Quad-band GSM/GPRS Enabled Low-Power Sensor Node Design For Outdoor IoT Applications

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***Abstract*—This paper introduces an energy-efficient and low-power sensor node tailored for outdoor Internet of Things (IoT) applications. The node establishes a direct connection with cellular base stations across GSM/GPRS quad-bands at 850 MHz, 900 MHz, 1800 MHz, and 1900 MHz. Comprising a central controller utilizing ATMega328, a communication module employing SIM800, and a DHT22 temperature and humidity sensor, the sensor node is equipped with a solar-powered charging system. Specifically designed for robust IoT outdoor applications, the implemented energy-saving mechanism relies on deep sleep scheduling, significantly reducing power consumption and extending the sensor node's uptime**

Keywords—IoT, GSM/GPRS, wireless sensor networks, industrial IoT

I. INTRODUCTION

Internet of Things (IoT) applications could consider as the most emerging area in electronics engineering. IoT applications exist in almost every field, such as smart agriculture, farming, intelligent transportations, intelligent buildings, etc. Further, many IoT applications exist both indoors and outdoors. The design architectures may vary on the IoT application deployed. For instance, indoor applications, sensor nodes could connect in a wireless LAN via a wireless router. And nodes connect with remote IoT cloud via broadband routers. It is impractical to use broadband routers in these designs in outdoor applications as the range between sensor nodes, and router may be far away. Such designs could use GSM/GPRS-based technologies where sensor nodes could directly connect with 3G/4G mobile base stations. SIM 800 supports four GSM bands 850/900/1800/1900MHz. This paper designed and deployed an IoT sensor node for outdoor IoT applications such as real-time environmental condition monitoring. In this design, the Atmega328 microcontroller is used as the central controller, and the SIM800 module is used to connect with the cellular network. To power up the node, 12V,500mAh battery has been used with a 50 watts photovoltaic charging system to ensure the continuous wakeup of the node. A novel wakeup scheduling mechanism has been proposed, deployed, and evaluated to save the node's power consumption.

One of the primary motivations behind our work is cost-effectiveness. While market ready IoT sensor nodes are readily available, their high cost renders them unaffordable for communities such as farmers seeking to employ environmental monitoring in their fields.

The rest of the paper has been organized as follows. Section II presents the recent works that exist on Atmega328 based systems and techniques used for power management. Section III discusses all the required steps of designing the sensor node, and section IV present the energy-saving mechanism used in the system. Section V presents the experimentation results and discussion and, finally, the conclusion.

II. RELATED WORKS

Related works are existing on designing low-power IoT systems using microcontrollers [1-5]. Many works, designed for indoor applications such as home automation systems, robotic systems. Moreover, systems designs are included with broadband wireless routers as applications are indoor. A limited number of related works exist on IoT designs on GSM [6]. Even these designs are limited to a prototype.

Generally, once deployed sensor nodes it is impossible to replace or recharge the batteries of the nodes. Therefore, applying an energy-saving mechanism to prolong the uptime. To save energy, several power-saving techniques have been used in the literature, such as duty cycling, transmitted data reduction, transceiver optimization, energy-provision schemes, overhead protocol reduction, voltage control, and current control [7-10]

This sensor node has been designed from scratch for the final product. This includes waterproof enclosed and a reliable power supply. The photovoltaic power panel support runs the sensor node even at night time also. Further, energy-saving techniques have been applied to save energy.

III. SYSTEM DESIGN

The system overview is as shown in Fig.1 Atmega328p microcontroller is used as the central controller. The DHT 22 is the sensor to monitor temperature and humidity. The DHT sensor is calibrated. The communication module is designed based on SIM 800 chip. The SIM800 is a complete Quad-band GSM/GPRS solution in an SMT module embedded in the customer applications. Featuring an industry-standard interface, the SIM800 delivers GSM/GPRS for bands 850 MHz,900 MHz,1800 MHz and 1900 MHz performance for voice, SMS, data, and low power consumption [11] with a tiny configuration of 24mm x 24mm x 3 mm, SIM800 can fit almost all the space requirements in IoT devices. The ThingSpeak cloud [12] is used as the IoT cloud. Where HTTP protocol was used to transmit data sensed by sensors to this cloud server. The Fig. 2 shows the power supply designed for the unit. Where LM2596 used with a buck—converter to separate 12V line for the main controller(ATmega328p) and

MIC23302 was used to have a sperate power connection of 4.8V to the communication node(SIM800). Fig.3, and 4 show the schematic diagrams for both the main controller circuit and communication module respectively. In communication module, there two separate LED indicators to indicate GPRS connectivity status and GSM connectivity status. The main controller also with additional GPIOs to connect additional sensors and actuators. Fig. 5-8 the final design view of the sensor node. The circuit was designed using Altium Designer and generated Gerber file used to manufacture the PCBs.

