Design and implementation wireless sensors network for monitoring applications using Arduino

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Abstract

Timely detection of building fires is essential to incident prevention or to reduce the negative impact on human health. This paper presents a Wireless Sensor Networks system for temperature monitoring in a building. In general, sensor nodes in WSN are small, run-on batteries with very limited power resources; it is important to explore power management approaches to enhance network lifetime. The main aim of this system is to save energy costs and reduce power depletion. Through the deployment of many sensors, they collect information about the temperature and send it to the sink. The proposed method is based on multi-hop communication to decrease the transmission energy consumption and increase the monitoring coverage area. Furthermore, we computed the energy usage of the proposed system using Arduino and real sensor networks deployed indoors in the building. The results showed that the proposed system reduced the amount of energy consumed and increased the network's lifetime.

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1. Introduction

In recent years, a large amount of research has focused on the applications of Wireless Sensor Networks (WSN) in fields like monitoring systems (Gulati et al., 2022). WSN technology is a self-organized network that can provide real-time monitoring by employing many small sensor nodes in the sensing area to collect environmental information (Prabakaran & Kannan, 2017). At the same time, there are many challenges faced by this type of network, like limited energy resources, limited computing capacity, long communication distance, and wireless connectivity, making the sensor network fail most of the time (El-Sayed, Hashem, & Saleem, 2023; Sharma, Prakash, & Roy, 2020). Additionally, when sensor nodes are distributed, the nodes with small batteries should work for a long time without any human intervention (Alabady & Raed, 2018). At the same time, one of the most important design matters in WSNs is to decrease energy consumption by allowing nodes to communicate with each other's and with Base Station (BS) via a multi-hop transmitting schema (Rezaeipanah, Amiri, Nazari, Mojarad, & Parvin, 2021).

Furthermore, nodes must be able to exchange and transmit the monitoring data effectively. In addition, one of the main strategies to reduce energy consumption in WSN technology in wide monitoring fields is multi-hop communication when sending data from remote sensor nodes to the BS (Evangelakos, Kandris, Rountos, Tselikis, & Anastasiadis, 2022; Huang, Ruan, & Meng, 2018). In the general WSN architecture, the end device sensor is located at a large distance from the sink node and transmits the acquired data to the sink (Tiglao, Alipio, Balanay, Saldivar, & Tiston, 2020). The hop means the number of nodes a data packet must pass to reach its destination address. In a single-hop network, when the source packet leaves, take only one hop to the destination without considering the distance. Therefore, using multiple hops in transmission will reduce power consumption by reducing the distance and thus increase the network's lifetime (Yousif, Badlishah, Yaakob, & Amir, 2018). In this paper, we concentrate on maximizing the WSN lifetime by placing intermediate nodes for forwarder between end devisees sensor nodes and BS analysis center for remotely building monitoring systems based on Arduino. The communication used in the proposed model is multi-hop communication.

A significant number of researches using WSN technology have been presented in recent years. For example, the authors (Benammar, Abdaoui, Ahmad, Touati, & Kadri, 2017) suggested a single-hop indoor air quality monitoring system. The gateway is built on the Raspberry Pi 2 platform, while the sensor node is based on the Libelium Waspmote. The system was tested in a school and can sense CO, $CO2$, ozone, clorine, temperature, and humidity. This does not take into consideration the distance between the BS and the sensor node. The authors (Tijani, Almannaee, Alharthi, & Alremeithi, 2018) proposed a building fire system based on WSN for indoor air quality monitoring. The network contains a fixed Arduino and a mobile sensor drone that uses Bluetooth communication technology to send information to a remote smartphone. Then the monitoring data are uploaded to the Cloud via WiFi. The authors (Durrani, Khurram, & Khan, 2019) proposed a smart weather monitoring station to collect weather parameters from the environment and predict them via a combination of the Internet of things (IoT) and deep learning. Numerous sensors built into this system gather information about users' locations and upload it to the cloud. Additionally, they can utilize machine learning techniques to forecast the weather for the future station.

