Real Time Universal Scalable Wireless Sensor Network for Environmental Monitoring Application

Idakwo M.A [1*], Umoh I.J [2,1], Tekanyi A.M.S [3,2], Adedokun E.A [4,1], Muazu M.B [5,1]

[1]Computer and Control Engineering Department, Ahmadu Bello University Zaria, Nigeria
[2]Electrical and Communication Engneering Department, Ahmadu Bello University Zaria, Nigeria
*modabutu@gmail.com

Abstract— *There are several wireless sensor network use for environmental monitoring applications. However, most wireless sensor network designed for real time environmental monitoring application are application specific and static in nature. Hence, the need for reprogramming of base station for every change in sensor type or the introduction of a new sensor node into the network. More so, since these sensors nodes are deploy by end users in a random region of interest, it is necessary to develop a new plug and play mechanisms with more software modules and more user-friendly interface that is scalable to ease larger area deployment, installation and maintenance. Hence, this paper developed a base station with an auto detection and configuration system for detecting new sensor node, faulty nodes, and update user in real time. The developed system is implemented on a mesh topology network and was calibrated using standard Davis vantage pro2 weather station in Ahmadu Bello University Liquefied Natural Gas Environmental Laboratory and a mean error of 0.12 and root mean square error of 0.14 were obtained.*

Keyword— Auto Detection, Auto Configuration, Base Station, Calibration, Real Time, Sensor Node, Wireless Sensor Network

1. INTRODUCTION

A wireless sensor network (WSN) consist of devices equipped with sensors, radio transceivers, microcontroller that cooperate to form fully connected network of a sensor node [1]. WSN technology has the capability to capture critical high resolution data quickly, process, and transmit for real time monitoring [2].

Most existing WSN real time environmental monitoring systems, are application specific and static in nature [3]. This means that they are programmed to monitor a specific environmental parameter, thereby, requiring reprogramming of the base station for every change in sensor type or introduction of new sensor nodes into the network which made the system to be user defined.

More so, to enable reliable detection of observed phenomena in real-life applications, thousands of nodes are usually installed throughout region of interest [4]. However, the nodes that are at a large distance from the base station will have poor quality connections to the base station [5] and these increases transmission power due to frequent retransmission. Hence, a mesh topology network is most suitable due to it scalability, self-configuration, self-healing and flexibility[13].The mesh topology also provides extension of network coverage without increasing transmission power or receive sensitivity, better reliability via route redundancy, easier network configuration and better device battery life due to fewer retransmissions [9]. For successful application of WSN in environmental monitoring, low cost, easy deployment, and maintenance are substantive but the current software technologies for WSNs lack the feature of dynamic sensing [6] which makes the system application dependent.

In order to increase effectiveness of WSN, sensor systems must increasingly become easily reconfigurable and adjustable to support system evolution and optimization [6]. Since most WSNs are deployed by end users, it is paramount to design new plug and play mechanisms with more software modules for friendly user interfaces [7] to ease installation and maintenance. These paper introduced an auto detection and configuration module into the WSN. These enables the end user graphical interface to be adaptable to any sensor type and give real time status of the sensor nodes for easy fault detection which might be due to power outage, communication failure, etc.

The contribution of this paper are highlighted as follows:

- The developed system has an auto detection and configuration system for real time detection of new sensor node, new sensor types and faulty sensor nodes on a friendly user interface.
- The developed system is scalable as it is implemented on a mesh network topology which allows sensors node communication beyond the base station range.
- The developed system is calibrated using standard Davis vantage pro2 weather station and a mean error of 0.12 and root mean square error of 0.14 were obtained.

2 WIRELESS SENSOR NETWORK DESIGN

The system developed includes a base station and nine (9) distributed wireless sensor nodes

2.1 The Sensor Node Design

In this research, a mesh topology network was implemented on Arduino and nRF24L01 transceivers which acted as the sensor nodes. A total of nine (9) sensor nodes were designed and used. An Arduino is an open source single-board microcontroller with easy-to use hardware and software components that is widely used due to its flexibility [10].It uses Atmel Atmega328 microcontroller with a clock speed of 16 MHz. Several sensors can be attached to a single board as it has 14 digital I/O pins and 6 analogue inputs [8]. The nRF24L01 is a 2.4GHz transceiver for low power wireless application with a data rate up to 2Mbps [11] and cover a distance up to 1.5km.The nRF24L01 also has six (6) transmit/receive hardware pipes and can transmit data on one (1) pipe why synchronously listen using the remaining five (5) pipes, this eases the implementation of mesh topology network [12].The sensor nodes designed is shown in Figure 1.

