

Research Article

Development of a 3-node LoRa-based hopping network for ambient Carbon monoxide Monitoring with MQ-7 and Carbon dioxide with MQ-135 gas Sensors

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A B S T R A C T

Clean and quality air is a basic requirement for every living organism on the Earth. Human activities, such as the burning of fossil fuels (combustion of natural gas, petroleum and coal in power generation, factories, vehicles, etc.), release carbon oxides (including dioxide and monoxide) into the air. Carbon oxides are among the largest contributors to air pollution. The diffusion of carbon monoxide (CO) into the blood can be life-threatening, while increased levels of carbon dioxide (CO₂) may lead to various complications, including headaches, drowsiness, rapid breathing, confusion, increased cardiac output, elevated blood pressure, and increased arrhythmias. To measure the concentration of carbon monoxide, MQ-7 sensors are a popular and low-cost choice. These sensors utilise metal oxide films that adsorb the respective oxides, reflecting changes in electrical properties. The increasing need for real-time monitoring of ambient air quality has driven the development of wireless sensor networks (WSNs) for environmental monitoring. LoRa (Long Range) is a low-power wide-area network (LPWAN) communication technology designed for long-distance data transmission with minimal energy consumption. It operates on sub-GHz frequencies, such as 433, 868, and 915 MHz, enabling reliable communication over a few kilometres. Unlike traditional wireless technologies, LoRa employs spread spectrum modulation, enhancing signal robustness, reducing interference, and ensuring connectivity even in remote or obstructed environments. Leveraging LoRa communication technology allows for long-range data transmission with minimal power consumption. Each node in the network is equipped with MQ-7 gas sensors capable of detecting carbon monoxide (CO) to measure air quality.

Keywords: LoRa, Air Quality Monitoring, Wireless Sensor Network, MQ-7, Carbon monoxide, MQ-135, Carbon dioxide, LPWAN, data Hopping

Introduction

The need for accurate, real-time, and cost-effective air quality monitoring systems has increased due to the growing global concern about air pollution and its subsequent impact on public health, environmental integrity, and climate stability. Traditional air quality monitoring methods, relying on fixed monitoring stations, are often limited by significant deployment and maintenance costs, restricted spatial coverage, and a lack of flexibility.¹ While these systems provide high-fidelity data, they are typically concentrated in urban centres, leaving rural and remote areas inadequately monitored and failing to capture the subtle variations in air quality across diverse geographical locations.¹ Consequently, there is felt a great need for innovative and scalable solutions that can provide comprehensive, decisive data to policymakers and the public.

Carbon dioxide (0.04%) and carbon monoxide (~100 ppb) are colourless and odourless gases naturally present in the atmosphere and are principal driving forces to climate change due to the greenhouse effect. Naturally, CO₂ is released from vegetation and animals as a result of respiration and does not cause harmful effects. However, energy generation using fossil fuels and deforestation leads to excessive emissions of CO₂, and incomplete combustion of these fuels results in the emission of CO into the atmosphere. Elevated CO₂ concentrations can occur, primarily due to inadequate ventilation. Increased CO₂ levels may cause headaches, dizziness, shortness of breath, and an increased heart rate and can affect a person's decision-making ability.^{2,3} Carbon monoxide also causes similar effects, but its impact is far more severe and can lead to serious health threats and, in extreme cases, loss of consciousness or death.^{4,5} Hence, monitoring of the same is undertaken here.

Traditional monitoring systems employ various types of high-precision tools for measuring the pollutants and need large installation space and dedicated air sample collection systems, and they sum up to a huge monetary investment.^{1,6} Due to huge monetary obligations, it is seldom possible to place a number of such systems in the same city/town.¹ Thus, the measurement represents only local information, where the monitoring system is placed. Again, these systems may or may not be connected as a network for creating a better perception of pollution at various locations in a city/town.

In response to these limitations, the development of wireless sensor networks (WSNs) has emerged as a promising approach for large-scale environmental monitoring.⁷ WSNs, composed of distributed sensor nodes that communicate wirelessly, facilitate the collection and transmission of data pertaining to various environmental parameters, including

air pollutants. The advent of semiconductor technology has made it possible to have low-cost miniature sensors (employing adsorption technology) to measure selected pollutant gases with adequate sensitivity and selectivity at a very reasonable cost.^{8,9} Such low-cost systems can be deployed at multiple places and networked using WSNs to facilitate more points of measurement and create a more reliable picture of the pollution level.^{8,10} However, the implementation of effective WSNs for air quality monitoring presents inherent challenges, such as optimising power consumption, extending communication range, mitigating interference, and ensuring data accuracy.^{8,9} This project aims to address these challenges through the development of a 3-node LoRa-based hopping network, designed to provide localised, real-time ambient air quality monitoring.

