Demo Abstract: Automated, Autonomous, and Repeatable Wireless Experimentation in Heterogeneous 3D Environments

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ABSTRACT

The performance of wireless networking approaches degrades under user's mobility. To objectively and reliably establish their performance under mobility, one has to guarantee highly repeatable experimentation with minimized external influences, which is currently a burdensome manual process for 3-dimensional (3D) environments. To address this issue, we propose a drone-based testbed for automated, autonomous, and repeatable experimentation with mobile wireless infrastructures in heterogeneous 3D environments. The developed testbed can be easily deployed in various environments, allows for simple integration of a new System Under Test (SUT), and guarantees the absence of interference with the SUT.

CCS CONCEPTS

• **Networks → Network experimentation**; **Mobile networks**.

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1 INTRODUCTION

It is well established that the performance of different wireless networking approaches degrades under user's mobility [1]. For example, user's mobility negatively effects the performance of wireless sensor networks across all layers of the protocol stack [2]. To accurately establish the performance, wireless networking approaches eventually have to be evaluated experimentally. Using real humans as device carriers during such experimentation is not enough as a high level of repeatability cannot be guaranteed. In other words, for achieving fair benchmarks one generally has to guarantee highly repeatable experimentation, which posits a significant challenge in case of experimentation under mobility.

Researchers started tackling the problems of experimentation featuring repeatable mobility by proposing testbed infrastructures with the means for autonomous carrying of the device(s) under test. This testbed-based approach has been utilized for experimentation

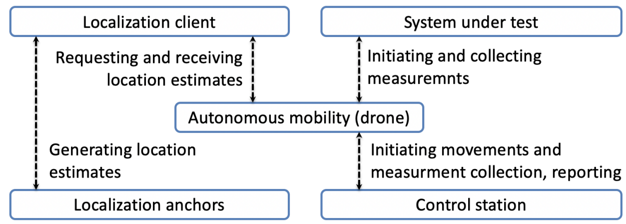

Figure 1: System design

with different aspects of wireless communication, for example for benchmarking of indoor localization solutions [3] and handover between wireless access networks [4]. However, these testbeds focus on one type of environment in which the testbeds are deployed, as well as 2-dimensional (2D) mobility by utilizing autonomous robotic platforms for carrying experimentation devices. Hence, to the best of our knowledge, testbeds that can enable 3-dimensional (3D) experimentation in heterogeneous environments and simultaneously enable repeatable mobility currently do not exist.

Along the discussion above, we propose a testbed for automated and repeatable experimentation with mobile wireless infrastructures in heterogeneous 3D environments. The proposed testbed features i) *automated and autonomous experimentation*, ii) *highly repeatable mobility* of communicating devices in 3D environments, iii) *straightforward deployments* of the testbed in various types of environments, iv) *simple integration between the testbed and new devices* to be benchmarked, v) *guaranteed absence of interference* from the system supporting the experimentation. The main component of our testbed is a Crazyflie drone that serves as a carrier of a device under test. The drone is equipped with an Ultra Wide-Band (UWB)-based positioning system that is able to accurately localize it in a 3D environment. In our demonstration, we show how the developed setup can be used for generating a 3D WiFi Radio Environmental Map (REM) in an indoor environment.

2 DESIGN AND IMPLEMENTATION

The high-level design of the testbed is given in Figure 1. An experiment is envisioned to be initiated from the control station by providing a set of waypoints to be visited by the drone. The drone then visits each of the provided points, instructs the System Under Test (SUT) to collect measurements, and upon each response it reports the obtained results to the control station. In order to visit the instructed locations, the drone requires a means for localizing itself, which is supported through its localization system consisting of a client mounted on the drone and a set of infrastructural devices (i.e., anchors) for the client's localization.

