The NITOS Wireless Sensor Network Testbed for Experimenting with Long-Range Technologies

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In this work we demonstrate the NITOS Wireless Sensor Network testbed that allows remote and reproducible experimentation at city-scale, employing long-range wireless protocols. Specifically, we deploy 10 custom-made LoRa-enabled nodes in the city of Volos, Greece, coupled with an embedded device utilized as a means to provide remote access and configuration as well as for monitoring the experiments upon execution. Moreover, the testbed offers power consumption monitoring capabilities being able to capture the power draw of the entire sensor node, while also of individual modules such as the attached wireless interface, to characterize the energy-efficiency of new protocols.

CCS Concepts: • **Hardware → Sensor devices and platforms**; *Wireless devices*; **Sensor applications and deployments**; **Sensor devices and platforms**; **Wireless devices**; • **Networks → Network measurement**; **Network performance analysis**; • **Computer systems organization →** *Sensor networks.*

Additional Key Words and Phrases: Testbed Experimentation, IoT, LoRa, Energy Efficiency

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1 INTRODUCTION

Experimentation under real-world settings is deemed essential when evaluating new protocols and algorithms in order to derive to safe results. During the last decade, several institutions developed large-scale set-ups focused on wireless sensor networks experimentation. SmartSantander [12] is a pioneering facility, counting a few thousands nodes deployed in the city of Santander in order to facilitate smart-city applications. On the other hand, w-iLab.t [4] provides a large-scale testbed deployed in an indoor environment allowing for reproducible experiments using short-range technologies. In the same page, FIT IoT-lab [1] accommodates several distinguished sites across France, again for testing short-range technologies in indoor spaces. Another remarkable work is the FlockLab [10] testbed, suggesting that every sensor node is equipped with an *"observer"* board, responsible for obtaining power consumption measurements and marking timestamps in various events when they occur.

Apparently, the main wireless IoT technologies employed by the aforementioned testbeds are short-range communication protocols, such as IEEE 802.15.4 and BLE, while lately, many of the them are upgrading their infrastructure to support the recently introduced Low-Power WAN (LPWAN) technologies, such as NB-IoT,

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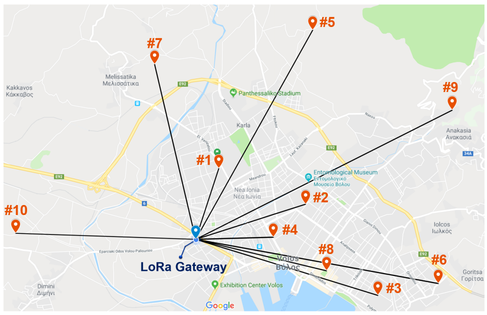
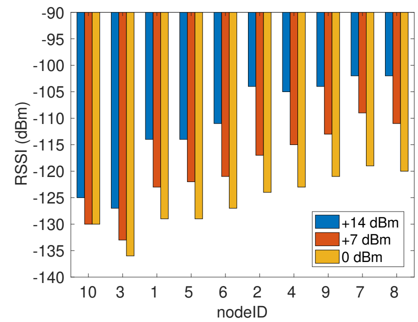


(a) Testbed Topology



(b) Uplink RSSI per LoRa link across different TX_P levels (*0*, *+7*, *+14 dBm*)

Fig. 1. NITOS Testbed Deployment Map & LoRa Uplink RSSI Measurements

LoRa and LoRaWAN that exhibit huge potential. These standards use a physical layer that sacrifices throughput performance, supporting throughput speeds ranging from hundreds of bits to a few kilobits per second, to provide long range communication in the order of tens of kilometers. In fact, entire cities can be covered with the utilization of only one Gateway node on top of it.

In this work, we leverage our previous works [6, 13] that presented a city-wide air-quality monitoring setup using the LoRa protocol for propagating the obtained measurements, and we develop a remotely controllable and configurable testbed based on long-range protocols.

2 NITOS TESTBED SETUP

In this section we describe the proposed architecture and we detail the technicalities of our system.

