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Design of Sensor Network with Long Distance Communication for Application in Building Energy Management Systems

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ABSTRACT

This paper presents the design of a sensor network capable of transmitting data over long distances (up to 1000 meters) achieving reliable data, with the aim of improving energy consumption efficiency in Bulding Energy Management Systems (BEMS). The processing system uses microcontroller, the communication protocol proposed is Zigbee and the IoT (Internet of Things) platform to remotely view and control sensor data is Ubidots. The main contribution of this project is the design of environmental sensor node with high range of communications capabilities using Zigbee devices and found the right combination of the different communication factors (distance, spreading factor, bandwidth, and power). The project seeks to contribute to the field of building automation and long-distance communications allowing greater efficiency in energy consumption, reducing costs and minimizing environmental impact. Finally, communication validation is planned.

INTRODUCTION

The rapid growth of urbanization and industrialization has significantly increased global energy consumption, with buildings accounting for a substantial share of total energy usage. This rising demand not only escalates operational costs but also contributes heavily to environmental issues such greenhouse gas emissions and climate change. As a result, improving energy efficiency in buildings has become a critical objective in the development of sustainable and smart cities.Smart buildings are an integral component of smart city infrastructure, leveraging advanced technologies to monitor, control, and optimize energy usage. These buildings integrate intelligent systems capable of managing heating, ventilation, air conditioning (HVAC), lighting, and other electrical equipment. The primary goal is to achieve enhanced occupant comfort while minimizing energy consumption and environmental impact. To enable such intelligent management, continuous monitoring and real-time data acquisition are essential.Wireless Sensor Networks (WSNs) have emerged as a key enabling technology for smart building applications. A WSN is composed of numerous small, low-cost, and energy- efficient sensor nodes distributed across a building environment. These nodes are capable of sensing physical parameters such as temperature, humidity, light intensity, air quality, and energy usage, and transmitting the collected data to a central system for processing and analysis. The adoption of wireless communication eliminates the need for extensive wiring, reducing installation complexity and cost while improving system scalability and flexibility. Despite these advantages, conventional Building Energy Management Systems (BEMS) often suffer from several limitations.

Most existing systems rely on short-range communication technologies, which restrict their ability to cover large buildings or multi-floor structures effectively. Additionally, many systems are designed using a single. High deployment costs, lack of real-time monitoring in remote areas, and insufficient data utilization further reduce their overall efficiency. Another major challenge lies in the incomplete implementation of the sensor network lifecycle. Many existing solutions focus primarily on data collection while neglecting critical stages such as network design, optimization, data processing, and intelligent decision-making. Furthermore, several proposed systems are evaluated only in controlled laboratory environments, which do not accurately reflect real-world conditions such as signal attenuation, interference, and dynamic environmental changes. To overcome these challenges, this work proposes the design of a sensor network with long-distance communication capabilities tailored for Building Energy Management Systems. The system integrates low-power embedded hardware, efficient wireless communication technologies such as Zigbee, and Internet of Things (IoT) platforms for remote monitoring and control. By optimizing key communication parameters such as transmission power, bandwidth, and network configuration, the proposed system achieves reliable data transmission over extended distances (up to 1000 meters).

The architecture of the proposed system is designed to be flexible and scalable, supporting heterogeneous communication technologies and enabling easy reconfiguration for different applications. It incorporates energy-efficient sensor nodes, gateway modules, and cloud-based data visualization platforms, allowing users to monitor and control building energy usage in real time. This approach not only enhances system performance but also reduces installation and maintenance costs.In addition to system design and implementation, this research also addresses key challenges associated with large-scale sensor networks, including energy constraints, network complexity, and cost optimization. A model-driven methodology is introduced to simplify the design process, improve system reliability, and reduce development time. This methodology provides a structured approach for developing efficient and scalable smart building solutions.In summary, the proposed work contributes to the advancement of smart building technologies by providing a comprehensive, practical, and cost-effective solution for energy management. By enabling long-distance communication, real-time monitoring, and intelligent data utilization, the system aims to significantly improve energy efficiency, reduce cost

I. EXISTING SYSTEM

Current building energy management systems (BEMS) primarily rely on short-range wireless technologies such as Zigbee, Bluetooth, or Wi-Fi, as well as traditional wired communication infrastructures. While these approaches are widely adopted, they present several limitations when deployed in large-scale or complex building environments.One of the major challenges is limited communication range, which restricts data transmission across large buildings or multi-floor structures. As a result, multiple repeaters or access points are required, increasing system complexity. Wired systems, on the other hand, involve extensive cabling, leading to high installation costs, longer deployment time, and reduced flexibility for future modifications. Additionally, existing systems often face difficulties in collecting real-time data from remote or hard- to-access locations such as basements, rooftops, or isolated sections of the building. This results in delayed data processing and reduced responsiveness in energy optimization. Scalability is another concern, as expanding the system requires significant infrastructure changes. Moreover, these systems may suffer from higher maintenance requirements, potential signal interference, and energy inefficiencies due to fragmented monitoring. Consequently, the overall performance and effectiveness of traditional energy management systems are often limited, especially in modern smart building applications.

