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DEVELOPMENT OF REAL-TIME LoRA-BASED AIR POLLUTION MONITORING SYSTEM

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ABSTRACT

Air pollution can cause long-term health effects on humans, such as heart disease, lung cancers, and respiratory disease. There are many forms of contamination induced by smoke or gas emissions due to fossil fuel burning from transportation. Furthermore, manufacturing operations also negatively impact the air quality, where the production of plastics, electronics, and rubber, has contributed to a rise in organic carbon, inorganic carbon, and dust contaminations. Therefore, in this work, a real-time air pollution monitoring system has been developed to monitor air quality considering three types of gas sensors which are MQ2, MQ7 and MQ135. Also, LoRa communication technology is used as the communication modules between the sensor node located at the site and the gateway. The system is also equipped with an additional notification system to send the monitored air concentration data to the control room via the Telegram application. For monitoring purposes, the monitored data from the sensors will be updated every 5 minutes in the server using the Node-Red platform. The performance of the developed system has been evaluated considering six different distances between the sensor node and gateway, and the results show that the system has high reliability. The results also indicate that the average received signal strength indicator (RRSI) value of the LoRa module between the sensors and gateway reduced with the increasing distance between the sensor node and gateway. However, this does not affect the performance of the developed system.

Keywords: air pollution, arduino, LoRa, Node-Red, received signal strength.

1. INTRODUCTION

Global air pollution has become a significant issue that undermines our planet. Air pollution refers to the release of toxic or harmful pollutants into the air, which is detrimental to human and the earth as a whole. Air emissions containing contaminants such as carbon monoxide, Sulphur dioxide, nitrous oxide, methane, chlorofluorocarbons, particulate matter (i.e., organic and inorganic), and biological molecules can cause diseases, asthma, and even death to the living human.

In Malaysia, the Air Pollutant Index (API) is categories into five classes; good, moderate, unhealthy, very unhealthy, and hazardous [1]. Table-1 shows the status of air quality based on the range of the gas concentration level. As reported by the World Health Organization (WHO), about seven million people worldwide were kills every year due to air pollution [2]. For instance, in March 2019, it has been reported that thousands of people were hospitalized due to the disposing of toxic in Sungai Kim Kim in Pasir Gudang, Malaysia [3] [4]. Due to this incident, many education institutions in the nearby area have to shut down their operation for at least three months as many people in that institution are affected by air pollution. Therefore, it is essential to stress the need for air quality monitoring by the government to reduce the health cases while controlling pollutants.

Table-1. Air quality index [1].

RANGE (PPM)	STATUS
0-50	Good
51-100	Moderate
100-150	Unhealthy for sensitive groups
151-200	Unhealthy
201-300	Very Unhealthy
301-500	Hazardous

The advancement of the Internet of Things (IoT) [5] and communication technology has accelerated the growth of monitoring application systems [6]-[9]. Several works have focused on developing the air pollution monitoring system. As in [10], a smart air pollution monitoring system has been developed to monitor and analyze the air quality in real-time using an Arduino microcontroller. The system is integrated with the ThinkSpeak application, where the collected real-time data will be updated and shared in the remote server using for monitoring purposes. The sharing of data enables the in-charge person to access the data in the server at any time and anywhere.

In [11], the author proposed a low-cost geo-sensor-based air quality control system to identify the air status in the existing and near-future pollutant sectors. In this work, the geo-sensor network is controlled using two main systems: air contamination tracking system and sensor network management system. Also, a warning alert containing the amount and form of emission as well as the safety guideline will be triggered when the system detects an unsafe situation in the immediate future. The warning alert persevered until the windows of each citizen in the building are locked. The building will be contaminated until the air quality level becomes normal, and the warning alert stops. The developed system will also show the status of the sensor, including the current value, last update period, and the status of the battery to help consumers recognize the actual status of the sensors.