We have compared a range of commercial off-the-shelf drones based on the design requirements. This comparison can be found in the accompanying technical report [5]. We have decided to utilize

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Figure 2: Crazyflie 2.1 drone

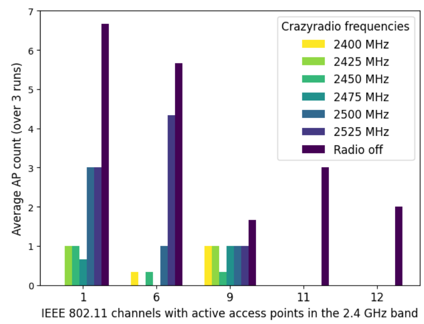

Figure 3: Interference between the testbed and device under test

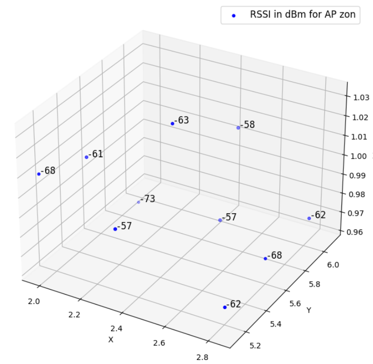

Figure 4: Radio environmental map

the BitCraze Crazyflie 2.1 drone (Figure 2) as it is an open hardware and software platform, allowing a straightforward integration of new SUTs. Crazyflie supports Loco, an UWB-based positioning system that can be easily deployed in different types of environments by deploying the localization anchors and initializing their automated positioning relative to each other. Once this procedure is finalized, Loco is able to localize a target (i.e., the Crazyflie drone) in a 3D space with the average accuracy of less than 10 cm [6]. The drone is controlled through the Crazyradio operating over a USB transceiver. This allows us to fully automate the experimentation by sending waypoints, instructing the SUT to perform measurements at given locations, and parsing and storing the obtained results.

There are three potential sources of interference from the testbed infrastructure toward the SUT. The first two are the positioning system and the propulsion of drone's rotational engines, although [6] showed that these interferences have a negligible effect on the SUT operating in 2.4 GHz Industrial, Scientific, and Medical (ISM) band. The third potential source of interference is the Crazyradio. The interference generated by the Crazyradio while the SUT is scanning for available Access Points (APs) at a given location is illustrated in Figure 3. The figure shows the average number of APs detected at different 2.4 GHz WiFi channels for 6 operating frequencies of the Crazyradio, as well as in case when the radio was turned off. As visible, the interference from the Crazyradio is significant, irrespective of its operating frequency. Hence, our experimentation setup features the (default) possibility of automatically turning off the Crazyradio while performing a measurement using the SUT.

Using the FreeRTOS-flavored Crazyflie 2020.06 firmware release as a basis, a custom driver is responsible for interfacing with the SUT. The driver should support: i) initializing and ii) checking the state of the SUT, iii) instructing the SUT to collect a measurement, and iv) enabling parsing of the output of the previous instruction. For integration with the drone, the user is required to provide the driver for the SUT to react to the four specified instructions. In terms of hardware integration, the user can choose between UART and I2C interfaces currently at disposal on the Crazyflie drone.

3 DEMONSTRATION

In the demonstration[1], we will show how the developed setup can be used for the generation of a 3D REM (i.e., a mapping between physical locations and radio measurements) of an indoor environment. To do that, we have mounted an AI Thinker ESP-01 module with an Espressif Systems' ESP8266 chip on the drone. The module is soldered on the Crazyflie prototyping deck and connected to the drone via the UART interface. We have written an AT Command Set-flavored driver enabling the four afore-discussed instructions. In our demonstration, we will visit 10 predefined locations in the environment of interest, instruct the drone to stop at each location, turn off its Crazyradio communication module, instruct the SUT to generate and report a measurement, obtain the measurement, turn on the Crazyradio, report the measurement to the control station, and proceed with the following location or land at the end of the experimentation run. One end result of such experimentation run is given in Figure 4, where we depict the Received Signal Strength (RSS) (in dBm) at 10 locations in a 3D environment.

[1]Demonstration video: https://youtu.be/fxDkR-Qat6w

4 CONCLUSION

We have demonstrated a system for repeatable experimentation with mobile wireless infrastructures in 3D environments. Our system can achieve a decimeter-level localization accuracy and run autonomously for 7 minutes. Although we have used traditional WiFi as the SUT technology, various others (e.g., BLE, ZigBee, mmWave WiFi) can be integrated with and tested using our testbed. Future work includes evaluating the testbed in outdoor environments, evaluating the effects of interferences (propulsion, localization system) in other frequency bands, introducing additional drones to enable coordinated experimentation with multiple SUTs, and providing support for repeatable experimentation with mobile obstacles.

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