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LoRa Radius Coverage Map on Urban and Rural Areas: Case Study of Athens' Northern Suburbs and Tinos Island, Greece †

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Abstract: As the use and development of Internet of Things is very popular nowadays, one of the most widespread ways of exchanging data from such arrangements is the use of the LoRa network. One of the advantages offered by this technology is the ability to provide low power consumption as well as wide wireless coverage in an area. Although in research, there are references regarding the coverage radius of a geographical area, differences can be detected between urban (cities) and rural (countryside) areas, as in the latter, there are no dense structures nor radio signal noise inside the operating frequency spectrum of LoRa. Thus, results are expected to be better in rural areas than urban areas. Especially in an urban area, apart from the signal noise caused by other LoRa devices (either commercial or private), the coverage varies according to the placement of the LoRa station inside a building, which is related to the height at which the gateway is placed in another building. In this work, the LoRa radio coverage study is presented in a radius of 2 km both in an urban and a rural environment using only one LoRa gateway. To better capture the coverage, LoRa stations are placed on every floor of the selected buildings periodically. The results show the difference in coverage between urban and rural areas which is related to radio signal noise. Furthermore, significant changes in the coverage map in urban areas can be observed, directly related to the installation height of the LoRa station. With the understanding of these variations in LoRa network performance in different environments, informed decisions can be made regarding the deployment of such networks, optimizing their efficiency and ensuring seamless data transmission in both urban and rural settings.

Keywords: IoT LoRa; radio coverage; map coverage

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1. Introduction

The development of IoT devices in recent years has mainly focused on LoRa protocol for wireless data transmission. LoRa uses wireless data transmission protocols, achieving long-range communication. It is based on Chirp Spread Spectrum (CSS) modulation with a fixed frequency shift step, where it can achieve long-distance data transmission plus low power transmission. It is utilized in a wide range of applications such as smart metering, vehicle and infrastructure monitoring, smart health applications, and industrial production monitoring and control [1–4]. IoT architecture consists of three parts: perception, network, and application. A LoRa network includes three different types of nodes, i.e., a LoRa server, a LoRa gateway (GW), and the end devices [5].

The rapid development of wireless communication technologies in IoT has enabled their widespread use in smart buildings, such as Zigbee, Wi-Fi, LoRa, etc., [6,7]. Smart buildings present an increasing research field because of their ability for real-time dynamic control of various activities and reduction in energy consumption in building operations [8].

In [9], an investigation of communication performance of LoRa wireless technology inside an office building is presented. The experimental measurements show the transmission delay and packet loss rate of LoRa nodes from the same or different floors. The study in [10] concluded that the effect of electromagnetic propagation changes under various environments and cities, as well as rainforests.

The combination of IoT solutions is used for automated control of services such as building access, security systems, lighting, heating systems, ventilation systems, etc. [11,12]. In [13], a wearable LoRa-based wireless sensor network including self-powered environmental sensors was used to monitor harmful environmental conditions. A LoRa-based low-power real-time air quality monitoring system in [14] was implemented to collect both air and gas pollutant values, such as NO_2, CO, PM10, and PM2.5. In the research work of [15], a LoRa-based smart metering system was proposed and applied to smart buildings and smart grid systems. In [16], the monitoring of environmental conditions took place in a university, with LoRa nodes installed indoors and outdoors. Based on measured data, the rate of packet loss in the outdoors under line-of-sight nodes was much smaller than the indoor ones. Ref. [17] showed the relation of throughput based on the installation position, presented using RSSI, SNR, and PER (packet error ratio), showing that the transmission signal was attenuated seriously in the basement.

In this work, the innovation of a low-cost water tank measurement device using an ultrasonic sensor is presented, while the data transmission was conducted through a LoRa network. An extensive study of the LoRa network coverage is also presented, using SNR and RSSI measurements. In the urban area, network coverage is studied as a result of LoRa terminal nodes being placed on all floors of buildings. The same experiment is conducted in a rural area without tall and dense buildings or significant radio interference.