(a) Temperature sensor (b) Piezo sensor

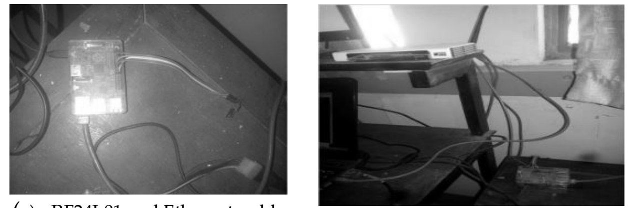
Figure 1: Sensor Nodes Hardware Setup

2.2 The Base Station Design

The base station comprised of nRF24L01 and Raspberry Pi Model B as shown if Figure 2. The Raspberry Pi board uses ARM processor CPU with a clock speed of 700 MHz. It has 512MB RAM, SD Card storage, and 8 GPIO port for expansion and varieties of interfacing peripheral such as HDMI port and USB port [8]. In this design, Raspbian operating systems was used. The Raspberry pi is connected to nRF24L01 transceiver which is configured as the Personal Area Network (PAN) coordinator and provide DHCP services to the sensor nodes.

More so, an Apache HTTP web server is built on the Raspberry pi to run the web server application for Graphical User Display (GUI). The client side web interface was implemented using PHP, CSS, Ajax, JQuery, Flot and HTML. The styling of the web page was done using CSS and HTML, while the interactive user interface and dynamic display was done using JavaScript. PHP, Ajax and jQuery fed the GUI with real time continuous data from the MySQL database without page refreshing.The nRF24L01 data rate is set to 1Mbps to enable compatibility with other radios like nRF2401A, nRF24E1, nRF2402, etc.

The base station node is connected to ABU Electrical and Computer Engineering router with a static public internet protocol address to enable remote monitoring within and outside the school premises as shown in Figure 2. More so, mesh code modules, auto detection and configuration modules were developed in C++ on the base station node. Figure 3 and Figure 4 shows the detailed block diagram and flow chart of the developed system repectively.



(a) nRF24L01 and Ethernet cable connected to Raspberry Pi. (b)Raspberry pi connected to ABU Network Router.

