Implementation of Wireless Sensors Networks Wsn Based On the IEEE 802.15.4 (ZIGBEE) Standard in Botanical Gardens

Juan Ochoa Aldeán, María E. Ochoa Azuero

Abstract.- This article describes the development and implementation of a Wireless Sensor Network WSN, in the Botanical Garden Reinaldo Espinosa owned by the National University of Loja. The simulator NS2 (Network Simulator V2 was used for this design, which allows to display the results of tests sending packages and power consumption, letting us analyze the advantages and disadvantages of each topology, thus we determined that the star topology is the best option when transmitting in real-time data provided by the sensor nodes. Through the simulation results we proceeded to implement a prototype WSN, based onXBee Pro S2B wireless communication modules, processing and energy units, and temperature and relative humidity sensor. Finally, weshow the data to the user with a graphical interface that enables real-time monitoring.

Keywords: Wireless Sensor Networks, IEEE 802.15.4, NS-2, ZigBee.

I. INTRODUCTION

Today, the WSN are booming because they are a very promising emerging technology for a wide variety of applications in engineering, they are currently in the crosshairs of many researchers. Globally, there are several countries that consider the WSN as a technological indicator. This paper aims to contribute to the study of the use of this technology in environmental variables monitoring within Botanical Gardens. We know that most of farm environments in our country do not have a real-time communication system for data processing and therefore the analysis of them always depends on the human factor who transfers the information to the data centers.

This project uses the IEEE 802.15.4 standard, and aims to support the experts to diagnose or to prevent a problem or environmental emergencies, using sensor nodes wirelessly connected, managing to establish farming precision techniques that allows the reduction of resources such as water, pesticides, etc., to contribute to the environment preservation.

II. WIRELESS SENSOR NETWORK WSN.

1.1 Definición

It is a wireless network consisting of nodes or standalone devices, which are composed of sensors distributed in a certain geographical area, to fulfill a common task.[1][2]

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1.2 Element

- ✓ **Sensor:** They take environmental information and convert it into electrical signals.
- ✓ **Sensor Node:** Device that process sensor data through its data ports, and send the information to the base station**.**
- ✓ **Gateway:** Elements designed for interconnection between the sensor network and the base station. It is a special node without sensor element, which aims to act as a bridge between two networks of different types.
- ✓ **Base Station:** Data collector based on a common computer or embedded system.
- ✓ **Wireless Network:** Typically based on the IEEE 802.15.4 ZigBee standards.[2][3]

1.3 Characteristics

- Fits any change in the network because the nodes are self-configurable, fault-tolerant and have high reliability.
- There is not a pre-determined network infrastructure, it means that a WSN has no infrastructure needed to operate because their nodes can act as transmitters, receivers or routers.
- Fault tolerance,means that a node within the network must be able to maintain its performance despite errors in the system.
- Low energy consumption, because they rely on batteries or power sources and have a long operating autonomy.
- Energy Saver, the hardware should be as simple as possible. This limits us to have a processing capacity.
- Supports multiple connectivity options: WSN are not limited to use a single wireless technology, this depends on the conditions presented on the place where the application is held and the most widely used technology is Zigbee;however, it can be used Wi- Fi, Wimax, Bluetooth, etc.
- Low production and implementation costs.

1.4 ZIGBEE.

1.4.1 Definición

ZigBee is a technology that belongs to Wireless Personal Area Networks (W-PAN), designed by the ZigBee Alliance; it becomes a solution inshort-range communication and low power consumption, based on the IEEE 802.15.4 standard. IEEE 802.15.4 is responsible for defining the two lower layers of the protocol stack: the physical layer and the data link layer [4], this can be seen in Figure 1.

