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IMPLEMENTATION OF ACTIVE WIRELESS SENSOR NETWORK MONITORING USING ZIGBEE PROTOCOL

MAHMOOD F. MOSLEH*, DUAA S. TALIB

Electrical Engineering Technical College, Middle Technical University
Al-Athorein Campus, Al-Dura, Baghdad, Iraq
*Corresponding Author: drmahfa@yahoo.com.

Abstract

Wireless Sensor Networks (WSNs) are used in enormous applications with different aspects of modern life due to the extensive services that shorten the time and reduce the effort with lower cost. Optimum design leads to better performance, low cost and long network lifetime. The aim of this paper is to design hardware and implements a flexible and active WSN depending on Arduino Uno and ZigBee for controlling and communication respectively. The designed network contains three sensors (lighting, temperature and gas) have been adopted as a sample of sensors for this network. It has been experimented a multi-hope network to get an efficient coverage for target building and can be an extension for a large area. Also, the proposed network is flexible in responding to the user's desire to get the information on his request or at selected times by the user, or in the case of an emergency to achieve full controlling of the facility which is under probation. The results confirm that the proposed network gives the best performance for three cases; first when the user need show the building environment at any time in addition to checking the network activity. Second, the results show that the network is records the reading of all sensors at a regular period to show the overall daily and weekly cases of an area under control. Third, the user can set various thresholds values, to adapt the work of the network to shoot an alarm or enable self-protection devices.

Keyword: WSNs, Multi-Hop, ZigBee, Arduino.

1. Introduction

Wireless Sensor Networks (WSNs) has been spread dramatically in the world because of its importance for modern techniques. WSNs usually contain a large number of sensing nodes which could be up to thousands of nodes, each node able to sense, process, and transmit information to the base station. The network task is to check, monitor and control a specific physical phenomenon.

Abbreviations

AC-DC	Alternative Current – Direct Current
ADC	Analog to Digital Convertor
E-SEP	Extended Stable Election protocol
IEEE	Institute of Electrical and Electronic Engineers
LEACH	Low Energy Adaptive Clustering Hierarchy
MAC	Medium Access Control
SEP	Stable Election protocol
USB	Universal Serial Bus
Wi-Fi	Wireless Fidelity
WSN	Wireless Sensor Network
XBee s2	ZigBee Series 2

WSNs in general designed to send a small amount of data, for example, the status of temperature or light intensity [1]. WSNs have been commonly used in several places particularly for surveillance and monitoring in climate and habitation monitoring. Environment monitoring is an essential field of security and providing a real-time system. The advance of environment monitoring system has been used in several applications to offer advanced services which reduce the cost and time. The applications of environment monitoring have developed quickly in farming, indoor, and woodland monitories [2].

The main challenges of WSNs are the limitation of power consumption, small memory size, short range communications, small battery and a limited microprocessor. In return, it is imperative a serious operation in high efficiency like extracting data from surrounding environments processes such data and manipulates it as per the requirement of its task and time synchronization. Therefore, the deployment must be done carefully to ensure the collection of information and deliver it to the sink (base station). Also, there are additional requirements for designing WSNs such as scalability, self-configuration, a higher degree of accuracy and sensor node co-operative [3].

Many researchers have been studied and applied WSNs for huge application to offer efficient service in various environments. The authors in [4] fixated on the study of smart sensors and their possible and existing usage in different fields. Also [5] demonstrated a novel of three types for control in WSNs. The first scheme is for attacking avoidance second is to build common sensing and the third proposal is to use less bandwidth for those applications. A design of temperature monitoring the current and history information for the location of the remote has been implemented in [6] using ZigBee protocol.

The objective of this paper is to design and implement hardware of an efficient WSN in real time applications. A sample of three sensors will be deployed for laboratory testing. Each sensor will set with Arduino and ZigBee to form an end node. With running the proposed network, several parameters will be changes for more times and choose the suitable values as according to beneficially need. The response of the trial network will be recorded for several times until getting a better case and then set such network to those values.

2. WSN Architecture

Wireless sensor networks consist of multi-nodes that are capable of interacting with the environment by sensing or controlling physical parameters. Because nodes are equipped with limited power and small size, there are several ways to transfer data to the base station; all share one goal is to reduce power consumption without compromising on the quality of transmitted information. The network is often divided into several clusters in order to cooperate with each other to deliver the data to the station. Each cluster consists of a number of nodes and one head which collect the data of such cluster and sent it to a base station.

