World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:17, No:5, 2023

Design of Wireless Sensor Networks for Environmental Monitoring Using LoRa

Shathya Duobiene, Gediminas Račiukaitis

***Abstract*—**Wireless Sensor Networks (WSNs) are an emerging technology that opens up a new field of research. The significant advance in WSN leads to an increasing prevalence of various monitoring applications and real-time assistance in labs and factories. Selective surface activation induced by laser (SSAIL) is a promising technology that adapts to the WSN design freedom of shape, dimensions, and material. This article proposes and implements a WSN-based temperature and humidity monitoring system, and its deployed architectures made for the monitoring task are discussed. Experimental results of developed sensor nodes implemented in university campus laboratories are shown. Then, the simulation and the implementation results obtained through monitoring scenarios are displayed. At last, a convenient solution to keep the WSN alive and functional as long as possible is proposed. Unlike other existing models, on success, the node is self-powered and can utilize minimal power consumption for sensing and data transmission to the base station.

***Keywords*—**Internet of Things, IoT, network formation, sensor nodes, SSAIL technology.

NOMENCLATURE

BLE	Bluetooth Low Energy
dBm	Decibel milliwatts
DMIPS	Dhrystone Million Instructions per Second
HTML	Hypertext Marked Language
IoT	Internet of things
LoRa	Long Range
LoRaWAN	Long Range Wide Area Network
LPWAN	Low Power Wide Area Network
LWIP	Lightweight Internet Protocol
MEMS	Micro electro-mechanical systems
MHz	Megahertz
RSSI	Received Signal Strength Indicator
Rx	Received Signal
SSAIL	Selective surface activation induced by laser
Tx	Transmitted Signal
Wi-Fi	Wireless fidelity
WSN	Wireless sensor network
SRAM	Static random access memory

I. INTRODUCTION

THE emergence and development of micro electro-mechanical systems (MEMS) have resulted in the development of reliable, low-cost, small-sized sensor nodes [1]. Nowadays, hundreds to thousands of heterogeneous sensors are deployed and connected wirelessly to form a sensor network. WSNs can be deployed on land, underground and underwater [2]-[4]. Based on the application requirements, they are designed to work for months and years.

The main objective of this research work was to design an IoT network for monitoring environmental parameters like temperature and humidity through an asynchronous webserver using SSAIL technology and LoRa protocols.

II. SYSTEM ARCHITECTURE

The overall system architecture of the sensor node consists of a LoRa radio transceiver, an ESP32 module (Espressif Systems) for data processing, and a DHT11 sensor (Adafruit Industries LLC) for data collection. A sensor monitoring system consists of ESP32 SX1276 LoRa, working at 868 MHz, LoRa internet antenna board that connects with DHT11 sensor that sends temperature and humidity readings via LoRa transceiver to an ESP32 LoRa receiver. The LoRa sender and LoRa receiver communicate using LoRa, which provides long-range communications: up to five kilometers in urban areas, and up to 15 kilometers in rural areas (line of sight) [5]. The receiver displays the latest sensor readings on a web server. A user can access sensor data from anywhere in the world. Fig. 1 shows the system architecture using LoRa alliance accessing the webserver to monitor sensor readings.

The LoRa sender transmits the DHT11 sensor readings over the LoRa radio every 30 seconds, and the LoRa receiver retrieves the readings and displays them on a webserver. Accessing the webserver enables users to monitor the sensor readings. Depending on their position, the LoRa sender and the LoRa receiver can be separated by several hundred meters. The LoRa receiver operates an asynchronous webserver and stores web page files on the ESP32 filesystem. The LoRa receiver also displays the date and time of the most recent readings.

III. WSN SYSTEM DESIGN

The IoT-based sensor monitoring consists of a network of nodes containing ESP32 SX1276 LoRa module with Wi-Fi antenna DHT11 temperature and humidity sensor compatible with a power source.

Shathya Duobiene and Gediminas Račiukaitis are with Department of Laser Technologies, FTMC- Center for Physical Sciences and Technology, Vilnius, Lithuania (e-mail: shathya.kodeeswaran@ftmc.lt).

