COBEM UBERLÂNDIA 2019

ABCM Associação Brasileira de Engenharia e Ciências Mecânicas

25th ABCM International Congress of Mechanical Engineering
October 20-25, 2019, Uberlândia, MG, Brazil

COB-2019-1410
MESH NETWORK COMMUNICATION USING ZIGBEE STANDARD

Arif Martins Sírio
Frederico Duarte Fagundes
Jalmira Regina Fiuza de Sousa
Automation and Control Laboratory, CEFET-MG, Araxá, Minas Gerais, Brazil
arifmsirio@gmail.com, fredericofagundes@cefetmg.br, jalfiuza137@gmail.com
Artur de Almeida Rios
Darizon Alves de Andrade
Electric Drives Laboratory (LACE), Federal University of Uberlandia (UFU), Uberlândia, Minas Gerais, Brazil
arturios.tec@gmail.com, darizon@ufu.br

Abstract. *This paper intends to address technical and practical aspects of the mesh network. The mesh network works as a multi-hop wireless or wired communication network, where all the nodes have links between them. This feature allows nodes to connect with any other point, keeping a network with optimum levels of reception and data transferring at all points. In this work the ZigBee wireless standard was used for the mesh network, through the XBee Pro S2 wireless communication modules, manufactured by Digi International®. These modules are capable of serial, digital and analog communication, allowing to interconnect sensors, actuators, converters and transducers, among other devices. The work involved the mesh network formation with range and rediscovery tests, the use of a specific analysis and configuration software and remote sensing and command tests. Through these tests it was possible to verify that the mesh network is, indeed, a reliable form of communication. The work also can be used as guide to form a wireless mesh network between sensors and actuators, using the input and output ports of the ZigBee modules.*

Keywords: *Sensors and Actuators, Mesh Network, ZigBee, Control Systems*

1. INTRODUCTION

Telecommunication is the transmission of messages and data at a distance through electric signals, electromagnetic waves, luminous pulses, among others. The flow of long distance communication is responsible for a considerable circulation of information, being a varied mechanism that uses several technologies. Industrial networks are telecommunication systems applied on machines and equipment for process control. There are many network types, with different communication protocols, patterns and topologies (such as mesh) (Sen, 2014; Lugli and Santos, 2014).

The mesh network is composed of nodes that behave as a large multi-link communication network. These nodes can be Network Coordinators, Routers and End Devices. To form a complete mesh network each node must have links with all other nodes, which brings great communication reliability and efficiency and can mask network temporary failures. The data packets can be transmitted from one node to the other, by different routes, taking into account the best route possible (IEEE, 2011; Ramos, 2012; Sen, 2014).

ZigBee is a wireless communication standard that uses mesh network topology. It has great applicability and presents low implementation cost and system maintenance. It is also easy to expand and its modules consumes less energy than other wireless communication standards, such as Bluetooth and WiFi (ZigBee Alliance, 2012; Ramos, 2012; Farahani, 2011).

In this paper, the main goal was to address the technical aspects of the ZigBee mesh network. The work included analysis of the dynamic routing of a ZigBee mesh network and the use of remote ZigBee modules to form a wireless sensor and actuator network.

2. RELATED WORK

The use of ZigBee mesh networks is well diffused in the most diverse fields. Thereafter, a considerable number of papers analyzing technical aspects of the network and / or presenting innovative applications were published. In this section a few of these related papers will be discussed.

All ZigBee mesh networks must have a coordinator and more than one router. The router is a device that can forward messages and, with the coordinator, is responsible for establishing the communication routes. The coordinator is a full function device responsible for starting the network, associating and disassociating devices, among other key functions for maintaining a reliable network (ZigBee Alliance, 2012). Hussein and Samara (2015) studied the interference of the positioning choice of the coordinator in ZigBee mesh networks. The conclusion was that the coordinator in a central position, compared to the dynamic allocation and the allocation in an extreme point of the network, not only makes the communication more efficient and reliable, but also reduces the energy consumption of the routers. With central positioning, the coordinator and routers could find the shortest route faster, saving energy and data transmission during the routing process.