The authors (Qasim, Hamza, Ibrahim, Saeed, & Hamzah, 2020) present a security system for home monitoring based on WSN capable of detecting and sensing a wide range of activities. Specifically, motion detectors, body temperature, humidity, and gas. Moreover, the sensed value sends directly using a single hop from the sensing node to the Arduino. The authors (Mabrouki, Azrour, Dhiba, Farhaoui, & El Hajjaji, 2021) suggested automatic weather conditions monitoring module that provides real-time information about a given area. This system is based on WSN and contains temperature and humidity sensors. Then the sensor node transmits the reading value directly to Arduino. After processing, the Arduino transmits the analyzed values to the server, including a database. Furthermore, the information can be viewed remotely through a web page. The authors (El-Fouly et al., 2022) present an energy-efficient and reliable clustering protocol (ERCP) for WSNs. The suggested routing protocol is based on the idea of an energy-efficient, dependable inter-cluster routing method. The authors in (Behera et al., 2022) summarizes the network's changes to the CH selection threshold value. The article briefly discusses LEACH-based and bioinspired protocols, their advantages and disadvantages, underlying presuppositions, and the selection criteria for CH.

As the literature shows, direct communication between sensor nodes and the BS node consumes a high amount of limited energy resources. In this paper, we proposed a wireless sensor system for temperature monitoring based on multi-hop communication. The proposed system is used to remotely and real-time monitor the temperature in a building or home. The module results prove the proposed system's effectiveness in terms of energy consumption. The rest of the paper is organized as follows, section 2 provides the proposed method and the system model, section 3 presents the practical results and results discussion, and section 4 illustrates the conclusion.

2. The Proposed Method and the System Model

This section shows the hardware components used in the proposed system model, and how to connect them to the microcontrollers. In order to have more control over the variables affecting our environment, it is now possible to create systems that gather, analyze, evaluate, and validate data from it. This is made possible by the rapid rise of wireless communications. More flexibility in addressing these environmental issues may be provided by these designs. A wireless sensor system is suggested in this paper for data gathering, processing, and validation. The open-source hardware platform Arduino is the foundation around which the system is built the Arduino Nano as shown in Figure 1 and can be programmed using the Arduino Integrated Development Environment (IDE). The system uses single-wire DHT11 temperature sensors as shown in Figure 2. A single digital pin on the controller can trigger many sensors of this type. As a result, a single sensor node can accommodate numerous single-wire sensors even when the controller only has a few digital pins available.

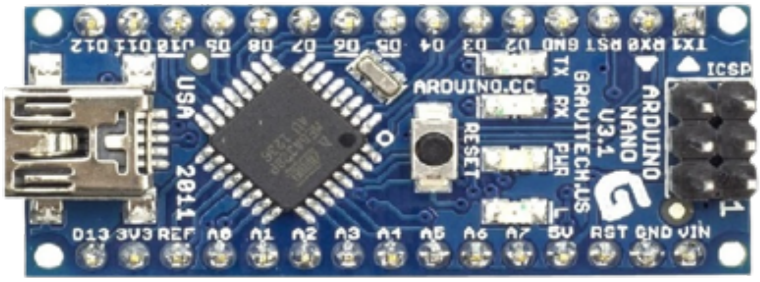
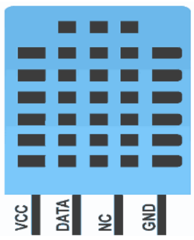