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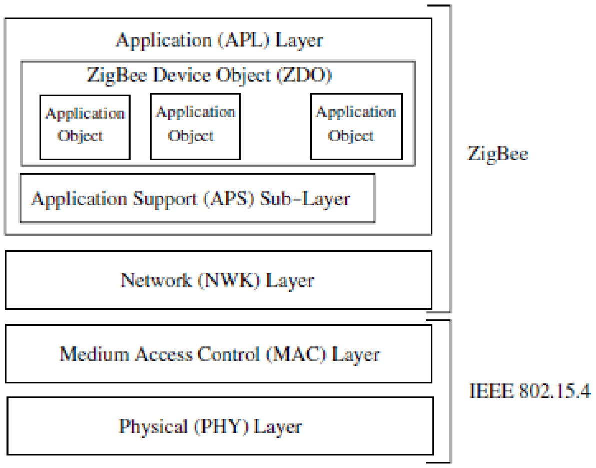


Fig. 1

1.4.2 Characteristics

- Works in the ISM (Industrial, Scientific & Medical) free band: 2.4 GHz, 868 MHz (Europe) and 915 MHz (USA).
- Rate transmission between 25-250 kbps makes it useful for applications requiring high data transmission.
- Coverage range of 10-75 meters, depending on the manufacturer it can theoretically achieve up to 1.6 Km.
- Ability to operate in high density networks.
- Supports different types of topologies like star, point-to-point, mesh, tree.
- Access channel using CSMA/CA.
- ZigBee has a consumption of 30mA when transmitting and 3μA at rest.
- Theoretically a ZigBee network may consist of up to 65 000 nodes, distributed in subnets, each subnet has 255 nodes.
- Zigbee is based on a standard multi-hop communication, that is, communication can be established between two nodes even if these are outthe transmission range, as long as there are other intermediate nodes that interconnect them; thus, this increases the coverage area of the network.
- The devices of these networks can operate in a low power mode, representing years of battery duration.
- Despite coexisting on the same frequency with other networks such as WiFi or Bluetooth their performance is not affected, this is due to its low transmission rate and characteristics of the IEEE 802.15.4 standard. [3] [5]

III. ASSESSMENT OF TOPOLOGIES

1.5 NS2 (Network Simulator V2).

The NS2 simulator was used to evaluate the best physical topology of WSN to be implemented in the Botanical Garden.

1.6 Parameters

In Tables 1 and 2 are detailed general parameters and power used for simulating implementation of WSN

Table 1.General Parameters

PARAMETER	VALUE
Propagation	Two-Ray-Ground
Network Interface	Wireless
Standart	IEEE 802.15.4
Routing Protocol	AODV
Rate	250 kbps
Frecuency	2.4 GHz
Antenna	Omnidireccional
Type of Traffic	CBR (Constant Byte Rate)
Simulation area size	225m x 225m
Nodes	11

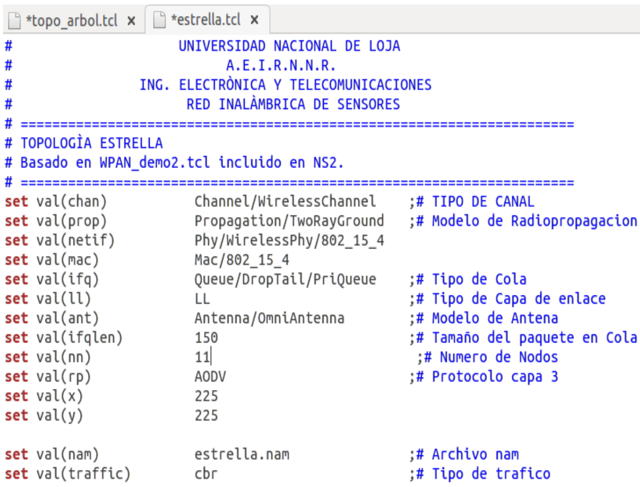
Table 2. Power Parameters.

