Design of a WSN for smart irrigation in citrus plots with fault-tolerance and energy-saving algorithms

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Abstract

The wireless sensor networks are widely used for monitoring different processes including the agriculture, in order to reach the sustainability. The water saving is extremely important in the arid and semiarid regions. In those regions, the citrus trees are cultivated and the drip irrigation is used to save water. In this paper, we propose a smart irrigation system for citrus trees using a WSN. We describe the employed sensors and nodes for this proposal. Next, we present the proposed architecture and the operational algorithms for the node function. Moreover, we designed different algorithms for fault tolerance and energy saving. The energy saving algorithm is based on the decision of sending or not the information depending on the relevance of the gathered data. We propose a TPC-base protocol for our system. In addition, we present different simulations of the proposed system. We show the consumed bandwidth and the remaining energy in the different nodes. Finally, we test different energy configurations to evaluate the network lifetime and the remaining energy when the first node depletes its energy.

Keywords: Energy saving; fault tolerance; WSN; environmental monitoring; irrigation; sensors; WiFi

1. Introduction

The water is a very important resource because without water the life cannot exist. the water scarcity is a very important problem in the world, 4 billion of people live under the condition of water scarcity at least one month a year [1]. The farming is the activity with the highest water consumption in the world with a 70% of water use [2] [3]. In the future, the augment of the population and global warming can cause wars for the water. To reduce the problems with water we have three options I) decrease the use of water II) Increase the available water by reusing the wastewater. III) Desalination of seawater. The high costs of water desalination make it possible to use it for agriculture if it is not with public incentives. Therefore, only the first two options are economically valid for agriculture.

The water scarcity is not the only problem for the irrigation crops. The water quality is very important for the crops. In Europe, in general, the water quality to irrigation is acceptable but in another region, the water quality is not good for irrigation. An example is the countries of North Africa and the Middle East [4]. Then we encountered two problems the water scarcity and its quality. To solve the water scarcity in arid and semi-arid regions, the reuse of wastewater is important. China has a long history of wastewater reuse [5], In Spain and Greece, it is foreseeable that in the future the regeneration of the waters will become a routine practice [3]. However, as we have seen previously the quality of these waters can cause problems. The irrigation with raw o diluted wastewater can cause problems in the environment and human health, the governments have to take measures to manage the risks [6]. In a study of reuse of wastewater concluded with a good control of the pollutants and the use of this water for irrigating the appropriate species, the regenerated wastewater can be used without problems [3]. So the use wastewater can be used for irrigation with the correct methodologies.

To treat contaminants that are not usually eliminated in a wastewater treatment plant or found in water it is necessary to use tertiary treatment. A tertiary treatment is a biosorption. The biosorption is a physicochemical process based on an adsorption, surface complexation, adsorption, and precipitation. This is highly important in the biotreatment processes and can removal or recovery of organic and inorganic substances from a solution. The biological material can be living beings or parts of living beings that have suffered some treatment [7]. The bioabsorption is a very popular technique for eliminating the presence of water of heavy metals. It is eco-friendly in nature and is considered as a low-cost [8] [9]. The biosorption has been observed in Lake Dianchi (China) for cyanobacteria [10]. Other studied showed that the use of *Acacia leucocephala* (Lam). bark can be used for removing Cu(II), Cd(II) and Pb(II) ions of the water [11].

To ensure that water does not cause problems to human health or the environment we can use sensors to ensure a good quality of water used for irrigation. In addition, for reduction the irrigation we need the use of smart systems based on sensors. The Wireless Sensor Networks (WSN) can be used for determining the water quality in irrigation an irrigation needs. An example is the conductivity sensor [12]. This can be used for determining the salinity of the water, a very important parameter of agriculture because an executive irrigation with salinity water can cause the loss of fertility of the soil. Another important parameter for detecting the quality of water in the presence of solids. This parameter is calculated indirectly with the turbidity of water. However, not only is it important to know the value of solids but also their nature. [13] Proposed a sensor with infrared and color LEDs to detect the value of the solids expressed in mg / l, differentiating between two species of algae and inorganic solids. The moisture sensors can prevent the moisture stress conditions in the plants and reduce the excessive irrigation [14]. The WSN have two important problems, energy savings, and failures that may arise in the sending of data. To solve the problems there are operating algorithms that allow saving energy and act in case one of the sensor nodes stops working.