Figure 2: Base Station Hardware Setup

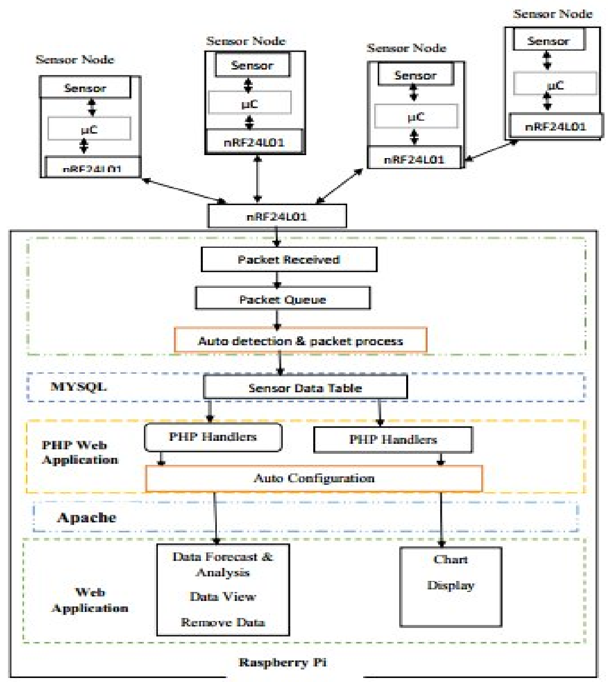


Figure 3: Detailed Block Diagram of the Developed System

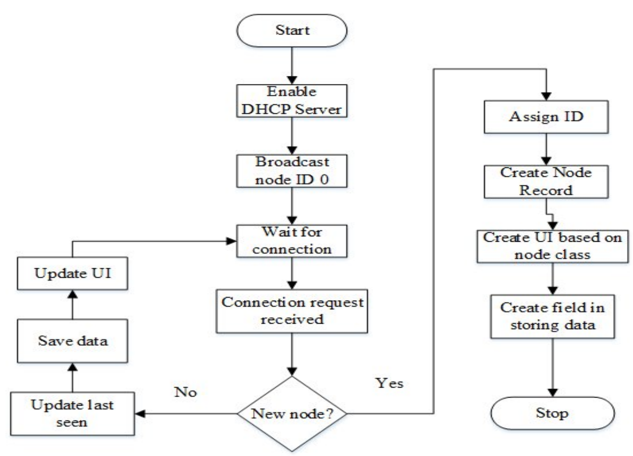


Figure 4: Flow Chart of Auto Detection and Configuration

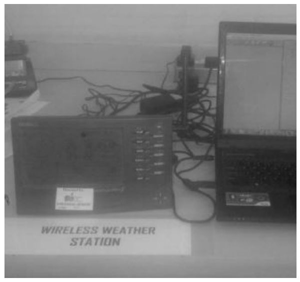
3 EXPERIMENTAL SETUP AND RESULTS

The experimental setup is carried out in ABU Electrical and Computer Engineering department while the sensor nodes calibration was done in ABU Liquefied Natural Gas Environmental Laboratory.

3.1 Developed System Calibration

In order to measure the accuracy of the developed system with standard device, the developed system node was placed under the same condition with ABU LNG Davis Vantage Pro2 weather station to capture real time temperature data as shown in Figure 5(a). These data were monitored and captured on Tuesday 24th December 2017 from 9:00 am to 12:00 pm at an interval of 10 minutes.

(a) Developed system and Referenced Weather station outdoor unit.



(b) Developed system and Referenced Weather station indoor unit.

Figure 5. Developed System and Reference Weather Station Monitoring.

Raw serial data which has not undergone analogue to digital conversion were extracted from Davis Vantage Pro2 using weather link software installed on the PC connected to the base station through a USB cable as shown in in Figure 5(b).These data were necessary to determine the accuracy of the developed system as the weather station only display digital value. The captured data graph is shown in Figure 6.

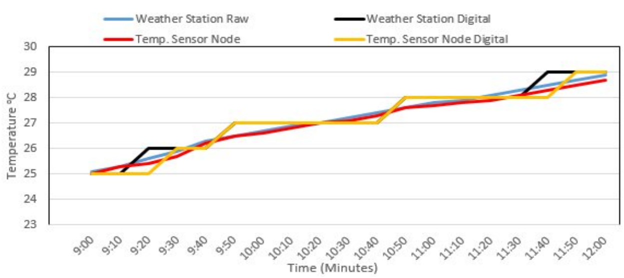


Figure 6. Comparison of Reference and the Developed Sensor Node Temperature Data.

From Figure 6 the digital data readings of the developed system showed a variation from the standard weather station between 9:10 am to 9:30am and also from 11:30 am to 11:50am. The variance in raw data readings is minimal and the difference is due to the elevation of the weather station, protection from direct sunlight, and microclimate. In order to evaluate the performance of the developed system, the calibrated performance result was compared with the calibrated result of Open Source Hardware Weather Station (OSH-WS) [10] which also used the same Davis vantage pro2 weather station as a referenced calibrator. The comparison is as shown in Table 1.

Table 1. Performance Evaluation

System	ME	RMSE
OSH-WS	0.3	0.7
Developed System	0.12	0.14

From Table 1, the performance evaluation shows a 60% improvement over OSH-WS.More so, further comparison was carried out with Zaria temperature data captured from wunderground website on 27th January 2018 between 10:00am to 3:00pm as shown in Figure 7.

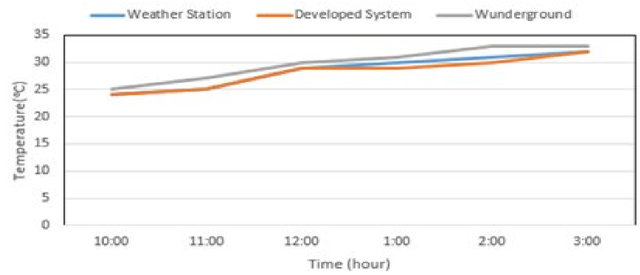


Figure 7: Weather Station, Developed System and Wunderground Temperature Data

From Figure 7, the temperature data obtained from the weather station and the developed system placed under the same conditions are the same with a little deviation between 12:10pm and 2:50pm. This deviation was due to a tree shadow casted on the developed system outdoor unit between the periods, while the deviation of the temperature data from the wunderground system was due to the location differences.

3.2 Auto Detection Test Result

In order to test the base station auto detection and configuration modules, eight wireless sensor nodes were introduced into the network. Four (4) sensor nodes were placed at a distance of 1.4km from the base station. The remaining sensor nodes were placed at a distance of 2.5km which is outside the base station network range and the terminal view is as shown in Figure 8.