II. PROPOSED SYSTEM

The proposed system introduces an advanced sensor-based network integrated with long-range wireless communication technology (such as LoRa, NB-IoT, or similar protocols) to overcome the limitations of existing systems. This approach enables reliable and efficient data transmission over long distances, making it suitable for large buildings and multi-floor structures. In this system, distributed sensors are deployed across various locations within the building to continuously monitor parameters such as energy consumption, temperature, humidity, and equipment usage. These sensors communicate seamlessly with a central control unit using long-range communication, eliminating the need for complex wiring or multiple intermediate devices. The proposed solution significantly enhances real-time monitoring and control, allowing facility managers to make data-driven decisions instantly. It also improves system scalability, as new sensors can be easily added without major infrastructure changes. Furthermore, the system reduces installation and maintenance costs by minimizing wiring requirements and simplifying network architecture. The use of energy- efficient communication protocols ensures low power consumption, increasing the lifespan of sensor nodes. Advanced data analytics and automation features can also be integrated into the system, enabling predictive maintenance, fault detection, and intelligent energy optimization. As a result, the proposed system leads to improved operational efficiency, reduced energy wastage, and supports the development of smart and sustainable building environments.

III. METHODOLOGY

The proposed system presents design and implementation of a long-distance wireless sensor network for Building Energy Management Systems (BEMS) using IoT and embedded technologies. The methodology focuses on efficient data acquisition, reliable communication, and real-time monitoring to optimize energy consumption in buildings.The system begins with the deployment of multiple sensor nodes across different locations within the building. Each sensor node is equipped with environmental sensors to measure parameters such as temperature, humidity, and energy usage. These sensors continuously collect real-time data, which is processed locally using a microcontroller.The processed data is transmitted wirelessly using the Zigbee communication protocol. Zigbee is chosen due to its low power consumption, robustness, and suitability for large-scale sensor networks. Communication parameters such as transmission power, bandwidth, and network configuration are optimized to achieve long- distance communication up to 1000 meters To enhance system flexibility and scalability, a heterogeneous communication approach is adopted by integrating multiple wireless technologies such as Zigbee and LoRa. This ensures reliable data transmission even in large or multi- floor buildings.A gateway node is used to collect data from all sensor nodes. The gateway acts as a bridge between the sensor network and the cloud platform. It aggregates the received data and forwards it to the IoT platform for storage and analysis.The IoT platform (such as Ubidots) enables real-time monitoring, visualization, and remote control of system. Users can access sensor data through web mobile of interfaces, allowing them to monitor energy usage and environmental conditions from anywhere. The system follows embedded system design principles, where each node operates with dedicated hardware and firmware. Power-efficient components and optimized communication intervals are used to reduce overall energy consumption. Additionally, the methodology covers the complete sensor network lifecycle, including network design, hardware and software development, deployment, and data utilization. A model-driven approach is introduced to address challenges such as energy constraints, system complexity, and cost, ensuring an efficient and scalable solution. Finally, the system is tested in a real-time environment to validate communication reliability, data accuracy, and overall performance.

