

LoRaWAN IoT System for Measuring Air Parameters in a Traffic Monitoring Station [†]

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Abstract

Traffic measurement systems are an essential part of intelligent transportation systems (ITS). These are specialized transport infrastructures where traffic data is collected and analyzed in order to optimize the use of road systems, improve transport safety, and implement future transport plans. The rapid development of transportation systems, urbanization, and industrialization have led to a global problem of air pollution. This has raised the topical issue of measuring and monitoring environmental parameters at traffic monitoring stations in ITS. In this paper, we present a wireless environmental monitoring system, which is a subsystem of a traffic monitoring station. Along with measuring traffic parameters, the station also collects useful meteorological information. A novel hybrid, dual-band IoT system based on LoRa and LoRaWAN for environmental parameters monitoring is presented. The hardware realization of a developed hybrid LoRaWAN end device, together with the sensors used for the measurement of air parameters, is described. Initial results from real test monitoring of environmental parameters on the road in urban environments are presented as a proof of concept. The presented wireless environmental monitoring system can also be used for indoor or outdoor air pollution monitoring, serving as a useful complement to intelligent transport systems.

Keywords: intelligent transport systems; environmental parameters monitoring; IoT system; LoRa and LoRaWAN



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1. Introduction

Intelligent transport systems help to better organize and optimize traffic in large cities. In addition to measuring and monitoring traffic parameters in transport systems, an essential aspect of these systems is the monitoring of environmental pollution parameters on roads and the urban transport environment [1]. Another very important part of these systems is the weather monitoring subsystem. It helps to perform analyses and correlations between traffic intensity, environmental pollution, and weather conditions. Various solutions of environmental monitoring systems can be found in the literature. In [1], the authors used sensors of the MQ family such as MQ-135 and MQ-9 for sensing, which are controlled by Arduino Mega 2560, and data are stored on an SD card for further processing.

The essential drawback of this solution is the use of sensors with high energy consumption. In [2], the sensors used in their implementation are MQ-135, MQ-136, MQ-9, DHT11, PMS3003, MiCS-4514, and others; but again, the major drawback of their solution is the higher power consumption. In [3], the authors examined the spatiotemporal variability of urban particulate matter with a network of low-cost air pollution sensors. In this case, the protocols used for wireless communication are based on Wi-Fi and 4G, which are not energy-efficient. In [4], the proposed real time indoor air quality monitoring system also used a communication protocol based on Wi-Fi.

The present work aims to overcome this drawback with using low-energy consumption digital sensors, a LoRaWAN module with low power consumption, and more effective real-time response communication. On the other hand, LoRaWAN gateways can be overloaded with too much traffic when too many devices are used in small urban areas. For this reason, new communication architectures are needed to overcome this problem.

There are different solutions in the literature like multihop networks that extend the coverage area and improve energy efficiency [5]. Because of the Aloha-like nature of LoRaWAN, there are some efforts made for improving reliability under large-scale deployments [6].

This work presents the architecture and implementation of a novel hybrid, dual-band IoT system based on LoRa and LoRaWAN as well the development of a hybrid LoRaWAN end device. The rest of the article is organized as follows: In Section 2, a new extended architecture of the system is proposed. In Section 3, the implementation of a hybrid LoRaWAN end device is presented. The initial results from real test monitoring of environmental parameters are presented in Section 4. Finally, the conclusion and ideas for future work are presented.

2. System Architecture

To overcome the abovementioned problems, we propose an extended architecture of the system presented in Figure 1. It is based on the classical LoRaWAN architecture, which consists of end devices connected to gateways, the network server, and the application server.

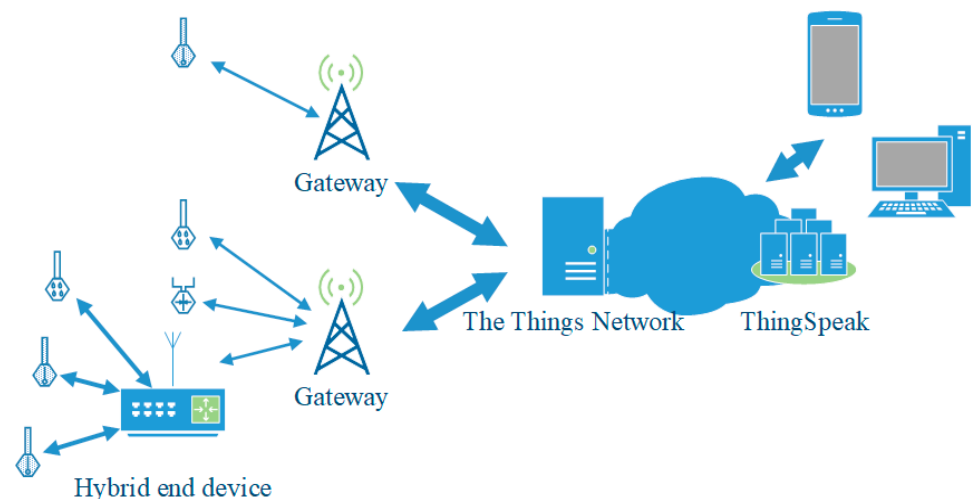


Figure 1. The proposed extended architecture of the system.