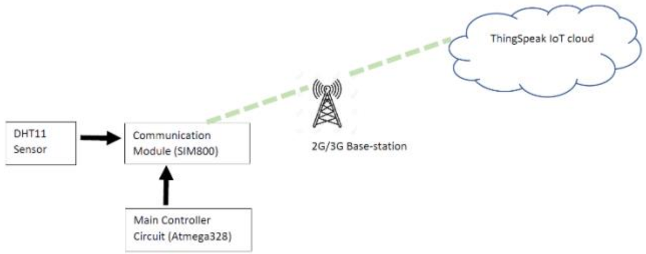

Fig.1: System overview

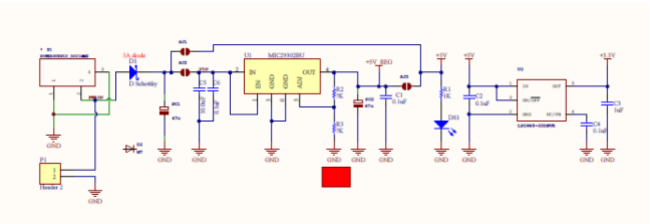

Fig.2: Power controller designed for the central controller

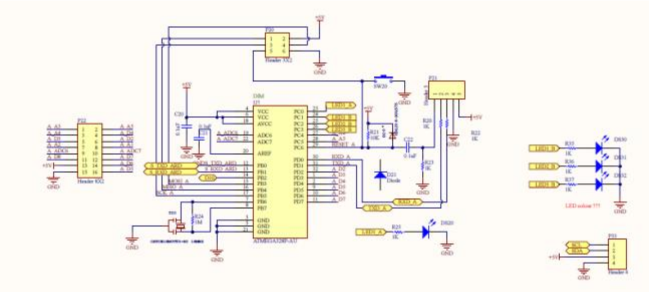

Fig.3: Main controller designed using ATMega328p

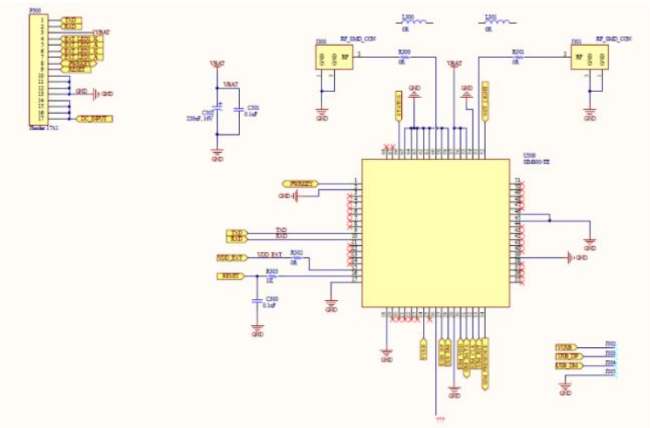

Fig.4: A schematic design for SIM800 based communication module

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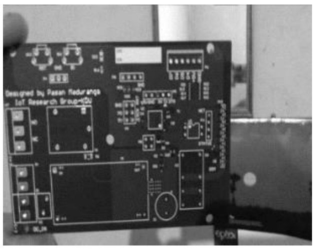

Fig. 5. PCBs

Fig.6. Assembled circuit

Fig.7. Sensor node inside the enclosed

Fig.8. Installation with 50W solar panel

IV. Real-Time Monitoring

The system can monitor the real-time temperature and humidity using any devices connected to the ThingSpeak cloud. Also, this cloud service is free, and it also allows to save the data with certain limitations. Fig. 3 shows the recorded temperate and humidity data for 24 hours. In IoT data analytics, it is essential to use data filtering techniques to remove the noises made by sensors. Thus Fig.9 shows filtered data, filtered using moving average filters.