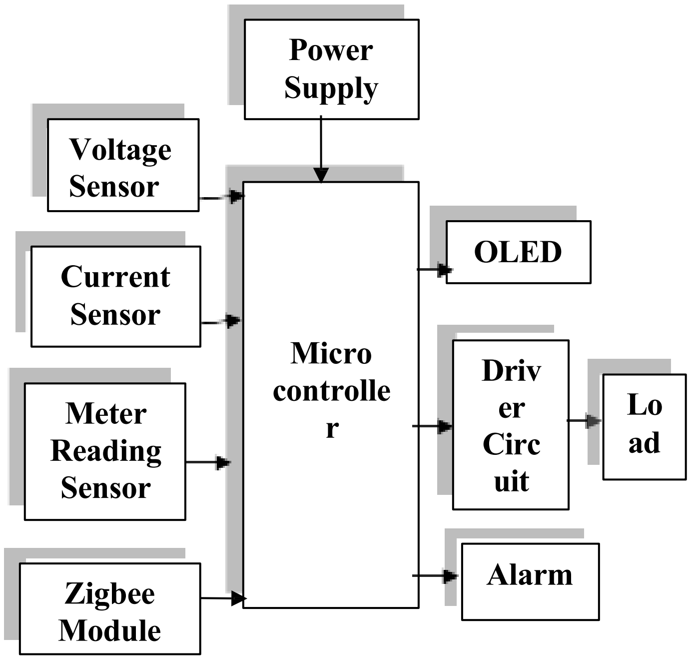

FIG 1 : BLOCK DIAGRAM

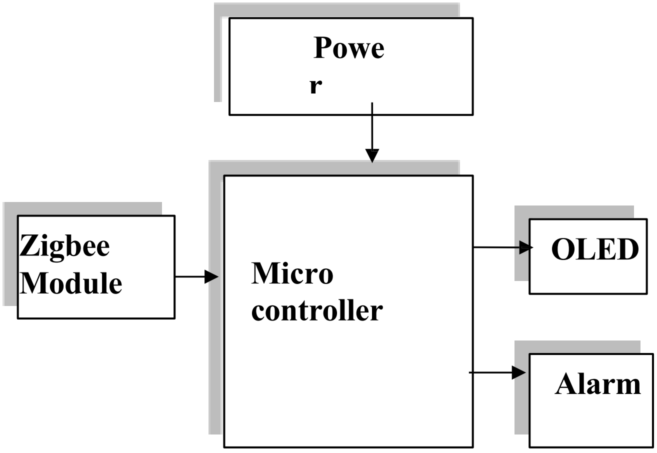

FIG 2: BLOCK DIAGRAM OF RECIEVER SECTION

APPLICATIONS

The proposed system has wide applications in smart building and energy management domains:

Smart Building Automation: Enables intelligent control of lighting, HVAC, and electrical systems to improve energy efficiency.

Energy Consumption Monitoring: Provides real-time tracking of energy usage, helping in reducing wastage and optimizing consumption.

Industrial Energy Management: Can be used in industries to monitor equipment performance and reduce operational costs.

Environmental Monitoring: Monitors temperature, humidity, and air quality to maintain comfortable indoor conditions.

Large Infrastructure Management: Suitable for multi- floor buildings, campuses, and commercial complexes requiring long-range communication.

Remote Monitoring Systems: Allows users to access and control building systems from anywhere using IoT platforms.

HARDWARE DETAILS

Raspberry Pi Pico Microcontroller

The Raspberry Pi Pico microcontroller acts as the central processing unit of the system. It is responsible for executing programmed instructions, processing input data from sensors, and controlling the overall operation of the system. Based on the RP2040 chip, it offers dual-core processing, low power consumption, and multiple input/output interfaces. This ensures efficient performance and reliable operation in embedded applications

Temperature Sensor

The temperature sensor is used to measure the ambient temperature of the environment. It continuously monitors temperature variations and provides real-time data to the microcontroller. This data is essential for maintaining thermal comfort and optimizing energy usage in building systems such as heating and cooling.

Humidity Sensor

The humidity sensor measures the moisture content present in the air. It helps in monitoring indoor environmental conditions and maintaining proper air quality. The collected data is used to control ventilation and air-conditioning systems, improving energy efficiency and comfort levels.

Environmental Sensor Node

The environmental sensor node integrates multiple sensors such as temperature and humidity sensors into a single unit. It collects real-time environmental data and transmits it to the central system through the communication module. This node enables efficient monitoring of different locations within the building.

Zigbee Communication Module

The Zigbee module is used for wireless communication between sensor nodes and the central system. It enables long- distance, low-power data transmission within the network. This module ensures reliable communication across different sections of the building and supports efficient data transfer.

Relay Module

The relay module is an electrically operated switch used to control high-power devices using a low-power signal from the microcontroller. It allows safe switching of appliances by providing electrical isolation between the control circuit and the load. The relay turns devices ON or OFF based on control signals, enabling automation and efficient system operation.

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SOFTWARE DETAILS

Embedded Firmware

The embedded firmware is the core software programmed into the microcontroller. It is responsible for reading data from sensors, processing the information, and controlling the overall system operation. The firmware ensures proper coordination between hardware components and executes a tasks such as data acquisition, decision making, and communication

IoT Cloud Platform (Ubidots)

The IoT platform is used for remote monitoring and control of the system. Sensor data collected from different nodes is transmitted to the cloud platform (Ubidots), where it is stored, visualized, and analyzed. This allows users to access real-time data and monitor system performance from anywhere.

