An experimental evaluation of sensors on a LoRaWAN-based GPS tracking system

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The idea of smart cities becomes more and more prevalent in our society. LoRaWAN is a network which provides the means to accomplish that. The main feature of this technology is the low cost of required parts and low power consumption compared to the alternative ones. Thus, it is becoming more and more widespread in the development of applications that forward the smart city mentality. In this work, we implement a LoRaWAN-based tracking system for the vehicle fleet of the municipality of Kozani, Greece. We perform an experimental study aiming to benchmark the developed LoRaWAN network using two GPS trackers, an industrial solution and a custom tracker. In addition, two external antennas are added to the GPS trackers in order to investigate if their addition will increase the number of packets that each GPS tracker sends. The experimental results point towards that the effectiveness of the custom solution is comparable to the industrial one, however, the industrial solution performs better thab the custom one with the addition of an external antenna.

CCS Concepts: • **Hardware** → **Sensors and actuators**; **Sensor devices and platforms**; • **Computer systems organization** → **Sensor networks**; • **Information systems** → **Geographic information systems**.

Additional Key Words and Phrases: LoRaWAN, Internet of Things, Smart cities, GPS, Tracking devices

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1 INTRODUCTION

Technology is developing rapidly in recent years. One of the ideas that is evolving so fast along with the development of technology is Internet of Things (IoT). IoT is a rapidly evolving technology that provides a way for different objects to perform tasks, share information, and coordinate decisions [1]. These objects may be devices such as sensors or end-nodes which use a telecommunication interface as well as processing and storage units [5]. This process integrates all objects on the Internet for the purpose of interaction, either human or device, or the interaction of devices directly with each other. This technique is also known as machine-to-machine (M2M) communication standard [2]. There has been a huge increase in devices connected to the Internet since IoT has multiple applications in many sectors. Many of its applications are in agriculture [11], medicine [7], economics [17], engineering [14], etc. Moreover, IoT applications are implemented in homes [19], creating the so-called smart homes up to the whole city scale, the so-called smart cities [3].

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One of the most popular wireless communication protocols that has been created to be compatible with IoT applications is Low-Power WideArea Network (LoRaWAN) [18]. LoRaWAN is an open source technology that has adequate range in combination with low power consumption, relatively cheep components that result in low cost and scalability. However, it has lower performance and higher latency when compared to more widely used wireless systems, such as Long Term Evolution (LTE) or Wi-Fi [12]. LoRaWAN can reach up to 15 km in rural areas and 5 km in urban areas. In addition, an average receiver sensitivity is -150 dBm but this changes depending on the antenna of each receiver [5]. LoRaWAN is an ideal solution for setting up an inexpensive wireless network with a long range to connect multiple sensors and communicate with each other.

Taking advantage of the LoRaWAN network, many applications have been created to detect the location of an object. The most well-known tracking system is Global Positioning System (GPS) that is a satellite-based navigation system used to provide geolocation and time data [6]. Most applications use GPS using an LTE network. However, there are applications that use GPS with the LoRaWAN network. Jaffar et al. [10] presented an experimental study to evaluate the performance and capabilities of a LoRaWAN-based motion monitoring system. The experiments took place in urban and suburban areas. Hadwen et al. [8] proposed an energy efficient small wristband that combines LoRaWAN communication and GPS. They managed to improve the performance of the battery for the wristband up to 40 hours of continuous monitoring over a distance of three kilometers. Arsyad et al. [4] presented as well a GPS tracker system on a wearable device. They implemented the time-slotted LoRaWAN method to perform bidirectional communication between the wearable GPS tracker device and the server. They managed to supply the node for 21 hours 27 minutes. James and Nair [13] presented a system that uses LoRaWAN wireless transmission and GPS trackers to communicate between the bus stops and a base station. Buses with integrated RF transmitters sent information to the stations about their identity. The information from the stations is sent by the network and processed on a server. They concluded that the proposed system is much cheaper and consumes less energy compared to the existing one. Hattarge et al. [9] presented a tracking system for buses based on LoRaWAN and GPS. Their main goal was to minimize the cost of maintaining GPS using LoRaWAN instead of GSM / GPRS modules. The system architecture of the proposed system consists of end-node, gateway, cloud database, server, and an Android application.

In this paper, a preliminary computational study for the performance of a LoRaWAN-based tracking system is developed and presented. In the beginning, we present the architecture of this tracking system. There are many studies dealing with the architecture of a GPS LoRaWAN-based tracking system, such as as [4, 9, 12, 13], but they do not provide useful insights in the study of different sensors and the performance of GPS antennas. In this study, we aim to evaluate the performance of two different types of sensors. The first type was an industrial solution and the second one was a custom solution. In both cases, modifications were made to the sensor antennas and different gain antennas were tested. The experimental process unfolded in an urban area in the 868 MHz band.

