ABUAD Journal of Engineering Research and Development (AJERD)
Volume 1, Issue 1, 23-31

Development of a Wireless Sensor Network for Monitoring an Automated Distributed Water Supply System

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Date of First Submission: 21/09/2017
Date Accepted: 08/10/2017

***Abstract**: Water control is very essential in every area of life in order to prevent wastage. Since the monitoring of water supply systems can be done locally, there is a need to also remotely monitor such systems. This study aims at monitoring the effectiveness of distributed water supply systems from a relatively long distance, to help reduce the wastage of water and fuel cost, as well as save useful time by carrying out real-time monitoring from a remote location using wireless sensor networks via a LabVIEW-designed user interface. The wireless sensor network system was developed from combinations of nodes which employ varying long-range RF modules deployed at different locations. The system is further enhanced with mesh networking capabilities to increase the communication range and overall reliability of the network. The system report the conditions of the water supply systems for different scenarios and the results are presented. The designed system is competent enough to monitor the water supply systems efficiently and can find application when monitoring water overflow in any environment.*

***Keyword**: automated, distributed, sensor network, water supply, wireless.*

1. INTRODUCTION

Water environment monitoring, as one of the major methods for water resource management and water contamination control, is found to be more and more indispensable [1]. According to [2], there are mainly four methods for monitoring water environments, each of which has its advantages and disadvantages: artificial sampling with portable water quality detecting devices and subsequent lab analysis; automatic and continuous monitoring of water environment parameters by an automatic monitoring system consisting of monitors & control centres, as well as several monitoring sub-stations. Data can be remotely and automatically transferred. Each station provides its real-time water environment parameters. These systems can be costly and have a great influence on the surrounding ecological environment. Water environment monitoring with remote sensing technology, namely detecting the spectrum specifics of an electromagnetic wave (radiation, reflection and scattering) in a non-contacting method with respect to the water body. After the processing of the information from the collection of illustrative spectra, its physics and chemical characteristics are to be identified. However, this method can only provide a low accuracy and it is also hard to perform real-time monitoring. Water quality monitoring technology realized using some sensitivity of aquatic organisms to the presence of poisonous substances in water bodies by measuring or analysing the change of activities of different organisms in different water environments, then coming to a qualitative evaluation report of the water quality. Still, these methods can by no means be expected to reach high accuracy for water environment monitoring [3, 4].

The need to create awareness of the occurrence of an event has been made possible through the use of Wireless Sensor Networks.

A sensor node is a small battery powered device that is capable of processing sensory information and communication with other nodes in the network [5]. The basic component units of a sensor node include: sensor, transceiver, microcontrollers, external memory and power source as shown in Figure 1.

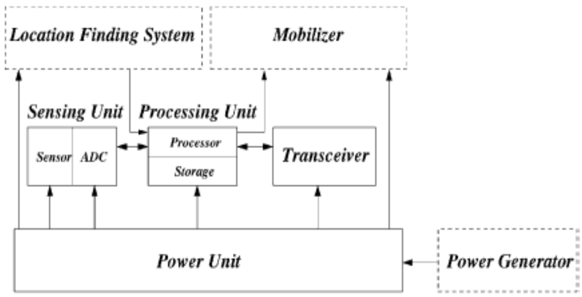


Figure 1: Components of a typical sensor node

1.1. Related Works

A wireless sensor network (WSN) is an ad-hoc network system composed of a great number of tiny low cost and low power consumption sensing nodes which are capable of sensing, calculating and communicating data). It is also an intelligent system, which automatically accomplishes all types of monitoring tasks in accordance with the changing environment. A more advanced approach will be to find a means of making decisions after an event takes place on say, a site. This has led to the development of a long-range WSN for remote decision indicators [6, 7, 8]

Wireless sensor nodes are low-power devices equipped with processor, storage, a power supply, a transceiver, one or more sensors and, in some cases, with an actuator. Several types of sensors can be attached to wireless sensor nodes, such as chemical, optical, thermal and biological. These wireless sensor devices are small and they are cheaper than the regular sensor devices. The wireless sensor devices can automatically organize themselves to form an ad-hoc multi hop network. Wireless sensor networks (WSNs), may be comprised by hundreds or maybe thousands of ad-hoc sensor node devices, working together to accomplish a common task. Self-organizing, self-optimizing and fault-tolerant are the main characteristics of this type of network [4].

A context-aware information system designed to deliver up-to date system information from the main office to the construction site. The objective was to help the user manage the complexity of the construction data by proactively tracking current resource requirements and proactively obtaining access to context-relevant information and services. To achieve this, the system used off-the-shelf handheld computing devices and an on-site wireless network for local communication. This allowed continuous access to data and resources as users moved around the job site. This work highlighted the benefits of context-aware computing for on-site information delivery at a construction site and the need for better communication methods [9].

Sensors are physical devices that produce electrical signals in response to physical changes in the surrounding environment [10]. A special water level sensor could be made by introducing some convenient materials such as iron rod, nozzles, resistor, rubber etc. A connecting rod made by iron and steel which should be connected with ground and we need at least four nozzles which should be connected with +5v via a 1kΩ resistance. We need to bind them together and put a rubber at their joint point which will act as an insulator for every nozzle. When the sensor touches water, nozzles and connecting rod get electric connection using water conductivity [11, 12].

