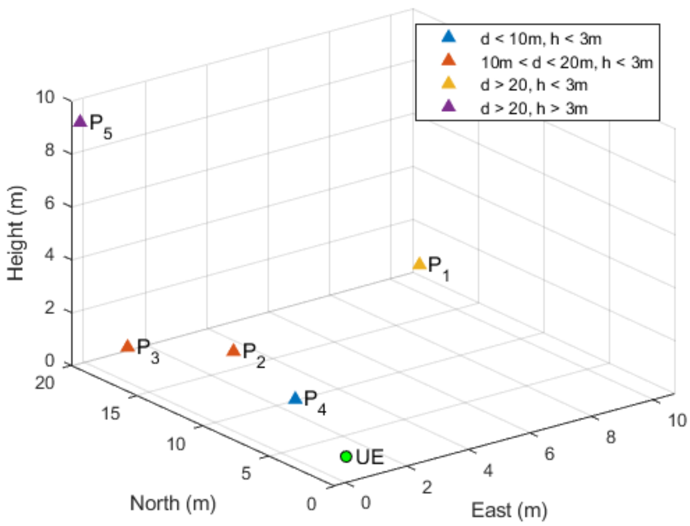


Figure 2. UAV hovering positions for the corresponding ranging measurements at the UE.

The position solution of the GNSS receiver within the UAV payload is logged and disseminated in real-time to the UE. The time of those UAV GNSS solutions are used to associate the 5G real-time measurements with the corresponding UAV hovering position. For each of those points, the 5G measurements are collected over 30s. Since the 5G PRS transmissions are scheduled once every 10ms, the 5G OAI UE produces a maximum of 5000 measurement messages over those 50s for each UAV hovering point.

The downlink 5G PRS are transmitted over a bandwidth of approximately 80MHz at 3.75 GHz and a subcarrier spacing of 30kHz. This 80-MHz bandwidth is defined as result of the supported sampling rate of the USRP X300, which is set to 92.16MSps. Each BS transmits its PRS in a different slot allocation to fully avoid inter-cell interference.

In addition to the flying BS, a ground-fixed BS is also deployed close to the UE, in order to fully stabilize the fine synchronization of the UE received radio frames. Thus, the measurement conditions are considered optimal.

3.2. Performance Metrics

The 5G ranging performance assessment within this paper is based on the variability of the measurements over a period of 1s. This assessment indicates the ranging precision of downlink UE measurements from the flying 5G BS.

Let us define the pseudorange measurement at the n-th time instant as follows:

$$\rho(n) = \|\mathbf{x}_{\mathrm{UAV}}(n) - \mathbf{x}_{\mathrm{UE}}\|^2 + c \cdot \left(\delta t_{\mathrm{UE}}(n) - \delta t_{\mathrm{UAV}}(n)\right) + \varepsilon(n), \quad (1)$$

where $\mathbf{x}_{\mathrm{UAV}}(n)$ is the three-dimensional (3D) position of the UAV, $\mathbf{x}_{\mathrm{UE}}$ is the 3D position of the static UE, $\delta t_{\mathrm{UE}}(n)$ is the receiver clock offset, $\delta t_{\mathrm{UAV}}(n)$ is the flying BS clock offset, and $\varepsilon(n)$ is the pseudorange error due to noise and multipath. As one can observe from this expression, the main sources of pseudorange variability are the slow-moving distance $d(n) = \|\mathbf{x}_{\mathrm{UAV}}(n) - \mathbf{x}_{\mathrm{UE}}\|^2$ due to UAV hovering movements, the BS and UE clock offsets, and the noise and multipath errors. The variation of these error sources can be calculated for each measurement as