Meanwhile, in [12], an efficient real-time air quality tracking system using wireless sensor networks (WSN) has been developed. This work aims to build a cost-effective, efficient, flexible and precise real-time air quality monitoring system where the sensors are integrated with the wireless sensors mote. The developed system is incorporated with a lightweight middleware and web interface to allow the monitored real-time air data can be viewed from anywhere via the Internet. An experiment has been conducted under various physical conditions to evaluate the performance of the developed system, and the results show that the system has high reliability.

Energy consumption is one of the main factors that are important in developing any system. Therefore, in [13], an air pollution monitoring system with recursive converging quartiles (RCQ) data aggregation algorithm has been developed with the aim to reduce the energy consumption of the wireless sensor nodes. In this system, the RCQ data aggregation algorithm will be performed at the cluster head using two techniques: remove duplicate method and recursive quartile method. Then, the processed data are sent to the Sink node from the cluster head before updated or stored in the server. The results show that using the RCQ data aggregation algorithm at the cluster head can minimize the power consumption compared to the conventional method with no algorithm.

In [5], an air pollution monitoring with a notification system is developed to track the air contamination through an internet-connected web server. In this system, an alert notification message will be sent to the in-charge person when the air quality falls above a certain point, implying that harmful gasses such as CO2, smoke, alcohol, benzene, and NH3 are present in the air. The MQ135 sensor is considered in this work to measure the gas level in the air in Parts Per Million (PPM). The obtained value of the gas level will be updated at both LCD and on a web page for monitoring purposes. The system's functionality is tested, and the results show that the system can run with less human involvement, hence reduced the human-intervention mistakes.

In [6], Arduino is used as a controller to develop an air pollution monitoring, and notification system. The system is equipped with an MQ135 sensor to detect the presence of gases in the air. WiFi technology is used as the communication module between the sensors (i.e. placed at the site) and the gateway. The monitored data are updated in the server to enables the citizens to track emission rate (i.e. the PPM value) at their locations through apps. In this system, a buzzer attached to the Arduino controller is used and will only be activated when the detected PPM value of the air quality is above 1000 PPM. Also, the LCD and web page will display “Poor air, Open windows”. Meanwhile, if the PPM above 2000 is detected, the buzzer will beep non-stop, and the LCD and the webpage will display “Danger! Move to Fresh Air”.

In [7], a Zigbee technology is used as a communication module between the sensor nodes and the control services centers is used to develop an air pollution monitoring system. Besides, the developed system used a data compression technique to minimize the amount of duplicate data so that the power consumed due to transferring the data across multiple nodes in the network is reduced.

Long Range (LoRa) communication [14] is a communication technology that can provide a wide range of communication with low power consumption [15]. Air pollution mainly happens in the industry area. Therefore to reduce the number of gateways to relay the monitored air quality data to the central office, LoRa technology is essential. In this work, considering the long-range distance between the sensors at the monitored area and the control room, a real-time fog-based air pollution monitoring system using LoRa technology to provide long-range communication with Arduino microcontroller is developed. The system is also equipped with a NodeRed and Telegram application, where the real-time monitored data will be updated in the servers for monitoring and notification purposes, respectively. To the best of our knowledge, there is no work focus on the reliability of the real-time air pollution monitoring system with LoRa communication technology that is also equipped with a notification system. Therefore, in this work, we evaluate the performance of the developed system using LoRa communication technology in terms of its reliability considering different distance between the sensor nodes and the gateway, and the environment. Also, we also evaluate the received signal strength indicator (RSSI) of the LoRa transmitter and receiver for each considered distances.

The paper is structured as follows: In Section 2, we present the methodology used to develop the air pollution monitoring system that includes the workflow and the architecture of the system. Section 3 presents the considered scenarios for the test-bed implementation to evaluate the performance of the developed system in terms of reliability. Also, the results obtained through the test-bed experiment with the discussion are also presented. Finally, Section 4 conclude the paper.

2. METHODOLOGY

This section presents the architecture and the operational flows of the proposed real-time air pollution monitoring system using LoRa technology. The types of controller, communication module and sensors utilized in this work and the explanation of the development of the system's dashboard are also presented in this section.