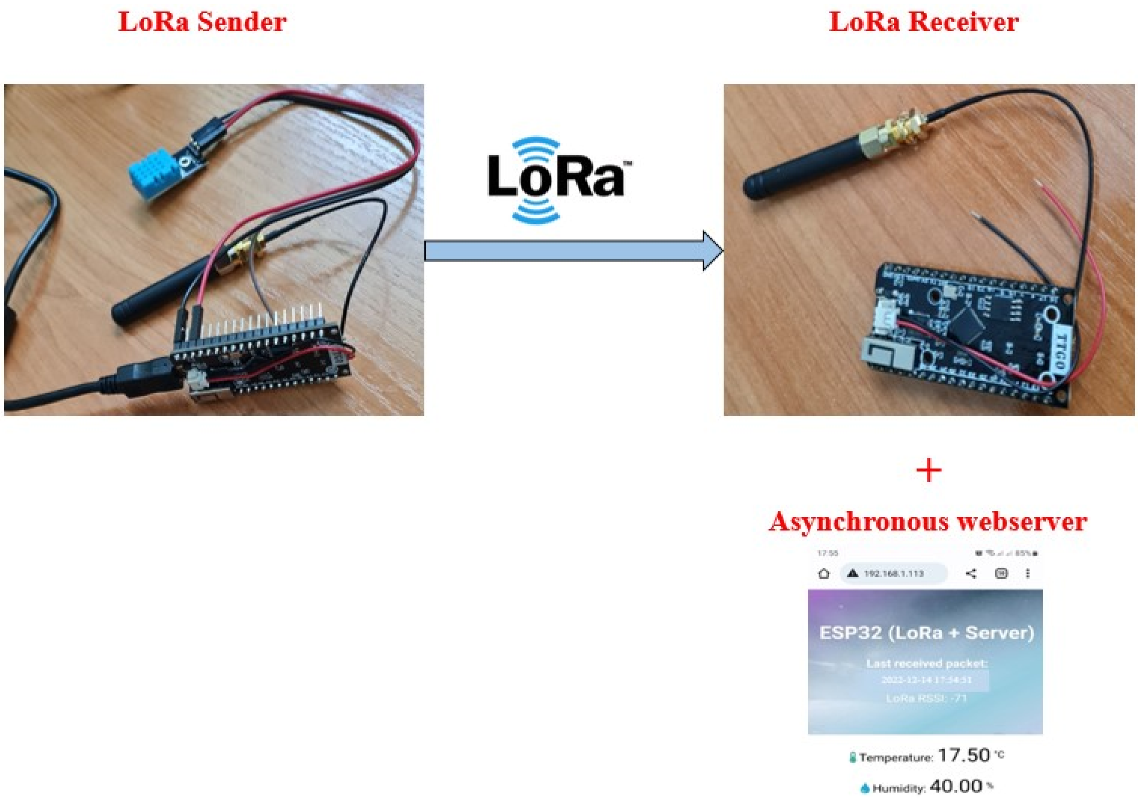

Fig. 1 Sensor node architecture

A. LoRa Module

LoRa is a wireless data communication system that employs a radio modulation technique that can be generated using the main chip in the Lexin ESP32 LoRa transmitter is a 240 MHz, Tensilica LX6 dual-core processor with 600 DMIPS of processing power, 520 KB of on-chip SRAM, an 802.11 b/ g/ N HT40 Wi-Fi transceiver, baseband, protocol stack and LWIP, and built-in dual-mode Bluetooth (traditional Bluetooth and BLE low power Bluetooth) were integrated. It is based on the Wi-Fi 32 enhanced SX1276 chip with LoRa remote modem, +20 dBm power output, -148 dBm high sensitivity, 868 MHz frequency and good reliability. The CP2102 USB to serial chip and onboard 128 MByte flash provide ideal compatibility for the Arduino development environment, making it easy and quick to test and build new programs and products [9], [10]. The modulation technique enables long-range communication of a small amount of data (which corresponds to a low bandwidth) and high immunity to interference while minimizing power consumption. Therefore, it enables long-distance communication with minimal power requirements.

B. Sensor

The Adafruit Industries LLC DHT11 digital temperature and humidity monitoring sensor are employed in the early stages of research to detect the significant environmental characteristics of temperature and humidity. The sensor measures the ambient air with a capacitive humidity sensor and a thermistor before releasing digital data on the pin. The sensor runs at 3-5 V and can detect air humidity in the range of 20-80% with a 5% precision and temperature in the range of 0-50 °C with a 2 °C precision.