Figure 1. Arduino Nano diagram



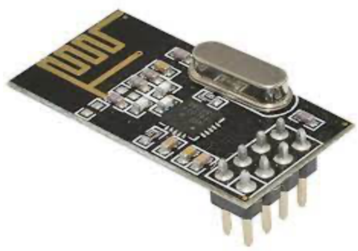
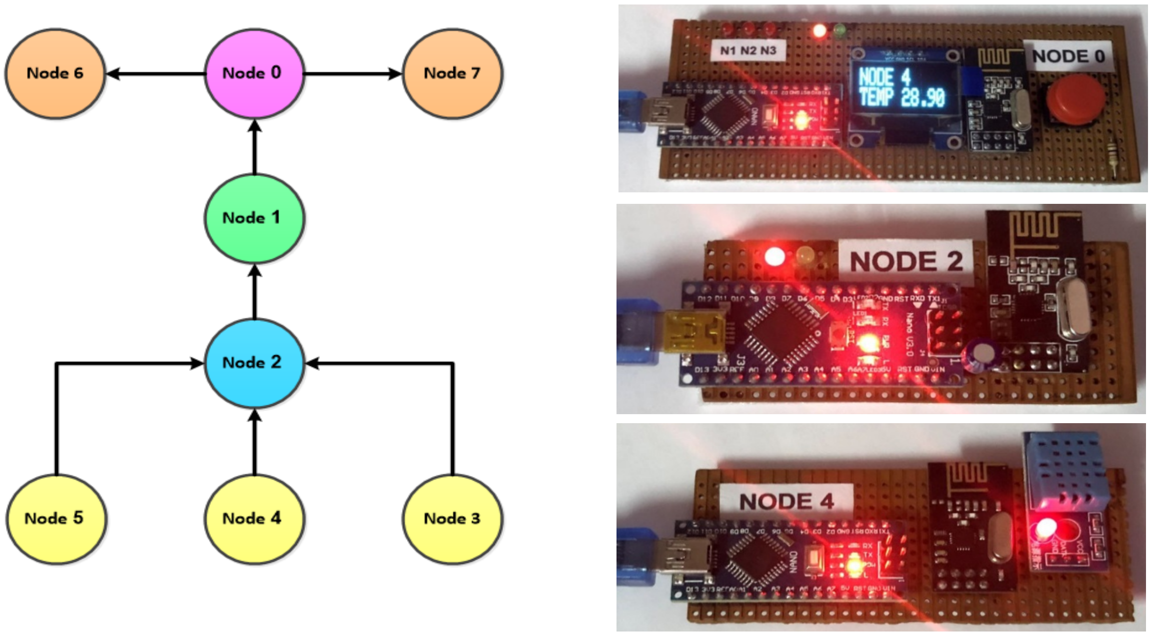


Figure 2. DHT11 Sensor **Figure 3.** nRF24L01

As a result, sensor nodes are very scalable. The voltage sensor also monitors the battery voltage that powers the sensor node to keep it operating. A mechanism is put in place that instantly connects a new sensor node that enters range with the system base receiving node in order to track data from the sensors. To send and receive data, nRF24L01 (+) radio modules are utilized, as shown in Figure 3. Eight Arduino boards will be used in this system proposal. Figure 4a shows the network topology of the proposal system, and Figure 4b shows practical wireless sensor nodes that are used in the WSN system. The function of nodes 3, 4, and 5 is sensing the environment (temperature, humidity, etc) it works as normal nodes. The function of node 2 is data gathering from the normal nodes (nodes 3, 4, and 5) it works as the cluster head (CH). The function of node 1 is forward the collection data from node 2 to node 0 which in turn works as a sink node or base station that is used to display the sensor results. The function of node 6 and node 7 is to run the alarm circuit it works as the actuator. The method of communication is through nodes 3, 4, and 5, which sense temperatures as the nodule is distributed in different geographical locations. This node will send data to node 2, which is an intermediate, in turn, will send data to node 1, which is similar to the work of node 2, and node 1 will send data to node 0, which is a base station or the sink through which data will be displayed on the OLED, which will connect to node 6 and node 7 and also connect a switch through which we control the OLED screen and node 0 will send data to node 6 and node 7, which is an alarm attached to it, a buzzer used for the alarm.



(a) (b)

Figure 4 (a). Network topology of the proposal system **(b).** Practical wireless sensor nodes

The details of the proposed algorithm for sent data and selecting the routing path are as follows:

Pseudo-code:

Notations:

SNs: Sensor nodes
BS: Base Station
D: Distance
n: number of nodes
T.H: THreshold
Temp: Temperature

Network Initialization Phase;

START → Initialize for all SNs
BS Broadcast Hello_Msg;
SNs Broadcast Hello_Msg;
Received by SNs = (SN1……..SNn)
for i=1 to n
  node-i Receives the Hello_Msg
  node-i Compute: RSSI Value of Received Signal

  Node(i) Calculate D for All Neighbors

15: $D = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$
16: Neighbor Table Creation at Each Node
17: **end for**
Information Transmission Phase;

18: SNs Sense Data
19: **if** SNs have Data to Send
20: Send Data Based on Minimum D
21: **else if** BS received a data packet
22: **if** Temp > T.H
23: buzzer ON
24: **end if**
25: **else** Return to Step 16
26: **end if**
27: **end**

2.1. Power Measurement

The power value is determined by the following equation:

$$P = V \times I \quad (1)$$

Where V represents the voltage, and I refers to the current. The following equation indicates that when the distance increases, the required energy increases. Thus, the small transmission distance reduces the energy consumed by the nodes and improves the network lifetime.

$$E = E_{elec} \times k + (E_{amp} \times k \times d^2) \quad (2)$$

Where d is the distance, k refers to the amount of data, E is the amount of energy consumption while transmission. E_{elec} is the energy expended to run the transceiver circuit, and E_{amp} is the energy required for the amplification of radio signals (Heinzelman, Chandrakasan, & Balakrishnan, 2000).