ZigBee uses the Hierarchical Routing Protocol (HRP) in conjunction with the Ad-hoc On-demand Distance Vector (AODV). The HRP works with a parent-child hierarchy in which End Devices are necessarily related to a Router or a Coordinator. The role of AODV is to make route requests, which are broadcast and consumes a considerable amount of data (ZigBee Alliance, 2012). Ha *et al.* (2007) proposed an Enhanced HRP (EHRP), which reduced the time to discover routes and to establish communication between nodes. This was made possible by using a better neighbor-node analysis, instead of only the parent-child association in HRP. The authors said that it was like taking shortcuts to find a better route more efficiently.

Related publications are also available for comparison with other mesh technologies, such as the work of Cervenka *et al.* (2014). LWM or LightWeight Mesh is a standard released in 2012 that also uses the AODV protocol. LWM does not have a central coordinating node and does not use parent-child hierarchy between nodes. Comparing LWM and ZigBee mesh performance over data throughput, LWM achieved higher rates. The difference was bigger when both applications used data encryption. As for the network rediscovery (when a node drops off the network and then is accessible again), there was a shorter latency time in the LWM, but the ZigBee was more efficient in the amount of data needed to reestablish the communication. The authors conclude that LWM may be a more suitable solution in applications where high data throughput is an important criterion, but ZigBee provides greater applicability, stability, and interoperability by being more consolidated and accessible.

As for ZigBee mesh network applications, one can cite the use in medicine, as in Du *et al.* (2011). The technology was used to monitor patients' blood pressure. The developed system monitors and stores the sensors' data in a medical record system. It is also possible to configure the system to send alarm situations, such as unusual blood pressure, to relatives and clinicians. The system is shown in Fig. 1.

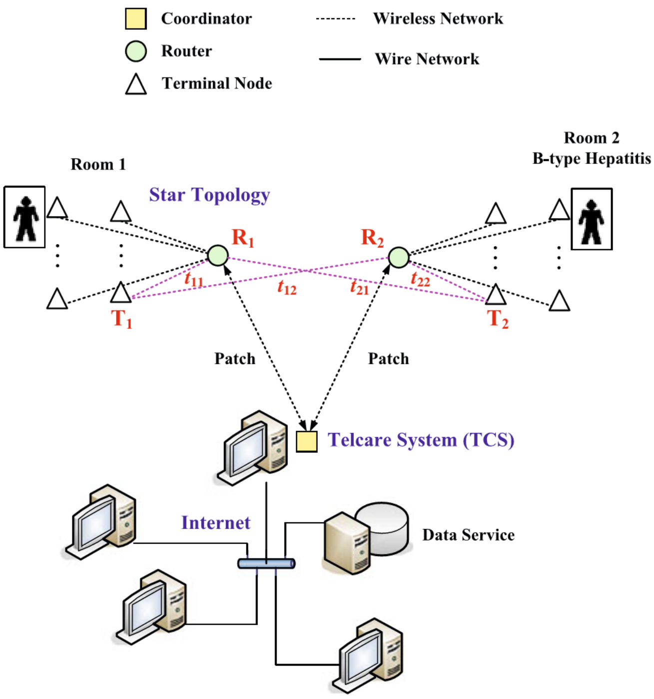

Figure 1. Schematic diagram of the system structure
Source: Du *et al.* (2011)

The use of ZigBee in home automation (domotics) is also common. Gill *et al.* (2009) brings an application where ZigBee devices are connected to a Wi-Fi gateway, providing interoperability and ease of access. The authors didn't noticed negative impacts caused by the co-existence of Wi-Fi and ZigBee networks. For home comfort and convenience, Gutierrez *et al.* (2018) developed a prototype for curtain control through ZigBee communication. Garroppo *et al.* (2016) shows that technologies such as SIPHG (Session Initiation Protocol Home Gateway), ZigBee and Bluetooth can be integrated to create a easy to use home automation system.