C. Power Consumption

LoRa uses unlicensed 868 MHz widely used frequencies in Europe and LoRaWAN protocol which is a low-power wide-area network based on LoRa technology defined by the LoRa Alliance.

The TTGO ESP32 SX1276 LoRa module measures 12 mA in a deep sleep and 30 mA in the normal mode of operation. The operational temperature of this module is between -40 °C ~ +85 °C. Table I shows the two-power mode operation of the LoRa module and their respective power consumption.

TABLE I
POWER CONSUMPTION OF A SENSOR NODE

Mode	Current (mA)	Power Consumption (mW)	Energy consumed per day kWh/day	Energy consumed per year kWh/year
Deep Sleep	12	39.6	0.00095	0.347
Normal	30	99	0.00237	0.867
Overall Total Power Consumption				1.214

A method of 30-minute intervals was described for monitoring the current in the receiving (Rx) and transmitting (Tx) modes during data transmission, and the voltage difference between the Rx and Tx modes was monitored using an oscilloscope. The total energy consumption per day was approximately equal to 0.00332 kWh/day. When two AA alkaline batteries are used to power the sensor node, it typically has a capacity rating of 2500 mAh, and the load current equals

0.1 mA. The battery life was estimated to be approximately 5 years without charging.

LoRa is a good choice for sensor nodes that transmit small amounts of data. However, LoRa is unsuitable for IoT devices that require high data-rate transmission, require frequent transmissions, or are in highly populated networks.

IV. System Implementation

A. PCB Design

A proprietary SSAIL technology of FTMC was applied to produce circuit connections on polymer substrates that can be used to assemble the sensor node electronics [2], [6]. Energy-harvesting antennas can be used instead of power units in sensor nodes that are compact enough to carry the needs of the sensor nodes.

B. Hardware Development

A fractal antenna, made of equilateral triangles, was made to demonstrate the prospect of using SSAIL technology [2], [6] in energy harvesting solutions. Fig. 2 presents examples of Greinacher doubler rectifiers with impedance-matching networks for Wi-Fi frequencies [1].

The sensor node prototype shown in Fig. 3 was created and tested. The modified prototype manufactured using SSAIL technology [4], [7] gives similar outputs compared to the standard LoRa module available in the market. This evidence that the approach of Moulded Interconnect Devices (MID) for IoT as electronic circuits can be directly integrated on 3D free-shape polymeric components removing connectors between various PCBs, reducing the manufacturing chain, and integrating surfaces of switches, sensors and antennas as one which saves material, weight and money [6].

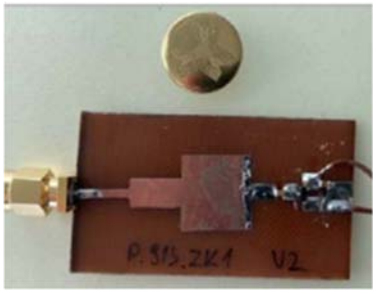

Fig. 2 Rectifier with impedance matching network [1]