Microcontroller is a self-contained system with peripherals, memory and a processor that can be used as an embedded system. It is a computer on a chip that is programmed to perform almost any control, sequencing, monitoring and display the function. Because of its relatively low cost, it becomes the natural choice to the designer. Microcontroller is designed to be all of that in one. Its great advantage is no other external components are needed for its application because all necessary peripherals are already built into it. Thus, we can save the time, space and cost which is needed to construct low cost devices. The microcontroller executes instructions, processes data and controls the correct operation of other peripheral devices in the sensor node [13, 14].

Transceiver is where the data communication and networking takes place. Transceivers can operate in three modes; transmit mode, receive mode and sleep mode. Most of the power consumption in the sensor node is during data transmission. The possible choices of transmission medium are radio frequency (RF), optical communication (laser) and infrared. Lasers have low power consumption, but need line-of-sight for communication and are sensitive to atmospheric conditions. Infrared, like lasers, needs no antenna but it is limited in its broadcasting capacity. Radio frequency based communication is the most widely used communication medium in wireless sensor network applications. Wireless sensor networks tend to use license-free communication frequencies: 173, 433, 868, 915 MHz and 2.4 GHz. Transceivers operating in the idle mode have power consumption similar to receive mode; therefore it is best to completely shut down the transceiver when not in use rather than leave it in idle mode. Most of the transceivers today have built in state machines that make transitions between operation states automatic [15].

Most of the sensor nodes rely on on-chip memory inside the microcontroller due to energy concerns. The most popular external memories used are flash and EEPROM due to their low cost and storage capacity. Off-chip RAM is rarely if ever used. Memory requirement of a sensor node is entirely application dependent. Memories are used for two purposes: storing application related or personal data and program memory used for programming the sensor node. In a sensor node, power is consumed for sensing, data processing and communication. Most of the power is consumed in data communication. The most popular power sources used in sensor nodes are rechargeable batteries. Recently solar panels are being used with rechargeable batteries to eliminate the need for replacing batteries. The development and deployment of WSNs have taken traditional network topologies in new directions. Different WSNs are Bus, Tree, Star, Ring, Mesh, Circular and Grid [16, 17]. Establishing a real-time continuous flow of sensor data on a stable wireless communications link will enable real-time monitoring of constructed and under-construction infrastructure projects. Many state-of-the-art sensors can work seamlessly with wireless technology since outdoor construction site conditions rarely permit the use of sensitive electronic cables [18, 19].

2. METHODOLOGY

An automated water supply system functions to switch ON when the water is unavailable and turns OFF when water is full, with no human intervention. A WSN monitoring system is therefore developed and integrated to supervise whether the automated water supply system functions effectively. The system comprises of: sensor nodes (end devices), a sink node (access point), a network integrating the sensor nodes and the