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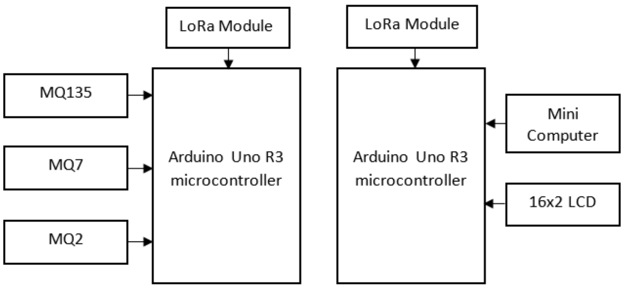
A. System Architecture of Real-time Air Pollution Monitoring System with LoRa

The proposed system consists of two main parts, which are the transmitter and receiver. We consider two Arduino Uno R3 as the controller for the transmitter and receiver. In this work, the transmitter refers to the sensor nodes located in the monitored area. The sensor node is equipped with three types of gas sensors which are MQ2 [16], MQ7 [17] and MQ135 [18]. The MQ2 sensor is used to measure the level of Liquefied Petroleum Gas (LPG), propane, methane, hydrogen, alcohol, smoke, and carbon monoxide gas. Note that the MQ2 sensor can detect the gas concentration between 300 to 10000 ppm. The MQ7 sensor is used to detect the carbon monoxide gas with a gas concentration between 20 to 2000 ppm. The MQ135 sensor is used to detect ammonia, sulfide and Benzene steam. For ammonia and sulfide gas, the MQ135 sensor can detect the gas concentration between 10 to 300 ppm, while 10 to 1000 ppm for Benzene gas.

Meanwhile, the receiver refers to the gateway that aggregates all the monitored data. Note that, in this work, the receiver is equipped with an LCD and CPU. Therefore, once the gateway receives the monitored data, it will process the data, send a notification to the in-charge person in case of emergency, and upload the processed data to the server.

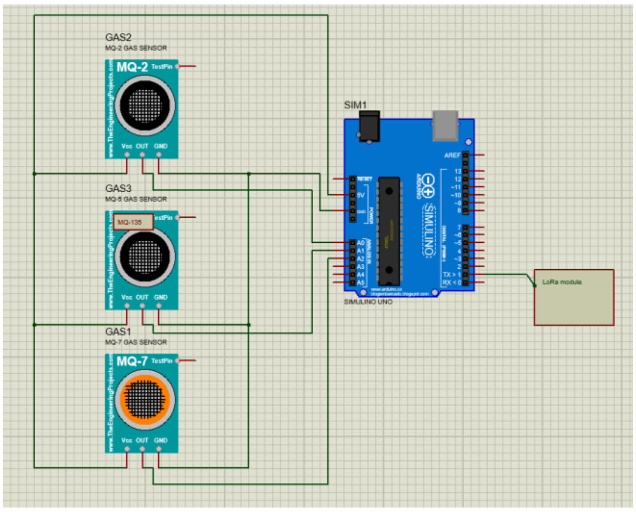
As mentioned in the previous section, we consider the LoRa module as the communication medium between the sensor node (i.e. transmitter) and gateway (i.e. receiver) due to its long-range communication and low power consumption. Figure-1(a) and Figure-1(b) show the block diagram for the developed real-time air pollution monitoring system to monitor the air quality near the industry area for the transmitter and receiver, respectively.



