Wireless Self Powered Environmental Monitoring System for Smart Cities based on LoRa

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***Abstract*—This work presents the design and implementation of a wireless sensor network based on the LoRa protocol. Sensor nodes with embedded temperature, humidity, luminance, carbon monoxide, methane, alcohol and smoke detection sensors transmit the collected data to a base station (gateway) using LoRa. The base station collects all the data and uploads them to the cloud using GPRS, where data gathered is stored and processed in order to be accessible to users.**

***Keywords*—LoRa protocol, Smart Cities, Wireless networks, Environmental monitoring, Cloud**

I. Introduction

As world population grows, population in cities grows as well. By 2050, 66% of the worlds population will live in cities, according to United Nations. The demand for high quality of life in urban areas, generates the necessity to create environmentally friendly cities. Smart innovative cities that provide data about the impact of human activity to the environment and services related to health, transportation, sustainability, economy, law enforcement, community and others affecting the overall wellbeing of the residents and businesses. could be the solution to that problem.

Information and communication technologies are fundamental in the development of Smart Cities [1]. A Smart City may gather data from smart devices and sensors embedded in the roadways, power grids and buildings. Communication across the network of nodes enables new capabilities, like statistical sampling, data aggregation as well as monitoring of system's health and status.

Wireless sensor networks are fundamental for these services as they offer very low cost of deployment, low power consumption and maintenance cost. Long range capability of the nodes allows deployment at remote locations. There are several projects where various sensors were installed on the public system [2]. Every wireless networking application has its own unique requirements. Smart Cities applications may have thousands of remote sensors. In order to cover an entire city, a long range wireless protocol is needed. Furthermore, access to the power grid is not always available, so battery life is a critical consideration. Cellular networks are commonly used in similar projects [3], but except from the higher cost, nodes using these networks also suffer from poor battery life. Finally, local RF technologies including Bluetooth and Wi-Fi, do not meet the range requirements to support Smart Cities applications.

Low-Power Wide-Area Network (LPWAN) is a wireless communication wide area network designed to support long range communications at a low bit rate among connected devices, such as sensors operated on a battery. The low power, low bit rate distinguish this type of network from the other wireless networks that are designed to connect users and carry more data, using more power. LoRa is a chirp spread spectrum (CSS) radio modulation LPWAN technology. LoRa uses license-free sub Gigahertz radio frequency bands like 169MHz, 433MHz, 868MHz (Europe) and 915MHz. LoRa protocol is designed specifically for low power consumption (typical 33 mW when resting and 116mW in transceiver mode), a single base station provides deep penetration in dense urban/indoor regions, plus connects rural areas up to 15 km away. Finally, it provides an embedded end-to-end AES128 encryption and high capacity which can support millions of messages per base station, ideal for public network operators serving many clients. As a result, it is the ideal technology for building Smart Cities networks worldwide.

We built a wireless, low cost, self powered and efficient environmental monitoring system described on this paper. In order to accomplish this goal, our system provides a variety of embedded sensors. In particular, temperature, humidity, ambient light and a plethora of gas sensors (CO, CO2, LPG, CH4, H2, Alcohol, O3) are supported. The system is self powered using solar energy for battery charging to maintain uninterrupted function.

The designed system is able to cover an entire city based on only a few base stations. The system is very promising and useful as environmental monitoring represents a class of sensor network application with enormous potential benefits for society. In particular, sensor networks to monitor environmental conditions in cities is the key to provide adequate information to government, organizations and citizens in order to take actions to protect the environment. Many companies, people, organizations use data of environmental monitoring to cope with the environment and to reduce the pollution to make life better. Furthermore, governments use environmental monitoring to ensure company's compliance with environmental regulations, evaluating efficiency of newly installed machine or health of employees.

II. System Architecture

The system resides in the general concept of Smart City services [4] which deploy a centralized network architecture for data collection and storage. A set of peripheral nodes is installed over the urban area collecting information about the environmental conditions. These measurements are transmitted to a base station device using LoRa wireless protocol.

The next step is to make the collected data easily available to authorities and citizens, in order to increase the responsiveness of authorities to city problems, as well as to promote the awareness and the participation of citizens in environmental issues. To that purpose, the base station device periodically uploads the collected data to the cloud through cellular communication services (GPRS).