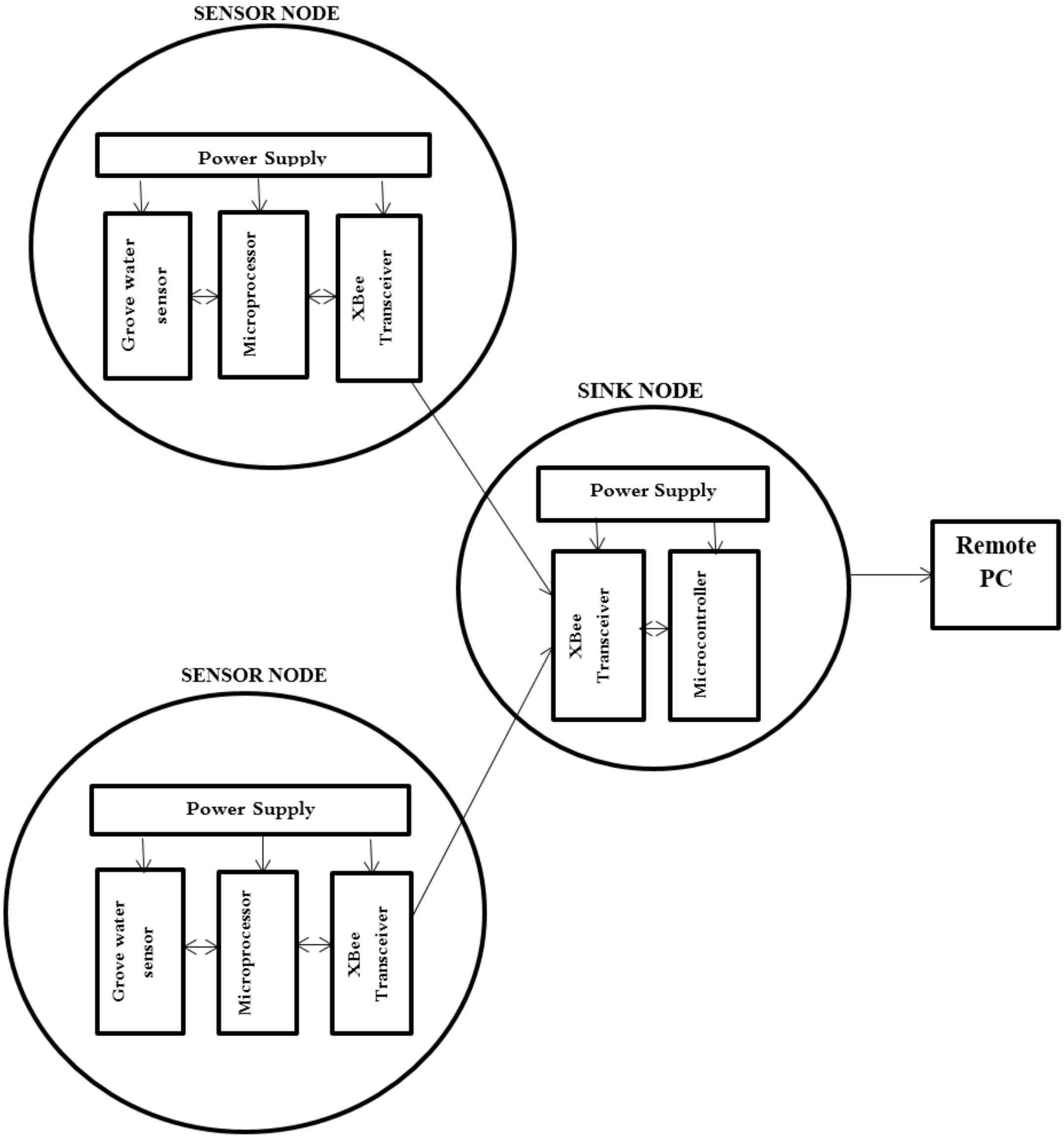


Figure 2: Block diagram of the Wireless Sensor Network

sink node, and a data collection user interface. The block diagram of the system is as illustrated in Figure 2.

2.1 Wireless Sensor Network System

The system consists of two sensor nodes, with capability for more, each located at different automated water supply systems locations. Each sensor node contains two grove water sensors. The first sensor is to detect an overflow at the edge of the reservoir, while the second sensor is to detect the unavailability of water at the base ebb. Both sensor nodes were networked together with the sink node in a modified mesh topology through RF link by their respective transceivers (the unit responsible for either low range or long range of data communication). Data is therefore acquired from the sink node through the USB port of a personal computer. The system is designed and implemented from a combination of hardware and software component units.

1) Hardware Design: The hardware unit involves the integration of various components which have been properly selected. The sensor nodes and the sink node were designed to achieve optimal performance in the system.

Sensor nodes: The sensor nodes of an external sensor for detecting water presence, a microprocessor for analyzing and generating data signal, memory for storage of data, radio frequency transceiver for transmitting and receiving of data and a power supply. The block diagram of the sensor node is as shown in Figure 3.

Various sensors were considered for water presence detection: grove water sensors, ultrasonic sensors, capacitance level sensors, pressure level sensors. For this work, the grove water sensor was selected based on its comparative advantages. The sensor detects the presence of water using exposed PCB traces. The sensor is made up of interlaced traces of ground and sensor signals. Its traces have a weak pull-up resistor of 1MΩ. The resistor will pull the sensor trace value high until a drop of water shorts the sensor trace to the grounded trace. It has the advantages of low power consumption and high sensitivity. Table 1 shows the specifications of the sensor.

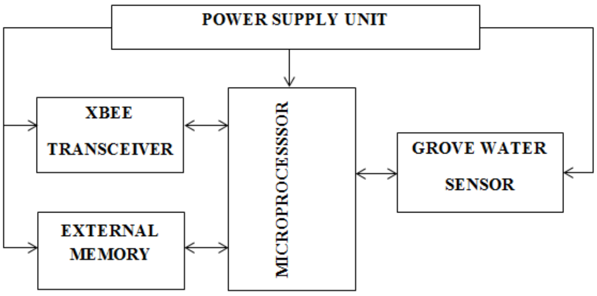


Figure 3: Block diagram of the sensor node

The sensor nodes also consists of XBee Digimesh 2.4 radio frequency module-XBee and XBee-PRO DigiMesh 2.4 embedded RF modules. The transceivers utilize the peer-to-peer DigiMesh protocol in 2.4GHz for global deployments. This innovative mesh protocol offers users added network stability through self-healing, self-discovery, and dense network operation. With support for sleeping routers, DigiMesh is ideal for power sensitive applications relying upon batteries or power harvesting technology for power. The XBee/XBee-PRO DigiMesh 2.4 supports the unique needs of low-cost, low-power, wireless sensor networks. The devices require minimal power and provide reliable data delivery between remote devices. These devices support routing table sizes of 32 nodes.

Table 1: Specifications of the Grove Water Sensor

Items	**Min**	**Typical**	**Max**	**Unit**
Working Voltage	4.75	5.0	5.25	V
Current	<20	<20	<20	mA
Working Temperature	10	-	30	℃
Working Humidity (without condensation)	10	-	90	%

Networks larger than this send a route discovery before each transmission. For larger networks this can be bandwidth expensive, so it offers RF optimization services to help properly configure a network. The transceivers are connected through the XBee Carrier. The specifications of the two range-variant XBee modules are shown in Tables 2,3 and 4.