In this case, the role of the network server plays is that it offers The Things Network (TTN) cloud service. It communicates with ThingSpeak, which is an open IoT platform with MATLAB R2016b analytics, and is used to integrate TTN. The developed hybrid end device creates a custom LoRa network for end devices with environmental sensors, which

operate in the 433 MHz band. The hybrid end device works as a master, and the end devices that communicate with it are slaves. The master sends requests to a selected end device at regular intervals and relays the data to the upper layers of the LoRaWAN network. This allows the network to cover a much broader area of interest without collisions with the 915 MHz LoRaWAN radio band and without traffic data overload.

3. Implementation of the Hybrid End Device

The block diagram of the developed hybrid LoRaWAN end device is presented in Figure 2. It is powered by a Lithium polymer battery with a capacity of 6600 mAh, which is the main power source for the device. In addition, there are two photovoltaic cells, each with a nominal voltage of 6 V and 1 W power for charging the Lithium battery. The hybrid end device is controlled by a system on module (SoM) CubeCell Dev-Board Plus (HTCC-AB02). The board has an embedded linear regulator for controlling the current that charges the lithium battery. The microcontroller is based on ARM[®] Cortex[®] M0+ Core processor, operating at 48 MHz. It has 16 Kbytes of SRAM and 128 Kbytes FLASH memory for the program. The module has an integrated lithium battery management system with an SH1.25–2 battery interface, as well as a solar energy management system that allows the direct connection of solar panels. The hybrid end device collects data for environmental parameters from the connected sensors. The sensors SCD40, AHT21, and ENS160 are connected to the module via an I²C interface bus operating at 3.3 V.

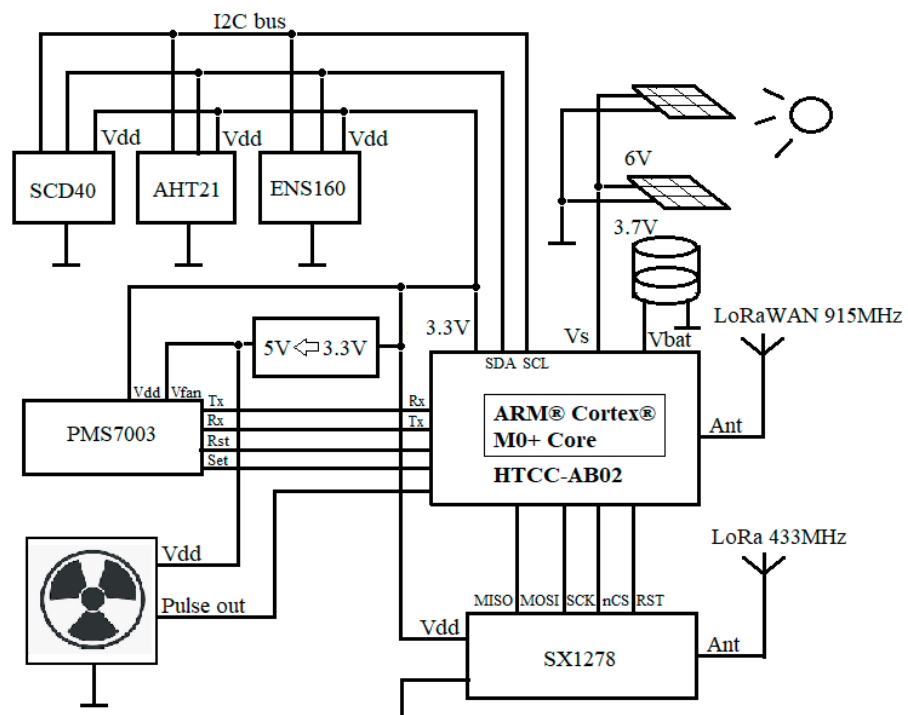


Figure 2. Block diagram of the developed hybrid LoRaWAN end device.

The SCD40 is a CO₂ sensor from Sensirion Corp. Its technology for sensing CO₂ is based on photoacoustic non-dispersive infrared spectroscopy. Infrared light at 4260 nm is used, which is absorbed by carbon dioxide molecules, causing excited molecular vibrations. These increase the translational energy, and this leads to a periodic change in pressure in the measuring cell, which is converted into sound waves measured by a micro-electromechanical systems (MEMS) microphone.

The sensor AHT21 is used for temperature and humidity measurement of the ambient air. The two sensors are paired for temperature and humidity compensation and are integrated into one module.