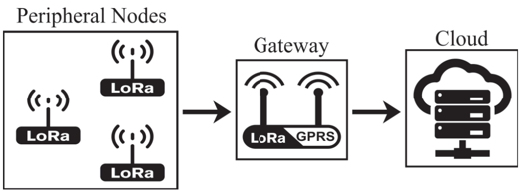

Fig. 1. System Architecture

The wireless communication protocol is based on a time slot scheme. The gateway's LoRa receiver is active in predefined time slots during the day. Peripheral nodes schedule data transmission based on these time slots. Cloud uploading is also perfomed periodically.

In the rest of this section, we describe the different components of the system, shown in Figure 1.

A. *Peripheral Nodes*

Peripheral nodes include all the necessary sensors for the environmental monitoring. Sensors data are locally stored and then transmitted to a base station device using LoRa wireless protocol. The peripheral node system architecture is shown in Figure 2.

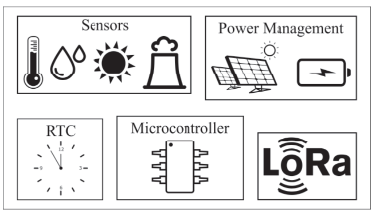

Fig. 2. Peripheral Node Architecture

Our system includes two peripheral nodes. The first is equipped with the the following sensors: Temperature - Humidity sensor (HDC1080 - Texas Instruments), Ambient Light sensorTEMT6000 - Vishay), Carbon Monoxide sensor (MQ7 - Winsen) and Smoke sensor (MQ2 - Winsen). The second : Temperature - Humidity sensor (HDC1080 - Texas Instruments), Ambient Light sensor (TEMT6000 - Vishay), Methane CH4 sensor (MQ4 - Winsen) and Alcohol sensor (MQ3 - Winsen).Details about the range and accuracy characteristics of those sensors can be found in Table 1.

TABLE I
Sensor's Characteristics

Sensor	Range	Accuracy
HDC1080 - Temperature	-40°C - 80°C	±0.2°C
HDC1080 - Humidity	0% - 100%	±2%
MQ2	10ppm - 500ppm	±5ppm
MQ7	300ppm - 10000ppm	±20ppm
MQ3	0.05mg/L - 10mg/L	±0.008mg/L
MQ4	200ppm - 10000ppm	±20ppm
TEMT6000	440-800nm	-

For data collection and system tasks scheduling, each node utilizes an 8-bit microcontroller (ATMega328 - Atmel). A Real Time Clock (DS1302 - Maxim Integrated) is used for node - gateway synchronization.

The wireless communication with the base station is implemented via the LoRa based wireless module (Microchip RN2483).

The need for the system to be able to run for extended periods of time with minimal maintenance was a critical consideration during the design procedure. Energy harvesting techniques were used in order to create an energy self sufficient system.

Each node is powered by a 3.7V - 2600mAh battery combined with a 6V - 3.5W solar panel for recharging. Battery charging is achieved using Texas Instruments BQ24090 battery charger IC. An analysis of the power consumption for each system task was made as shown in Table 2.

TABLE II
Peripheral Node Power Consumption Distribution

Task	Power Consumption (mW)
Standby (Only MCU and RTC working)	8
LoRa Transceiver	116
Temperature - Humidity Measurement	0.16
Gas Sensors Measurement	400
Ambient Light Sensor Measurement	1.6

Sensors measurements and wireless tranmission are performed at the programmed intervals. The power consumption of each node is determined by the following formula.

$$P_{Total} = P_{Standby} + P_{Tranceiver} \times L + P_{Temp-Humid} \times O + P_{Gas} \times 2 \times R + P_{Light} \times A \quad (1)$$

Where constants L,O,R,A are the duty cycles of 24 hours operation. For Athens, Greece the estimated daily power output of a 3.5W solar panel during a sunny day is 21Wh. In aggregation with the power consumption the following duty cycles were chosen: L=0.016, O=0.016, R=0.33, A=0.016. The total power consumption of the device during a day is 870.81 mWh. As a result, the batteries can charge during a sunny day in order to be able to power the system even on cloudy days. In figure 3, the battery level during a sunny day is shown.