Other ZigBee application is in the monitoring and control of industrial didactic plants (Fagundes *et al.*, 2016). The plants had no communication between them, only a serial RS-232 channel with a dedicated workstation for monitoring and control. The work involved the signal processing for converting RS-232 into ZigBee standard and the establishment of a previously non-existent network among the control plants of level, flow and temperature. The conversion system is shown in Fig. 2. It is important to notice that the ZigBee module had no directly communication with the transmitters and actuators of the plants, but it captured the serial signals containing those data.

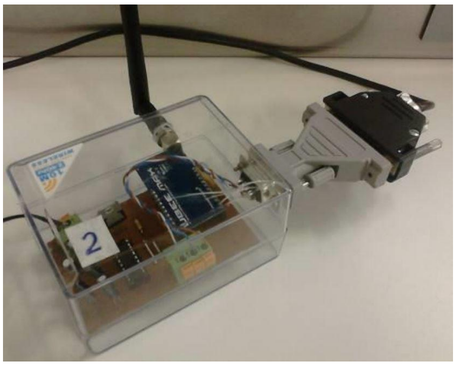

Figure 2. Communication module connected to the plant RS-232 serial port
Source: Fagundes *et al.* (2016)

3. METHODS

This application used XBee Pro S2 modules, by Digi International®, as network nodes; a notebook with an Intel ® i5 1.7 GHz processor and 6GB memory; network manager software Digi XCTU, by Digi International®; and an XBee USB adapter to connect the XBee module to the notebook. Figure 3 shows the schematic diagram of the network formed by the modules, notebook and adapter. This arrangement was used in all tests, only adding or removing routers as required by the test. There were no adaptations for signal improvement, so the tests can be verified with factory restrictions.

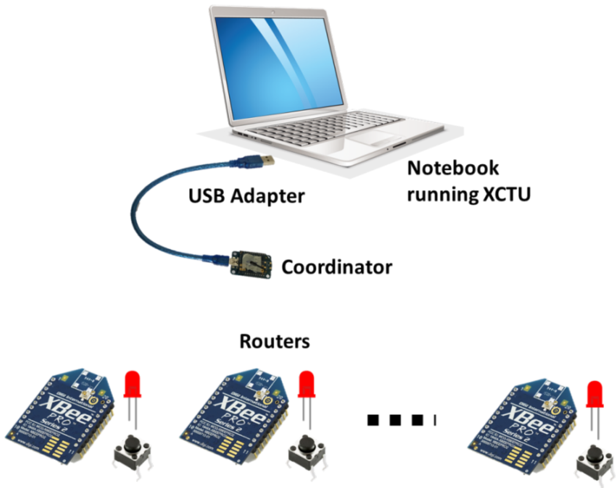

Figure 3. Schematic diagram of the network

3.1 Range test

Radio Range Test is XCTU software tool that verifies the connection quality between two modules (Digi International Inc., 2018b). To perform the range test a local module, configured as a network coordinator, was connected to the notebook and a remote module was configured as a router (Router 1). The tool sends data to the remote module and waits for acknowledgments. Then it calculates the received data ratio and the detected remote signal strength. The range test involved reallocating Router 1 until the communication was interrupted.

Next, another router (Router 2) was configured and powered down. The same range test conditions were repeated, until the communication loss between coordinator and Router 1. Then the Router 2 was powered on and positioned between the others. This test aimed to show dynamic reconfiguration and masking of link faults by alternate routing.

3.2 Mesh Network Test

The next test involved setting up a mesh network with 7 devices. For a complete mesh network six devices had to be configured as routers and one as coordinator. The XCTU software graphically displays the network topology and the connection quality through color coding (red connection is a weak connection, blue is strong and green is stronger). A red device indicates that is temporarily unavailable or with limited communication (Digi International Inc., 2018b).