The remainder of the paper is organized as follows. An overview of the architecture of the system is presented in Section 2. Section 3 provides the obtained results and insights. Finally, conclusions are provided in Section 4.

2 SYSTEM DESIGN AND ARCHITECTURE

In this section, we present the equipment used to implement the application, the necessary technical work needed to install the antennas, and the installation of software in the server. Then, we divide the architecture of the system into four basic stages (End-nodes, Gateways, Server, Application). In Figure 1, we present the architecture of the proposed system.

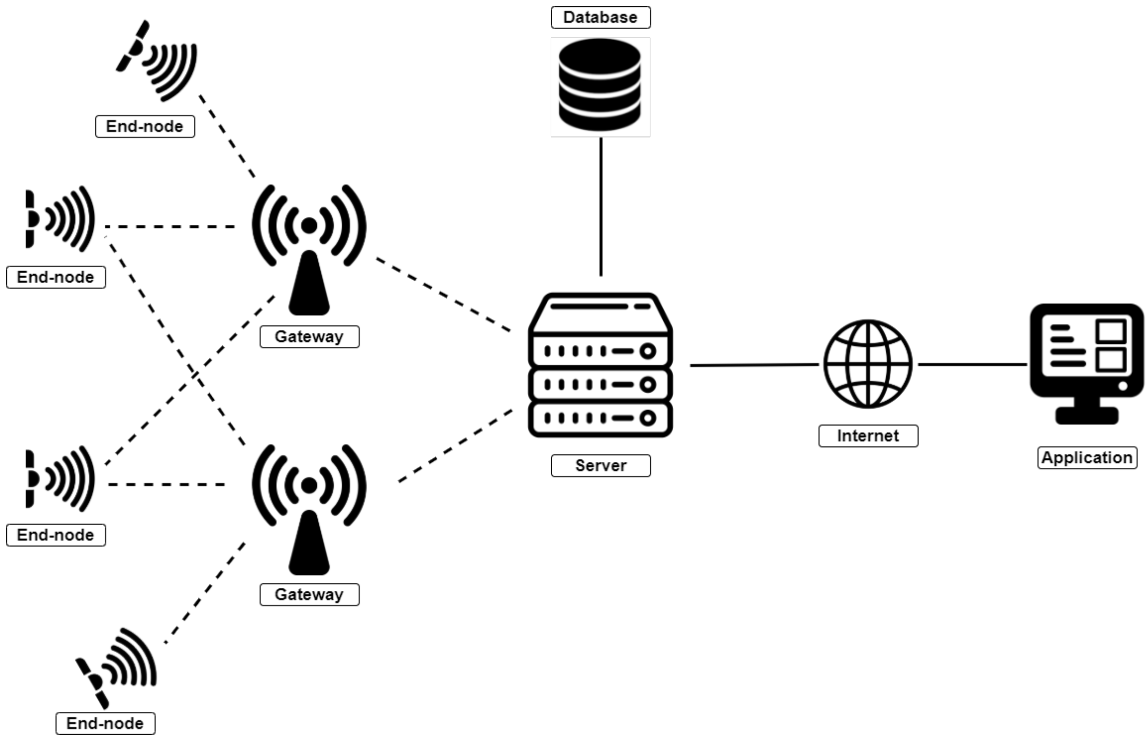

Fig. 1. System architecture

2.1 End-nodes

The end-nodes are the sensors which have GPS and LoRaWAN receivers and are responsible for sending the data received from the GPS receiver via the LoRaWAN protocol to the gateways over the air. We chose two specific sensors as end-nodes in the system. For the selection of the specific sensors, an extensive search was made on various sensors that provided us with a complete picture of the advantages and disadvantages of each solution. The sensors that were tested in this paper are the RAK7200 [16] and TTGO T-Beam [15] sensors. The RAK7200 sensor is a complete solution as it offers built-in sensors, a GPS antenna and three other sensors (a triple-axis gyroscope, a triple-axis accelerometer, and a triple-axis magnetometer) that may be needed for future applications. RAK7200 is a LoRaWAN monitoring device with a 3.7V rechargeable lithium ion battery and a GPS modem. It is based on the low power LoRaWAN protocol and integrates the ultra low power STM32L073 microcontroller, the SX1276 LoRa long range modem, and the CXD5603GF GPS modem.