PARAMETER	VALUE
Power	18dBm (63mW)
Sensitivity	-102 dBm
transmitting antenna gain	Gt (dBi) 5.0
receiving antenna gain	Gr (dBi) 5.0

In Figures 2 and 3, it can be seen the script for two topologies: tree and star. This script aims to get the results of tests network performance and check operation with a total number of eleven nodes distributed in the simulation scenario.

3.3. *Evaluación Métricas*

To extract the information of simulation files and get the data, filters were used in AWK language and analyzed in WSN typical metric analysis as:



```
*topo_arbol.tcl ×   *estrella.tcl ×
#                  UNIVERSIDAD NACIONAL DE LOJA
#                        A.E.I.R.N.N.R.
#             ING. ELECTRÒNICA Y TELECOMUNICACIONES
#                  RED INALÀMBRICA DE SENSORES
# ======================================================================
# TOPOLOGÌA ESTRELLA
# Basado en WPAN_demo2.tcl incluido en NS2.
# ======================================================================
set val(chan)          Channel/WirelessChannel    ;# TIPO DE CANAL
set val(prop)          Propagation/TwoRayGround   ;# Modelo de Radiopropagacion
set val(netif)         Phy/WirelessPhy/802_15_4
set val(mac)           Mac/802_15_4
set val(ifq)           Queue/DropTail/PriQueue    ;# Tipo de Cola
set val(ll)            LL                         ;# Tipo de Capa de enlace
set val(ant)           Antenna/OmniAntenna        ;# Modelo de Antena
set val(ifqlen)        150                        ;# Tamaño del paquete en Cola
set val(nn)            11                          ;# Numero de Nodos
set val(rp)            AODV                       ;# Protocolo capa 3
set val(x)             225
set val(y)             225

set val(nam)           estrella.nam               ;# Archivo nam
set val(traffic)       cbr                        ;# Tipo de trafico
```

Fig. 2. File .tcl star topology.

```
*topo_arbol.tcl ×   *estrella.tcl ×
#                    UNIVERSIDAD NACIONAL DE LOJA
#                          A.E.I.R.N.N.R.
#               ING. ELECTRÓNICA Y TELECOMUNICACIONES
#                     RED INALÁMBRICA DE SENSORES
# ======================================================================
# Simulación Topología Árbol
# Basado en WPAN_demo2.tcl incluido en NS2.
# ======================================================================
set val(chan)           Channel/WirelessChannel     ;# Tipo de Canal
set val(prop)           Propagation/TwoRayGround    ;# Modelo de Radiopropagacion
set val(netif)          Phy/WirelessPhy/802_15_4
set val(mac)            Mac/802_15_4
set val(ifq)            Queue/DropTail/PriQueue     ;# Tipo de cola
set val(ll)             LL                          ;# Tipo de capa de enlace
set val(ant)            Antenna/OmniAntenna         ;# Modelo de antena
set val(ifqlen)         50                          ;# Tamaño del paquete en cola
set val(nn)             11                          ;# Numero de nodos
set val(rp)             AODV                        ;# Protocolo de enrutamiento
set val(x)              225
set val(y)              225

set val(nam)            arbol.nam
set val(traffic)        cbr                        ;# cbr
```

Fig. 3. file .tcl tree topology.

✓ **Packet Delivery Ratio**

$$\boldsymbol{PDR} = \frac{\sum Packetsreceived}{\sum \text{Packets send}} \text{Equation 1}$$

✓ **Throughput**

$$\textbf{Throughput} = \frac{\text{\# of Bits}}{\text{Time of simulation}} \text{Equation 2}$$

✓ **End-to-End Delay**

$$\boldsymbol{Delay} = \frac{\sum(\text{Tr} - \text{Te})}{\text{\# of connections}} \text{Equation 3}$$

Where:

Tr = Time the packet is received.
Te = Time the package is sent.

✓ ***Power Consumption***: Obtained with a simple subtraction of the total initial energy on each node and power consumption in each event of the network.