3.3 Use of Modules for Sensing and Remote Control

The XBee Pro S2 devices have eight terminals that can be configured as digital inputs or outputs (ADx/DIOx), seven of them can also be configured as analog inputs, as shown in Fig. 4 (Digi International Inc., 2018c) (the XBee Pro and XBee Pro S2 pinouts are the same). These terminals allow modules to function as remote controllers and sensing units.

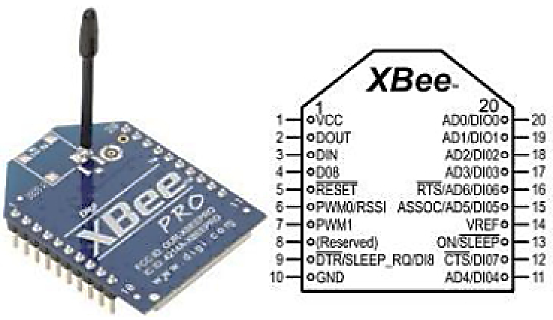

Figure 4. XBee Pro pinout

The first four pins (AD0/DIO0 to AD3/DIO3) of the remote routers were configured as Digital Inputs. The configured pins were connected arbitrarily either to the negative terminal of the source voltage or to the positive, representing low and high logic states, respectively. The coordinating module is responsible for requesting the information from the remote modules. For this, the XCTU software has a tool to generate frames, which helps the user to configure protocol, frame type, destination and command options. Figure 5 shows the frame generator tool (the MAC address to send a broadcast frame and the code to sample all inputs (AT Command IS) are highlighted) (Digi International Inc., 2018a).

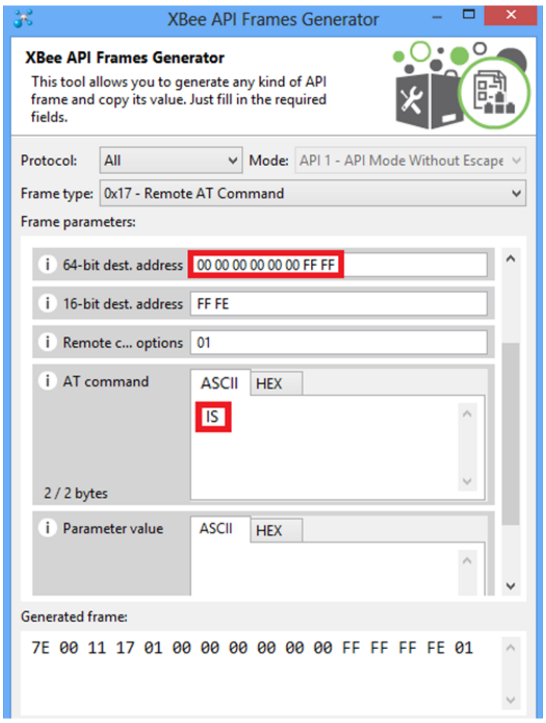

Figure 5. Frame generation tool used for remote input sampling

Some of the pins were configured as digital outputs. To verify the remote commands LEDs were connected to these pins as seen in Fig. 6.

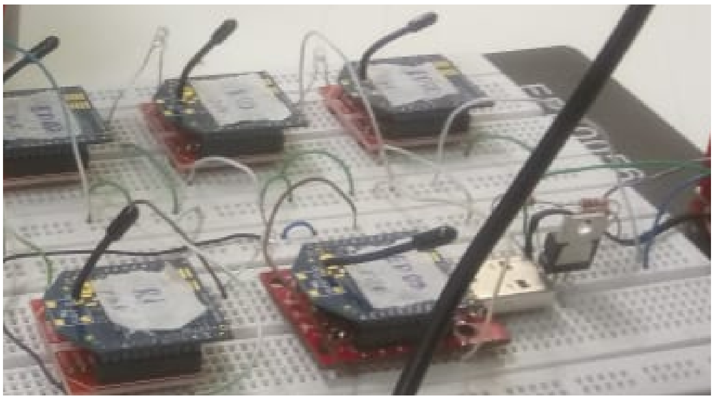

Figure 6. Breadboard with the remote modules and the connected LEDs

The command frame must be composed of an indication of both the pin and the logic level. Figure 7 shows a command frame to turn off the terminal one of the remote devices (broadcast message with AT Command D1 (terminal 1) and Parameter Value 04 (low logic level)) (Digi International Inc., 2017).