The energy is an important problem in the WSN. It is needed energy for the sensors and microcontrollers to work, to powered the WSN in general exist two options batteries or solar panels. Solar panels cannot always be used because in some cases the light does not hit the panel directly. Do not exist an only way for saving energy in WSN. The strategies will depend on the needs we have to monitor [15]. The selection of WSN standard each can transmit at a certain distance, at a speed and they suppose greater or lesser energetic consumptions. There are other energy-saving techniques: radio optimization, data transmission reduction, sleep, and wake-up techniques, routing protocols. [15] [16]. In our case, we must choose a WSN standard that does not consume a large amount of energy to avoid having to replace batteries and communications in relatively close distances

Another problem that the WSN have are the failures that may arise in the sensor nodes and that affect the communication. The sensor nodes can be broken, can be stolen, communication link errors, malicious attack, and simply run out of power. To avoid fault problems there are routing algorithms to act in case of failure (fault-tolerant algorithms) In a WSN the fault-tolerance can be existing in the layers of: software, hardware, network communication and apliccation [17]. According to the routing protocol, different techniques are used to save the failure. In addition to the efficiency of the system for fault-tolerant, as we have seen previously, this affects energy consumption. Therefore, a balance between energy consumption and efficiency must be sought to save the fault.

In this paper, we propose an intelligent system for the irrigation of crops. Our system does not only take into account the water needs of the crops but also the quality of the irrigation waters. For this, we install temperature and moisture sensors in the soil, and rain sensor. In the channel of water to irrigation, we install filters for the bioabsorption of contaminants; to check the quality of the water and the operation of the filters we install sensor nodes before and after the filter. The nodes are composed of a conductivity sensor and a turbidity sensor. We used microcontrollers (Arduino Mega 2560 with wifi module) for controlling the sensors and sent the information. In the sensor nodes for irrigation there are a sink node that collects the information and sends it to the database. In the water quality sensors, these have wifi antenna and send the data to the database. The topology of the network is mesh topology and we use an algorithm to avoid possible failures of the network (Fault tolerance algorithm).

The rest of paper is structured as follow: In section 2, we show different works related. In section 3, we present the sensors used in the system, the node selected, the architecture of the system, and fault tolerance algorithm. The simulation parameters are described in Section 4. In section 5, we present the results of our system and finally in section 5 we present the conclusions and future works.

2. Related work

In this section, we show different works about smart irrigation for saving water and fault-tolerant algorithms.

The use of WSN to monitor the irrigation needs of crop fields is very common. Dursun and Ozden, [14] developed a low-cost WSN (96 dollars) to control the irrigation in dwarf cherry trees. The system has been based on 3 units. A sensor unit base station unit and valve unit. The sensor unit has a moisture sensor and sent the data to base station. The base station analyzes the data and decided the parts that need irrigation and open or closed the valve units. This system allows eliminated the moisture stress and reduced the excessive irrigation.

Yao et. al.[18] Proposed a WSN for monitoring the irrigation in agriculture and saving water. The sensor nodes are composed of soil moisture, air temperature, pressure and light intensity sensors. The sensor node transmits the data to gateway node and this to LAN or WAN. For decision making, they used a fuzzy neural network. The neural network capacity of self-learning and the fuzzy logic to represent knowledge are good for irrigation monitoring. The simulation results confirm that system can be used for irrigation monitoring.

Abd El-Kader, and Mohammad [19] Studied the use of WSN in the potato crop in Egypt. They demonstrated that the cost of the WSN is compensated by the increase in profits and the reduction of costs. The sensor nodes contain sensors for temperature, humidity, light intensity, soil pH, and soil moisture. The sensor nodes are placed in the tubs of potato crops with a distance between them of 6 meters. The different sensor nodes communicate through with a radio frequency. The Periodic Thresh- old-sensitive Energy-Efficient sensor Network (APTEEN) is used for routing strategy. In this protocol, node sensors are regrouped in a cluster and a sensor node that responsibility of receiving, aggregating and transmitting the data of cluster members to the gateway. They used APTEEN because is the most suitable routing idea for theirs.

The WSN can also be used for monitoring water quality. He and Zhan [20] designed a water quality monitoring system for environmental protection department. They used a microprocessor CC2430 and many different sensors, like water temperature, pH, turbidity, etc. The network is builted in Zigbee wireless transmission. The sensor sends the data to the internet.