IV. PROTOTYPE OF WSN.

4.1. Considerations for the design and implementation of WSN prototype.

✓ **Classification of Nodes**

The network nodes are classified according to their role in the prototype, considering a physical star topology and following a similar classification established by the ZigBee protocol wireless communications structure, two types of nodes were designed: coordinator node and sensor node.

✓ **Energy**

The aim is that nodes consume the least amount of energy resources; especially when they have to operate in environments where there is no continuous power supply.

✓ **Wireless Communications**

In the design of the WSN is essential to ensure the correct operation of wireless communication, for that reason it was decided to use the wireless communication module XBEE PRO S2B, a device that is based on the IEEE 802.15.4 standard, thereby it ensures that the network of environmental sensors are not affected by aspects such interference. Also, thanks to the results obtained from the simulation of the network is decided to implement a physical star topology to optimize communications performance, reducing the number of hops between nodes that the information must make to reach its destination

✓ **Error**

Because some sensor nodes may fail or be blocked by the lack of power, physical damage, etc. the network design is conducted under the condition that the malfunction of a sensor node does not affect the overall task of the WSN.

✓ **Frames**

The structure and size of the communication network frame is another important consideration that was taken into account in the design of the WSN, it depends on minimizing the most optimal use of the network and the proper functioning of it. It is imperative to have a processing unit of the signals captured by the sensors, in this way, only the data that are strictly necessary are sent over the network; thereby, reducing traffic and energy consumption of the network.

✓ **Software**

When developing the software for the prototype WSN it is mainly considered:

Sensor node software: it is considered to be an open source and easily accessible program; in this case the Arduino processing unit has its own programming language and IDE, this is regarded as a hardware platform and free software, very easy to get, learn and implement.

Software XBee module: in this case the device manufacturer provides the X-CTU application that is the proper software for these devices to configure the different parameters of the modules: their role in the network, connections to other devices, energy parameters and download firmware updates modules.

Software for the graphical interface: is chosen according to the functions that interface must comply; such as storage and processing of data coming from the network, as well as being designed so that the property has scalability accepting the integration of new nodes to the network.

The prototype sensors be composed of two nodes and a coordinator node such as shown in Figure 3.

Fig. 4: WSN: Star Topology

4.2. Design of a sensor node

The sensor node design is based on five components:

- ✓ Sensors,
- ✓ processing unit,
- ✓ wireless transmit-receive unit,
- ✓ conditioning unit and
- ✓ Power unit, as shown in Figure 5

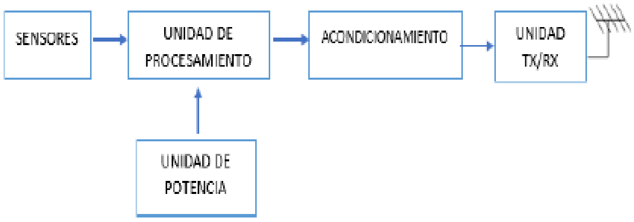


Fig. 5: WSN Node Sensor.

4.3. Design of a cordinator node

The coordinator device design is based on three components.

- ✓ wireless transmit-receive unit,
- ✓ conditioning unit and
- ✓ power unit, as shown in Figure 6.

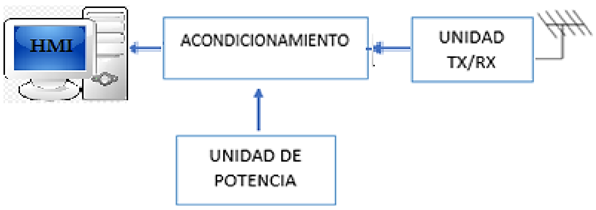


Fig. 6: WSN cordinator node.

4.4. Diseño de la interfaz gráfica HMI.

For creating a monitoring application a VS Express 2013 programming language is chosen, this tool offers an academic license with easy access. The function of the monitoring interface is to process API frames from the sensor nodes and allow real-time viewing information flowing through the WSN. In this case, we have two sensor nodes sending information every 10 minutes, and through the interface, temperature and humidity variables are known. This information can be displayed in the application through a graphic and a file of historical measurements. The programming of the GUI design was performed using the flow chart shown in Figure 7.