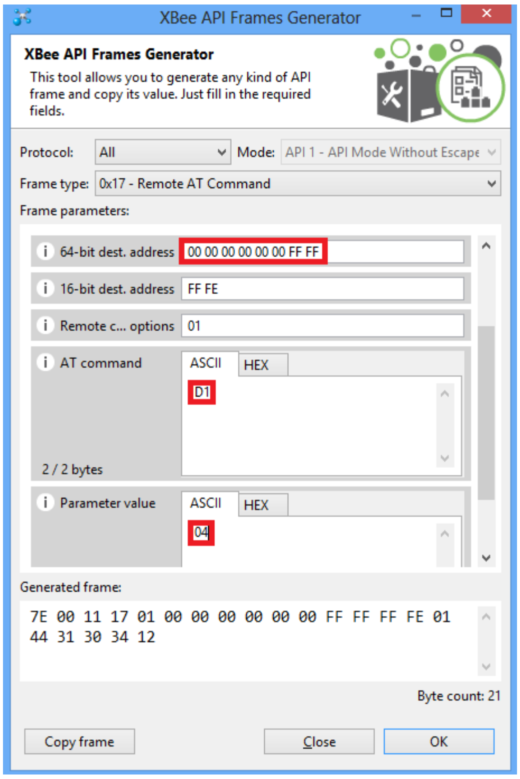

Figure 7. Frame for turning off remote digital output

The AD1/DIO1 pin of one of the modules was configured as an analog input. The inputs of the XBee Pro S2 module receive voltage signals from 0 to 1.33 Volts (Digi International Inc., 2018c). For this test a variable voltage source was connected to the aforementioned pin and the coordinator module performed the remote reading.

4. RESULTS

For the Radio Range Test, total loss of communication happened with 20 meters and obstacles between the modules. After the addition of Router 2, the connection was reestablished. Figure 8 shows the software screen at that moment.

During the mesh network test with seven devices, module shutdowns and removals were performed and network reconfiguration was shown as effective. Shutdown modules still appeared in the network (with the indication of no connection), since the other modules kept their information and recognized them as soon as the reclosing was done. During network recognition, the topology initially adopted could sometimes be star, bus or tree. But as soon as the devices discovered the links, the mesh network was formed. The XCTU screen displaying the topology and connection quality is seen in Fig. 9.