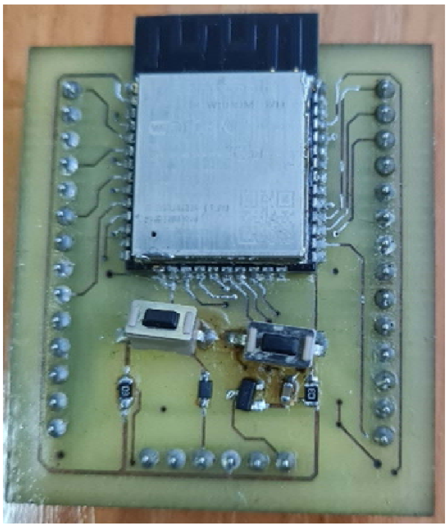

Fig. 3 Sensor node prototype

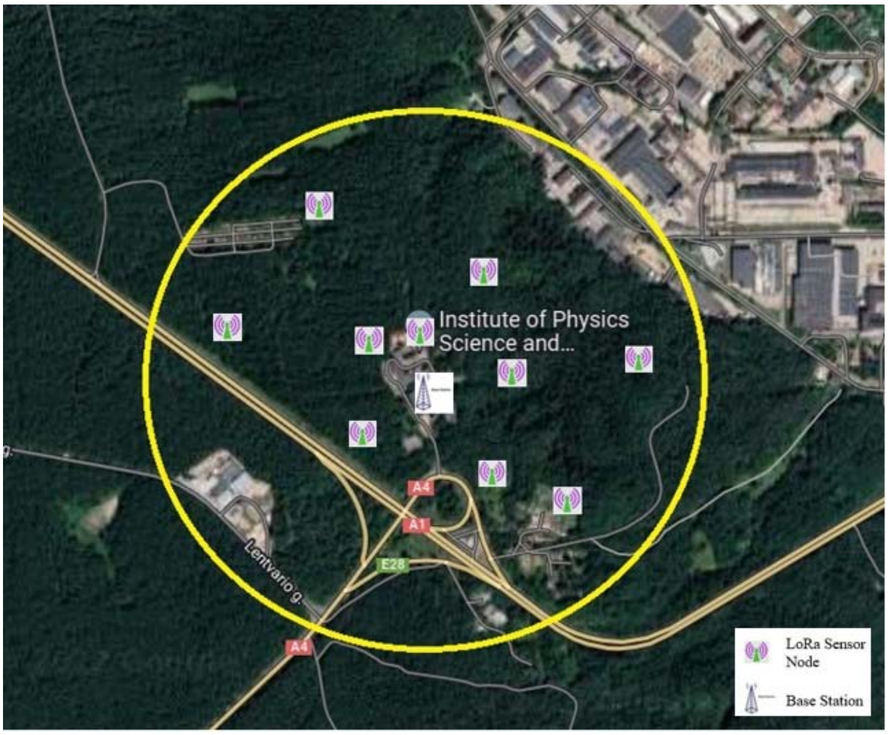

Fig. 4 Location of sensor nodes

The sensor nodes were implemented in the surroundings of the FTMC laboratory, as shown in Fig. 4. Each LoRa sender node sends information every 30 min to the LoRa receiver (base station), where the data are stored and retrieved from the asynchronous webserver for later processing.

The DHT11 communicates with the ESP32 using the I2C communication protocol. LoRa sender code is uploaded using Arduino IDE, which supports all the necessary libraries for the operation. The sketch of the LoRa receiver program has a hypertext markup language (HTML) format that commands how to display the webpage. The LoRa receiver gets incoming LoRa packets and displays the received readings on an asynchronous webserver. Fig. 5 shows the webserver, which displays the latest DHT11 sensor readings, the time those readings were received and the RSSI (received signal strength indicator).

LoRa receiver webserver contains a background image and styles to make the web page more attractive. To display the images on an ESP32 webserver, the ESP32 filesystem (SPIFFS) was organized and stored in the HTML file on SPIFFS. Three different files of Arduino sketch, the HTML file and the image were used to build the web server. The HTML file and the image should be saved inside a folder called data inside the Arduino sketch folder, as shown in Fig. 5

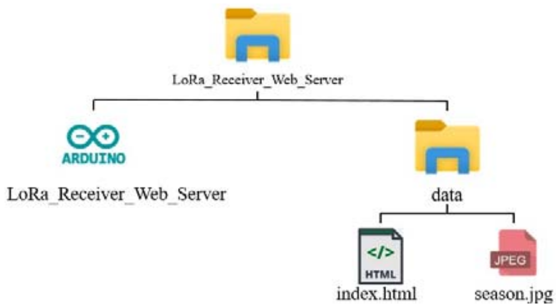

Fig. 5 File organization for the webserver

The LoRa receiver code is uploaded to the LoRa receiver, and the system is ready for testing. Users can access the LoRa sender sensor readings by opening the browser and typing the respective ESP32 IP address.

V. Results and Discussion

By knowing the ESP32's local IP address using Arduino IDE serial monitor, the sensor reading from the LoRa sender can be viewed on the web server. Temperature and humidity sensor data are automatically updated every 30 minutes on the LoRa receiver webserver. The sensor data received in real-time are displayed as shown in Fig. 6.