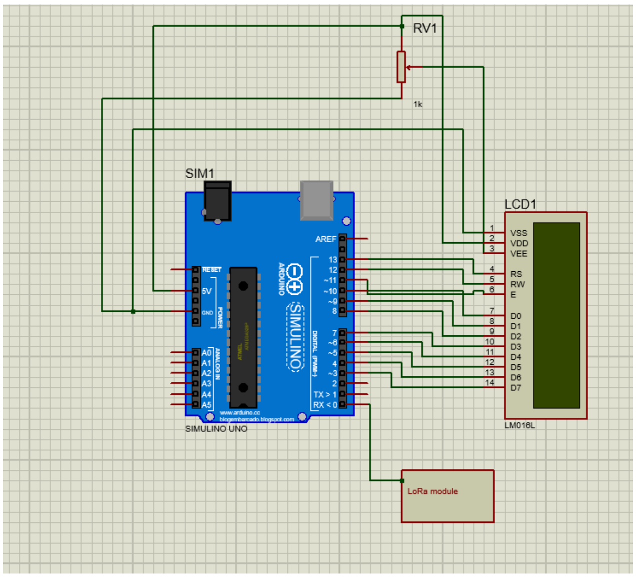
(a) (b)

Figure-1. Block diagram of (a) sensor node and (b) gateway; of the proposed system.

We used the Proteus software to design the circuit for the transmitter and receiver with the Arduino Uno R3 microcontroller. The circuit diagram of the transmitter and receiver is shown in Figure-2(a) and Figure-2(b), respectively.



(a)



(b)

Figure-2. Circuit diagram of (a) sensor node and (b) gateway; of the proposed system using Proteus software.

Meanwhile, Figure-3(a) and Figure-3(b) show the prototype of the sensor node and gateway, respectively.

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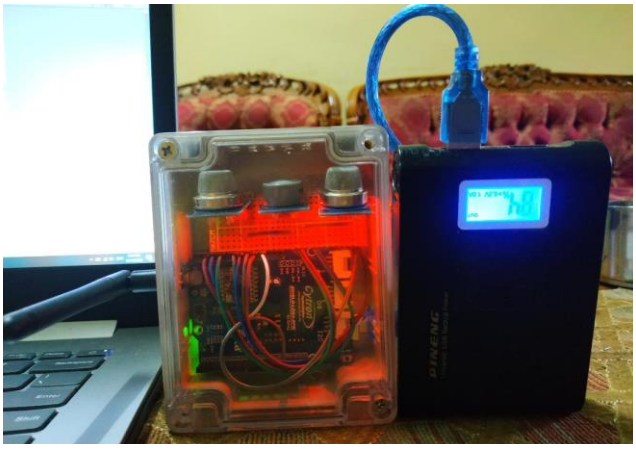
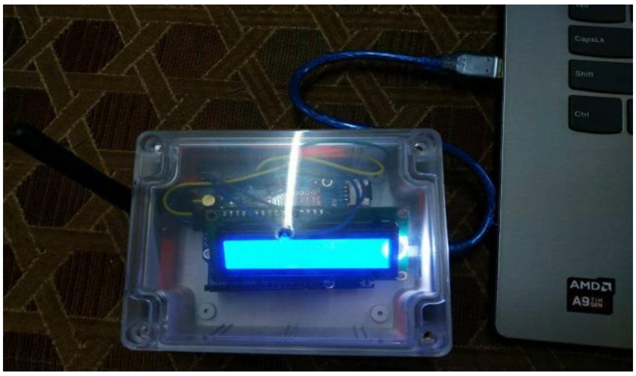


(a)



(b)

Figure-3. The prototype of (a) sensor node and (b) gateway of the proposed system.

B. System Flow of the Real-Time Fog-Based Air Pollution Monitoring System

The operational flow of the developed air pollution monitoring system is, as shown in Figure-4. The system works by activating both the sensor nodes (i.e. transmitter) and the gateway (i.e. receiver). Once the sensor node is powered ON, the gas sensors the MQ2, MQ7 and MQ135 will be calibrated. Then, the sensor node will continuously measure the level of gas concentration and send the measured value (i.e. in ppm value) to the gateway every 5 minutes. Once the gateway received the data, it will process the data to extract the information. Then, the processed data (i.e. level of gas concentration in ppm value) will be displayed on the LCD and updated at the server. Also, the gateway will send a notification to the in-charge person via Telegram applications. The same processes above will be repeated until the system is turned OFF.