Figure 8. Radio Range Test showing the connection reestablishment

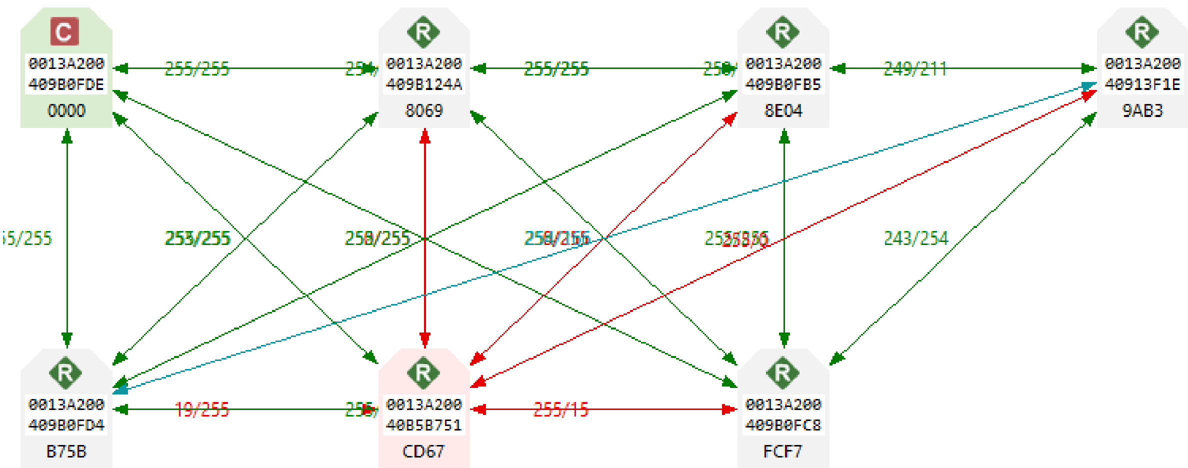

Figure 9. XCTU screen showing the mesh network and connection quality

In the inputs and outputs tests, it was verified that the modules can be used for remote sensing and control. The digital read can be used to receive data from presence and position sensors, level switches, thermostats, among many other devices. The response of the remote modules is shown on the right side of the software screen, as seen in the example in Fig. 10.

Remote commands were also performed and the LEDs were turned on or off accordingly. For analog reading, however, the XCTU software did not display the value of outputs ranging from 0 to 100% or voltage levels, but as a four-digit hexadecimal code. Equipment such as distance meters, level probes, and temperature sensors that are connected to an analog input of an XBee Pro S2 module will have their data displayed as such. The values are embedded in the response message and can be seen highlighted in Fig. 11. The analog read ranges from 0000 to 03FF (0 to 1023 in decimal values), representing the 10-bit analog conversion of values from 0 to 1.33V.