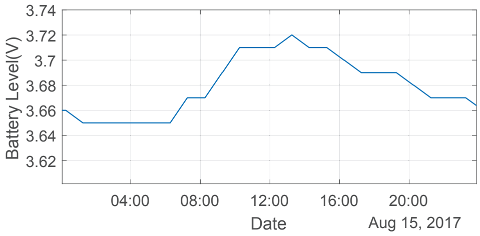

Fig. 3. Battery Level

B. Gateway

The gateway provides the interconnection between peripheral nodes and cloud networking, where data is accessible by users. The gateway system architecture is shown in Figure 4.

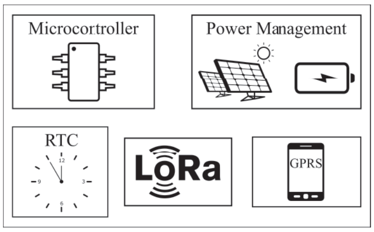

Fig. 4. Gateway Architecture

Similarly with the peripheral nodes, a LoRa module is used for the wireless communication and an 8-bit microcontroller handles the data storage and processing. An RTC is also used for network synchronization purposes. For the communication with the cloud, a quad-band GSM/GPRS module is used (SIM800 - SimCom). The gateway device is also equipped with a rechargeable battery (3.7V - 4000mAh) and a 6V - 3.5W solar panel.

An analysis of the power consumption for each gateway's task is presented in Table 3.

TABLE III
GATEWAY POWER CONSUMPTION DISTRIBUTION

Task	Power Consumption (mW)
Standby (MCU, RTC)	8
LoRa Transceiver	116
GPRS Connection / Data Upload	1200

Given that data uploading time interval is predefined, it is easy to calculate the total power consumption of the gateway for one hour of operation.

$$P_{Total} = P_{Standby} + P_{Tranceiver} \times T \times N + P_{GPRS} \times G \times N \quad (2)$$

The duty cycle of each peration depends on the number of peripheral nodes (N). This happens because of the data load added to the wireless transmission with every extra node. In this case N=2, T=0.008 and G=0.008. So the total power consumption of gateway device during 24 hours is 697.3 mWh.

C. Cloud

Cloud service is the link between the base station device and the end-user applications [5]. All the collected data are stored and easily accessible at any time from any internet enabled device. For proof of concept purposes, we used ThingSpeak.com cloud services.

III. MEASUREMENTS

The described peripheral node and base station architectures was implemented to printed circuit boards (PCBs) as shown below.

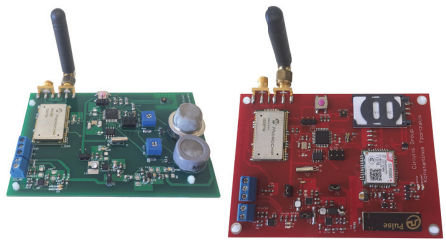

Fig. 5. Peripheral Node PCB

Two peripheral node devices and one gateway device was placed around the university campus as shown in figure 6.

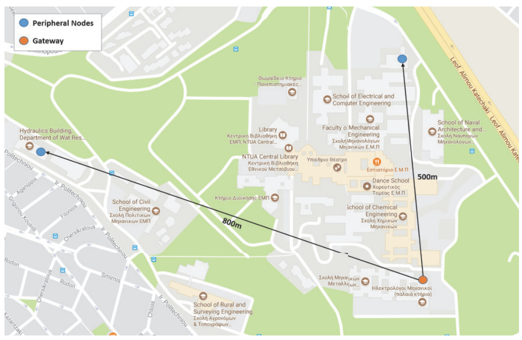

Fig. 6. Geographic location of the wireless nodes and gateway inside the NTUA campus.

After 10 days of continuous operation, the following measurements were collected.