Depending on the distance between cluster head and its other members, a network can be categorized into a single hop and multi-hop clustering architecture as shown in Figs. 1 and 2 respectively. In a single hop, each node transmits directly to its cluster head while in multi-hop, the far node transmits packets through intermediate nodes which lead to power saving [1]. This research adopts hybrid network, if a node is close to base station (cluster head), a single is applied and for the far node, the closed node will perform as intermediate node like multi hop.

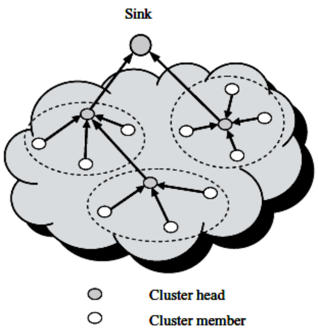

Fig. 1. Single hop clustering.

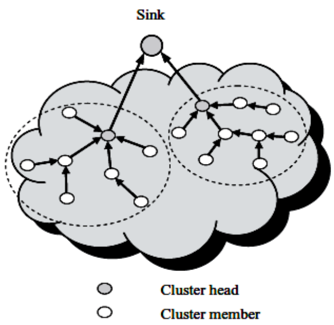

Fig. 2. Multi hop clustering.

Each sensor generally comprises of four main components: sensing, processing, communication and power units, as shown in Fig. 3. All sensors are connected to a processor unit for holding and storage or other applications. The processing unit normally comprises a microcontroller or microprocessor with memory. The power unit contains a battery for providing power to drive all other components in the network. The communication unit contains a short range radio for execution data transmission and reception over a radio channel. All these units should be constructed into a minor unit with low power consumption and low cost [1]. This research adopts ZigBee protocol for wireless communication link because of its reliable data transfer, small size and low cost.

There are many protocols included different ways to select cluster head. For example, in Homogeneous networks, all sensor nodes have the same capabilities in terms of energy, computation, and storage and selected base station periodically according to a specific protocol. The most important protocol is LEACH [7]. There are other protocols used in heterogeneous networks, equipped with more processing and communicating capabilities than normal sensor nodes, where the nodes that nominated as cluster head with greater ability than others. The most important of these protocols are SEP [8] and E-SEP [9].

3. Zigbee Technology

ZigBee communication is especially technique built for wireless connection between sensor nodes in WSNs. It defines physical, data link, network, transport and application layers to handle many devices at low-data rates. ZigBee is low cost, low power and small size. It connected in the form of point to point and mesh network (10-100 meters range) for monitoring and controlling applications. This technology is cheaper and simpler than the other short-range wireless sensor networks such as Wi-Fi and Bluetooth. Using the router in the ZigBee network makes the network more expansion [10].

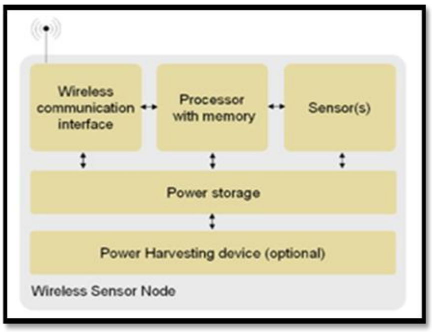

Fig. 3. Sensor node structure.

3.1. ZigBee architecture

The basic architecture of ZigBee is shown in Fig. 4. It is consisting of four main layers: application layer, network layer, medium access control layer and physical layer. The Application and Network layers of the ZigBee standard are defined by the ZigBee specification, the Physical and MAC layers are defined by the IEEE 802.15.4 standard. The physical layer has two alternative choices for the RF transceiver functions 868MHz, 915 MHz and 2450MHz. But the embedded firmware and software layers above them will be basically the same no matter what physical layers are used.

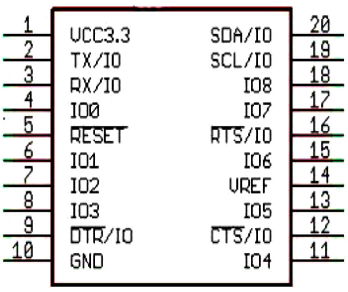

Fig. 4. ZigBee pin configuration.

The MAC is in charge of the management of the physical layer and among its functions are channel access, keeping track of slot times, and message delivery acknowledgment. The Logical Link Control is the interface between medium access control layer and physical layer and the upper application software.