On the other hand, the TTGO T-Beam is an integrated circuit suitable for mobile operations because it has a built-in 18650 (LiPo) lithium battery, GPS receiver, LoRa transceiver module (using LoRa SX1276 chip) for the 868MHz band, and a built-in battery charger. The unit is powered by the Espressif ESP32 microcontroller board, which contains a dual-core Xtensa 32bit LX6 processor running at up to 240MHz, 4 MB of flash memory, and 520KB of RAM.

Fig. 2. Kozani's network coverage with two installed gateways

2.2 Gateways

The gateway we used was the LORIX One [21]; this model provides the antenna and the gateway in one device. The gateway is the intermediate stage of the server and the end-nodes. The function of the gateway is to receive data form the end-nodes and root to the server via UDP/IP protocol. The minimum receiving sensitivity of this gateway is -140 dBm.

The choice of points for the installation of the gateways was decided after extensive radio coverage study with the usage of the radio coverage tool named Radio Mobile [20]. Radio Mobile is an online application that calculates the radio coverage of a network with the usage of Longley–Rice model. With the installation of two antennas, the theoretical model shows that there is over 90% coverage in the city of Kozani, Greece. However, the model does not calculate the signal strength in urban areas. In Figure 2, we present the resulted coverage provided by the two gateways at the city of Kozani.

Each gateway has two ways to connect to the Internet to communicate with the server: (a) a DSL Internet connection at the mounting point in order to connect directly to the Internet, or (b) a satellite network. The latter case is used in places where access to a terrestrial Internet line is difficult. This is achieved with a SIM card and a router that accepts a SIM card. The router used in one of the two places, where there was no terrestrial Internet connection, was MikroTik's LtAP mini.

2.3 Server

The server is the cornerstone of the network. It is the device that manages the network traffic, data storage, and provides detailed reports on the state of the network where in our case it consists of the server, gateways, sensors, and routers. The operating system installed on the server is CentOS 8. The system consists of two 32-nanometer Intel Xeon E5-2643 lithography processors clocked at 3.30 GHz, 10MB cache, and 130W TDP each. The processors are mounted on a motherboard with a FCLGA2011 socket. The RAM size is 80GB and is divided into 10 DDR3 DIMs of 8GB clocked at 1,333MHz. Finally, the system has two 300GB hard drives in RAID 1 mode for the best possible reliability.

2.4 The Things Network

The Things Network (TTN) is an open-source platform that hosts a plethora of tools that are meant to be used in order to build a LoRaWAN network. TTN is backed up from a large community that strives for constant improvement and further development of already existing tools as well as creating new ones. In this work, the tool of choice was The Things Stack (TTS) Community Edition which was configured and installed locally in a way that covers the needs of this study. TTS is a combination of services that are required in order to have a complete LoRaWAN server. Essentially, TTS provides the means to configure, monitor, and manage LoRaWAN sensors, gateways, and applications through a user friendly web interface. However, in our implementation we chose to built a custom interface for even more convenience. In order to create this interface, we used the API that TTS provides. Not only we recreated the services that the TTS console provides but we further expanded and simplified them in order for adding devices without the technical burden.

2.5 Third-party applications

The usage of third-party software was imperative for the completion of this work. One of those important third-party software is the InfluxDB. InfluxDB is a well-known database system that handles time series and it was used in order to store the data from the transmitted packets. We also used an MQTT client, which is a sub/pub process, in order to draw information from the packets that the server received. Another tool that was used in this work was Docker. Docker resembles, in many ways, the virtual machines but with some differences. The most notable one is the fact that the virtualization takes place on software level instead of hardware level. The usage of Docker came as a way to combine multiple and conflicting software. The way that Docker handles these kinds of problems is that all applications run in independent environments called containers. So with Docker in the role of the composer, we could guarantee the trouble-free execution of all these, and many more, applications.

2.6 Application

All of these elements are combined and displayed in an application that shows the most plausible route of a vehicle that is equipped with one of these trackers. The route shown by the application is an estimation of the actual route that the vehicle followed. The randomness comes from two facts, one is that the interval between two packets and the second one is that the route building tool that we used selects the shortest route between the given points. An example of this application is shown in Figure 3

3 EXPERIMENTAL PROCESS AND RESULTS

The goal of this computational study is to compare various combinations of end nodes and antennas. We focus in the aspects of how many times the sensor managed to send a packet, the quality of the packet, where we define it by the existence or not of GPS information withing the packet, and last but not least the strength of the signal. As mentioned before, we used two types of sensors, the RAK7200 sensor, and the TTGO T-Beam. Note that the TTGO T-Beam can use different antennas to send and receive LoRa packets. RAK7200 typically uses the antenna provided by the manufacturer. In the context of this work and to provide a fair comparison, we modified the RAK7200 sensor to be able to use different