Table 2: Performance specification of the XBee modules

Specification	**XBee DigiMesh**	**XBee-PRO DigiMesh**
Indoor/urban range	Up to 100 ft (30 m)	Up to 300 ft (90 m) standard or up to 200 ft (60 m) international variant
Outdoor RF line of sight range	Up to 300 ft (90 m)	Up to 1 mile (1.5 km), with a 2.0 dB dipole antenna. Up to 6 miles (10 km) with a high gain antenna.
Transmit power Output	1mW (0 dBm)	63 mW (18 dBm) standard or 10 mW (10 dBm) for the international variant
RF data rate	250 kb/s	250 kb/s
Receiver Sensitivity	-92 dBm	-100 dBm
Serial interface data rate (software selectable)	1200 bps - 250 kb/s (devices also support non-standard baud rates)	1200 bps - 250 kb/s (devices also support non-standard baud rates)

Table 3: Power requirements of the XBee modules

Specification	**XBee DigiMesh**	**XBee-PRO DigiMesh**
Supply voltage	2.8 – 3.4 VDC	2.8 - 3.4 VDC
Transmit current	45 mA (@ 3.3 V)	250 mA (@ 3.3 V)
Idle/receive current	50 mA (@ 3.3 V)	55 mA (@ 3.3V)
Power down current (pin sleep)	< 10 µA	< 10 µA
Power down current (cyclic sleep)	< 50 µA	< 50 µA

Table 4: Network and security specifications

Specification	XBee DigiMesh	XBee-PRO Digimesh
Supported network topologies	Mesh, point-to-point, point-to-multipoint, peer-to-peer	Mesh, point-to-point, point-to-multipoint, peer-to-peer
Number of channels (software selectable)	16 direct sequence channels	12 direct sequence channels
Addressing options	PAN ID, channel and 64-bit Addresses	PAN ID, channel and 64-bit Addresses

Sink node: The sink node is also referred to as the access point (AP). This is the node which has direct connection to the personal computer. This node acts as a medium between the sensor nodes and the GUI, data from the sensor nodes are transferred through this node to the interface. The sink node comprises of the same components as in the sensor node except for the use of a sensor. Also, there is a difference in the configuration of the XBee transceiver modules. The internal block diagram of the sink node is as shown in Figure 4.

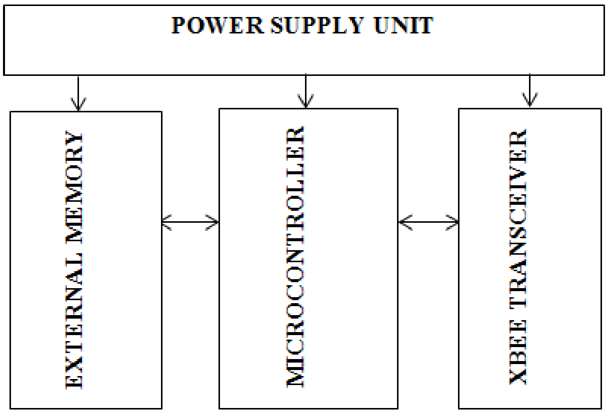


Figure 4: Block diagram showing Sink node

The sink node consists of the Arduino UNO board. Some features of the Arduino UNO board include: It is a microcontroller board based on the ATmega328P. The ATmega328P on the Arduino/Genuino UNO comes preprogrammed with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. Arduino UNO has resettable polyfuse that protects your computers USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed. The Arduino/Genuino UNO board can be powered via the USB connection or with an external power supply.

Unlike the sensor nodes that are powered by a lithium battery, the Sink node is powered by the personal computer which it is connected to. The sink node located remotely consists of XBee DigiMesh 2.4 radio module in connection with XBee Carriers mounted on an Arduino UNO microcontroller. An alert system (a buzzer) was connected to the node in order to create awareness and inform the operator of a particular occurrence. The sink node was programmed to communicate the collected data to a personal computer through the use of a Graphical User Interface (GUI).

2) Software design

Node configuration: Configuration of the nodes is done using the X-CTU software; this enables communication between the PC and the XBee modules. Figures 5 and 6 shows the flow charts for the sensor and sink nodes respectively.

Configuration as the coordinator using X-CTU: Once the PC is able to communicate with the XBee module in the sink node, click the Modem Configuration tab. In order to read the module's current configuration, press the Read button. It is desirable to set a specific PAN ID number to differentiate the network from any other. This option exists under the Networking section of the configuration pane. The same PAN ID number will be needed to set the End devices so that it joins the Coordinator's network. The Serial Number High and Serial Number Low are located within the parenthesis preceding the option name and is not user configurable. The Node Identifier option was set to COORDINATOR; this is a user configurable text name that a user can set to easily identify a module. The Changes made were written to the module by checking the 'Always update firmware' check box and clicking the Write Button. Checking the box ensures that the X-CTU utility will write the new firmware to the XBee. Once the write process is completed successfully, click the Read Button to get the module's current settings.

Configuration as the End device: The XBee module used in the sensor node was inserted for configuration, using the X-CTU utility, click on the Read button to read the module's current configuration. The PAN ID of each end device was set to match that entered into the Coordinator. Both the ED's Destination High and Low Address were changed to the Coordinator's High and Low address respectively. It was recommended that the end device be given a name for identification; this was done by changing the Node Identifier field to ROUTER. The 'Always update firmware' check box was checked to update the XBee module's firmware and the Write button clicked to write changes to the module. Once the write process was completed, the 'Read' button was clicked to verify the programmed settings.