Application software is not a part of the IEEE 802.15.4 specifications, and it is expected that the ZigBee Alliance will prepare profiles or programming guidelines and requirements for several functional classes to comfort product interoperability and vendor independence. These profiles will define network formation, security, and application requirements while keeping in mind the basic ZigBee features of low power and high reliability. ZigBee is optimized for automation sensor networks, where there is no need for high bandwidth, but low power usage, low latency and high quality-of-service are required. The ZigBee networking protocol supports up to 65536 nodes in one network [11].

3.2. ZigBee topologies

There are many network topologies using in ZigBee but frequently used topologies are star topology, mesh topology and cluster tree topology. Any one of these topologies must contain at least one coordinator (base station) as shown in Fig. 5.

Star topology: Fig. 6 shows a star topology which contains one base station (coordinator) which is in charge of initiating and managing devices of the network. Also, it contains many end devices nodes that connected to a centralized communications coordinator. Each end device can't communicate with one another. This topology is easy to install in homes and offices, it’s a star-shaped where all end devices communicate with a coordinator.

Mesh and cluster tree topologies: in a mesh topology, the network consists of a coordinator, several router nodes (which make the network more extendable) and several end devices. In cluster tree topology, each one of cluster consists of a coordinator, several router nodes and several end devices, and these coordinators communicated with a parent coordinator which is in charge of initiating the whole network. In these two topologies, each node connects to all other nodes in the network. So in the case of failure of node, data and information are routed automatically to other nodes [12].

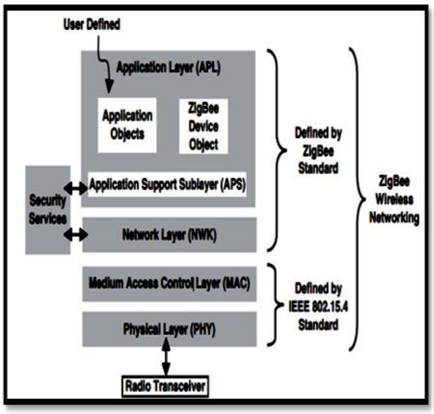

Fig. 5. ZigBee architecture.

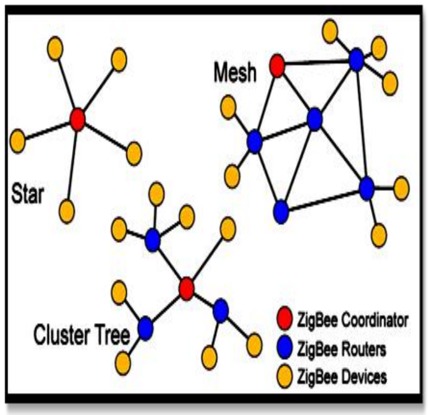

Fig. 6. The ZigBee topology.

4. The proposed network

The idea of proposed network is to adopt hybrid network (single and multi-hop). The nodes which are close to the base station are sent their packets directly while the far end will choose another node as an intermediate node. Choose the intermediate node is under two conditions. The first, is to be the closest to the base station and the second, is to be the higher residual power from all other near nodes. Therefore, the network will be characterized by long-life and high flexible to cover a variable area.

The block diagram of the proposed is network shown in Fig. 7. It comprises a coordinator node, router node, and three nodes as the end devices. As it cleared from Fig. 7, node 1 and 2 is a sample of closest nodes while node 3, is the far end. In fact, any closest node can play the role of a router (intermediate node) in addition to its duties.

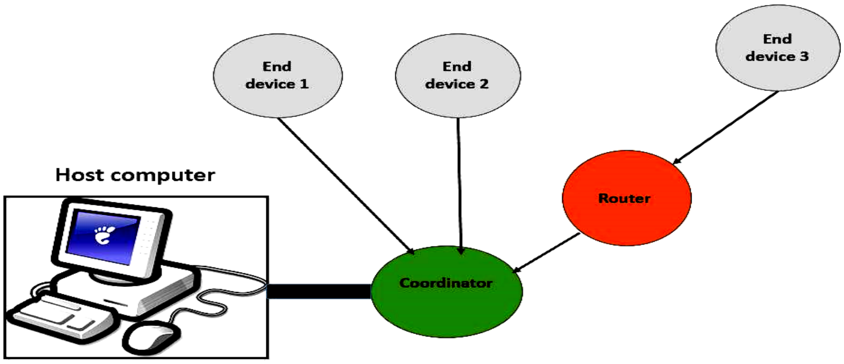

Fig. 7. Block diagram of proposed network.

