Low-Power LPWAN-Based Environmental Monitoring System with Edge Analytics

Saranya S, Nethra M A, Dr. K. S . Vishvaksenan
SRM Institute of Science & Technology, Tiruchirappalli Campus
Department of Electronics and Communication Engineering

***Abstract*—Increasing pollution levels, changing climate conditions, and rapid growth of urban populations all make environmental monitoring more important than ever before. Traditional methods of monitoring the environment are challenged by high energy consumption, limited ability to scale, and dependence on centrally located, cloud-based data storage and processes. To overcome these challenges, we develop a low-power sensor network for environmental monitoring based on Low- Power Wide Area Network (LPWAN) technology and edge analytics.**

In our proposed solution, we use multiple distributed sensor nodes that continuously gather data about their environment (e.g., temperature, humidity, air pollution, noise levels). The sensor nodes share their gathered data among themselves using low- power wide area network protocols to enable very long-range (up to 100 miles) communications while consuming minimal amounts of power. We use edge analytics to perform local data processing and analysis at gateway or edge devices, enabling faster data transmission times, lower data transfer volumes, and reduced reliance on cloud- based services.

Using real-time analysis at the "edge" (out in the field) helps to respond to changes within a managed environment more quickly and improves how quickly anomalies can be detected, which results in faster response times. By leveraging low-power wide-area network (LPWAN) communications and edge intelligence, the proposed approach will improve all aspects of the scalability, energy usage, and reliability of the overall monitoring architecture. This type of monitoring will be well suited for smart cities, agricultural monitoring, industrial processes, and remote environmental monitoring. In fact, for large-scale environmental monitoring solutions, this approach will be cost- effective and sustainable.

I. INTRODUCTION

With increasing pollution, unsteady climate conditions and urbanization occurring at an unprecedented rate; the need for reliable, consistent and effective environmental monitoring has grown exponentially over time. Collecting data about the environment (such as temperature, humidity, air quality & noise) will allow us to have an analytical picture of what is happening in our environment and allow us to act quickly and appropriately to significant events. However many conventional methods of monitoring today are not suitable for long- term sustainable use due to a variety of factors including; high power consumption, limited range and reliance on cloud-based data processing.

Using LPWAN technology to transmit data across large distances while consuming very little energy enables large area monitors to be developed that analyse data at the medium to low resolution. By combining Edge Analytics and LPWAN communication technologies, processing data can occur at the edge as opposed to in the cloud resulting in reducing lag time, conserving bandwidth and improving overall efficiency.

Problem statement

Environmental monitoring systems face issues related to energy consumption and coverage area. Additionally, most of the environmental monitoring systems rely on cloud-based data processing, which is less efficient and can be costly to maintain. As a result, the aim is to develop an alternative low power long-range monitoring system using LPWAN communication technology with edge analytics to provide real-time processing capability, thereby providing more efficient, better responsive and scalable monitoring systems for environmental data.

Much of the traditional monitoring networks have difficulty in scaling because of wide areas. Systems send raw data to the cloud instead of processing locally, which means they lack local intelligence .Some systems can be expensive to deploy as a long-term solution in remote or rural areas.

Monitoring environmental parameters such as air quality, temperature or humidity normally requires continuous monitoring; using high-power devices could be cost prohibitive to deliver this requirement.

Objective

This project aims to develop a low-power, long-range environmental monitoring network capable of running efficiently for extended periods with minimal maintenance. The network will use LPWAN technology for reliable connectivity in urban and remote locations, while the addition of Edge Analytics allows for real-time processing of environmental data, reducing dependence on cloud servers and providing immediate visibility into air quality, temperature, humidity and pollutants. The products developed through this project will be sufficient in terms of providing value so that they can support applications like:

- Pollution monitoring (e.g., tracking levels of pollutants in the air and water)
- Smart agriculture (e.g., providing data about photo periods; soil moisture; temperature; etc., to develop optimum planting plans)
- Disaster response (e.g., determining where to send assistance after a disaster)
- Tracking climate change (e.g., developing a way to monitor long-term changes)

All information created/delivered through this project will provide decision-makers with accurate and usable information to make educated decisions.

In addition to providing sufficient information for application, this project will also be focused on reducing energy consumption by utilizing optimized hardware and associated communications protocols, with a goal of reducing the operating costs of those hardware items.

In summary, the final product of this project will be an intelligent, flexible, and trustworthy monitoring solution that will promote healthier living and more informed decision-making.

II. LITERATURE REVIEW

Monitoring environmental data through an environmental monitoring system allows users to effectively monitor their air quality, temperature, humidity, and pollution levels. Traditional methods are reliant on systems that consume a lot of energy using high power sensors and relying on cloud-based processing, which leads to excessive energy usage and costs of operation.