The proposed system leverages LoRa (Long Range) technology, a low-power wide-area network (LPWAN) solution renowned for its extended communication range and minimal energy consumption, thereby making it suitable for deployment in diverse environments, including those with limited power infrastructure. The implementation of a multi-hopping LoRa network architecture, where data is relayed through intermediate nodes, enhances the system's effective range and resilience to environmental obstacles.^{11,12} Each node is equipped with an MQ-7 gas sensor, collecting the CO concentration at the node and transmitting the data. The integration of these sensors with LoRa communication modules enables continuous/periodic data collection and transmission, providing real-time/intermittent information about the pollutant concentrations.

The primary objective of this project is to develop a scalable and deployable air pollutant monitoring system that effectively addresses the limitations of conventional monitoring methods. By utilising the long-range capabilities of LoRa and the affordability of MQ-7 sensors, this system aims to provide accurate and timely data for public health initiatives, environmental management strategies, and community awareness campaigns. The hopping network architecture ensures adaptability to diverse monitoring needs, making it a versatile tool for tackling air pollution challenges. Ultimately, this project seeks to contribute to the advancement of accessible and effective air quality monitoring solutions, empowering stakeholders to implement proactive measures for pollution mitigation and public health protection.

The sensor nodes wirelessly transmit data to subsequent nodes, finally reaching the terminal node, where it is aggregated and processed. The terminal then sends the processed data to a centralised server or cloud platform for further analysis, visualisation, and decision-making.

Materials and Method

The main objective of this project is to realise a low-cost, long-range network-based yet free air quality monitoring system. The LoRa (RA-02) SX1278 module, specifically in its 433 MHz configuration, offers an excellent solution for long-range, low-power wireless communication.¹³ Using LoRa's spread spectrum modulation, it achieves much greater distances than traditional wireless communication methods, making it ideal for low-data-rate IoT applications.^{14,15} The 433 MHz frequency band, which is commonly used for unlicensed communication, provides a favourable balance between range and signal penetration, enabling effective communication even in environments with obstacles (which is common in dense cities/towns crowded with high-rise buildings).¹⁵ Known for its impressive range, often spanning a few kilometres, the SX1278's performance is further enhanced by its low power consumption and high sensitivity, allowing it to receive weak signals in challenging conditions.¹ This makes it suitable for a wide range of applications, including remote monitoring, smart agriculture, smart city initiatives, and wireless sensor networks.^{16, 17} However, successful implementation requires careful attention to regional regulations to ensure compliance with frequency usage, appropriate antenna selection to maximise range and reliability, and consideration of potential interference from other wireless devices.^{12, 16, 17}

The MQ-7 carbon monoxide sensor was selected for this project after a comprehensive comparison of available sensors, including those from various manufacturers, including Guangzhou Aosong, AMS, Zhengzhou Winsen, and Mettler. Practical factors such as availability and its extremely low cost further affirmed its choice, ensuring the feasibility of the project while adhering to budget constraints. The MQ-7's simplicity, suitable detection range (10-10000 ppm), high sensitivity, and fast response time make it ideal for monitoring ambient CO levels on a microcontroller platform like Arduino or any other microcontroller.¹ Its tin dioxide (SnO₂) sensing mechanism, heated operation, warm-up period, and analogue resistance output were also important considerations. However, careful planning and implementation of calibration routines, power management strategies, and data compensation techniques are mandated for proper calibration, managing the power for its heater circuit, environmental influences (such as temperature and humidity), and long-term potential drift.

For designing the sensor circuit and integrating it with a microcontroller, the Arduino UNO was chosen from a wide variety of available options. This decision was driven primarily by the Arduino UNO's widespread availability, its status as an open-source platform, and its universal acceptance within the electronics and maker communities.

Built around the ATMEGA328 microcontroller, the Arduino UNO operates at 16 MHz, providing sufficient processing power for the intended application.^{19,20} Its versatile feature set, including USB programming capability,²⁰ 14 digital input/output pins, 6 analogue input pins, 6 PWM outputs, and dual-channel full-duplex serial communication, and implemented SPI and I2C protocols²⁰ makes it an ideal platform for interfacing with the MQ-7 sensor and LoRa modules for managing the data acquisition and transmission processes.