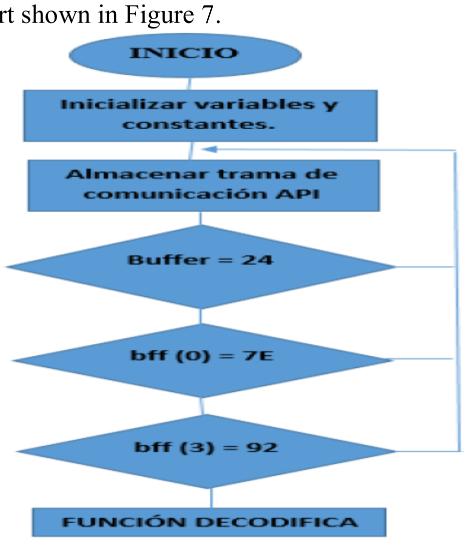


Fig 7: Flowchart of the HMI for WSN.

V. RESULTS

Simulation results of the WSN.

✓ **Star Topology.**

Figure 8 allows us to observe the result of the structure of the WSN with a star topology, this network is composed of eleven nodes, ten of them configured as end nodes and one coordinating node. In the same way,we observe the wireless links among nodes of the network. The simulation is saved in a file .tr as shown in Figure 9. AWK filters were applied to get, through the terminal Ubuntu, the results shown in Figure 10.

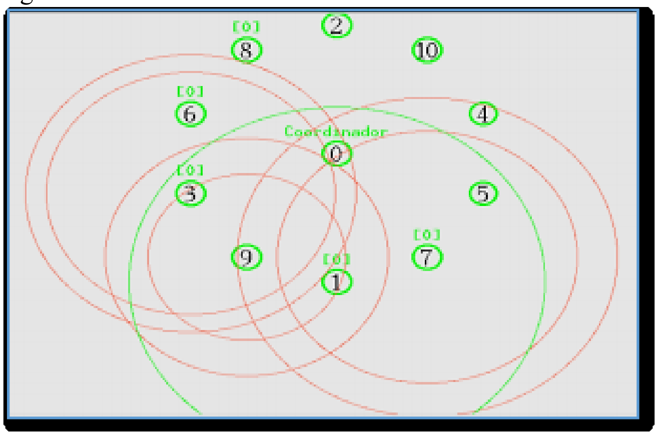
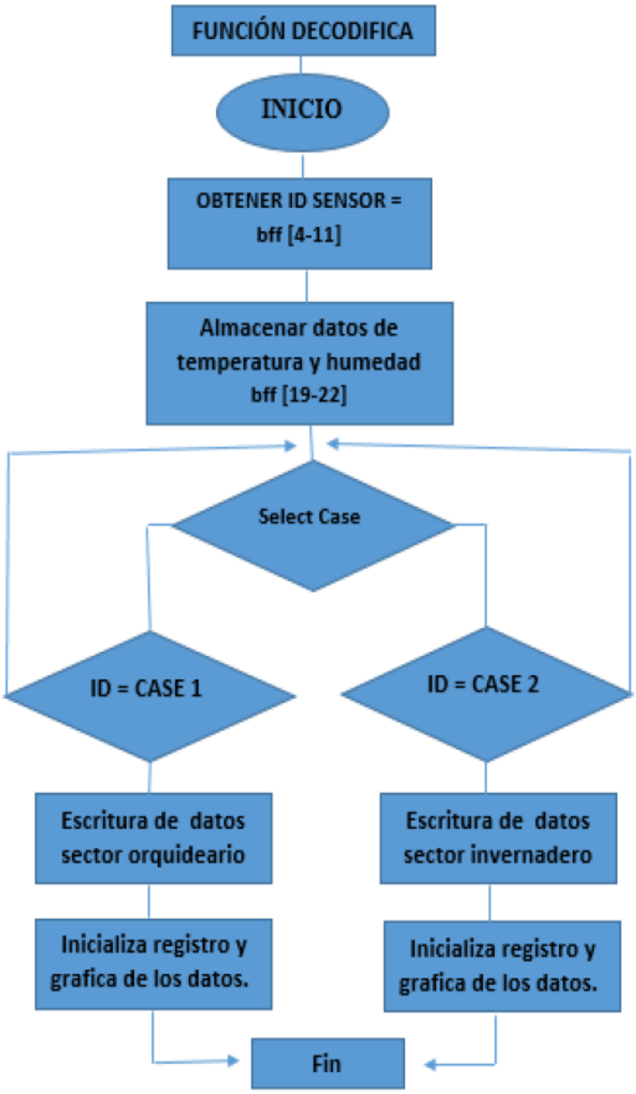


