Low-Power Wireless IoT System for Indoor Environment Real-Time Monitoring and Alerting

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***Abstract* - As the Internet of Things (IoT) continues to evolve, IoT device sensors today have reduced in size and cost and are now easily available. Modern IoT device sensors are also able to give accurate remote real-time data measurement. Some of IoT technologies are optimized for low power use, making them ideal for IoT and sensor applications with requirements on low system energy usage. Example is a wireless sensor node that is required to do its job for an extended period (in some cases, years) while powered by a battery.**

Connecting the device to a IoT cloud network can create a system for collecting and storing data measurements. The collected data could then be used for more complex application scenarios like data visualization, alerting and machine learning tasks.

This paper demonstrates an open source based real-time indoor environment monitoring system for collecting, storing and visualization of data with a simple alert notification system.

The results show that proposed low-cost, low-power, open-source based systems can provide high reliability while ensuring low energy consumption.

Keywords – Internet of Things; LoRaWAN; remote monitoring; real-time monitoring; indoor environment; alerting system.

I. Introduction

Today IoT devices coupled with sensors allow connectivity to the Internet. They collect data by measuring physical or environmental conditions (such as temperature, pressure, relative humidity, CO2, position, light, sound, etc.). Sensor measurement data are transmitted to the Internet with some wireless communication standards, which enables real-time monitoring, data storage and visualization of environmental measurements [2]. Traditionally, these sensors tend to consume a lot of power and decreasing the power consumption increases the lifetime of the sensor devices and creates space for battery-powered application, i.e., today IoT device sensors can be installed at many points where it would be impractical to do so just a few years ago (i.e., high ceilings in a hall) [1]. With the expected increase in the number of IoT devices, a question of energy-efficiency arises as well.

In this paper we focus on testing low-power IoT devices where low-power consumption is a requirement.

II. Methods

Our system is based on two main blocks as shown in Figure 7. The first block is a low-power data collection system which comprises of three different types of IoT sensors.

The second block is the IoT cloud (compute) block. It is running on Raspberry PI4 2GB computer with InfluxdB as database, Grafana and Hastic as visualization and analytics module and Telegram mobile application as alerting system.

We used the following hardware: Raspberry PI4 2GB as IoT cloud block, Mikrotik wAP LR8 kit as LoRaWAN gateway and WiFi access point, Adafruit Feather 32u4 Lora with DHT11 sensor (Figure 1), Arduino MKRWAN 1010 with DHT11 sensor (Figure 2), and Raspberry PI Zero with DHT22 sensor (Figure 3). For this work we did not used any of the sleep modes on IoT devices that can reduce energy consumption.

For the measurements of typical power consumption of IoT sensors we used Joy-IT JT-UM25C measuring device for USB application. Regarding the Table II and the measurement of typical device energy consumption, all measurements were taken with Joy-IT JT-UM25C device using recording of charging/discharging mode (Figure 4). The measurement lasted for few hours. We can consider that time as typical power usage for operating IoT device. The device measures energy and lapsed time so we can easily find the typical power consumption **E** measured in watt-hours.

Regarding the Table III and the method for calculation of typical estimated battery endurance we used a simple formula:

$$\mathbf{T} = \frac{\boldsymbol{Q}}{\boldsymbol{E}}$$

Where:

Q is declared battery capacity measured in amp-hours (ie. 5000 mAh)

E is typical energy consumption measured in watt-hours (measured results shown in Table II).

T is expected battery discharge time

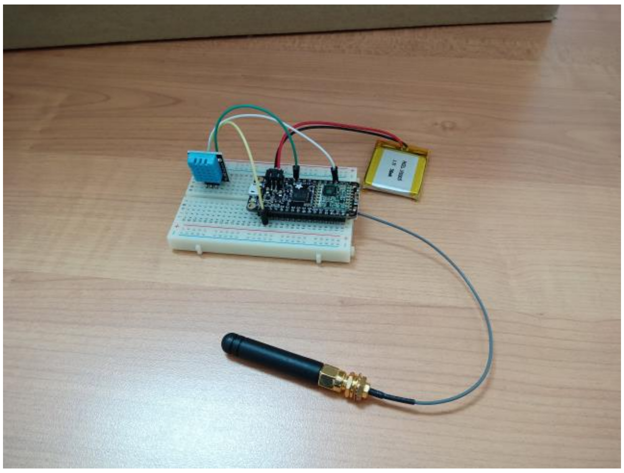

Figure 1. LoRaWAN system
(Adafruit Feather LoRa model with DHT11 sensor and LiPo battery)

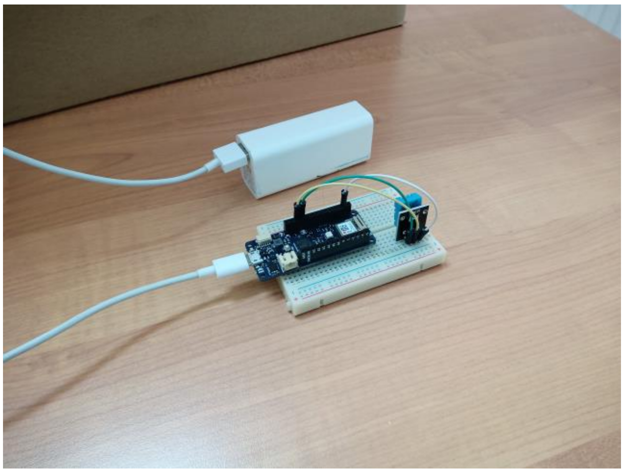

Figure 2. WiFi on microcontroller
(Arduino MKRWAN 1010 with DHT11 sensor and Power Bank)