System Block Diagram

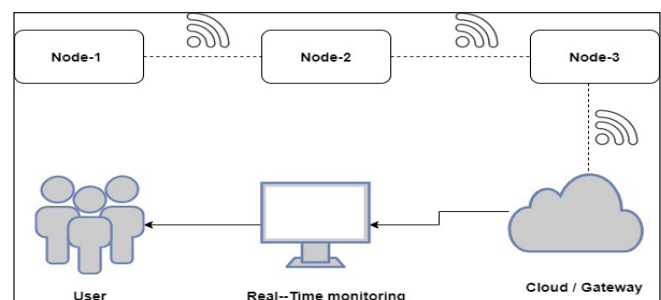
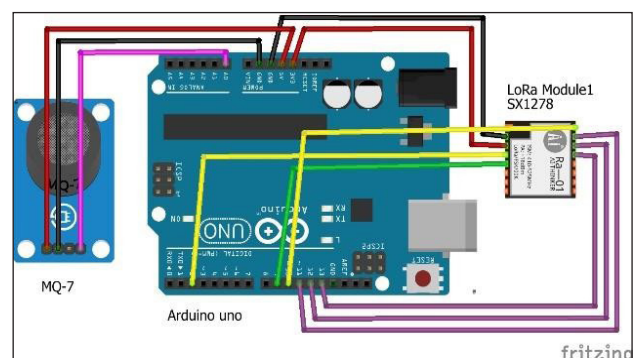


Figure 1. Hopping network System block diagram

The system, as depicted in the block diagram (fig-1), realises a hopping network. The system comprises 3 nodes that can be extended indefinitely (only limited by data latency). Here, node-1 measures the sensor value and processes it to estimate the pollution level and transmits the same to node-2 using the LoRa module by writing the data string using `LoRa.write()`. Node-2 receives the data packet, also reads and processes the sensor value, appends the same to the data packet received and transmits it further to Node-3. Here, Node-3 is designed as a terminal node having no sensor; hence, it receives the data transmitted from the previous node and relays data to a Cloud/Gateway component, facilitating remote data storage and processing capabilities. The information is presented via a real-time monitoring interface, enabling users to observe and potentially interact with the system's operational state.

Schematic Diagram



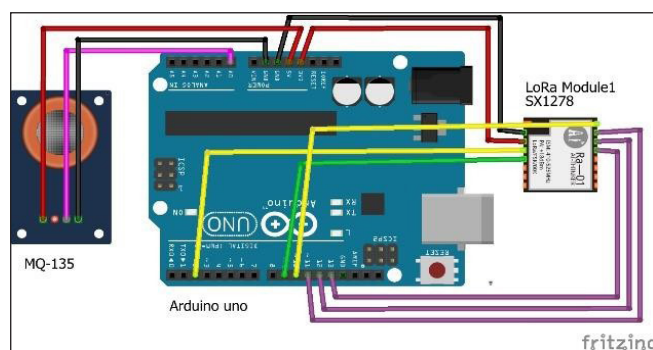


Figure 2(b).Schematic diagram of a node-2

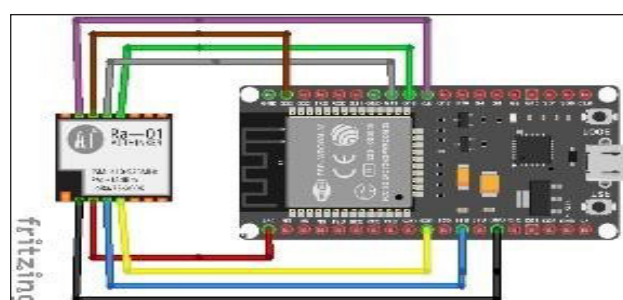


Figure 2(c).Schematic diagram of a node-3

Node 1 and Node 2 are comprised of an Arduino UNO as a processing device, an RA-02 LoRa module for data communication and an MQ-7 carbon monoxide sensor and an MQ-135 air quality sensor, respectively. The sensor MQ-7/MQ-135 output is connected to respective A0 pins to feed analogue data, which is further scaled, while the LoRa module is connected through SPI protocols to facilitate data communication between Arduino and itself. The program is written in Arduino IDE to listen to the previous node (if any), facilitate periodic reading from the sensor, append the processed data to the string listened to, and transmit the same to the next node. The schematic diagrams of such nodes are shown here in fig-2(a) and fig-2(b).

Node 3 (fig. 2(c)) is configured as a gateway/terminal node. It is built around an ESP32 interfaced with a LoRa module to facilitate easy connectivity to the cloud using its built-in Wi-Fi feature. This node does not have any sensors and works as a receiving terminal. It receives data from the previous (relaying) node and conveys it to the cloud.