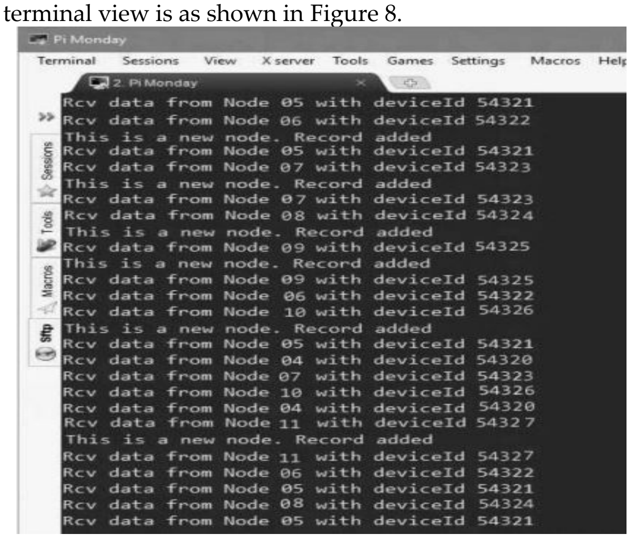
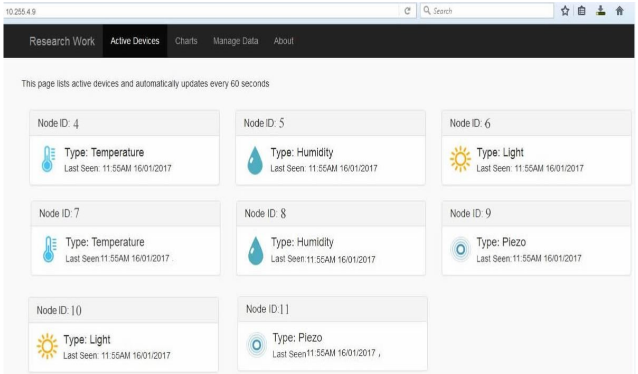


Figure 8. Raspberry pi terminal view of nodes

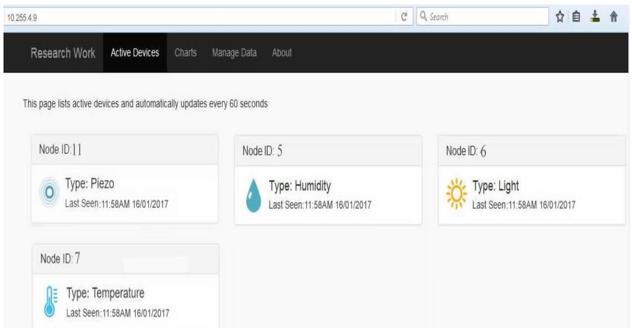
Figure 8 shows Raspberry pi terminal view of auto detected nodes. Four (4) nodes (4, 5, 6, and 7) were auto detected within the network range. The first time the nodes were introduced into the network the auto detection modules detected and recorded their device ID. The mesh code libraries implemented on the PAN Coordinator route node (7, 8, 9, 10 and 11) through the neighboring node (4, 5, 6, and 7) using shortest path as metric.

3.3 Auto Configuration Test Result

The auto configuration module automatically configures detected sensor nodes on GUI as shown in Figure 9.



(a) GUI of Eight active nodes (4,5,6,7,8,9,10,11)



(b) GUI of Four active nodes (11,5,6,7)

Figure 9. Auto configuration of actives sensors nodes

A 60 seconds time slot was assigned to monitor active devices for quick detection of faulty nodes. Once the base station did not receive data from any connected devices and the 60 seconds time slot elapsed, the device is tagged inactive and removed from the UI. This help the users to easily detect failed sensors nodes which might be due to loss of power, connection problem etc. Figure 9(a) shows the GUI of eight (8) active auto detected sensor nodes (4, 5, 6, 7, 8, 9, 10, and 11). In other to test the implemented mesh topology network, two nodes (4, 10) within the base station were removed and after 60 seconds, nodes (8, 9) route to the base station through them were removed automatically as shown in Figure 9(b).

4 CONCLUSION

In this paper, a real time universal scalable wireless sensor network for environmental monitoring application has been presented. The developed system was calibrated using standard David Vantage Pro2 weather station and a mean error of 0.12 and root mean error of 0.14 were obtained.The developed system has an auto detection and configuration modules which uses a 60 seconds time slot for detecting active devices. This help in detecting faulty or failed sensor nodes on the user friendly interface.

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