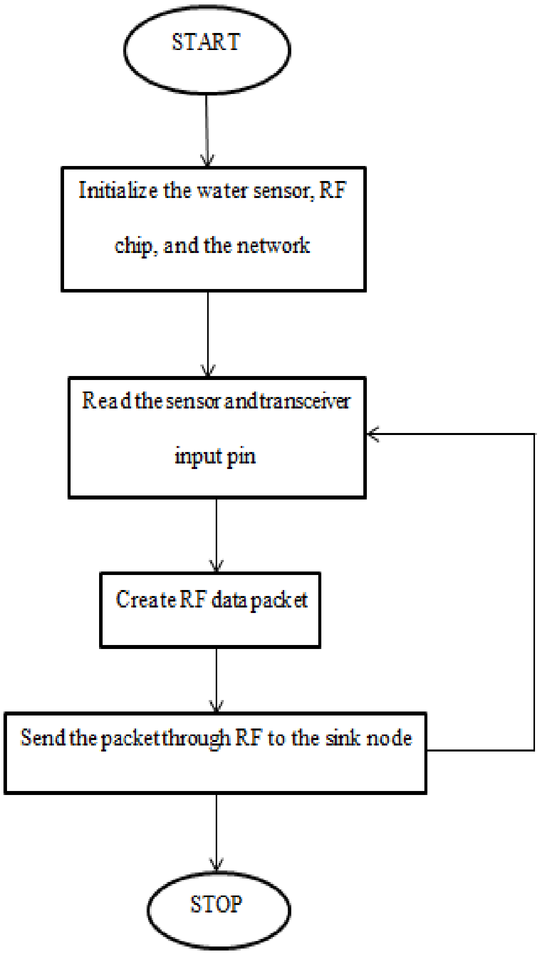


Figure 5: Flow chart of sensor node configuration

Network design: The network uses a Tree-Mesh topology. The advantage of using this topology is that it allows data to be routed through several nodes to a final destination but for this system only data will be routed through only two nodes before getting to the access point. The Tree-Mesh adapts DigiMesh protocol. It sets an entirely distributed network with all nodes using peer-to-peer connection among themselves. In this configuration, besides each node capturing and disseminating its own data, it also serves in relaying data for the other node. Each node collaborates to propagate the data in the network.

User interface design: The graphical user interface was designed using Laboratory Virtual Instrument Engineering Workbench (LabVIEW) and XBee Configuration and Test Utility (X-CTU) softwares.

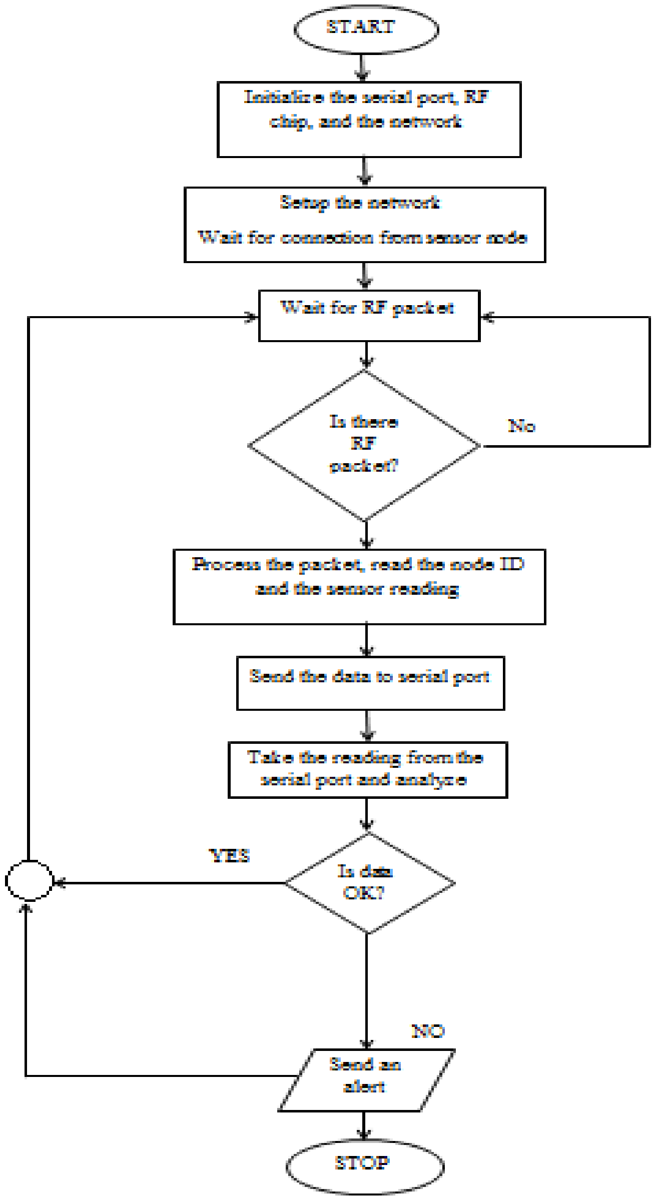


Figure 6: Flow chart of sink node configuration

LabVIEW is a system-design platform and development environment for a visual programming language from National Instruments (NI). X-CTU is a multi-platform program that enables users to interact with radio frequency (RF) devices through a graphical interface. The application includes built-in tools that make it easy to set up, configure, and test Digi RF devices. The block diagram for the graphical user interface is as shown in Figure 7.