Figure 3. WiFi on microcomputer
(Raspberry Zero with DHT22 sensor and PoE)

In the experimental setup IoT devices collected temperature and humidity from the DHT sensors and sent data to IoT cloud. The Things Network cloud platform was used for collecting data from LoRaWAN based IoT sensors. Data from all the sensors were stored in the InfluxDB database. After data was collected, we used Grafana for real-time visualization and interpretation.

The system tests were made in two ways: first we tested real-time functionality of the system with a simple experiment i.e., with an open window during the cold day and we got an alert due to a drop in temperature in the office; In the second test we measured the reliability of the system, i.e., the data from all sensors were collected for several weeks without detecting any problem.

III. RESULTS

We compared three IoT technologies by experimenting with applications, range, number of nodes, optimal power source (Table I) and power consumption (Table II).

Our testing confirms that Long-Range Wide Area Network (LoRaWAN) technology has the longest range and the lowest power consumption, but also the lowest bandwidth. Therefore, data suggest that the LoRaWAN technology is the most suitable for non-critical applications e.g., measurement and monitoring of temperature, relative humidity, CO2 concentration etc.

Furthermore, our testing confirms that WiFi technologies (on microcontroller or on microcomputer) are more suitable for real-time applications e.g., fire detection, security alarms, remote control, and with ARM microcomputer (like Raspberry Zero) even machine learning (ML) capabilities are possible e.g., image processing for IR camera or sound detection.

TABLE I. COMPARISON BETWEEN PROPOSED TECHNOLOGIES

	Technologies		
	LoRaWAN (Feather Lora)	***WiFi on microcontroller (Arduino)***	***WiFi on microcomputer (Raspberry Zero)***
IoT application	Environment measurement and monitoring	Real-time capability (fire detection, alarms, remote control of various actuators.)	Real time and machine learning capability (IC camera, sound detection.)
Range	< 1 km	< 100 m	< 100 m
Number of nodes	Large	Medium	Small
Optimal power source	LiPo Battery	Power bank	Power over Ethernet (PoE)
Optimized for	Long range, Low power	High bandwidth	High bandwidth IoT edge

As expected, the drawback was higher power consumption (Table II), requiring power bank (for microcontroller) or power-over-Ethernet (PoE) supply (for microcomputer), which also limited the autonomy of IoT nodes if only 5000 mAh battery was used (Table III).

It is also necessary to point out that the typical energy consumption of the whole system is no more than 10W.

TABLE II. TYPICAL POWER CONSUMPTION OF PRESENTED IOT SENSOR MODELS

Model	**Energy consumption**
Adafruit Feather Lora	50 mW
Arduino MKR WiFi 1010	150 mW
Raspberry Zero	450 mW

TABLE III. POWER AUTONOMY OF IOT NODE WITH 5000 MAH CAPACITY BATTERY

Model	**Device autonomy**
Adafruit Feather Lora	100 hours
Arduino MKR WiFi 1010	25 hours
Raspberry Zero	11 hours

Figure 4. Measuring typical IoT device power consumption with Joy-IT JT-UM25C device using *recording of charging/discharging* mode

Fig. 8 shows proposed solution we used for monitoring based on open-source Grafana visualization platform, which we used for e.g., triggering alert and sending automatic notification to Telegram mobile application (Fig. 5) or for machine learning anomaly detection e.g., window opening in the room (Fig. 6). Grafana alert notification system supports Telegram as notifier (using Telegram API).

Figure 5. Example of triggered alert sent to Telegram mobile application.

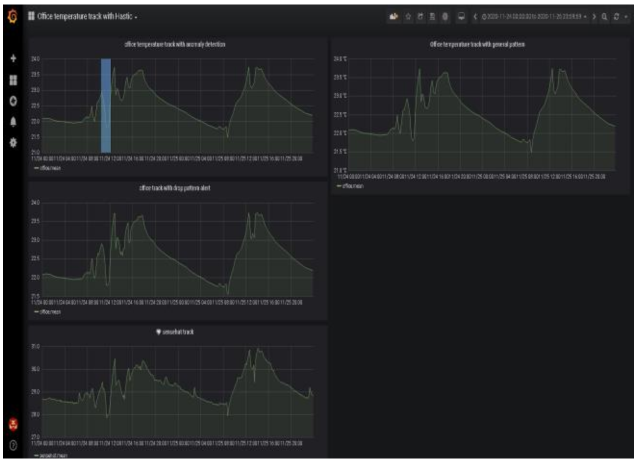

Figure 6. Example of monitoring with machine learning (ML) anomaly detection (for example opened window in room – marked with blue color)

IV. DISCUSSION

We found that visualizing collected data is simple using Grafana. InfluxDB as a time series database is chosen because it can easily be fitted with Grafana. One dashboard can have multiple panels for showing the data plotted in order to allow comparison in real time. For example, it is interesting to correlate temperature and humidity. Also, panels allow showing the same measurement (e.g., temperature) from multiple sensors placed at different positions in space which allows comparison in real time.