Flowchart

The flowchart (fig. 3) clearly indicates the functionality of the system. Here, Arduino UNO is used as the core of the system, responsible for all data processing and decision-making. The system starts by powering on the nodes (Arduino microcontroller, LoRa modules, and MQ-7 gas sensors) to detect CO. The Arduino processes sensor data, converting analogue signals to digital values and calculating pollutant concentrations, and manages communication using LoRa modules. For the same, we have configured

each node by its number. Here Node-1 is configured to only transmit the data. Node-2 may be considered as an intermediate or repeater node, and the number of such nodes can be extended as required. Such nodes receive data from the previous node and transmit it to the subsequent node. Node-3 is configured as a terminal node, where all data received is relayed to the cloud/server for further processing. The server/cloud accumulates the data, processes it and prepares a visualisation for real-time monitoring and decision-making.

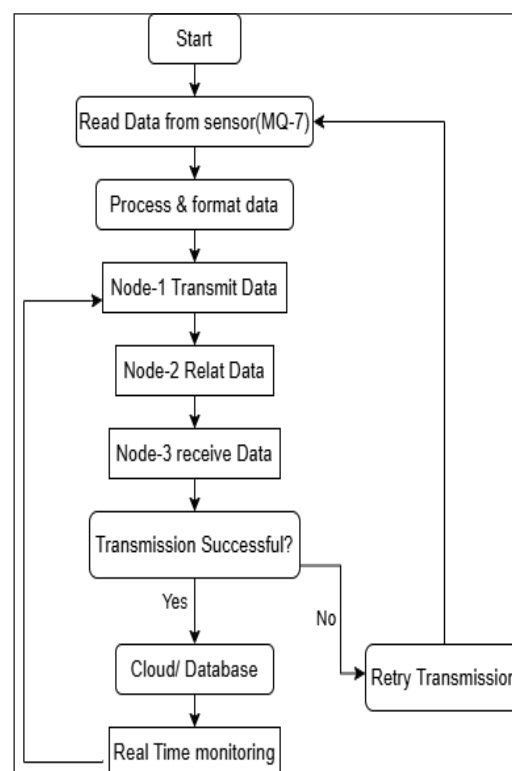


Figure 3.Flowchart depicting functioning of the-program

Results

Based on the visualised data from the LoRa Sensor Dashboard, several observations were made regarding the system's performance in indoor air quality monitoring and real-time data acquisition.

Sensor Data Acquisition and Accuracy

The sensor nodes effectively captured environmental data in real time (fig 4):

- Node 1 (MQ-7) recorded carbon monoxide (CO) concentrations ranging from 147 to 162 ppm. These consistent fluctuations indicate responsive and reliable sensing of CO levels in the indoor environment.
- Node 2 (MQ-135) showed stable air quality readings between 470 and 485 ppm, confirming proper sensor functionality and consistent data acquisition.

These results demonstrate that both sensors are operating within expected ranges, providing accurate and timely data critical for indoor air quality assessment.

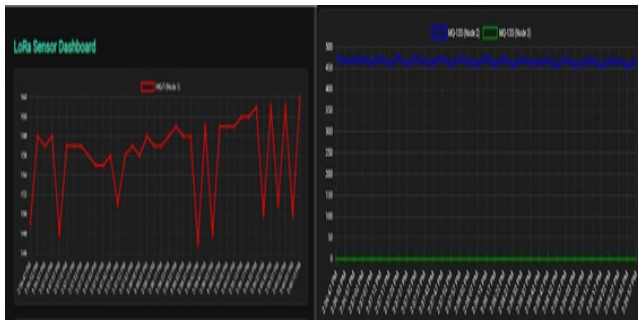


Figure 4. Sensor data from MQ-7 and MQ-135 connected with nodes 1 & 2

LoRa Communication Performance

To evaluate the reliability of the LoRa-based communication network, RSSI and SNR metrics between Node 1 and Node 2 were analysed (Fig 5).

- RSSI (Received Signal Strength Indicator) values ranged between -39 dBm and -51 dBm, indicating strong signal strength and low attenuation.
- SNR (Signal-to-Noise Ratio) remained between 5.75 dB and 9.50 dB, suggesting minimal interference and high signal clarity.

These values confirm that the LoRa communication link between Node 1 and Node 2 is stable and robust, ensuring reliable data transmission.



Figure 5. RSSI and SNR between Node 1 and Node 2

Network Hopping Efficiency

While the dashboard does not provide a direct visualisation of network hopping behaviour, the presence of data from multiple nodes (Node 1 and Node 2) reaching the central dashboard suggests basic multinode communication is functioning in a satisfactory pattern.