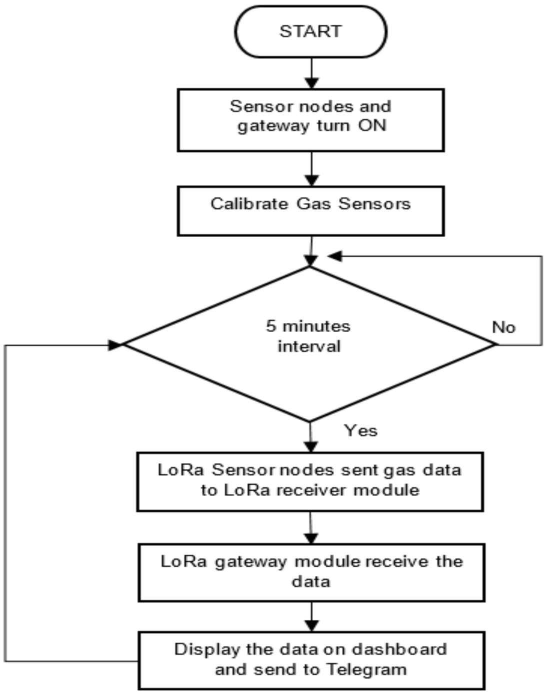


Figure-4. The operational flow of the developed system.

C. Dashboard and Notification Platform

In this work, we consider a Node-Red dashboard to create live dashboards to store the monitored data. Node-Red is a programming tool to integrate the hardware device, APIs and online services. The Node-Red used flow-based programming tools, which reduces the complexity of the programming by describing an application behaviour as a network of nodes (i.e. each node in the programming is defined for a specific purpose). In this work, a personal computer connected to the gateway is used to run the Node-Red dashboard to continuously record the real-time data (i.e. received from the sensor nodes) in the server for monitoring purposes. Figure-5 shows the Node-Red programming network for the air pollution monitoring system. Meanwhile, Figure-6 shows the overview of the Node-Red dashboard with the measured value of all gases (i.e. in ppm value) received from the sensor nodes together with the received signal strength indicator (RSSI) value (i.e. in dBm) between the sensor node and the gateway.

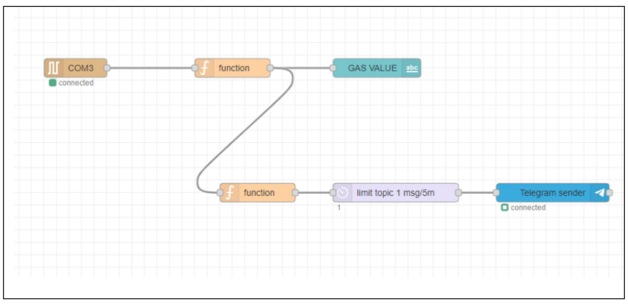


Figure-5. Node-Red programming network.

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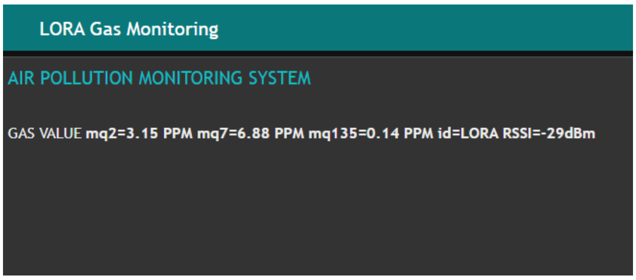


Figure-6. Node-Red dashboard.

In this work, the Telegram application is used to increase the effectiveness of the developed system to monitor the air quality where a notification will be sent to the in-charge person besides updating the data in the server only. In order to do this, the Telegram plugin is installed in the Node-Red software. This plugin enables the Node-Red to communicate with the Telegram API by sending the data via the Internet. The Telegram ID is created to receive information from the Node-Red [5]. Note that, in this work, the Telegram will receive the monitored data from the Node-Red every five minutes interval. Figure-7 shows an overview of the Telegram apps with the related measured data every 5 minutes interval for the developed air pollution monitoring system.

