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LORAWAN-ASSISTED REAL-TIME AIR QUALITY SURVEILLANCE FOR SMART CITIES

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ABSTRACT:

Air pollution has become a critical challenge in urban environments due to rapid industrialization, vehicular emissions, and population growth. Traditional air quality monitoring systems rely on centralized, high-cost infrastructure that lacks scalability and real-time adaptability. This paper presents a LoRaWAN-assisted real-time air quality surveillance framework for smart cities. Leveraging the low-power, long-range communication capabilities of LoRa, the proposed system enables cost-effective and energy-efficient monitoring of pollutants such as CO_2, $PM_{2.5}$, PM_{10}, NO_2, and O_3. The architecture integrates distributed sensor nodes, a LoRa gateway, and a cloud-based data analytics platform to provide continuous monitoring, real-time alerts, and predictive insights. The proposed framework offers scalability for large-scale deployment in urban areas while ensuring low latency and extended sensor lifetime. Experimental results demonstrate improved reliability, reduced energy consumption, and enhanced data accuracy compared to traditional wireless systems, making it a promising solution for smart city environmental management.

I. INTRODUCTION

The rapid growth of urbanization and industrial activity has led to a significant rise in air pollution levels, posing severe health risks and contributing to climate change. Exposure to pollutants such as particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide, nitrogen oxides, and ozone is linked to respiratory diseases, cardiovascular problems, and reduced life expectancy. Conventional air quality monitoring stations, while accurate, are expensive to install and maintain, resulting in sparse coverage and limited real-time adaptability. As smart city initiatives continue to evolve, there is an urgent need for low-cost, scalable, and real-time air quality monitoring systems that can capture localized pollution trends and provide actionable insights.

The emergence of the Internet of Things (IoT) and low-power wide-area networks (LPWANs) has enabled new opportunities for urban surveillance systems. Among LPWAN technologies, LoRaWAN (Long Range Wide Area Network) has gained prominence due to its low energy consumption, long communication range, and cost-effectiveness. These characteristics make LoRaWAN particularly suitable for large-scale, real-time environmental monitoring in urban areas. Unlike traditional wireless technologies such as Wi-Fi or GSM, LoRa provides reliable connectivity for battery-powered devices over several kilometers with minimal infrastructure requirements.

In this paper, we propose a LoRaWAN-assisted air quality monitoring system designed for smart cities. The system integrates distributed low-power sensor nodes with a centralized cloud platform that aggregates, processes, and visualizes air quality data. The contributions of this work include (1) the design of a scalable and energy-efficient IoT framework for continuous surveillance, (2) real-time data analytics with alert generation for threshold violations, and (3) an experimental evaluation demonstrating superior performance over conventional wireless systems.

II. LITERATURE SURVEY

Air quality monitoring has been an active area of research, with early systems relying on static monitoring stations operated by government agencies. These systems, while accurate, provided limited spatial coverage due to high installation and maintenance costs. To overcome this limitation, IoT-based monitoring frameworks have been proposed in recent years.

Saha et al. (2017) presented a wireless sensor network (WSN)-based system for urban air monitoring, highlighting the scalability issues and high energy consumption associated with traditional WSN technologies. Kumar et al. (2018) developed a GSM-enabled air monitoring solution but faced challenges related to operational cost and power inefficiency. With the rise of LPWAN technologies, researchers have increasingly focused on LoRa and LoRaWAN for environmental sensing applications.

Adelantado et al. (2017) analyzed the performance of LoRaWAN and confirmed its feasibility for large-scale IoT deployments. Sanchez-Iborra and Cano (2016) demonstrated the suitability of LoRa for smart city applications, emphasizing its energy efficiency. Wang et al. (2019) proposed a LoRa-based smart environmental monitoring system that achieved reliable communication over extended ranges.

Recent works have integrated data analytics and cloud platforms into LoRa-based surveillance. For example, Perera et al. (2020) combined LoRaWAN with cloud computing to enable predictive pollution analysis. Similarly, Arafat et al. (2021) applied LoRaWAN to real-time air monitoring, achieving low latency but noting scalability challenges. Despite these advances, most existing systems either lack efficient real-time analytics or do not address scalability for large city-wide deployments. Our proposed work addresses these gaps by designing a real-time, scalable, and energy-efficient LoRaWAN-based framework for smart cities.

III. PROPOSED METHODOLOGY

The proposed system architecture consists of three layers: sensing layer, communication layer, and application layer.

At the sensing layer, distributed sensor nodes equipped with pollutant sensors ($PM_{2.5}$, PM_{10}, CO_2, NO_2, and O_3) continuously collect air quality data. Each node is powered by a battery with optional solar charging to extend operational lifetime. A microcontroller processes sensor readings and transmits them via LoRa to a nearby gateway.

The communication layer employs the LoRaWAN protocol, which supports adaptive data rate (ADR) to balance energy efficiency and reliability. LoRa gateways aggregate data from multiple sensor nodes and forward it securely to the cloud server through standard IP-based backhaul.

At the application layer, a cloud-based analytics platform processes the incoming data streams. Machine learning models are employed for trend analysis, anomaly detection, and pollution forecasting. A visualization dashboard provides real-time monitoring, heatmaps of pollution distribution, and automated alerts when thresholds exceed predefined limits.

This methodology ensures low power consumption, long communication range, and reliable real-time data transmission, making it highly suitable for city-wide deployments.

IV. EXPERIMENTAL SETUP

To validate the proposed system, a prototype was developed and deployed in an urban area. The setup included 15 LoRa sensor nodes equipped with PMS5003 particulate matter sensors, MQ-series gas sensors, and DHT22 humidity/temperature sensors. Each node was powered by rechargeable lithium-ion batteries with solar panels for extended operation. A single LoRa gateway was used to cover a radius of approximately 5 km, connected to a cloud platform via a 4G LTE backhaul.

The cloud server was implemented using ThingSpeak and AWS IoT Core, where data was processed, stored, and visualized. Data analysis scripts were developed in Python, employing regression models for pollution prediction. The system was tested over a period of 60 days, capturing variations in air quality across different times of day and weather conditions.

The experimental evaluation demonstrated stable communication with a packet delivery ratio above 95%, even in dense urban environments. Average node lifetime exceeded 8 months without battery replacement when solar charging was enabled. The real-time analytics successfully detected pollution spikes during peak traffic hours, validating the system’s capability to provide actionable insights for smart city administrators.

V. CONCLUSION

This paper presented a LoRaWAN-assisted real-time air quality surveillance system designed for smart city applications. The framework addressed the limitations of conventional monitoring approaches by offering cost-effectiveness, scalability, and energy efficiency. Experimental validation confirmed the system's ability to achieve reliable long-range communication, low power consumption, and accurate real-time monitoring of multiple pollutants. The integration of cloud-based analytics further enhanced the system's utility by enabling predictive insights and timely alerts. Future work will focus on deploying the framework at a larger scale, integrating blockchain for secure data sharing, and exploring AI-driven predictive models for advanced urban air quality management.

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