Fig. 8: File .nam (Star Topology)



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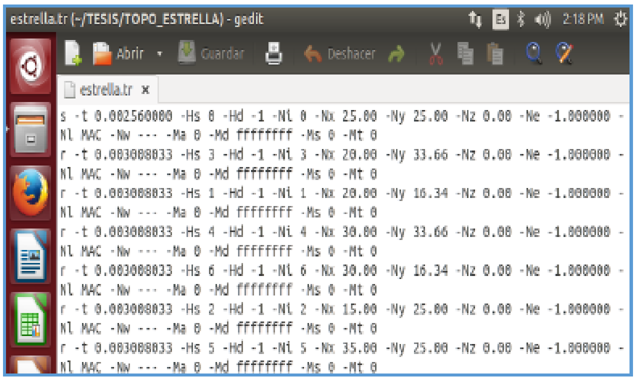

Fig. 9: File .tr (Topología estrella)

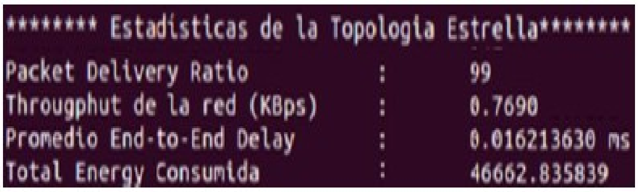

Fig. 10: Simulation Ubuntu terminal.

✓ **Tree Topology.**

Figure 11 allows us to observe the result of the structure of the WSN with a tree topology, this networkis composed of eleven nodes, five of them configured as end nodes, five as router nodes and one as a coordinating node.In the same way,we observe the wireless links among nodes of the network. The simulation is saved in a file .tr as shown in Figure 12. AWK filters were applied to get, through the terminal Ubuntu, the results shown in Figure 13.

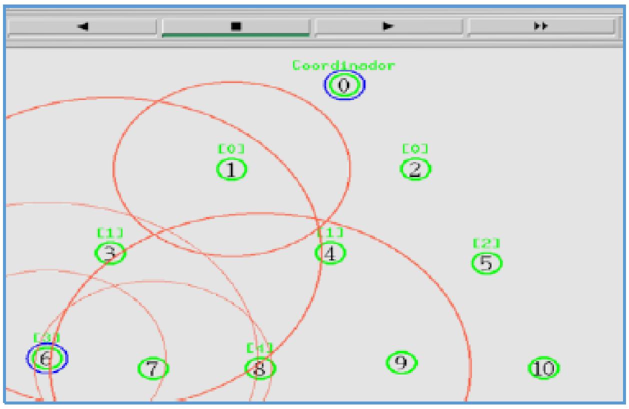

Fig. 11: File .nam (Tree Topology)