A sensor in each end device is responsible for converting a physical phenomenon such as temperature, light, or motion into an electrical signal that may be further manipulated by another device. The sensors used in this research, (lighting, temperature and gas sensors) are connected to Arduino through analogue input pins. In wireless communication part represented here by XBee S2, the data will be encoded, modulated and transmitted to a coordinator. The coordinator consists of XBee S2 as a wireless communication part and Arduino for data collection, processing and storage.

In this research, it has been implemented all parts of proposed scheme as a hardware system to apply the idea in real time. One building was selected to test such system and record the results of sensor reading in three cases; on user's request to check the system in any time, on a threshold for emergency situations and on a regular timer to show the daily reading for any sensor. The hardware implementation is outlined in *Appendix A*.

5. Results and Discussion

The implementation of full network is shown in Fig. 8. This system has been implemented and tested for a coordinator node, router node, and three nodes of an end device. The information can be aggregated into three categories:

5.1. On Request:

Here, the data will be aggregated and displayed on the screen of the base station based on the user's request at any time wanted. It has been designed a special program for this purpose to enable to apply such task by defining special character chooses by the researcher. For example, by writing "#1" code on serial monitor of Arduino, the screen will indicate the information of lighting sensor and by typing "#2" and "#3" it will indicate the information of each temperature and gas individually respectively. The current network can transfer data and information that far away from the base station and which is outside the coverage of base station.

In this subsection, it has been putting node 1 outside the coverage of base station. But, by using router node that has been explained in section 4, the data can transfer from node 1 to base station via router node. Figure 9 shows the results of information about lighting, temperature, and gas sensors on serial monitor in case of on request.

For this application, many benefits and uses are possible to apply in real time. For example, the user needs to know environmental conditions that covered by the network from time to time. Also for the purpose of either to check on the network work well or to know about the current environmental conditions according to the user's immediate need.

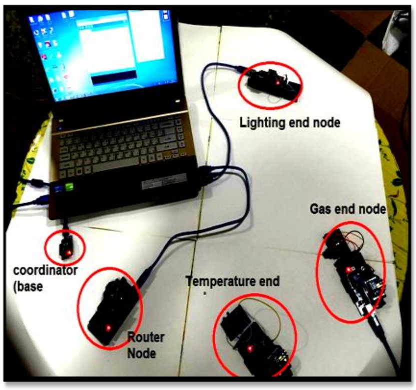

Fig. 8. Hardware design of full network.

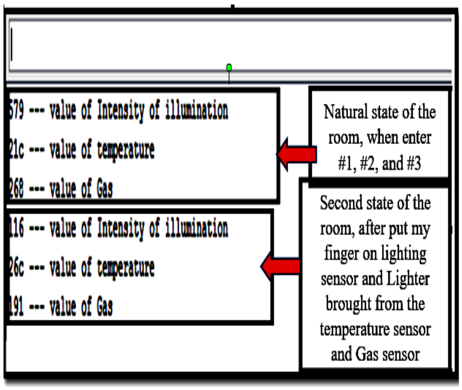

Fig. 9. Results of on request.

5.2. On Threshold:

In many applications of WSN, the user needs to alert in case of emergency, as high temperature or high gas (in a case of fire), or to turn on the contingency system automatically. In this case, the user can identify a threshold value of each reading for the three sensors. The system in this subsection will display the reading only in the case of the value will exceed a threshold. Figure 10 shows the results in the case of exceeding the threshold.

5.3. On Timer:

This application is useful in a survey for values of temperature, lighting and pollution that cover a period including many days or week to set a detailed study about environmental changes in the areas that covered by the network. In addition, it is possible to use this application to increase the reliability of reading through calculation the average of values during certain time periods. Figure 11 shows the results of information about lighting, temperature, and gas sensors on serial monitor in case of on the timer.

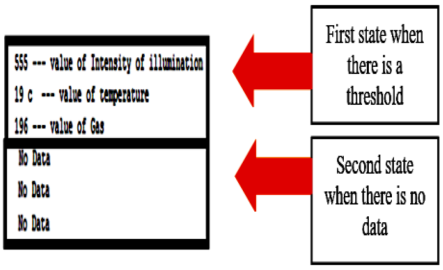

Fig. 10. Results of on threshold.