Fustine et. al. [21] The need to monitor the Lake Victoria Basin has increased due to anthropomorphic pressures. Presented a WSN for monitoring the Lake Victoria Basin. An Arduino microcontroller, water quality sensors (water temperature, dissolved oxygen, pH, and conductivity) and a wireless network connection compose the system. They used an open source hardware and the use of web portal and mobile phone platform for display the value of sensors. The experiments showed can be used for working in the real world.

In the first place, we have seen the techniques for the detection of irrigation needs and later to know the quality of irrigation water. Unlike our system that does an evaluation not only of the needs of irrigation but of the quality of the water that is used in the irrigation. The systems presented separately analyze irrigation and water quality.

In the WSN, failures may occur in the sensor nodes that prevent the correct operation of the network. Now let us analyze some algorithms that reduce these problems.

Bagci et al. [20] developed a new distributed fault-tolerant topology control algorithm called Disjoint Path Vector (DPV) and that is used for heterogeneous WSNs. These have two layers; a layer is nodes with low-cost ordinary sensors, limited power, and short transmission range. The other layer is supernodes with more energy reserves and better processing, data capacity, actuators. These collect the information of nodes. In the topology, each sensor is connected with at least one supernode by k-vertex disjoint paths (Paths with common endpoint but that no have other vertices in common.). Being the typology tolerant to a failure of k-1 in the worst case. The algorithm minimizes the transmission in the network to get to a supernode. The simulation showed that algorithm is most efficient of other algorithms. DPV have a savings of 4-fold in total transmission power of distributed anycast topology control under the assumption of no packet losses and a 2.5-fold with a packet loss rate of 0.1.

Azharuddin et al. [16] Showed an algorithm they called Distributed Fault-tolerant Clustering and Routing (DFCR). This algorithm is proposed for WSNs. The sensor nodes are grouped in clusters and a sensor node of the cluster it is selected how cluster head (CH). The CH changes in each round of information sending. This is selected based on the residual energy of the CH, the distance between the sensor node and CH and the distance from the CH to the base station. In case of failure, the sensor nodes send a help message to other clusters and if they receive replies, they join this new cluster. They compared their algorithm with Minimum Hop Routing Model (MHRM) and Distributed Energy Balanced Routing (DEBR), in simulations, the results of the simulation showed that DFCR is better respect to the number of live sensor nodes, energy consumption, etc.

Kaur and Garg [23] Developed an improvement of the DFCA, the Improved Distributed Fault-Tolerant Clustering Algorithm (IDFCA). In DFCA when CH fault moves the operation to neighboring CH and causes a greater workload in the neighboring CH. In this when a CH fault the sensor node select the CH that was going to be chosen in the next round.

Our system evaluating the water quality for irrigation and the needs of irrigation. To solve the possible problems that may arise when broking or exhausting the energy of the nodes. We have opted for a mesh network instead of the options that we have explained previously because the meshed network has greater confidence and is easy to install. We have opted for a meshed network to solve the errors because its installation is simpler, due to its reliability when all the nodes are connected to each other.

3. System description

In this section, we are going to describe the proposed smart irrigation system. First, we will describe the used sensors to gather data from the field and the selected node to transmit the data. Then, the architecture of the proposed system is shown. Finally the fault tolerance and energy saving algorithms will be presented.

3.1 Sensors

In this subsection, the used sensors for monitoring the water quality and the irrigation needs in the farmland are described.

First, we will show the used sensor for the water quality monitoring. The monitored parameters in the water are the turbidity and the conductivity. For the turbidity sensing, optical sensors are selected. On the other hand, for conductivity monitoring, inductive sensors are used.

The turbidity sensor is composed by two LEDs emitting at different wavelength and two light detectors. The sensor is based on the one presented in [24] and [25]. One of the LEDs has the peak wavelength of 612-625nm and the other at 850 nm. The light detectors are a Light Dependent Resistance (LDR) sensible to the visible light for the first LED and a photodiode sensible to the Infrared (IR) light for the second LED: The turbidity sensor is placed before and after the application of the filters for purifying the water. The LEDs are powered at 3.3V using the 3.3V output voltage. The light detectors are connected to the node at the analog input (AI) 1 and 2.

The conductivity sensor is composed by two copper coils. The first coil is powered with a sine wave and the second coil which is induced. The induced voltage depends on the conductivity of the water. The selected sensor is based on the prototype described in [26]. The powered coil is powered with the Arduino using an analog output (PWM) pin, the PWM 2. The generated voltage in the induced coil is measured in the AI 3. As the turbidity sensor, the conductivity sensor is places before and after the filters.