Infrastructure that employs Low Power Wide-Area Networks (LPWAN) have been released such as LoRa, NB-IoT, Sigfox and LTE-M which allow for long-range communications with low power consumption, making them ideal solutions for monitoring environmental data.

LoRa is the most commonly used LPWAN technology as it is capable of covering portions of both urban and rural areas and reaching distances of up to 10-15 km.

LPWAN technologies allow for the deployment of more sensors and more sensors to be deployed; but some obstacles remain, such as low data rate and network congestion. Using edge analytics (data analytics conducted at the source (sensor) or on the local edge (gateway), as opposed to in the cloud), allows for a significant reduction in latency and bandwidth.

Utilizing LPWAN networks with edge computing provides the capability of monitoring and making real-time decisions more quickly than before. The results of a number of studies indicate that energy-efficient protocols will reduce energy consumption, extending the battery life of an IoT sensor. The integration of edge analytics capability will allow users to detect anomalies in the environmental data almost instantaneously, enabling them to provide timely alerts. IoT-based environmental monitoring has the capacity to be used in the creation of smart cities, for agriculture, disaster management, and monitoring climate changes. According to a number of studies, the creation of autonomous low power wireless networks (LPWAR) reduces operating costs when compared to traditional cloud-based systems. In addition to creating networks that are autonomous and low power, some challenges remain concerning the accuracy of the data within the network, data protection from unauthorized users, the reliability of the network, and supporting a sustained period of autonomous operation.

III. PROPOSED SYSTEM

We provide a solution to environmental monitoring over long distances and with low energy consumption. Sensors deployed will monitor environmental parameters such as air quality, temperature, humidity, and pollution. The network can accommodate a large number of sensors deployed in both densely populated and desolate locations around the globe and can scale in size. Local analytic processing at the edges of the network can also reduce the reliance on cloud-based servers for data processing. The ability to continuously monitor and detect anomalies provides the opportunity for timely alerts and interventions. Using LPWAN for communications enables the sensors' batteries to be extended and reduces how often sensor maintenance will occur.

Data captured can be made available via dashboards that can be viewed by decision- makers and other pertinent individuals. Propose-system-level design concepts that enable the system to be self-sufficient, dependable, and adaptable to all types of environmental conditions.

Optimized Communication Methods Reduce Network Congestion and Also Decrease the Likelihood of Losing Data (Not Reading/Receiving Data). Potential Applications of This Include Smart Cities, Smart Agriculture, Air Quality and Pollution Monitoring, Disaster Management and Climate Tracking.

IV. SYSTEM ARCHITECTURE

The proposed layered architecture system is designed to combine low power-enabled sensor nodes, edges analytics, LPWAN communication, and cloud-based observation, to provide an optimal solution for emergency environmental response systems and to reduce energy consumption while operating in normal operating conditions.

The sensor nodes are equipped with various environmental sensors to measure various environmental conditions, which are connected to a low powerbased microcontroller. The environmental data collected by the sensors are processed locally using edge analysis techniques consisting of thresholding, multi-source data fusion, and anomaly detection. The processed environmental data received from the sensors is evaluated and subsequently, the sensor node utilizes the results of the environmental data processing to invoke the appropriate response to the evaluated condition by dynamically switching between a sleep mode, alert mode, or emergency mode. The processed/triggered environmental data is subsequently sent to a centralized gateway using LPWAN technology where the gateway collects and aggregates environmental data from all of the sensor nodes and sends the data to a cloud-based server for storage, visualization, or alerts. The user is able to monitor environmental conditions via a web or mobile application.

Hardware required

The environmental data is captured locally by the sensor node. The following electronic devices perform the functions of sensor interfacing inside the sensor node; sensor data analysis (edge analytics) and managing the power supply to the sensor node.

Microcontroller unit (MCU)

This type of MCU unit is used for interfacing the sensors; performing edge analytics and managing the sensor node with low power and sleep modes.

Environmental sensor DHT11 or DHT22 Temperature and Humidity Sensor MQ2 or MQ135 Gas and Smoke Sensors BMP280 Pressure Sensors Water Level Sensors for flood monitoring. Low Power Wide Area Networking Module LoRa SX1276 or SX1278 is the transceiver that enables long-distance low power RF communication with wireless sensors.

Power Supply Rechargeable Lithium-ion battery is being used. There is also the option to add solar to the node to provide extended service.

Gateway Hardware

Raspberry Pi or ESP32 Landed Gateway. LoRa Concentrator module.

Gateway to the internet via Ethernet or WiFi.

Software requirements

1) Embedded Software

The embedded software will acquire sensor data, perform edge processing, and provide adaptive power control.

Embedded C / Arduino Programming Language

Functions of the Embedded software Sensor data collection Anomaly Detection utilizing threshold and pattern-based techniques dynamic Power Mode Switching low Power Wide Area Network transmission of data.