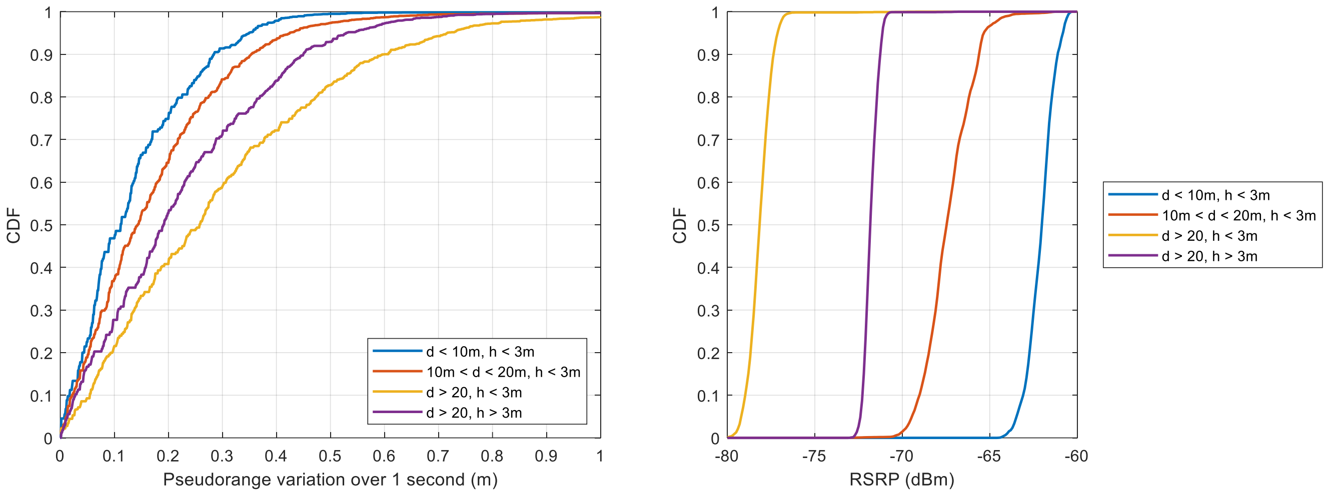
$$\Delta\rho(n) = \rho(n) - \mu_\rho\,, \quad (2)$$

where μ_ρ is the average of all pseudoranges over the measurement period of 1s. Note that the 50s measurement set is split in subsets of 1s, and μ_ρ is computed for each subset. Thus, in the absence of large pseudorange outliers, the pseudorange variation $\Delta\rho(n)$ is a suitable performance metric to assess the ranging precision of the 5G measurements.

As a complementary metric, the 5G downlink PRS reference signal received power (RSRP) in [11] is computed to further assess the results in terms of propagation conditions.

4. Field Results

The cumulative density function (CDF) of the pseudorange variation over 1s and the CDF of the RSRP is computed for each of the UAV hovering points grouped per distance to the UE and UAV height from ground. As it is shown in Figure 3, there is a correlation between ranging precision and distance between flying BS and UE, due to the favorable LoS propagation. A remarkable ranging precision is obtained within UAV hovering and optimal receiver conditions. As it is summarized in Table 1, the static UE achieves a ranging variation below 1m on the 95% of the cases, under the operational conditions of this experiment. Furthermore, the outlier rate (or amount of non-available measurements per full UAV hovering point) is kept to around or below 1% depending on the experimentation point. Indeed, the first point (i.e., P_1) shows the worse degradation, even with respect to the fifth point (i.e., P_5). This degradation is assumed to be associated to the multipath errors due to ground reflections, although further experimentation and analyses are required as part of future work. Also as part of future work, further field tests are expected in dynamic UE conditions, as well as with additional radio conditioning equipment to enhance the measurement coverage.



(**a**) (**b**)

Figure 3. Preliminary field results of the downlink UE ranging measurements to a flying 5G BS: (**a**) CDF of the pseudorange variation over 1s; (**b**) CDF of the RSRP.

Table 1. Ranging precision at 95% of cases and overall outlier rate of 5G ranging measurements for each group of UAV hovering points.

Point group	Point	d	h	Ranging precision @ 95%	Outlier rate
$d < 10\text{m}, h < 3\text{m}$	P_4	7.1m	1.10m	0.35m	0.18%
$10\text{m} < d < 20\text{m}, h < 3\text{m}$	P_2	10.8m	2.23m	0.42m	0.28%
	P_3	16.3m	1.43m		
$d > 20\text{m}, h < 3\text{m}$	P_1	22.2m	0.39m	0.72m	1.14%
$d > 20\text{m}, h > 3\text{m}$	P_5	21.1m	9.35m	0.53m	0.32%

5. Conclusions

This paper presents the first field ranging measurements with a dedicated fifth generation (5G) flying base station (BS) for positioning purposes. This field experimentation is performed within the Hybrid Overlay Positioning with 5G and GNSS (HOP-5G) testbed, which exploits a 80-MHz downlink positioning reference signals (PRS) to achieve real-time ranging measurements at the user equipment (UE). Considering hovering and optimal conditions for a static UE, a ranging precision is achieved below 1m in the 95% of cases, when considering the pseudorange variation over periods of 1s within test points of 50s. Future work is envisaged to further demonstrate the positioning capabilities of dedicated 5G positioning networks under static and dynamic UE conditions.

Supplementary Materials: The following supporting information can be downloaded at: www.mdpi.com/xxx/s1, Figure S1: title; Table S1: title.

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