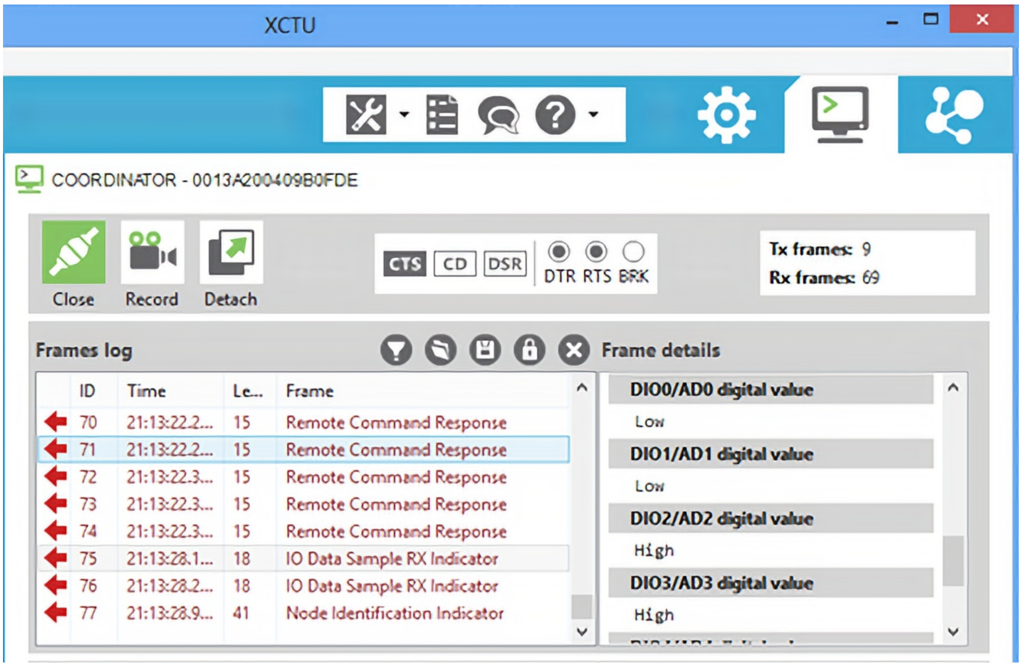

Figure 10. XBee remote module response with digital values

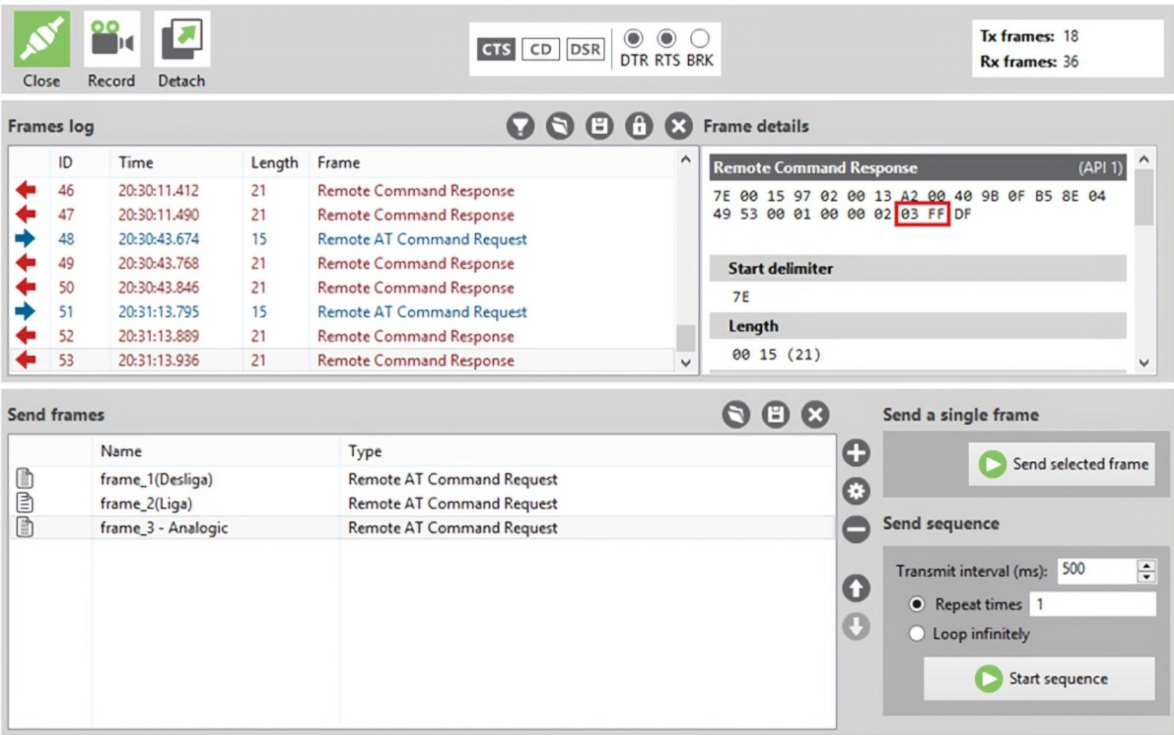

Figure 11. Remote module response showing the hexadecimal value equivalent to the analog input value

5. CONCLUSIONS

The objective of the work was to demonstrate the physical, structural and technical aspects of the mesh Network using the ZigBee standard. With the use of the XBee Pro S2 devices and the help of the XCTU software, both network and dynamic routing tests were performed. With this work, it was possible to demonstrate the mesh network rearranging and adapting. The modules were also used simulating a sensor and actuator remote network. These tests demonstrated that the wireless mesh network can be used as a remote data monitoring and control network. The application possibilities are numerous, as shown in the state of the art.

For future work, it is suggested to apply the mesh topology in a real industrial network of sensors and actuators, including testing adverse conditions such as atmospheric and electromagnetic interference.

6. ACKNOWLEDGEMENTS

This research was supported by CEFET-MG. We thank our colleagues from the Automation and Control Laboratory at CEFET-MG and from the Electric Drives Laboratory at the Federal University of Uberlandia, who provided insight and expertise that greatly assisted the research.

We would also like to show our gratitude to the Digi International Support Forum for the shared wisdom. We are also immensely grateful to Kleber Fontoura, Herbert Radispiel Filho and Carlos Dias Jr, professors at CEFET-MG, for their comments on an earlier version of the manuscript, although any errors are our own and should not tarnish the reputations of these esteemed persons.

