Demo: SkyRoute, a Fast and Realistic UAV Cellular Simulation Framework

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***Abstract*—There is a growing interest in reusing cellular base stations on the ground to provide long range, high-speed wireless connectivity to UAVs. Towards this goal, we present SkyRoute – a novel and powerful simulation platform for rapid and realistic assessment of UAV cellular connectivity. SkyRoute combines real base station locations and antenna data with a lightweight version of the widely-used ns-3 simulation platform for full-stack wireless channel and cellular network simulation. As an exemplary application, we demonstrate realistic coverage and cell selection prediction in a large metropolitan area.**

I. Introduction

Large and medium unmanned aerial vehicles (UAVs) are being used for video streaming and data collection, weather and geography analysis, and emergency rescue in cities and suburbs. These applications require the UAV to operate beyond the visual line-of-sight with respect to the remote ground controller, and thus cellular connectivity will be vital to provide reliable wide-area network coverage [1], [2], [3], [4].

Accurately evaluating UAV connectivity remains difficult. It is well-known that aerial coverage from terrestrial base stations often depends on sidelobes from down-tilted antennas [1], [2]. Hence the exact 3D antenna patterns, base station locations and build environment can strongly influence radio coverage. Packet-level full stack emulation is also necessary to model many important features including rate adaptation, handover, congestion control and application-layer phenomena, particular in high mobility environments. While open source network tools such as ns-3 [5], [6] have been successfully used for these studies [7], [8], they are prohibitively slow for wide area simulations with large numbers of cell sites and UAVs.

II. Overview of SkyRoute

To address these challenges, we have developed a computationally efficient, yet accurate full-stack simulation platform that we call SkyRoute. As shown in Fig. 1, the SkyRoute platform consists of three interrelated components: a deployment database, a network simulator, and a UAV flight path planner.

For the deployment modeling, we have worked closely with one of the largest telecommunications and cellular network company in the United States to use base stations and antennas data to achieve near-realistic simulations. The database includes but, is not limited to, base station internal number, city and market which it belongs, antenna name, antenna sectors, latitude and longitude, height, transmit power, transmission

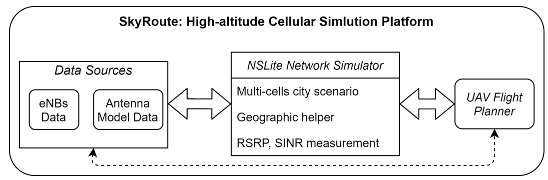

Fig. 1. SkyRoute platform integrates three parts.

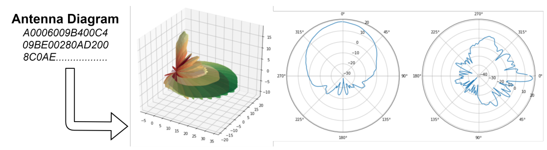

Fig. 2. Decoding a binary code into an understandable antenna pattern.

loss, and noise figure. The data pertaining to the antenna includes the specific model of the antenna, the horizontal orientation of the antenna, the tilt angle of the antenna in relation to the ground, beamwidth, and binary antenna model information. In addition, most commercial base stations are constructed with multiple antenna arrays (multi-sectors) to provide signal coverage in multiple directions and at multiple frequency bands. Our database includes the specification and orientation of all antennas used in the network.

The antenna patterns are stored in a binary representation to reduce the size of the database. We decode antenna patterns from their binary representation to an easily understandable format as per the description of this binary encoding. We show an example of this decoding in Fig.2.

Medium and large UAVs have a high flying height and cannot fly in the no-fly zones of high-rise buildings. Hence, SkyRoute assumes the UAV and the base station are in the line-of-sight (LOS). However, since the locations of the cellular base stations sites are known, the cellular base stations can easily be integrated into ray tracing tools [9], [10], [3] to capture non-line-of-sight (NLOS) paths as well in the future. Our database includes detailed antenna and sectorization data, hence SkyRoute can accurately model sidelobe coverage, which is key in cellular air-to-ground links [1], [2].