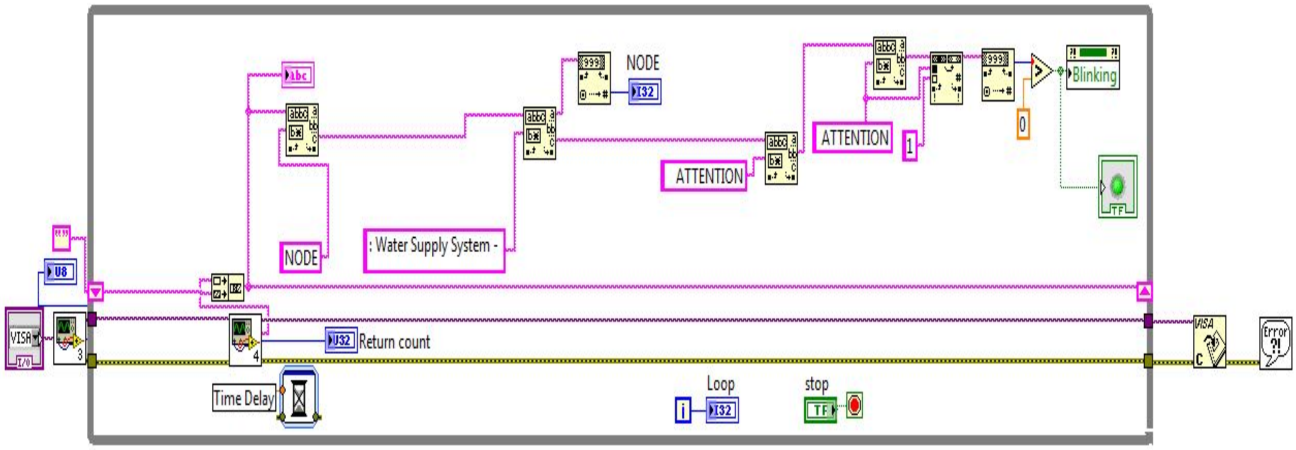
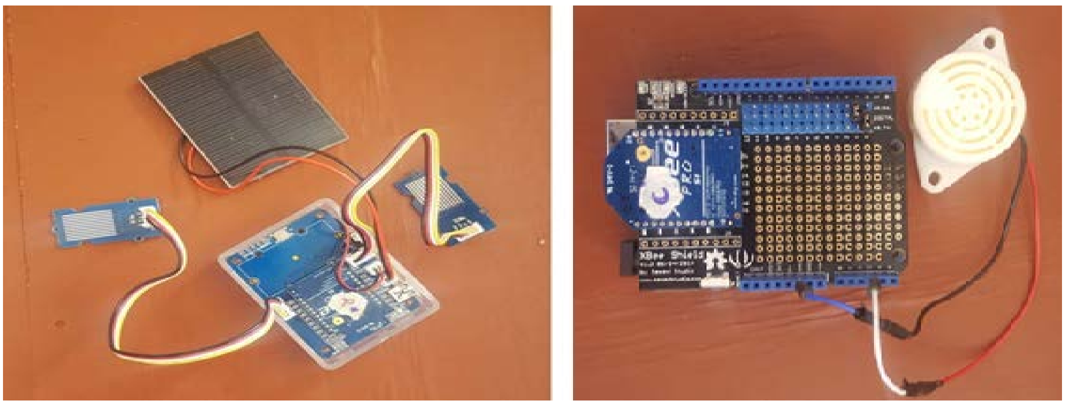


Figure 7: Block Diagram of the User Interface

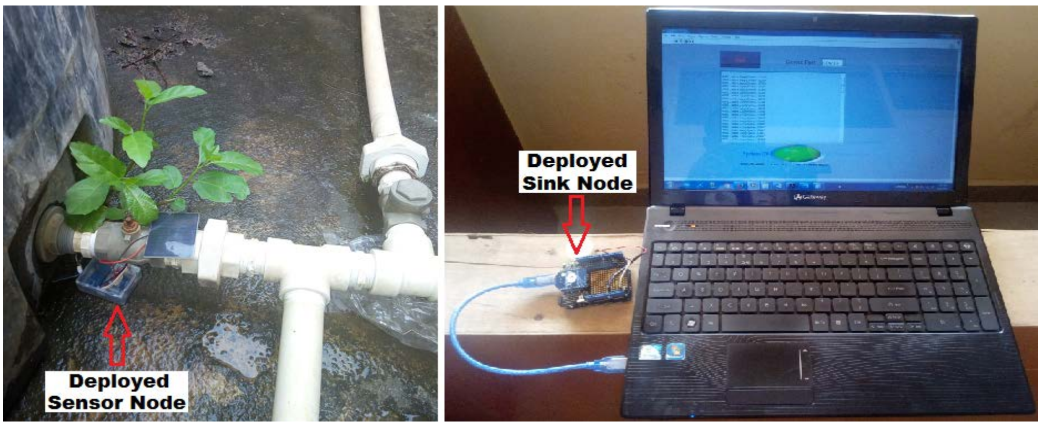
3. RESULTS AND DISCUSSION

The wireless sensor network system resulted from various hardware and software units being integrated together. The pictorial views of the sensor and sink nodes are as shown in Figure 8. A solar panel is connected to each lithium battery in the sensor nodes for the purpose of charging the batteries. This ensures real-time monitoring and all time data-availability. The deployed sensor nodes and sink nodes are as shown in Figure 9.