2. Materials and Methods

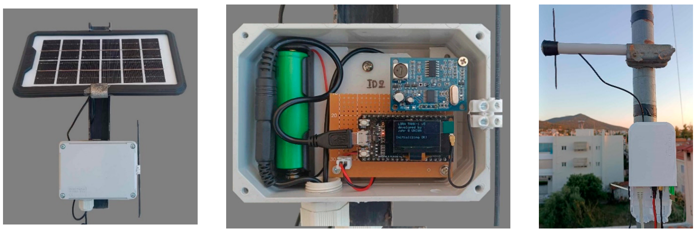
2.1. Experimental Setup

This study presents the implementation of a low-cost water tank monitoring station. It is focused on the reception and network layer of LoRa architecture. The measurement analysis concerns the radio coverage of an area between the LoRa node and LoRa gateway. The low-cost water tank stations are implemented to measure the depth of a water tank. For portability purposes, a small solar panel with a lithium battery pack energizes the nodes. Every station is based on the TTGO@ESP32 (Shenzhen, China) (868 Mhz) [18] module (Figure 1a), meanwhile, LoRa gateway a Mikrotik wAP LR8 kit (Riga, Latvia) [19] (Figure 1b) is used. In addition, custom dipole antennas are made and used for both nodes and the gateway. The antenna performance measurements are shown in Figure 1c. To measure the distance (depth), the ultrasonic JSN-SR04T (Shenzhen, China) sensor is utilized [20].

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

Figure 1. LoRa node construction: (**a**) TTGO@ESP32. (**b**) LoRa gateway. (**c**) Antenna frequency response.

The final construction of the autonomous LoRa node is presented in Figure 2a. The internal setup parts of the LoRa node are shown in Figure 2b and of the LoRa gateway in Figure 2c. This setup is based on the 868 Mhz frequency band, spread factor 8, bandwidth 125 Khz, and code rate 4/5. Measurements are obtained via the web interface of the LoRa gateway.

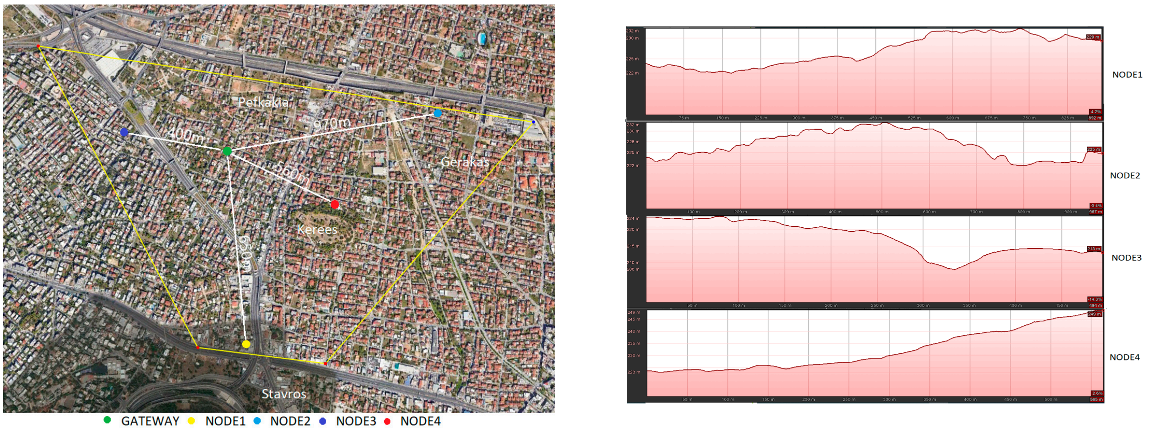


(**a**) (**b**) (**c**)

Figure 2. LoRa node and gateway. (**a**) LoRa node. (**b**) The parts of LoRa node. (**c**) LoRa gateway.

2.2. Experimental Results

The experiment was conducted in two phases. The LoRa nodes and LoRa gateway were at first installed within an urban area in the northeast of Athens in the municipality of Agia Paraskevi, Attica, Greece. The second phase took place in a rural area in the northwest of Tinos Island, in the village of Pirgos. The urban area and the installation points of the LoRa gateway and nodes are shown in Figure 3a. Measurements were obtained in the first two weeks of June 2023 and refer to an area of 1.6 square kilometers. In this area, the surface level comprises two hills, while the average building height is 15 m tall. The visualization of surface elevation (Figure 3b) between the gateway and nodes was retrieved using Google Earth's application.