Both sensors will monitor the correct operation of the purification filters by registering the changes in water quality before and after the filters. The conductivity and turbidity sensors are connected to the same node.

Next, we are going to describe the employed sensors for the field monitoring. Four different parameters will be monitored including rain, soil moisture, soil temperature.

The rain sensor used is a raindrops module compatible with Arduino. The sensor is composed by a printed circuit that acts as a variable resistor. The resistance of the sensor depends on the presence of drops in the module. The minimum resistance, when it is wet, is 100KΩ and the maximum resistance, when it is dry, is 2MΩ. The sensor is powered at 3.3V. The sensor output voltage is connected to the AI 10. The sensor is located in the field where the orange trees are placed. The sensor is deployed at 1m of the soil in an area which is not covered by trees. The rain sensor is not included in all the nodes deployed in the field.

The soil moisture sensor is based on an available module for Arduino. The sensor is composed by two electrodes with a gap between them. Once the sensor is introduced in the soil, the current will be transmitted from one electrode to the other according to the water content of the soil. The output voltage of the sensor changes from 0V, when the soil is completely dry, to 4.2V. The soil moisture sensors will be placed next to each orange tree. The soil moisture sensor will be connected to AI 1.

The temperature sensor is based on a thermistor Negative Temperature Coefficient (NTC). The sensor is based on the temperature sensor used in [27]. The sensor is powered at 3.3V and the output voltage is connected to the AI 4 of the node. The temperature sensor is used to measure the soil temperature. The sensor is placed next to each tree over the soil.

The sensors in the field will be used for monitoring the state of the soil in order to define the irrigation needs of the different plots.

3.2 Nodes

In this subsection, the description of the characteristics of the node is performed.

In our proposed system, the nodes are deployed throughout the expanse of the plots. The quantity of nodes depends on the size of the plot and its specific needs. The employed nodes are Arduino Mega 2560 [28] nodes provided with WiFi connection employing the ESP8266 module [29] which supports IEEE 802.11 b/g/n. This node has 16 analog input pins and 54 digital input/output pins, allowing to connect many sensors to one single node. Moreover, it provides a USB connection, 4 UART serial ports, a power jack, a 16 MHz crystal oscillator, an ICSP (In-Circuit Serial Programming) header and a reset button. This node however, does not provide an integrated wireless interface. Thus, it is necessary to incorporate a Wi-Fi module. The connections between the node and the Wi-Fi module are the ones presented in figure 1, similar to the ones performed in our previous work [27].

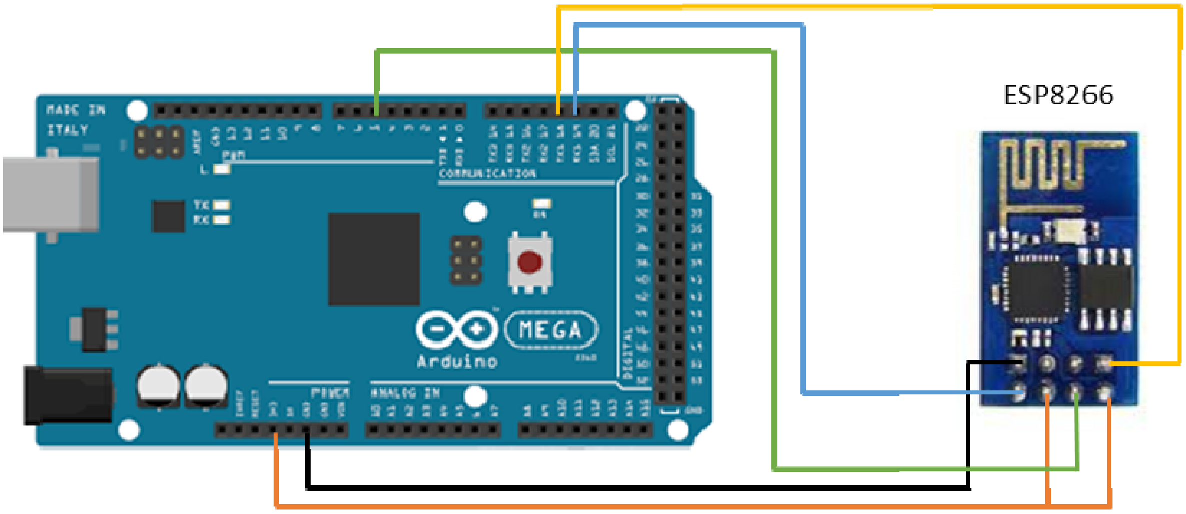

Figure 1. Connections between the Arduino Mega 2560 and the ESP8266.