(a) (b)

Figure 8: The network nodes: (a) a sensor node components, (b) sink node



(a) (b)

Figure 9: The deployed nodes: (a) a deployed sensor node, (b) the sink node and data collector

The transceiver module in each sensor node depends on the relative range of coverage designed for the node. Node 1 contains XBee PRO module for longer range, while the Node 2 contains low-range XBee module. The range of actual data transmission by the two nodes are as shown in Table 5. The output results of the condition monitoring of the water supply system are as shown in Figures 8 and 9. In Figure 8, the output indicates that the two water supply systems are functioning very well, while Figure 9 indicates that attention was needed at system 1 at a particular point in time. Upon the rectification of the fault at system 1, the system continued to function well.

Table 5: Result of the range of actual data transmission by the nodes

Specification	Sensor Node 1	Sensor Node 2
Indoor/urban range	26 m	84 m
Outdoor RF line of sight range	81 m	955 m

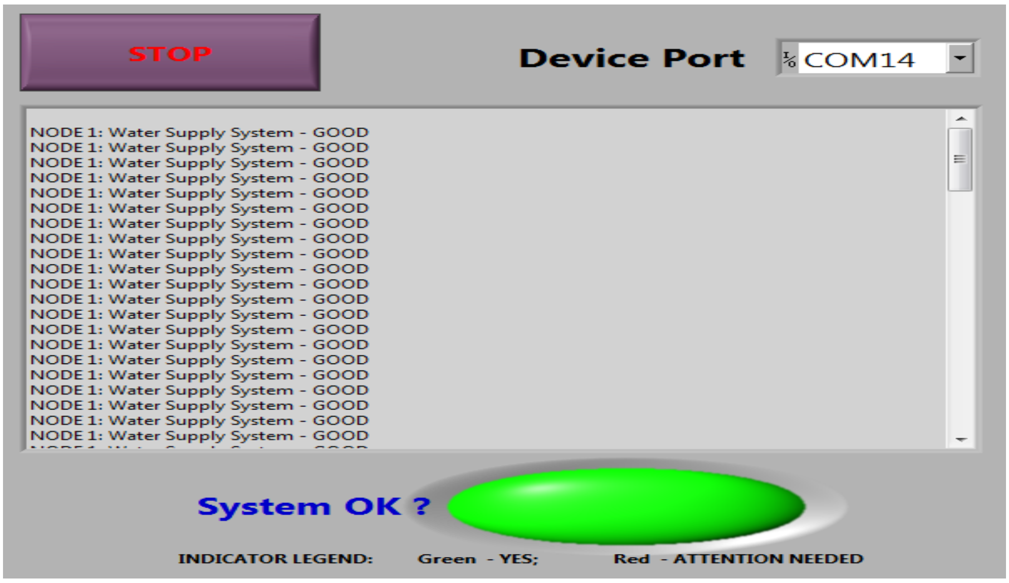


Figure 9: Sensor not in contact with water

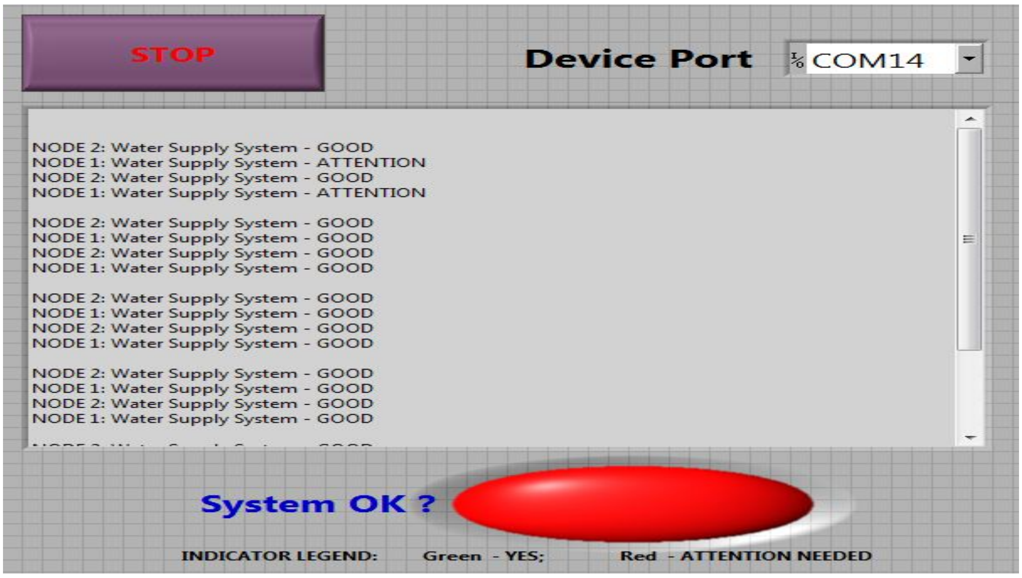


Figure 10: Sensor in contact with water

4. CONCLUSIONS

A wireless sensor network system has been developed to monitor an automated distributed water supply scheme. The system has proven to be a very reliable, easy, safe and efficient way of monitoring water supply system at different locations in real-time over relatively long distances. The system has a composite units which include Arduino microcontroller, XBee and XBee pro transceivers with data rate of 250 kb/s. It implements the wireless network using DigiMesh modules because of its efficiency and low power consumption. The designed system can find application in homes, industries, and farmlands thereby ensuring low power consumption, prevention of water wastage, reduced cost, and time saving. It can also be deployed in any area where overflow is being monitored such as a swimming pool, and environment prone to flooding.

REFERENCES

[1] Tubaishat, M., & Madria, S. (2003). Sensor networks: an overview. *IEEE potentials*, vol. 22(2), pp. 20-23.

[2] Jiang, P., Xia, H., He, Z., & Wang, Z. (2009). Design of a water environment monitoring system based on wireless sensor networks. *Sensors*, vol. 9(8), pp. 6411-6434.

[3] Baronti, P., Pillai, P., Chook, V. W., Chessa, S., Gotta, A., & Hu, Y. F. (2007). Wireless sensor networks: A survey on the state of the art and the 802.15. 4 and ZigBee standards. *Computer communications*, vol. 30(7), pp. 1655-1695.

[4] Akyildiz, I. F., Su, W., Sankarasubramaniam, Y., & Cayirci, E. (2002). A survey on sensor networks. *IEEE Communications magazine*, vol. *40*(8), pp. 102-114.

[5] Ko, J., Lu, C., Srivastava, M. B., Stankovic, J. A., Terzis, A., & Welsh, M. (2010). Wireless sensor networks for healthcare. *Proceedings of the IEEE*, vol. 98(11), pp. 1947-1960.