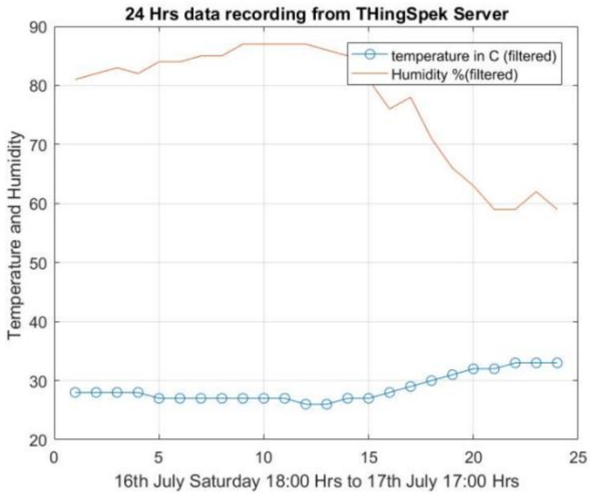

Fig. 9. Temperature and humidity data for 24 hrs

V. Energy Saving Techniques

Applying energy-saving techniques to a sensor node is crucial. In most practical applications, the battery is not replacing or recharging once the sensor node is deployed. Therefore, saving limited energy in the batteries is essential to prolonging the sensor wakeup. Generally, the radio module consumes more power as it consumes more power for transmission [1, 13]. Therefore, our proposed sleep scheduling method is applied to the communication module. Usually, the SIM800 module consumes 453mA during the data transmissions and 1mA in deep sleep mode [7, 11]. Fig. 10 shows the proposed duty cycling for the SIM800 module in the communication module.

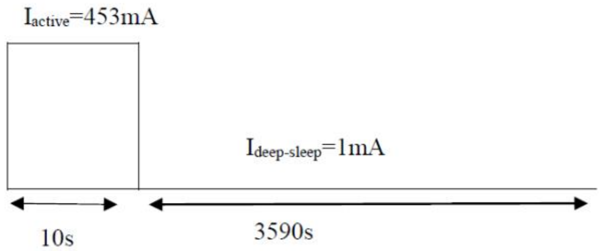

Fig.10: Duty cycle for communication module

Capacity of the used rechargeable battery is 1Ah,

$$Capacity, C = 500mAh$$
$$= 500mA * 3600s$$
$$= 1{,}800{,}000mA - secs$$

When the SIM800 module transmits data to the internet via Wi-Fi, let's assume that the active state current (Inactive) is measured as 453mA.

$$Iactive = 453mA$$

While the SIM800 module is in deep-sleep mode, let's assume that the deep-sleep current ($I_{deepsleep}$) measures as 1 mA.

$$Ideep - sleep = 1mA$$

1 cycle of current measurement contains T secs

$$T = t1 + t2 \quad (1)$$
$$T = 10\,secs + 3590\,secs = 3600secs$$

Hence, the average current consumed in 1 cycle is:

$$Iaverage = \int_0^{10} 453mA\,dt + \int_{10}^{3590} 1mA\,dt \; (2)$$
$$Iaverage = 8110mA - sec$$

The average current in mA Iaverage(mA) is given by:

$$Iaverage(mA) = \frac{Iaverage(mA - sec)}{T} \; (3)$$
$$= \frac{8110mA - sec}{3600sec}$$
$$= 2.2527mA$$

If L denotes the estimated life-span of the sensor node

$$L = \frac{C}{Iavarage} \; (4)$$
$$L = \frac{500mA - hr}{2.2527mA}$$
$$L = 221.95\,hrs$$
$$L = 9\,days\,approximately$$

VI. Experimentations and Discussion

We conducted outdoor testing of our system over several consecutive days, divided into two phases. Initially, the system was deployed without energy-saving techniques to observe node uptime. Subsequently, we applied an energy-saving mechanism and monitored node uptime. The results indicated that the sensor node could remain active for two days after fully charging the batteries without implementing energy-saving techniques. In contrast, when the experiment was repeated with a deep-sleep-enabled schedule, the sensor node remained operational for approximately five days. Notably, during both experiments, the solar panel was not connected.

It was observed that the application of the energy-saving mechanism resulted in a deviation between the theoretically calculated and experimentally observed values for the sensor node's wakeup time. This discrepancy arose from solely considering the current theoretical values provided in the SIM800 datasheet. However, in the entire communication circuit, the current draws and power consumption could be higher, contributing to the observed differences.

VII. Conclusions

In this paper, we present a comprehensive design for a GSM/GPRS-based IoT sensor node tailored for outdoor applications. Notably, this system eliminates the need for additional routers as an access point to connect with the IoT cloud. The communication model, powered by GSM/GPRS, enables direct data transmission to the nearest mobile base station via GPRS. The simplicity of this design renders it versatile for various outdoor IoT applications, including environmental condition monitoring, animal tracking, military applications, and more. Given its support for 2.5G/GPRS and incorporation of an additional solar power backup, the system proves particularly useful in rural areas with only 2.5G coverage. An innovative energy-saving mechanism, employing duty cycles, has been introduced in the sensor node, significantly extending its wakeup time.

Acknowledgment

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