3. Results and Discussion

We have set up the sensor nodes for development and testing requirements at the monitoring area. According to Figure 4, the system consists of a coordinator node, two intermediate sensors, and three sensor end nodes. Each sensor node is sent data to the next hop node based on distance. Figure 5 presents sample power consumption results based on collected and routing data from sensors. This data is collected from sensor node 3, sensor node 4, and 5 and sent based on path routing selection to the coordinator node. As can be seen the energy consumed increases as the distance increases, it has significantly reduced the power consumption of monitoring sensor system development.

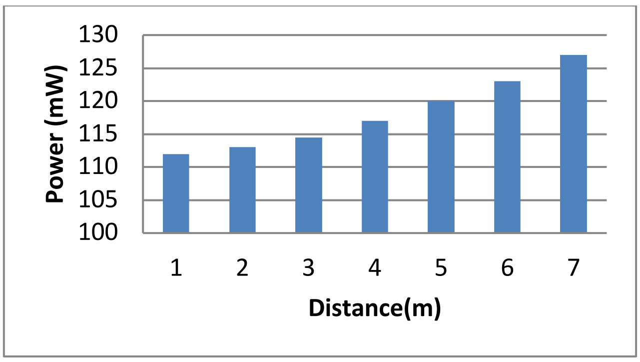


Figure 5. Power consumption in node number 3, 4, and 5

Figure 6 shows the power consumption of intermediate sensors number 1 and number 2. The results show that the power consumption of these intermediate sensors is higher than the end sensors number 3, 4, and 5 because they are always used as forward nodes to deliver data to the coordinator node.The energy consumed by the node that detects an event is shown in Figure 7. According to the graph, there is a relationship between the amount of distance between the source and the destination and the amount of energy used. But we can reduce part of the wasted and consumed energy by reducing the distance by choosing the path based on multiple hops to provide the data to the sink. The results show the reduction of energy consumed through multiple hops to overcome long distances. Figure 8 shows the energy consumption of the sink node. We conclude that the sink is the most energy-consuming compared with previous results, and this is because all nodes send their data to this node and the highest load is on this node.