7. REFERENCES

Cervenka, V., Mraz, L. and Komosny, D., 2014. “Comprehensive performance analysis of lightweight mesh and its comparison with zigbee pro technology”. *Wireless Personal Communications*, Vol. 78, pp. 1527–1538. doi: 10.1007/s11277-014-1832-x.

Digi International Inc., 2017. “Knowledge base: Using remote AT commands to toggle an IO on a remote XBee ZB radio”. `Available at: https://bit.ly/2JLLITS`. (Accessed 28 Mar. 2019).

Digi International Inc., 2018a. “Knowledge base: Digital and analog sampling using XBee radios”. `Available at: https://bit.ly/2TI9joa`. (Accessed 28 Mar. 2019).

Digi International Inc., 2018b. “XCTU user guide”. `Available at: https://bit.ly/2uzLYem`. (Accessed 28 Mar. 2019).

Digi International Inc., 2018c. “Zigbee RF Modules XBee2, XBee Pro 2 and Pro S2B: User guide”. `Available at: https://bit.ly/2sfp6kx`. (Accessed 28 Mar. 2019).

Du, Y.C., Lee, Y.Y., Lu, Y.Y., Lin, C.H., Wu, M.J., Chen, C.L. and Chen, T., 2011. “Development of a telecare system based on zigbee mesh network for monitoring blood pressure of patients with hemodialysis in health care centers”. *Journal of medical systems*, Vol. 35, pp. 877–883. doi:10.1007/s10916-010-9513-0.

Fagundes, F., Fagundes, L., da Cunha, M. and da Silva, F., 2016. “Comunicação zigbee aplicada em um sistema de controle”. *HOLOS*, Vol. 1, pp. 263–271. ISSN 1807-1600. doi:10.15628/holos.2016.3786.

Farahani, S., 2011. *ZigBee wireless networks and transceivers*. Burlington, USA: Newnes.

Garroppo, R.G., Gazzarrini, L., Giordano, S., Pagano, M. and Tavanti, L., 2016. “A sip-based home gateway for domotics systems: From the architecture to the prototype”. In *CN*.

Gill, K., Yang, S., Yao, F. and Lu, X., 2009. “A zigbee-based home automation system”. *IEEE Transactions on Consumer Electronics*, Vol. 55, No. 2, pp. 422–430. ISSN 0098-3063. doi:10.1109/TCE.2009.5174403.

Gutierrez, S., Acero, C. and Rodrigo, P.M., 2018. “Domotic control system for blinds with zigbee communication mobile device”. In *2018 International Conference on Research in Intelligent and Computing in Engineering (RICE)*. pp. 1–4. doi:10.1109/RICE.2018.8627899.

Ha, J.Y., Park, H.S., Choi, S. and Kwon, W.H., 2007. “Ehrp: Enhanced hierarchical routing protocol for zigbee mesh networks”. *IEEE Communications Letters*, Vol. 11, No. 12, pp. 1028–1030. ISSN 1089-7798. doi: 10.1109/LCOMM.2007.071325.

Hussein, A. and Samara, G., 2015. “Coordinator location effects in AODV routing protocol in zigbee mesh network”. *International Journal of Computer Applications*, Vol. 127, pp. 263–271. ISSN 1807-1600.

IEEE, 2011. *IEEE Std 802.11s*. New York, USA: IEEE.

Lugli, A.B. and Santos, M.M.D., 2014. *Redes Industriais: características, padrões e aplicações*. São Paulo: Érica.

Ramos, J.D.S.B., 2012. *Instrumentação Eletrônica Sem fio*. São Paulo: Érica.

Sen, S.K., 2014. *Fieldbus and Networking in Process Automation*. Boca Raton, USA: CRC Press.

ZigBee Alliance, 2012. “ZigBee specification”. `Available at: https://bit.ly/2LgEv9E`. (Accessed 28 Mar. 2019).

8. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.