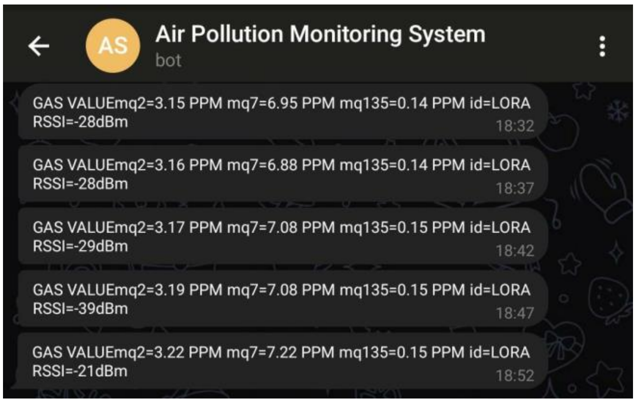
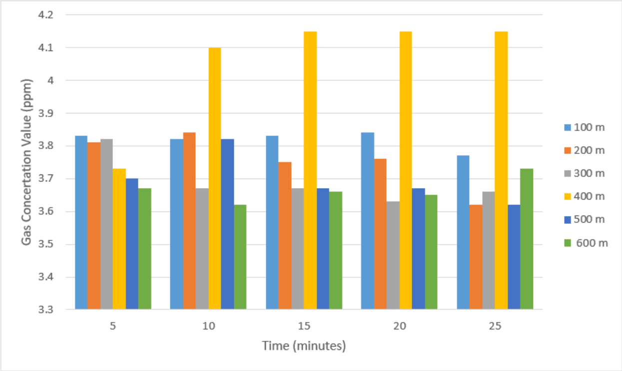


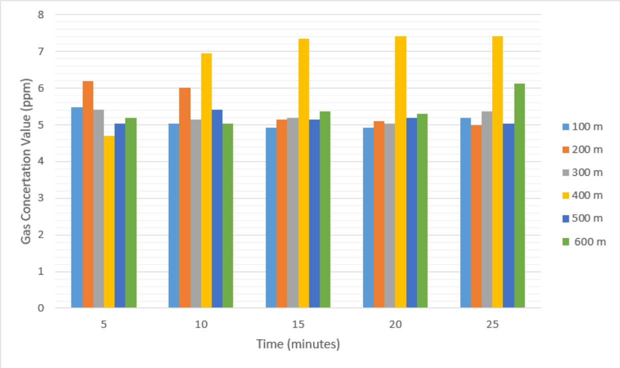
Figure-7. Sample of data monitored received in Telegram.

3. RESULTS AND DISCUSSIONS

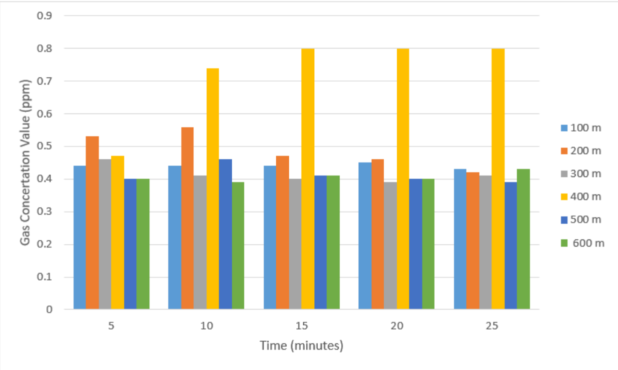
This section presents the results and discussion on the performance of the developed air pollution monitoring system using LoRa communication technology. We performed a real-time test-bed implementation considering scenarios related to the distance between the sensor nodes and the gateway, which is in a range of 100m to 600m with 100m interval. We evaluate the performance of the developed system in terms of its reliability to detect the value of gas concentration for different types of gases with a data logging system and the signal strength (i.e. the RSSI value) of the LoRa signal considering the different distance between the sensor node and the gateway. Note that the experiment is conducted for 25 minutes with 5 minutes interval to show that the system can work for monitoring purposes (i.e. continuous monitoring).