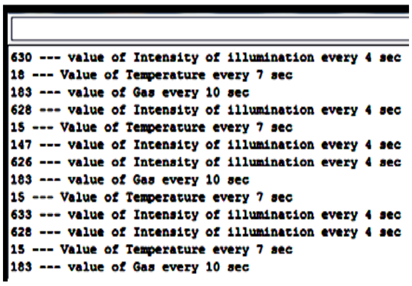

Fig. 11. Result of on timer.

5.4. Discussions

This research has been implemented the proposed network in hardware scheme. Unlike of many researchers that got his results from simulation to avoid the difficult results in real time. This network is characterized by high flexibility and easy installing to perform multiple tasks, depending on how desired by the user. For example, a user can be seen at any time on the status of the building under monitoring using "on request" case and can deliver the information on the internet to enable the user to control remotely. Also, anyone can be used "one-time" case, to conduct a study to show the daily, weekly and state for the area under monitoring. In addition, the last case "on-threshold" can be used to active alarm and self-protection when an emergency.

6. Conclusions

In this paper, it has been designed a WSN that consisting of coordinator node, router node and three end devices node. In addition to the sensor, each end device consisted of Arduino and ZigBee as a processing with storage memory and as a transceiver unit respectively. The three nodes above have been selected in this research as a model for experimental purposes and for practical; it can be extended to a large network of the same basis of such network. The proposed network is running to check its performance in real time. The results confirm that it can be used such network in three main cases: First, the condition of the building under control can be tested at any time depending on user desired. Second, by identifying a threshold value for each sensor the network can be used for alarming as well as to enable a self-protection. And finally, it can achieve a case study for any area to clear out its environments for any type of environment depending on the type of sensor like the studying of temperature distribution along day, week, month and year in the case of the temperature sensor. Also, the same situation is in relation to the relation to rest of sensors. Some of the challenges that limited the proposed network, that is the shorter distance of communication link using ZigBee and its low data rate in spite of its advantages.

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Appendix A

Hardware implementation of proposed network

As motioned in section 5 the task of the base station is to collect the data from all end nodes and display them on serial monitor of Arduino. In this research, it has been used ZigBee (XBee S2) connected to the computer through an adapter and linked with all nodes wirelessly as shown in Fig. A-1. It is assumed that the end device 3 shown in Fig. 8 is a far node, so it need intermediate node, hear the router is assumed as an intermediate node is consists of only ZigBee and the Arduino used here just as adapter as shown in Fig. A-2.

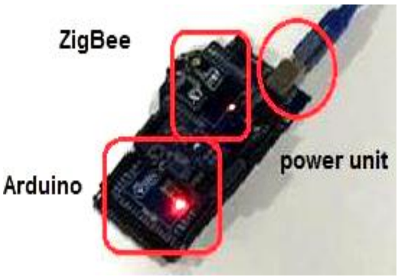

Fig. A-1. End device 3.

Fig. A-2. Router node.

The structure of the rest three end devices is identical; each one consists of Arduino Uno and ZigBee as microcontroller and communication link respectively. Just differ by the type of sensor, Figs. A-3, A-4 and A-5 illustrate the hardware structure of lighting, temperature and gas end devices respectively.

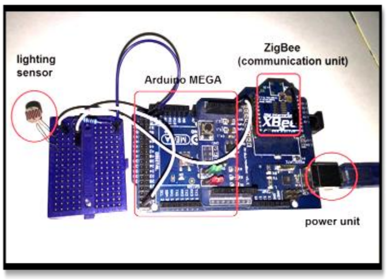

Fig. A-3. Lighting end device.

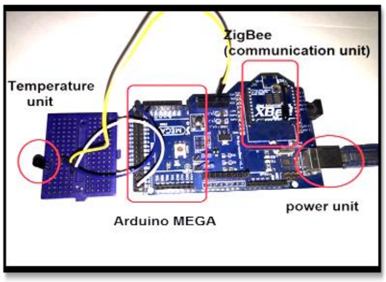

Fig. A-4. Temperature end device.

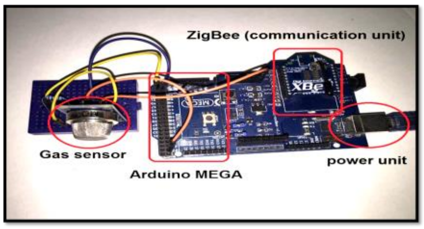

Fig. A-5. Gas end device.