The sensor ENS160 measures total volatile compounds (TVOCs) and equivalent CO₂ (eCO₂) using a MEMS hotplate coated with a metal oxide semiconductor (MOx). It has a broadband sensitivity for both reducing and oxidizing gases—H₂, ethanol, methane, toluene, acetone, n-octane, CO, and formaldehyde.

For particulate concentration measurement, the sensor PMS7003 is used. It employs the Rayleigh scattering effect [7,8]. The sensor uses lasers to radiate suspended particles in the air. The concentration of particles is given in three ranges as follows: 0.3 ÷ 1.0 µm, 1.0 ÷ 2.5 µm, and 2.5 ÷ 10 µm, in µgr per cubic meter volume of air. The sensor communicates with the microcontroller via a serial interface.

The gamma ray detector module is based on J305 tube, which supports ionizing radiation measurement from 20 mR/h to 120 mR/h. The output signal is a pulse train. The required supply voltage for the fan, as well as the supply voltage for the particulate matter sensor, is 5 V. Therefore, a pulsed voltage boost converter from 3.3 V to 5 V is added, as shown in Figure 2. All measured parameters by the sensors are summarized in Table 1.

Table 1. Measured environmental parameters.

Sensor	Parameter	Range	Unit	Accuracy
ENS160	TVOC	0 ÷ 65,000	ppb	-
ENS160	eCO ₂	400 ÷ 65,000	ppm	-
AHT21	Temperature	−40 ÷ 120	°C	±0.3
AHT21	Relative Humidity	0 ÷ 100	%	±2
SCD40	CO ₂	400 ÷ 2000	ppm	±50
PMS7003	Particulate matter 0.3–10 µm	0 ÷ 500	µg/m ³	±10
J305	Gamma radiation	20 ÷ 120	mR/h	-

The microcontroller module has integrated a SX1262 module on the board that supports LoRaWAN v1.0.2 connection. In the developed hybrid end device, an additional LoRa module SX1278 is added, which is used for the custom LoRa network operating in the 433 MHz band. This LoRa module is connected to the microcontroller using the SPI interface.

4. Results

The developed hybrid LoRaWAN end device and the operation of the system for monitoring the environmental parameters are tested in a real-world scenario. The hybrid end device transmits the measured data to The Thing Network, which acts as a network server. A connection is made to the ThingSpeak platform, where the data is visualized and further processed in MATLAB. The test results of the air parameters monitoring can be seen on the ThingSpeak chart, as shown in Figure 3. The presented test results were measured during the summer period (2 August 2024) from 6:00 to 19:00 in the city of Plovdiv, at 63 St. Petersburg Blvd. The developed hybrid LoRaWAN device was installed at the traffic monitoring station located on the boulevard. The initial tests were carried out to measure parameters CO₂, TVOC, and the concentration of particles in the air as a proof of concept.

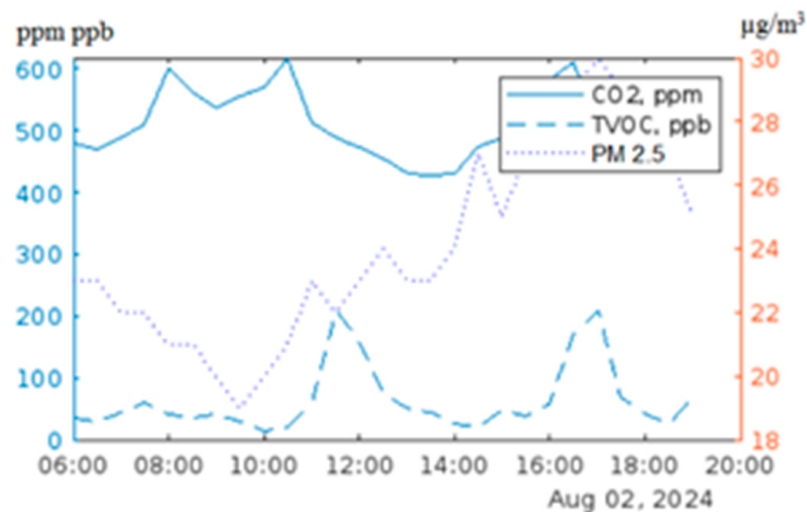


Figure 3. The test results of the air parameters monitoring.

5. Conclusions

This paper presents the architecture and implementation of a novel hybrid, dual-band IoT system based on LoRa and LoRaWAN, along with the developed hybrid LoRaWAN device. The initial tests carried out for measurement of some air parameters serve as proof of our concept. Future work includes designing and testing more end devices connected to the developed hybrid LoRaWAN device and the development of a network that can be evaluated in terms of system latency and reliability. One limitation of this study is the use of inexpensive sensors that have not yet been calibrated, and this is a further issue in future investigations.

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Abbreviations

The following abbreviations are used in this manuscript:

ITS	Intelligent Transportation Systems
LoRa	Long-Range wireless sensor network
LoRaWAN	Long-Range Wide Area Network
IoT	Internet of Things
TTN	The Things Network
SoM	System on module

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