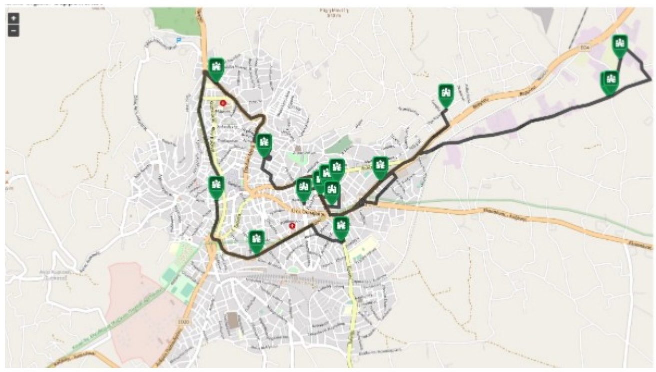

Fig. 3. Mapped path of a GPS sensor

Fig. 4. RAK7200 SMA to UFL modification

antennas other than its default. We achieved that by drilling a hole to the shell of the sensor and installing an SMA to UFL adaptor as shown in Figure 4.

In this work, we used two antennas plus the default RAK7200 setup, the first one has 2 dBi gain and the second one has 3 dBi gain. The geographical morphology of the route can be described as a mix of dense urban parts, sparsely populated rural parts, and hilly roads. The total distance of this route was 40km that could be covered in approximately 40 minutes. Due to the nature of this route, for the most part, the vehicle had no eye contact with the placed gateways. Finally, we placed all sensors in a vehicle and followed the route that we described before. We repeated this experiment five times. All sensors were programmed to send a packet every 20 seconds.

Sensor ID	Number of packets	Max signal strength	Min signal strength	Average signal Strength
rak1	33	-100	-113	-108.50
rak2	37	-88	-113	-106.86
rak3	28	-109	-113	-111.56
ttgo1	23	-97	-113	-107.56
ttgo2	28	-89	-112	-106.66

Table 1. Experimental results

In Table 1, the experimental results are presented. In the first column, there are the IDs of the sensors; the second column represents the number of quality packets that the sensors managed to send; the third column shows the maximum signal strength of the packets sent by the sensor measured (dBi); the fourth column shows the minimum signal strength (dBi); and the fifth column shows the average signal strength (dbi). We refer to the sensors that have the 2 dBi gain antenna as rak1 and ttgo1, the sensors that have the 3dbi gain antenna as rak2 and ttgo2, and finally, rak3 is the default RAK7200 sensor, i.e., without an external antenna. Judging from the results we can deduce that RAK7200 sensors provide more quality packets than the TTGO T-Beam ones in all cases. We also observe that RAK7200 sensors benefit from the addition of external antennas, thus, increasing the number of the quality packets by 5-10; this translates to 17-32% increase of packets. The minimum signal strength is around -113 dBi across the board, which is close to the minimum receiving sensitivity of our gateways. The maximum signal strength of RAK7200 sensors with an external antenna increased significantly compared to the RAK7200 sensor with the default internal antenna. Both RAK7200 and TTGO T-Beam sensors with the 3 dBi gain antenna had a larger maximum signal strength that the corresponding sensors with the 2 dBi gain. Evidently, the information from the average signal strength adds to the notion that the usage of external antennas provides better results. Based on the provided data it is reasonable to assume that RAK7200 sensors outperform the TTGO T-Beam ones in number of quality packets while providing the same average signal strength. As far as the comparison between the antennas, the one with the 3 dBi gain proves to be the most effective for both sensors, which was expected. The rak2 sensor, i.e., a RAK7200 sensor with a 3 dBi gain external antenna, was the most effective combination with 37 quality packets, -88 dBi maximum signal strength, and an average signal strength of -106.86 dBi.

4 CONCLUSIONS

In context of a smart city ecosystem, we developed a LoRaWAN network and a route tracking application. We also compared to benchmark two sensors, an industrial and a custom one, using two different external antennas. During the experimental process, we examined five different combinations of antennas and trackers. The main focus of the work was to study the effectiveness of these combinations via measuring the signal strength and number of packets. This experimental study provided useful insights for the comparison between an industrial and a custom sensor, as well as the benefits of using external antennas. The results point towards the combination of the customized RAK7200 with a 3 dBi gain external antenna to be the most effective one. For a more holistic approach, in future work, we plan to use a broader selection of gateways, antennas, and sensors.

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