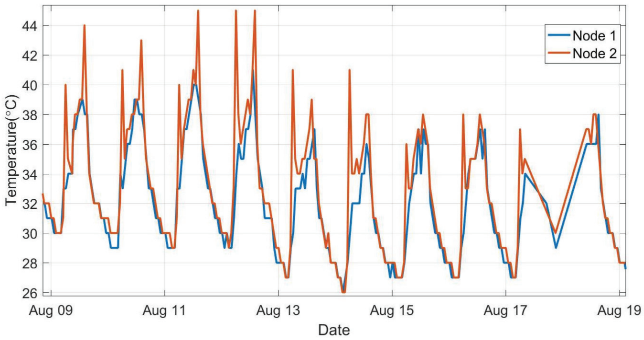

Fig. 7. Temperature Measurements

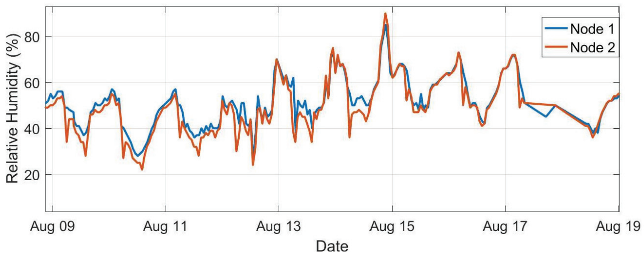

Fig. 8. Humidity Measurements

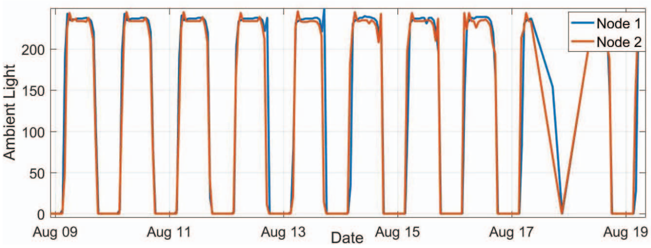

Fig. 9. Ambient Light Measurements

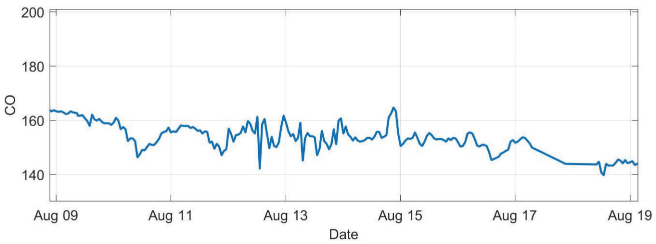

Fig. 10. CO Measurements (Node 1)

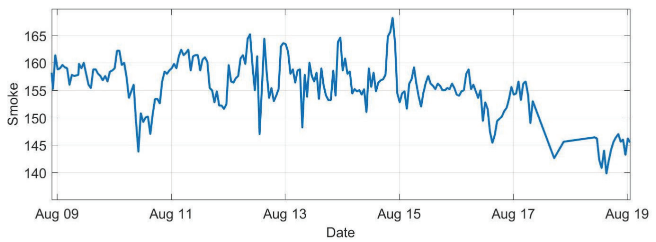

Fig. 11. Smoke Measurements (Node 1)

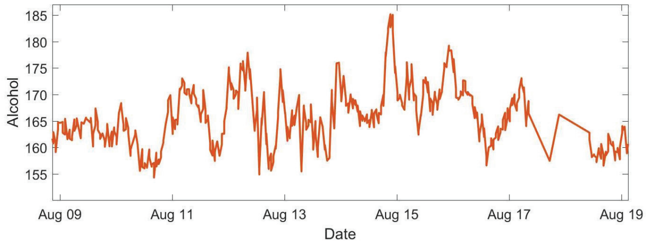

Fig. 12. Alcohol Measurements (Node 2)

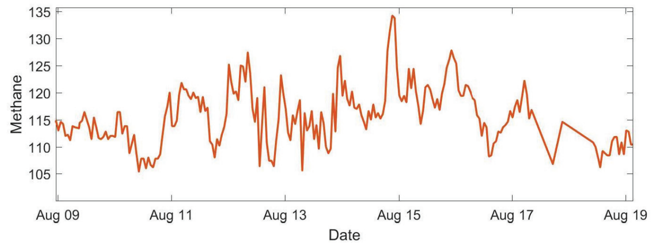

Fig. 13. Methane Measurements (Node 2)

As far as gas measurements are concerned, the data collected from sensors are processed and translated into analog readings. It should be mentioned here that the conversion as well as the accurate calculations from analog reads to S.I. units, is beyond the scope of this work and thus is not presented.

IV. Conclusions

In conclusion, results prove that the system is completely reliable and this is justified by the lack of drop points to zero throughout the measuring window. This also ensures that there is no packet loss between the connectivity of the system and that energy provided is sufficient. Therefore, this system based on the LoRa protocol can find place as a part of a Smart City architecture.

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