(a)



(b)



(c)

Figure-8. The value of gas concentration for (a) MQ2 (b) MQ7 and (c) MQ135 received at the gateway every 5 minutes considering different distances.

Figure-8(a) - (c) show the measured value of the gas concentration for MQ2 sensor, MQ7 sensor and MQ135 sensor, respectively, considering the different distance between the sensor node and the gateway every 5 minutes interval. The results show that the developed system managed to obtain the gas concentration values for each considered distance and time. This indicates that the developed system is reliable for the real-time air pollution monitoring system, where it can work continuously to detect the gas concentration. However, Figure 8 shows that the value of the gas concentrations for each sensor (i.e. MQ2, MQ7 and MQ135) is slightly different with different distances between the sensor node and gateway.

This is due to the different environment considered during the test-bed implementation. Note that the location of the sensor node is not fixed to vary the distances between the sensor node and gateway. Therefore, different amount of gases are emitted at different location of where the sensor nodes are located. For instance, when the distance between the sensor node and gateway is 400m, the sensor node is located near the main road. Hence the amount of gases such as carbon monoxide and etc. are emitted from the vehicles. This applies to all type of gas sensors considered in the test-bed implementation.

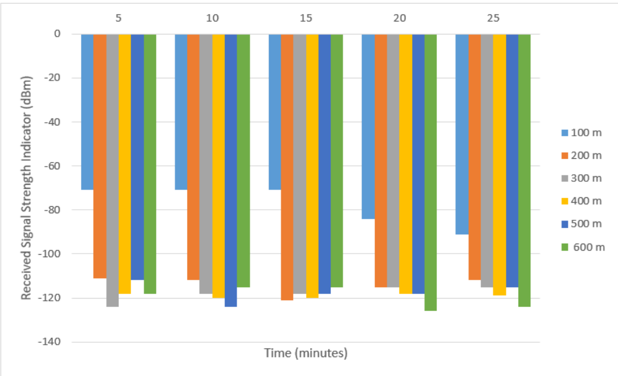


Figure-9. Transmitter RSSI value with different communication range.

Figure-9 shows the RSSI value between the sensor node and gateway at different distance and time. The results show that, in general, the RSSI value reduced with the increasing distance between the sensor node and gateway. This is because the higher the distance, the higher the interference occurs in the transmission due to the reflection of the signal during the transmission. The high interference reduces the signal strength, hence reduced the RSSI value. However, this also depends on the location of the sensor node and gateway. For instance, locating the sensor node or gateway at a low height may cause more interference compared to locating them at a high place. As for this work, we placed the sensor node at a high place which is 2 meters from the ground. The results also show that the RSSI value is stable over time for all considered distance between the sensor node and gateway. Therefore, LoRa communication technology is suitable for the developed real-time air pollution monitoring system.

4. CONCLUSIONS

In this work, a real-time air pollution monitoring system with LoRa communication technology has been developed to measure the gas concentration in the air considering three different gas sensors. The system consists of two-part which are sensor node that acts as the transmitter and a gateway as the receiver. Note that, in this work, Arduino is used for both sensor node and gateway. For monitoring purposes, the system is integrated with the Node-Red platform for data logging. The real-time monitored data will be stored in the server every 5 minutes. Also, the Telegram application is also considered for notification purposes to increase the effectiveness of the developed system. Several scenarios related to the distance between the sensor node and gateway have been considered to evaluate the reliability of the developed system besides the compatibility of the LoRa technology for the developed system.

The results reveal that the developed system is reliable in measuring the gas concentration levels from the three different gas sensors (i.e. sensor node) and successfully transmitted the measured value to the gateway considering different distances between the sensor node and gateway. We also evaluate the RSSI value of the LoRa communication between the sensor node and the gateway. The results show that the RSSI value reduced with the increasing distance. This is mainly due to the interferences that occur over the distance. However, the results reveal that the signal strength is almost stable for each considered distance. Therefore, LoRa technology is compatible to be used for real-time air pollution monitoring system.

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