[6] Chen, J., Cao, X., Cheng, P., Xiao, Y., & Sun, Y. (2010). Distributed collaborative control for industrial automation with wireless sensor and actuator networks. *IEEE Transactions on Industrial Electronics*, vol. 57(12), pp. 4219-4230.

[7] Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R., & Anderson, J. (2002). Wireless sensor networks for habitat monitoring. In *Proceedings of the 1st ACM international workshop on Wireless sensor networks and applications*, p. 88-97.

[8] Hammoshi, M. and Sayed, A. (2014). An analysis for a cluster tree zigbee topology, *Journal of Theoretical and Applied Information Technology*, vol. 64(3), pp. 674 - 680.

[9] Carbonari, A., Giretti, A., & Naticchia, B. (2011). A proactive system for real-time safety management in construction sites. *Automation in Construction*, vol. *20*(6), pp. 686-698.

[10] WhatIs.com. [Online]. (2017). Available: *http://whatis.techtarget.com/definition/sensor.* Date Accessed: 17th august, 2017

[11] Das, S., Dhar, S., Deb, P. B., Biswas, D., & Majumdar, P. S. (2017). Microcontroller Based Water Level Indicator and Controller. *Asian Journal of Applied Science and Technology (AJAST)*, vol. 1(5), pp. 181-182.

[12] Reza, S. K., Tariq, S. A. M., & Reza, S. M. (2010). Microcontroller based automated water level sensing and controlling: design and implementation issue. In *Proceedings of the World Congress on Engineering and Computer Science*, vol. 1, pp. 20-22.

[13] Ward, M., Thorpe, T., Price, A., & Wren, C. (2004). Implementation and control of wireless data collection on construction sites. *Journal of Information Technology in Construction (ITCon)*, vol. 9(21), pp. 297-311.

[14] Mazidi, M. A., Mckinlay, R. D., Causey, D., & Microcontroller, P. I. C. (2009). Embedded Systems. *New Delhi, Personal Education*.

[15] Cummins, J. D., Thomson, B. E., Kern, W. F., & Dinh, D. X. (2001). *U.S. Patent No. 6,278,864*. Washington, DC: U.S. Patent and Trademark Office

[16] Sfendourakis, M., Nilavalan, R., & Antonidakis, E. (2016). Sensors Networks-Localization and Topology. In *Mathematics and Computers in Sciences and in Industry (MCSI), 2016 Third International Conference* IEEE, p. 143-154.

[17] Chen, C. W., Wang, Y., & Kostanic, I. (2005). A chain-type wireless sensor network for monitoring long range infrastructures. In *Sensors, and Command, Control, Communications, and Intelligence (C3I) Technologies for Homeland Security and Homeland Defense IV*, vol. 5778, pp. 444-456.

[18] Brilakis, I. K. (2007). Long-distance wireless networking for site office data communications. *Journal of Information Technology in Construction (ITCON)*, vol. 2(9), pp. 151-164.

[19] Onibonoje, M. O., Jubril, A. M. and Owolarafe, O. K. (2012). Determination of Bulk Grains Moisture Content in a Silo Using Distributed System of Sensor Network. *Ife Journal of Technology*. vol.8, pp. 55-59.