Data Processing and Monitoring Software

The data processing software analyzes the sensor data received from the network. It helps in identifying patterns, monitoring environmental conditions, and optimizing energy usage. The processed data is presented in a user- friendly format for easy understanding and decision- making.

User Interface

The user interface provides a platform for users to interact with the system. It displays real-time data, alerts, and system status. The interface can be accessed through web or mobile applications, enabling remote control and monitoring of the system.

Communication Interface Software

The communication interface software manages data exchange between the microcontroller, sensor nodes, and external systems. It ensures proper transmission and reception of data using communication protocols such as UART or serial communication.

Zigbee Communication Protocol

The Zigbee protocol is used for wireless data communication between sensor nodes and the gateway. It enables low-power and long-distance transmission of data. The protocol ensures reliable and secure communication within the sensor network, allowing efficient data exchange across different modules.

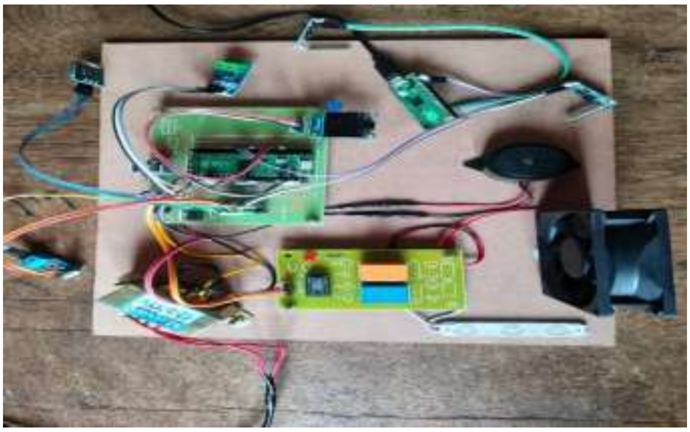

Fig 3: Prototype of Sensor Network with long distance communication for application in Building Energy Management Systems

CONCLUSION

This paper presented the design and implementation of a sensor network with long-distance communication for building energy management systems. The proposed system integrates environmental sensors, a microcontroller-based processing unit, and Zigbee-based wireless communication to enable efficient and reliable data transmission over extended distances. The architecture supports real-time monitoring of environmental parameters such as temperature and humidity, which are essential for optimizing energy consumption in smart buildings. The incorporation of an IoT platform further enhances the system by enabling remote access, data visualization, and analysis. This allows users to monitor building conditions and make informed decisions to improve energy efficiency. The use of low-power communication technologies ensures reduced energy consumption while maintaining network reliability and scalability across large infrastructures. Additionally, the system addresses key challenges in conventional building management systems, such as limited communication range, high installation costs, and lack of real-time data access. By providing a flexible and cost-effective solution, the proposed model contributes to the advancement of smart building technologies. Overall, the developed system demonstrates significant potential in improving energy efficiency, reducing operational costs, and supporting sustainable development. It serves as a foundation for future enhancements in smart environments, including integration with advanced analytics, automation techniques, and intelligent control systems.

REFERENCES

[1] Akyildiz, I.F., Su, W., Sankarasubramaniam, Y. and Cayirci, E. (2002) 'Wireless sensor networks: a survey', Computer Networks, Vol. 38, No. 4, pp.393–422.

[2] Al Saad, M., Fehr, E., Kamenzky, N. and Schiller, J. (2008) 'ScatterClipse: a model-driven tool-chain for developing, testing, and prototyping wireless sensor networks', in Parallel and Distributed Processing with Applications, 2008, ISPA'08, International Symposium on, pp.871–885, December.

[3] Atkinson, C. and Kuhne, T. (2003) 'Model-driven development: a metamodeling foundation', IEEE Software, Vol. 20, No. 5, pp.36–41.

[4] Boonma, P. and Suzuki, J. (2011) 'Model-driven performance engineering for wireless sensor networks with feature modeling and event calculus', in Proceedings of the 3rd Workshop on Biologically Inspired Algorithms for Distributed Systems, June, pp.17–24.

[5] Borges, L.M., Velez, F.J. and Lebres, A.S. (2014) 'Survey on the characterization and classification of wireless sensor network applications', IEEE Communications Surveys & Tutorials, Vol. 16, No. 4, pp.1860–1890.

[6] Digi (2017) Digi XBee s2c 802.15.4 rf modules, Technical report, Digi International Singapore [online] https://www.digi.com/ pdf/ds_xbee-s2c-802-15-4.pdf, (accessed 30 January 2018).