However, the lack of response from Node 3 (flatline data) may indicate:

- A communication breakdown due to weak signal coverage.
- An unimplemented or inefficient hopping mechanism,
- Or a sensor/device fault.

This points to partial network hopping efficiency, highlighting the need to optimise signal relays or mesh connectivity for more distant nodes.

Real-Time Dashboard Output

The dashboard offers a user-friendly interface with both graphical and tabular data visualisation (Fig 6):

- Time-stamped graphs display trends in gas concentration, RSSI, and SNR, enabling quick environmental assessments.
- A real-time data table provides continuously updating readings of CO, RSSI, and SNR for Node 1, and CO values for Node 2.

This setup supports rapid decision-making and monitoring for indoor air quality applications, especially in dynamic environments.

Time	Node 1 CO (ppm)	Node 1 RSSI (dBm)	Node 1 SNR (dB)	Node 2 CO (ppm)
2:43:37 PM	159	-37	9.25	460
2:43:40 PM	159	-37	9.00	456
2:43:47 PM	158	-37	9.50	466
2:43:52 PM	158	-38	9.00	469
2:43:57 PM	158	-40	8.50	455
2:44:02 PM	158	-36	9.50	461
2:44:07 PM	158	-36	9.25	468
2:44:12 PM	158	-35	9.75	458
2:44:17 PM	158	-34	9.50	455
2:44:22 PM	158	-35	9.50	463
2:44:27 PM	158	-35	9.50	469
2:44:32 PM	158	-34	9.50	460
2:44:37 PM	159	-45	9.00	455
2:44:42 PM	158	-34	9.50	457
2:44:47 PM	152	-34	9.50	464
2:44:52 PM	156	-34	9.50	467
2:44:57 PM	156	-33	9.00	464
2:45:02 PM	159	-35	9.50	460
2:45:07 PM	157	-34	9.50	456
2:45:12 PM	158	-34	9.00	455

Figure 6. Real-Time Data Table from Node 1 and Node 2

Challenges

The system devised has been found to be satisfying our objectives, namely, realising the hoped-for network communication using LoRa in a reliable and scalable way. However, the process was not a cakewalk. Here are mentioned key challenges faced in this process.

Node 3 dropout: The last node, which is configured as terminal one, dropped to collect signals from relay node a few times. Upon diagnosis, it was found that the loop code written for relaying data to the cloud as well as other stuff to be performed disabled the ESP32 from timely receiving the data from the relay node. When we reframed the code to connect to the cloud once every 5 seconds after the data is received from the relay node, the problem got resolved.

Frequency Regulations: We have used 433MHz LoRa modules for communication. Later we came to know that in India the licence-free frequency band designated by the Department of Telecommunications (DoT), known as the

IN865 frequency plan, ranges from 865 MHz to 867 MHz. Accordingly, we need to switch from 433 MHz modules to 868 MHz modules.

Antenna positioning and range: The LoRa modules seldom give the range claimed in documents. These modules also offered flawless communication at a range of 1 km, much greater than claimed. The reasons can be the terrain, buildings, trees and other obstacles hindering the signals and communication in turn. Antenna positioning is also a challenging task.

Power management for MQ-7 and MQ-135: We planned to collect samples every 5 minutes, mandating making controllers sleep. The sensors mandate heating the substrates in order to work. Every time we cut the power from sensors to save power during sleep time, upon wakeup, it took extra time to measure the gas concentration. Making extra power dissipation.

Conclusion

The LoRa-based indoor air quality monitoring system demonstrated effective real-time sensor data acquisition and reliable communication performance between nodes. The MQ-7 and MQ-135 sensors provided accurate and consistent readings of carbon monoxide and air quality parameters, validating the system's capability to detect environmental changes.

The communication link between Node 1 and Node 2 exhibited strong RSSI and favourable SNR values, confirming stable and interference-free LoRa transmission. However, the absence of data from Node 3 highlighted limitations in network hopping efficiency and coverage, indicating the need for improved relay mechanisms or node placement strategies to ensure comprehensive monitoring across larger or more complex indoor spaces.

The real-time dashboard facilitated immediate visualisation and analysis of sensor and network performance metrics, enhancing situational awareness and enabling timely decision-making.

Overall, the system shows promise for scalable, low-power indoor air quality monitoring, though future work should focus on enhancing network robustness and fault detection for a fully reliable multi-node deployment.

Future Work

We are expected to improvise the network hopping and coverage and expand the array of nodes, making the system more scalable and reliable. The ultimate target is to prepare a seamlessly scalable remote monitoring and alert system. Also, improvement in energy efficiency is well desired.

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