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

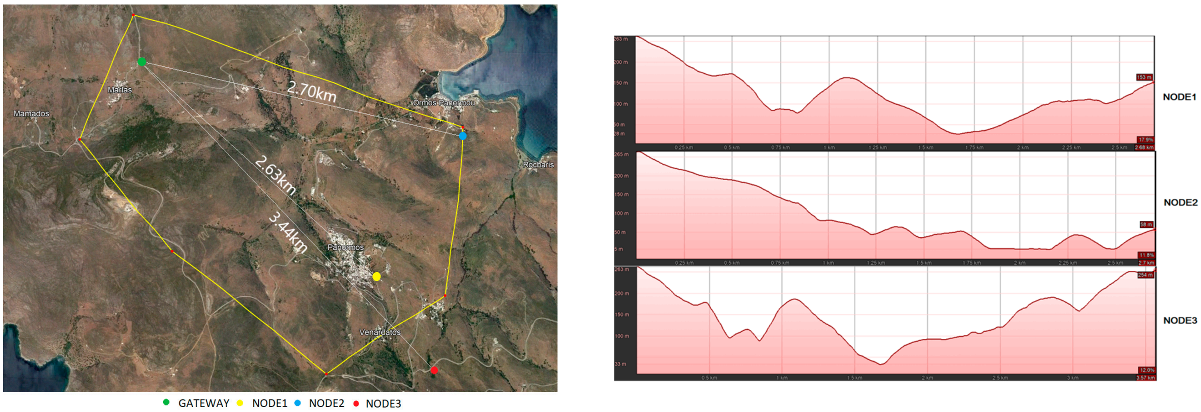
Figure 3. Urban area of northeast of Attica. (**a**) Nodes and gateway installation points. (**b**) Elevation graphs between nodes and gateway.

The measurements between the nodes and the gateway are summarized in Table 1. The height of the antenna of the LoRa gateway was 3 m higher than the top roof of the building (total height around 18 m).

Table 1. SNR and RSSI measurements from nodes (urban area).

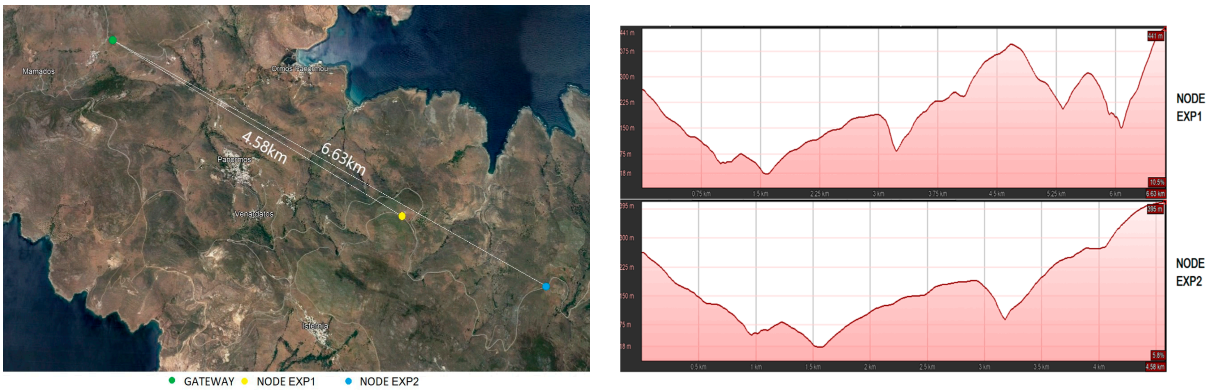
Node	GW Dist. (m)	Roof (dB)		2nd Floor (dB)		1st Floor (dB)		Ground (dB)	
		SNR	RSSI	SNR	RSSI	SNR	RSSI	SNR	RSSI
1	892	0~2.5	−110~−113	−5.5~−7.5	−112~−114	N/A	N/A	N/A	N/A
2	967	−7.5~−9.5	−113~−115	N/A	N/A	N/A	N/A	N/A	N/A
3	494	−7.0~−10.0	−114~−117	N/A	N/A	N/A	N/A	N/A	N/A
4	565	3~6	−103~−107	−2.0~−1.0	−108~−111	−7.0~−10.0	−115~−118	N/A	N/A

The installation points of the LoRa gateway and LoRa nodes in the rural area are projected in Figure 4a, while the surface elevation between the gateway and the nodes is shown in Figure 4b. For the research purpose, the radio coverage distance extension is presented in Figure 5a,b; measurements were obtained in the first two weeks of July 2023 and refer to an area of 6.0 square kilometers. This area is surrounded by mountains that offer excellent isolation from radio frequency noise. In this area, the average residential building height does not exceed 6 m. Table 2 shows the measurements between the nodes and the gateway.