The evolution of WSN toward WSN-IoT has structured architecture and protocols compatible to create a robust connection with the internet [8]. Ten LoRa senders were deployed around the surroundings of FTMC laboratories. Table II shows the distance between the LoRa sender and the LoRa receiver, and its location is shown in Fig. 4.

Future work includes collecting real-time data from the LoRa sender to the LoRa receiver and storing the data for further processing.

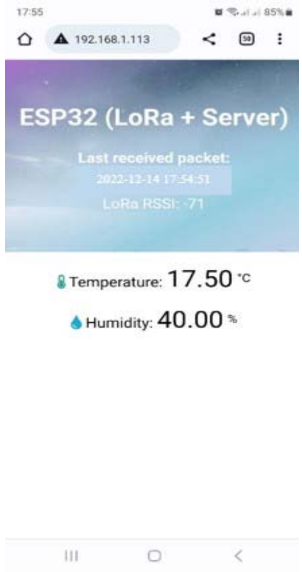

Fig. 6 Asynchronous webserver LoRa receiver

TABLE II
DISTANCE TO THE BASE STATION

Nodes	Distance to Base station (m)
1	124
2	217
3	186
4	226
5	189
6	320
7	505
8	325
9	530
10	583

VI. Conclusion

The primary goal was to use SSAIL technology to develop and produce embedded temperature and humidity sensor nodes and establish a low-cost asynchronous web server. Each time sensor sends 5 bytes of data to ESP32. The total power consumption of the individual sensor node is estimated to be 0.00332 kWh/day for the suggested operation regime. Future work includes covering denser areas, traffic communication through intermediate nodes from a network of sensors covering more distance, and data collection retrieved the web clients in real-time that can be accessed anywhere in the world instead of knowing the ESP32 local IP address.

References

[1] P. Ragulis *et al.*, “Prospect of manufacturing WiFi energy harvesting system using SSAIL method,” *2022 Wireless Power Week (WPW)*, 2022, pp. 824-827.

[2] K. Ratautas, A. Jagminienė, I Stankevičienė, E. Norkus, and G. Račiukaitis, “Laser-assisted selective copper deposition on commercial PA6 by catalytic electroless plating - process and activation mechanism”, Appl. Surf. Sci., 470, 405-410, 2019.

[3] A. Barrios-Ulloa, P.P. Ariza-Colpas, H. Sánchez-Moreno, A.P. Quintero-Linero, E. De la Hoz-Franco, “Modeling Radio Wave Propagation for

Wireless Sensor Networks in Vegetated Environments: A Systematic Literature Review", Sensors, 22, 5285, 2022.

[4] S. Duobiene, K. Ratautas, R. Trusovas and G. Raciukaitis, "Design of an Internet of Things Network for Temperature and Humidity Monitoring and Its Implementation Using SSAIL Technology," 2021 International Conference on Electronic Communications, Internet of Things and Big Data (ICEIB), 2021, pp. 23-27.

[5] LoRa developers "https://lora-developers.semtech.com/documentation/tech-papers-and-guides/lora-and-lorawan/" accessed on 24th December 2022.

[6] K. Ratautas A. Jagminienė, I. Stankevičienė, M. Sadauskas, E. Norkus, and G. Račiukaitis, "Evaluation and optimisation of the SSAIL method for laser-assisted selective electroless copper deposition on dielectrics", Results in Physics, 16, 102943, 2020.

[7] S. Duobiene, K. Ratautas, R. Trusovas, P. Ragulis, G. Šlekas, R. Simniškis, G. Račiukaitis, "Development of Wireless Sensor Network for Environment Monitoring and Its Implementation Using SSAIL Technology", Sensors, 22, 5343, 2022.

[8] R. Dhiman; J. Thakur., "Evolution of WSN into WSN-IoT: A Study on its Architecture and Integration Challenges", 2022 International Conference on Innovative Computing and Communications, 2022, pp.185-207.

[9] Anodas "https://www.anodas.lt/en/ttgo-esp32-sx1276-lora-868-915mhz-bluetooth-wifi-lora-internet-antenna-development-board" accessed on 24th December 2022.

[10] Storemax "https://storemax.mybigcommerce.com/2pcs-lilygo-ttgo-esp32-sx1276-lora-868mhz-bluetooth-wi-fi-lora-internet-antenna-development-board/" accessed on 25th December 2022.