3.3. Architecture

In this subsection we show the architecture and the operation algorithm of the proposed smart irrigation system.

First, the architecture is show. In Figure 2 we can see an example of deployment of the different nodes in an orchards area. The black dots represent the nodes with the field sensors, the field node (FN). They are measuring the soil moisture at different depths and the temperature sensor. We place one node with moisture and temperature sensor in the base of each orange tree. In each plot one or more nodes will be used as sink nodes are used (SFN). The sink node is in charge of collect the data from each node via WiFi and to forward the data to the database (DB) using 3G technology. Moreover, the sink node has also a rain sensor. Along the river, different channels are used to get the water to the different plots. At the beginning of each channel, the filters for water purifying are placed. Two nodes are placed to measure the water quality, one before the filter (WNB) and one after the filter (WNA).The nodes that measure the water quality have WiFi antenna and they send the data to the closest FN, which will transmit this information until it get the SFN.

The path that follows the data from a WNB to the DB can be seen in Figure 3. In blue we can see the nodes that measure the water quality, in light orange the sensors that measure the data from soil status, in dart orange the sensor that measures the data from soil and rail and in grey the database.

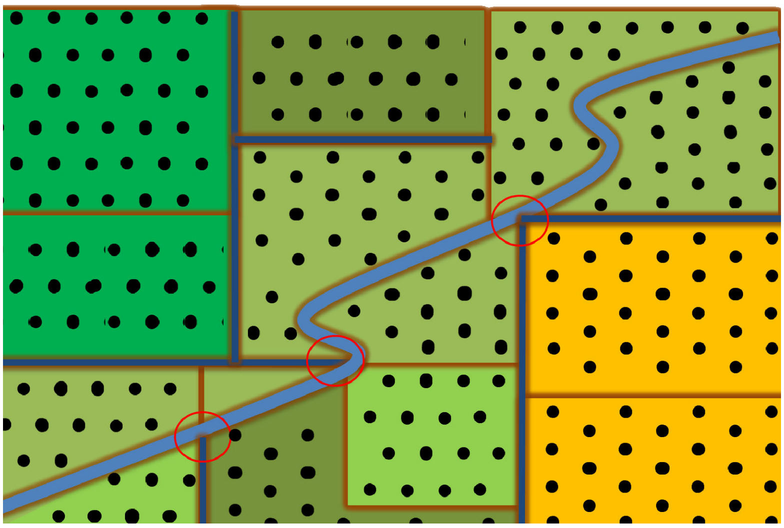

Figure 2. Example of location of nodes in the field.

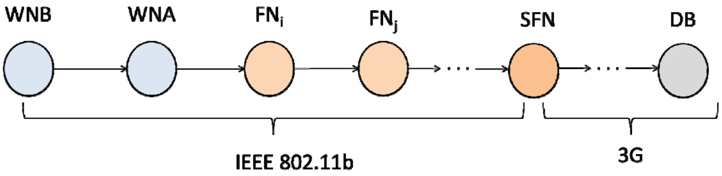

Figure 3. Data forwarding from the WNB to the DB

Next, we are going to describe the operation algorithm applied in the nodes that monitors the water quality, the WNB and WNA, and activates the filters when it is need. The algorithm presented in Figure 4, shows the procedure of the nodes. First the WNB gathers data from salinity and turbidity. Then, the node evaluates if it is necessary to send the data or not. This will be performed applying the algorithm described in the following subsection. If the data have changes from the previous send value, the WNB must send the new gathered data to the WNA. Thus, the WNA will evaluate the needed action. The actions are to activate the filters to purify the water, if pollution is detected or irrigate with the river water id the water is clean. To determine the pollution of the water the data from the WNB is compared with stablished thresholds. However, if it is not necessary to send the data from the WNB to the WNA, the data is not send and no actions are taken on the filters. If no data is received, the WNA gathers new data as usual. If data from WNA is higher than a threshold it indicates that the filters are not operating properly, then an alarm is sent. The last step is to evaluate if it is necessary to send the data gathered by the WNA. Then, according to the need of sent the data of WNA and WNB the WNA will forward the data that required to be sent.