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

Figure 4. Rural area of northwest of Tinos Island. (**a**) Nodes and gateway installation points. (**b**) Elevation graphs between nodes and gateway.



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

Figure 5. Rural area of northwest of Tinos Island. (**a**) Experimental nodes and gateway installation points. (**b**) Elevation graphs between nodes and gateway.

Table 2. SNR and RSSI measurements from nodes (rural area).

	Gateway Distance (km)	SNR (dB)	RSSI (dB)
Node 1	2.68	5.5~5.7	−108~−109
Node 2	2.70	4.5~5.1	−109~−110
Node 3	3.57	3.9~4.78	−108~−110
Node EXP1	4.58	9.5~10.5	−95~−91
Node EXP2	6.63	−3.75~5.5	−116~−102

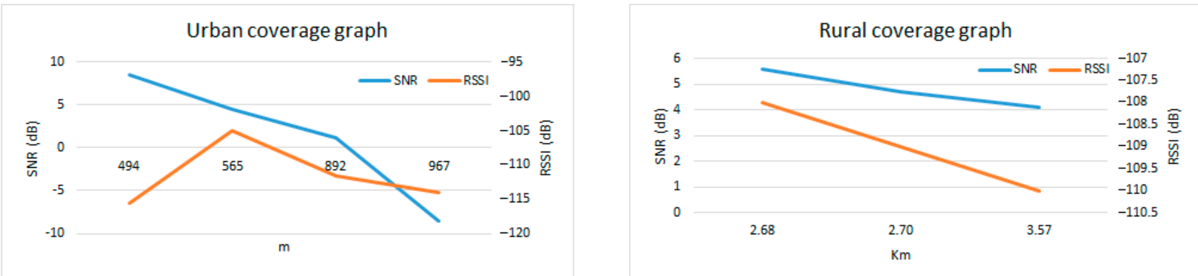
3. Results and Discussion

The visualization of the deepness of each water tank via the ultrasonic sensors is presented dynamically under the Grafana lab environment using a web browser (Figure 6). Figure 6a shows the water tanks' depth measurements, and Figure 6b displays the battery voltage. The reliability of the distance sensor's measurements has previously been verified by calibrating it at different distance lengths with a high accuracy laser measuring device. These measurements prove that the LoRa signal is reliable enough for accurate data acquisition from the stations at long distances.

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

Figure 6. Grafana lab visualization interface. (**a**) Water tanks' depth. (**b**) Battery voltage.

According to the measurements in Tables 1 and 2 (SNR; RSSI) of the LoRa radio coverage between the urban and rural area, the coverage graphs are shown in Figure 7 (Figure 7a shows the urban coverage and Figure 7b shows the rural coverage).



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

Figure 7. SNR and RSSI coverage graphs. (**a**) Urban area. (**b**) Rural area.

From the coverage graphs, it is concluded that the radio coverage of the rural area is greater than the urban area. The reasoning for this behavior is because in the urban area, there is a dense structure of buildings that affects the transmission of the signal. Buildings act as attenuators, according to the SNR measurements. This becomes more evident particularly from the fact that there was no reception when the station was installed on the ground or the first floor. In addition, in urban areas, many forms of radio transmission have been developed, as well as other LoRa networks, that create radio noise in the transmission signal, as derived from the RSSI measurements. On the other hand, small villages and the low height (max 6 m) of their houses do not interfere with the signal as much. Also, radio noise is much weaker as the installations of radio transmitters (television; mobile network) are also weaker in relation to the urban area. According to the above, the results of the LoRa radio coverage in both urban and rural areas are shown; the radio coverage in the urban area refers to an area of 1.6 square kilometers, while in the rural area, it refers to an area of 6.0 square kilometers.

4. Conclusions

In this work, a LoRa-based water tank measuring system was presented. As part of the research study, radio coverage measurements were performed both in urban and rural areas on a similar terrain. The maximum distance of the radio coverage in the urban area was 1 km, while in the rural area, it worked up to 6.5 km. The measurements taken in the city were also conducted for each floor, where in many cases, especially on the ground and first floor, the system could not operate properly. In summary, it was confirmed that in non-line-of-site cases, the LoRa network did not work, as a radio noise affected the radio coverage. In provinces with no radio frequency noise, this system showed excellent radio coverage. On the other hand, the operation of monitoring systems, especially in rural areas, improved the lifestyle of the citizens, hence directly addressing their needs in terms of people's quality of life and livelihood with simple, low-cost but highly important methods.

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