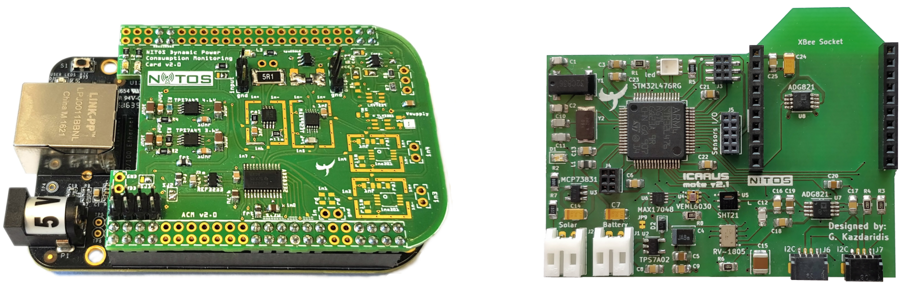
2.1 Architecture

The architecture of our testbed consists of one LoRa Gateway (*GW*) that is deployed on the rooftop of our University's premises and ten Sensing nodes that employ the custom-made ICARUS mote as sensing device that are scattered across the city of Volos, Greece. The end nodes feature various sensor modules, while using the LoRa standard [2] to communicate with the Gateway. Fig. 1(a) illustrates the testbed topology, which forms a unique experimentation setup, since the established links differentiate in terms of communication distance, elevation difference and *LOS/NLOS* conditions. In addition, Fig. 1(b) spotlights the variation among different nodes in terms of uplink RSSI across different *Transmit Power* (TX_P) levels.

The unique feature supported by the developed testbed is that each sensing node employs an embedded device, which is always connected to the Internet in order to support remote access and configuration as well as experiment monitoring.

2.2 Embedded Device

The *Embedded Device* used is the BeagleBone Black Rev. C board [3] which is a low-cost, embedded platform characterized by sufficient processing power capabilities (*ARM Cortex-A8 Processor* at *1 GHz* with *512 MB RAM*) and several I/O pins, while it also embeds an Ethernet port for communicating with the backbone network. Of course, a WiFi version is also available for connecting to wireless networks instead of wired. In our setup we use the BeagleBone along with a ST-Link programmer to remotely upload firmware to the sensing nodes as well as to



(a) BeageBone Device attached with custom-designed cape with power consumption monitoring electronics

(b) The ICARUS prototype IoT node

Fig. 2. NITOS Wireless Sensor Network Testbed Elements

monitor their program execution through a serial port. To this end, an automated procedure is developed that allows the testbed user to build the desired firmware locally and to upload it to any of the remote ICARUS nodes.

Furthermore, we use the BeagleBone board to measure the power draw of the ICARUS node in real-time in order to characterize new protocols in terms of energy-efficiency. To this aim, we employ our custom-designed PCB board (cape) that integrates the required electronic components presented in our previous works [5, 8, 9]. Specifically, the monitoring board features several power monitoring channels that are capable of operating in parallel, thus we fix it to monitor both the entire node's consumption as well as individually the power draw of the LoRa interface. Additional components can also be monitored with the required hardware interventions. Fig. 2(a) illustrates the developed testbed's element.

2.3 ICARUS mote

The *ICARUS* mote [7], illustrated in Fig. 2(b), features the ultra-low power STM32L476RG which is an ARM Cortex-M4 32-bit RISC core MCU operating at a frequency of up to 80 MHz. It embeds high-speed Flash memory of 1 MB and an SRAM of 128 KB. Moreover, it embeds a *SHT21 temperature & humidity*, a *VEML6030 light intensity* and a *MAX17048G+ battery gauge* sensors, while extra sensing modules can be interfaced through the available *I2C* and *I/O* ports. The mote integrates an XBee-footprint socket for plugging-in wireless interfaces, such as LoRa, ZigBee, BLE, etc., In our setup ICARUS features a LoRa transceiver that integrates the SX1272 [11] chipset manufactured by Semtech paired with a 4.5 dBi antenna. Notably, alternative radio modules can be used to support experimentation with different protocols, such as LoRaWAN or other subGHz technologies. In our experiments we have also used the RN2483 LoRaWAN module.

For measuring the power consumption draw of the attached wireless interface we utilize a intermediate circuit board that is placed between the ICARUS and the LoRa interface. This board features a precise shunt resistor of *1* Ω placed in series with the power supply and the LoRa chipset. Across this resistor we measure the voltage drop in order to infer power consumption data.

3 DEMONSTRATION

In the actual demonstration, we will showcase how the testbed users can upload their experimentation sketch to the ICARUS nodes as well as conduct live experiments using the LoRa technology. In particular, we will conduct live experiments in our testbed in order to evaluate collision avoidance schemes in LoRa technology under realistic city-wide conditions. In the actual experiment we will showcase how different TX modes interfere with each other or not, using PDR metrics and deploying a jammer node in the network. Moreover, we will compare how the usage of a collision avoidance mechanism can improve the PDR metrics under the same experimentation setup. Lastly, real-time experiments will be executed in order to showcase the instantaneous current consumption of the ICARUS node and the communication radio separately, under various stages of experiment execution.

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