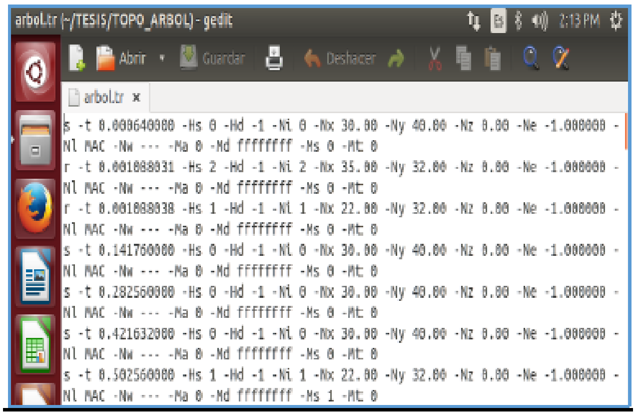

Fig. 12: File .tr (Tree Topology)

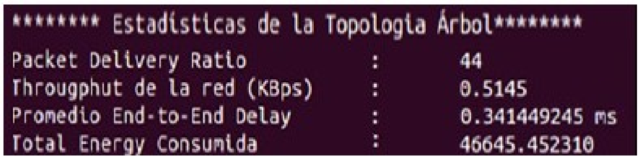

Fig. 13: Simulation Ubuntu terminal.

In Table 3 we can find a comparison between the two topologies simulated

Table 3:Comparison between the metrics used in the simulation.

PARAMETER	STAR	TREE
Packet Delivery Ratio (%)	99	44
Throughput de la Red (Kbps)	0.7690	0.5145
End-to-End Delay (ms)	0.016213630	0.341449
Consumo de energía (J)	46662.8	46645.4

After the simulation, we have determined that the star topology is the most suitable for the implementation of a WSN at the Botanical Garden.

4.5. Testing Coverage.

To measure the reception level signal among XBee Pro S2B modules, tests and calculations of the received power at 50 m, 100 m, 200 m, and 300 m were performed. All coverage information is summarized in Table 4

Table 4: Reception level signal

Distance (m)	Prx (dBm)
50	-50.48
100	-57.18
200	-62.98
300	-70.23

4.6. Performance results of the prototype.

It was possible to design a WSN prototype with two sensor nodes and a coordinator node as shown in Figure 19.Moreover, an application that enables real-time monitoring of temperature and humidity variables of each section of the botanical garden was designed.This application shows the sensor nodes information through graphs and indicators (Figure 14), as well as, records measurements of these variables with date and time. (Figure 15).

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Fig 14: WSN implemented prototype

Fig. 15: HMI (Human Machine Interface)

VI. CONCLUSIONS

WSN´s are a promising emerging technology and an active area of research in the field of Wireless Networks for the development of society, its inexpensive, reliable, fast and dense deployment capabilities of self-organization and fault tolerant network architecture, allows us to have a wide range of applications that enable interaction between human beings and the environment. Analyzing the simulation results conducted in NS2 it was determined that the physical topology suitable for implementing a wireless sensor network for monitoring environmental variables in the Botanical Garden is the star topology.

A WSN prototype was developed based on an IEEE 802.15.4 standard and the ZigBee technology, for monitoring environmental variables like:temperature and relative humidity, thus supporting farming precision techniques. After testing signal reception outdoors and analyzing the results, it was determined that the XBee PRO S2B communication modules are suitable for implementing a WSN with a star topology in Botanical Gardens; one of the main qualities of these modules is that they are based on the ZigBee protocol stack which ensures energy saving devices, so it is ideal to use batteries as a power source of the sensor nodes. It was designed an HMI interface, which allows the user to monitor real-time data provided by the system in an efficient, fast, and simple way.

RECOMMENDATIONS

For future work, it is possible to make an extension and improvement of this system, increasing different types of sensors depending on the destined network application; equally, to have an IP Network on monitoring stage enables to interconnect the WSN to internet through different gateway options that now manufacturers offer for XBee modules, thus a monitoring system can be developed from any geographical location.

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