V. CONCLUSION AND FUTURE WORK

Energy consumption is one of the important requirements for design and implementation of an IoT application. In this paper, we analyzed the power consumption and described the energy performance of three types of IoT device sensor technologies.

Furthermore, our research confirmed that the proposed experimental IoT system is a powerful, reliable, scalable indoor environment monitor system suitable for use in example for monitoring the environment in the small to medium datacenter room.

It is worth mentioning that there is no software cost. All used software is open source and free. The cost of the whole hardware for the proposed system with all components including LoRaWAN gateway, IoT sensors, Raspberry PI4 2 GB is around 300$.

One of the first things we should analyze in our future studies is the impact of sleep modes on power consumption of the system. This is especially important in use with microcontroller based IoT devices (Arduino based).

There are several possibilities for future improvement. For improvement of the power autonomy of the IoT sensors we should study and analyze the impact of Wake-up Radio technology to optimize energy consumption of the IoT sensors and to analyze the new Ultra-low power technology for battery-less IoT sensors. Furthermore, we plan to analyze the energy consumption of LTE-M sensors and new 5G technology based IoT sensors.

VI. Acknowledgment

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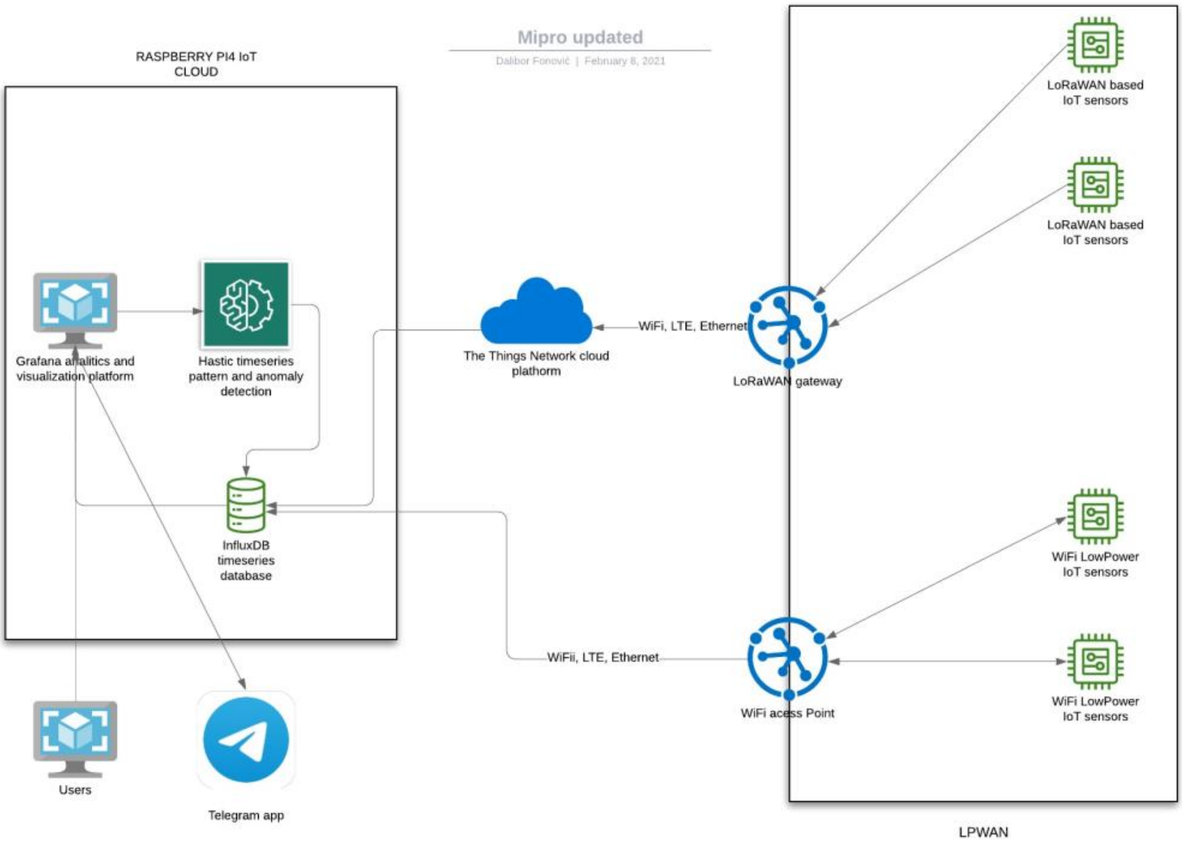

Figure 7. Proposed system architecture for low power IoT system with data acquisition, monitoring and alerting

Figure 8. Monitoring system based on Grafana visualization platform