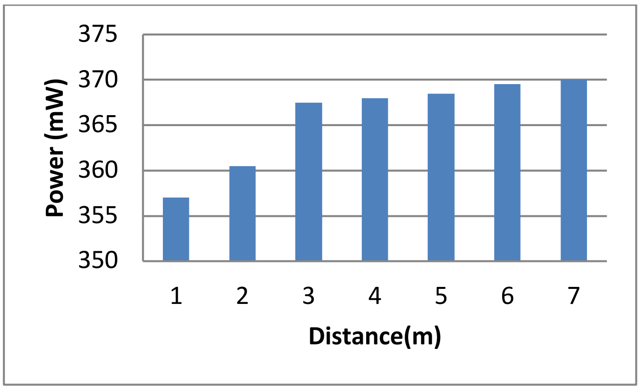


Figure 6. Power consumption in intermediate node number 2, and 1

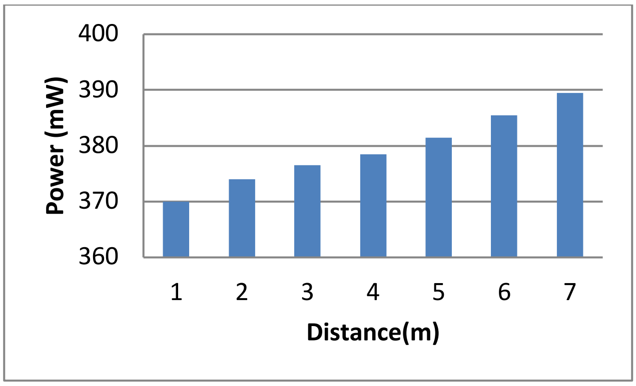


Figure 7. Power consumption of alarm nodes number 6 , and 7

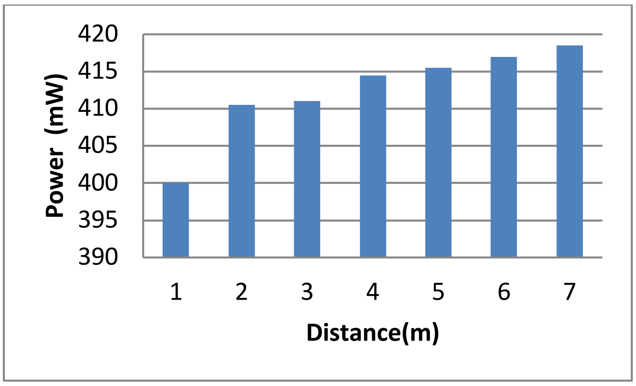


Figure 8. Power consumption of a sink node (node number 0)

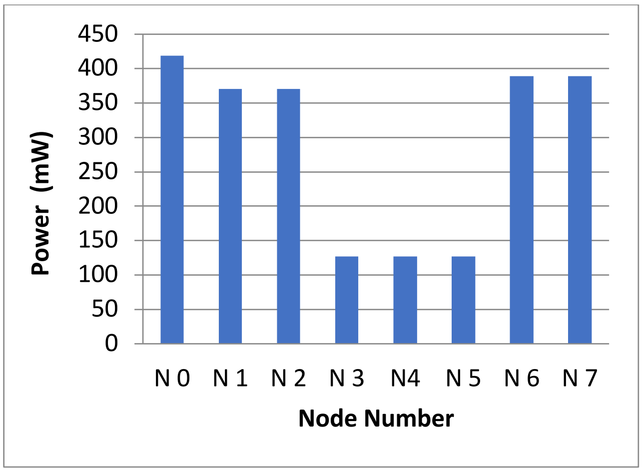


Figure 9. Power consumption of all nodes at distance 7 meter

Figure 9 shows the comparison of the consumed power values for all nodes at a distance of 7 meters. As can be noted in Figure 9 node number 1 and node number 2 consumed a large amount of energy because they were used as the cluster head and intermediate node, respectively. The sink node (Node 0) consumed the highest amount of energy because all nodes in the network send their data to this control node. Furthermore, Table 1 summarizes the power consumption results of all sensor nodes in the proposed system.

Table 1: Power consumption in all nodes

Distance (m)	1	2	3	4	5	6	7
Power consumption (mW) in nodes 3, 4, 5	112	113	114.5	117	120	123	127
Power consumption (mW) in nodes 1, 2	357	360.5	367.5	368	368.5	369.5	370
Power consumption (mW) in nodes 6, 7	370	374	376.5	378.5	381.5	385.5	389.5
Power consumption (mW) in node 0	400	410.5	411	414.5	415.5	417	418.5

4. Conclusion

In this paper, a practical multi-hop wireless sensor network was designed and implemented using an Arduino Nano microcontroller board, a number of sensors, and an nRF24L01+ radio transceiver module. The results show how the power consumption increased when the distance between the nodes increase. The sink node consumes the most energy in comparison to the other nodes. Given that all nodes submit their data to the sink, which carries the heaviest load. The monitoring system is based on small wireless sensor nodes and is dependent on a multi-hop wireless communication paradigm. So, the main aim of this proposed network is to perform continuous and real-time detection of building fires. Furthermore, aims to reduce the power consumption of nodes and increase the lifetime of the network. To reduce energy consumption, each node selects the next hop depending on the minimum distance. Results show the effectiveness of the suggested building monitoring system by increasing the network lifetime and reducing the energy consumption of the sensor nodes. Results show the proposed system saves energy by reducing the power consumption for example from 418.5 mW when the distance 7m to 400 mW when the distance is 1m in case the node 0 (sink node). For future work, network performance will be measured and tested over wide monitoring areas.

Conflicts of interest: The authors declared that there is no conflict of interest.

Authors Contributions: The first author "Salah Abdulghani Alabady" contributed to designing the proposed hardware system and configuring all the components, and collecting the results. In addition to correcting and revising the language, giving appropriate directions on how to write, and analyzing and discussing the results. The second author "Sara Raed" contributed to writing the draft paper and collects all the information in this paper.

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