The RF propagation model is combined with a lightweight version of the widely-used ns-3 discrete-event network simulator [5]. The ns-3 simulator includes full stack emulation of 3GPP 4G [6] and 5G [11] systems. The platform models the PHY, MAC, RLC, PDCP and RRC layers in radio access

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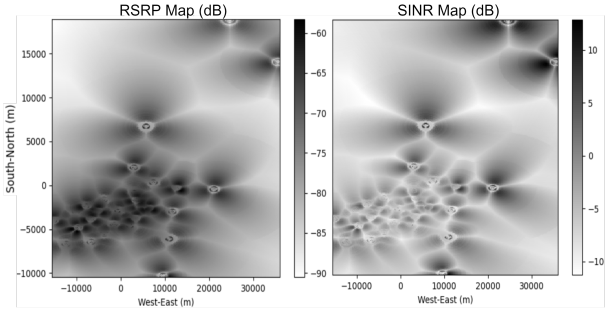

Fig. 3. 200 height RSRP and SINR map in a middle-size city with 25 base stations (85 sectors).

networks as well all key protocols in the core network.

While accurate and flexible, a key challenge with ns-3 has been the prohibitive computational cost for large cellular simulations. For this reason, SkyRoute includes NSLite – a streamlined and optimized version of ns-3. NSLite simplifies the protocol stack, which skips control messages, PDU (protocol data unit) and SDU (service data unit) construction between layers, among other improvements that reduce the simulation's running time. At the same time, NSLite has expanded network functions and focus PHY layer signal strength measurement, MAC layer scheduling and advanced multi-carrier multi-cell traffic management modules. We added a wide variety of auxiliary methods into NSLite for constructing multi-cell scenarios and measuring high-altitude cellular environments.

The UAV flight path planner in SkyRoute allows flexible customization of UAV's flight mission including way-point trajectory, flight altitude and speed. In the simulator, the UAV acts as a UE and its location in 3D space can be monitored at each discrete time-step and is updated as the UAV moves. The relative azimuth and elevation angles between the UAV and the base stations are used to calculate the antenna gain. On the basis of the real-time UAV location, a local tangent plane coordinate are established to determine the relative angles between the UAV and the antennas of the base stations.

III. High-altitude Cellular Environment

As an exemplary application in SkyRoute, we drew the RSRP and SINR maps shown in Fig.3 to illustrate the coverage of the high-altitude cellular network. The base stations data from the E-UTRA band (700 MHz NPSBN E-UTRA) was used for our study in a southern state of the US. In this test environment, there are a total of 25 base stations and 85 antenna sectors. The altitude of all UEs is set at 200 meters.

Heat maps in Fig.3 show that the densely populated urban center in the lower left corner is equipped with a large number of base stations to ensure the quality of calls for users on the ground. Because the antennas at the base station are inclined toward the ground, the RSRP value is relatively low when the UAV is located directly above the tower of the base station. In general, UAVs and base stations operate in LOS condition when there are no obstructions such as trees and buildings. Therefore, the UAV can receive relatively strong signals from multiple base stations. This results in strong received power but also strong downlink inter-cell interference at the UAV. On the other hand, although the base stations at the outer part of the city are more sparse, their antennas are generally located higher than those in the city center. Therefore, the UAV is able to maintain a stable communication signal for a long time when flying across different regions of the cities.

With the streamlined network simulator, it is possible to simulate a UAV flight in a short period of time using the platform. During our test, we used a small-sized city with 36 base stations (108 sectors) as the environment. A UAV flies a distance of 21000 meters at a speed of $25\ [\mathrm{m/s}]$ and performs wireless signal measurement every 2 seconds. It only takes 2420 seconds for the platform to complete the simulation.

Future Work: SkyRoute allows us to study in an efficient and realistic manner a wide range of complex problems in UAV cellular connectivity. These include but are not limited to cell selection and handover management, UAV flight path optimization and air-to-ground interference mitigation.

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