Cloud and Application Software

AWS / Firebase / Things Board Cloud Platform

Firebase Realtime Database / MySQL Database

Python / Node.js Backend

Web based front end for monitoring and alerts in real time.

V. METHODOLOGY/ WORKING

The methodology of this system proposed will facilitate an energy-efficient means to monitor the environment by combining LPWAN technology with edge analytics and adaptive power management. This system operates by continually collecting data about the environment, processing it locally at the sensor level, and only sending relevant information to a cloud server for storage or analytics.

To begin with, environmental sensors will capture real-time information such as: temperature, humidity, gases and water levels. The environmental data collected is subjected to edge-based processing, using a low-power microcontroller attached to the sensor, and will utilize edge analytic techniques (threshold testing, validating multiple sensor input, recognizing a pattern) to determine if there are any abnormal conditions in the environment.

After performing edge analysis, the system will identify which operating mode is appropriate for the current conditions. Typically, the sensor will remain in a low- power, sleep state and transmit data less frequently. In the event that the system detects suspicious patterns, the system will move into an alerting mode where the sensor will be monitored more closely. If a confirmed emergency is detected (fire, flood, etc.), the system will move into an emergency mode and will be allowed to sense at a higher frequency and communicate prioritised.

Acquisition of Data

The environmental sensor deployed in an area that is monitored continuously collects and measures the physical parameters for a given location. These sensors will remain inactive most of the time to conserve battery power with intermittent activation.

Processing and Analysing Data at the Edge

A microcontroller processes the data acquired by the sensor at the edge of the environment. The threshold- based evaluation of the sensor data as well as correlation of information from multiple sensors allows for evaluation of abnormal events, thus reducing false alarms.

Mode Switching: Intended Power Modes

The system adopts one of three modes to operate based on edge analytics output:

1. Sleep mode indicates normal environmental conditions and little to no battery power consumption.
2. Alert mode indicates suspicious changes to the environment.
3. Emergency mode indicates there are confirmed hazardous material, events or emergency - and, therefore, a need for urgent action.

LPWAN Data Transmission

To limit the amount of communication and energy used in sending data, only processed/actual data will be transmitted through the LPWAN transmitter module.

Gateway and Cloud Communication

The gateway collects/aggregates data from multiple sensor nodes and sends it to the server using Internet.

Monitoring and Alerting

The cloud-based platform provides users/authorities with notifications/alerts so they can take action. In addition, it provides real-time updates for situation monitoring and also produces visualizations of the status of the monitored environment.

Automatic Recovery

Upon cessation of an Emergency, the system will automatically begin Operations with Lower Power to maximise battery life efficiency over long periods of time.

Implementation (real case)

A notification system has been designed which will alert fishermen to impending cyclone activity or severe weather events. Many of these fishers are located in remote marine environments with limited access to the internet, therefore the notification system was developed to provide alerts without an opportunity to use a smartphone or have continuous access to network coverage.

Environmental parameters including wind speed, atmospheric pressure, and relative humidity at the sensor node are processed utilizing edge analytics; When the calculated risk exceeds a predetermined value, an alert will automatically be sent to the gateway using the Low Power Wide Area Network (LPWAN) communications.

The first level of notification will occur through a SMS based alerting mechanism.

An SMS message will be transmitted from the GSM module (attached to the gateway) to every registered fisherman; this provides a means of initiating

communication to the fisherman regardless of whether or not they have access to the internet. A portable receiver device that employs LoRa Technology and is equipped with a buzzer and LED's will provide fishermen with a real-time alert while at sea. A coastal siren system will serve as a means of notification for the fisherman and residents in the surrounding coastal community.
The use of this multiple- layered alert system is designed to provide an expeditious, dependable, and redundant means of notifying fishermen of cyclone-related emergencies thereby increasing the level of safety for fishermen during those incidents.

VI. CONCLUSION

This document describes an energy- efficient environmental monitoring system for early detection of dangerous environmental conditions using a low-power LPWAN two-way data communications and analytics approach using Edge processing of sensor data to reduce both energy and communications overhead while ensuring accurate environmental monitoring performance.

The incorporation of adaptive modes of operation allows the system to function at an energy-efficient level, under normal conditions, and respond appropriately and in a timely manner during confirmed emergency situations (via the multi-layered alerting system that was specifically developed for coastal community fisheries).

The ultimate goal of this research study is to provide a scalable, energy-efficient, and socially responsible means to monitor environmental conditions and provide disaster alerts through a long-lasting technology-based monitoring and alerting infrastructure throughout coastal communities. The development of this type of environmental monitoring system and disaster alert systems will assist in enhancing safety, decreasing the likelihood/severity of disasters, and promoting the sustainability of these systems in remote and coastal areas.

REFERENCE