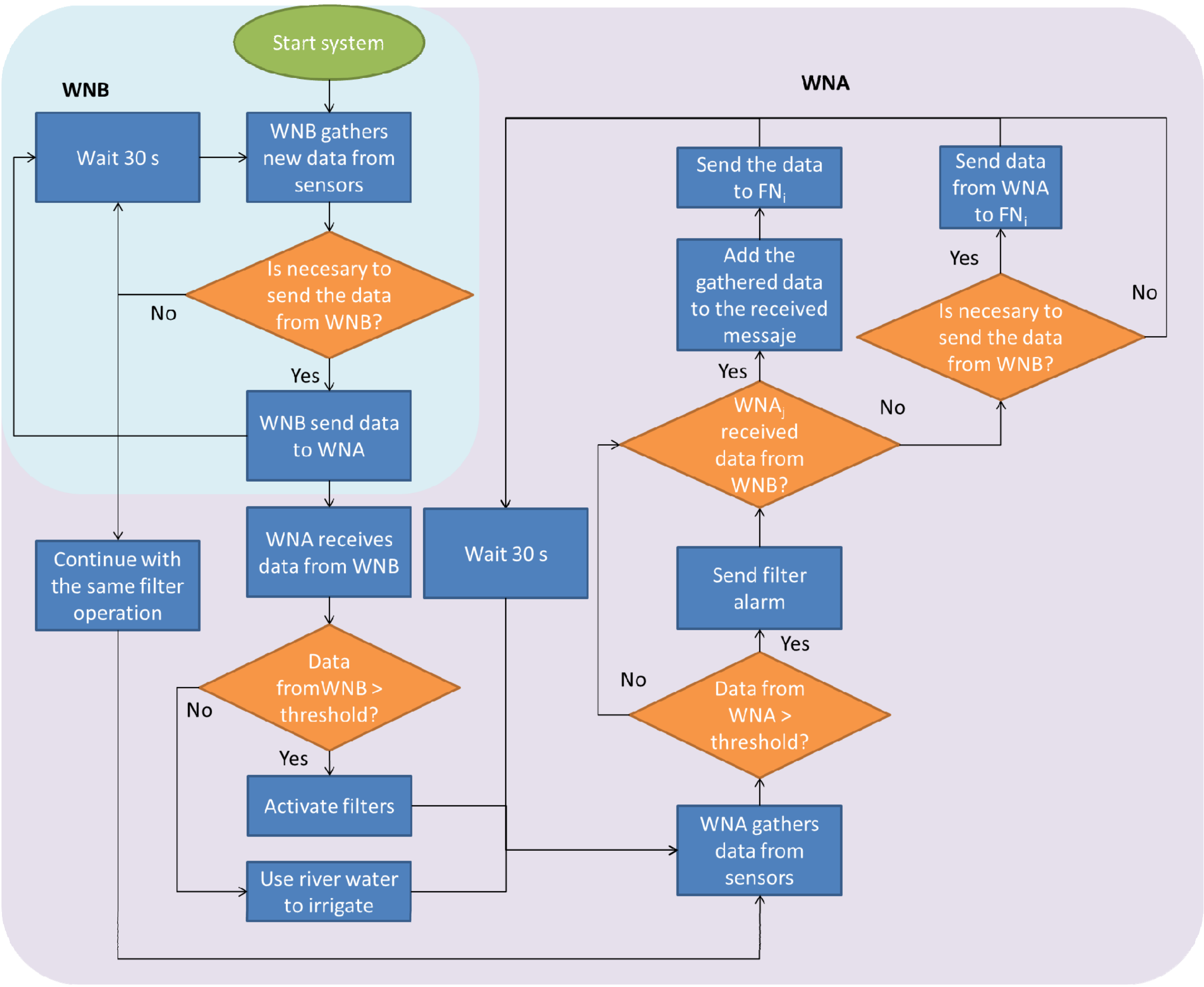

Figure 4. Operation algorithm of WNA and WNB

In the FN, the operation algorithm includes the gathering of new data, the activation of local irrigation and the need of sending data. The algorithm can be seen in Figure 5. First the node gathers new data, if the humidity level is lower that the stablished threshold the node activate the local irrigation. If the soil moisture is higher than the threshold level no action is taken on the irrigation system. Then, the node check if in the last 5 minutes any message with data from other node was received. If data were received, the node adds the gathered data to the received message and forwards it. If no data were received, the node evaluates if the gathered data must be send or not. If the data must be send the node sends it to the next node. Then, the node waits 5 minutes to gather new data.

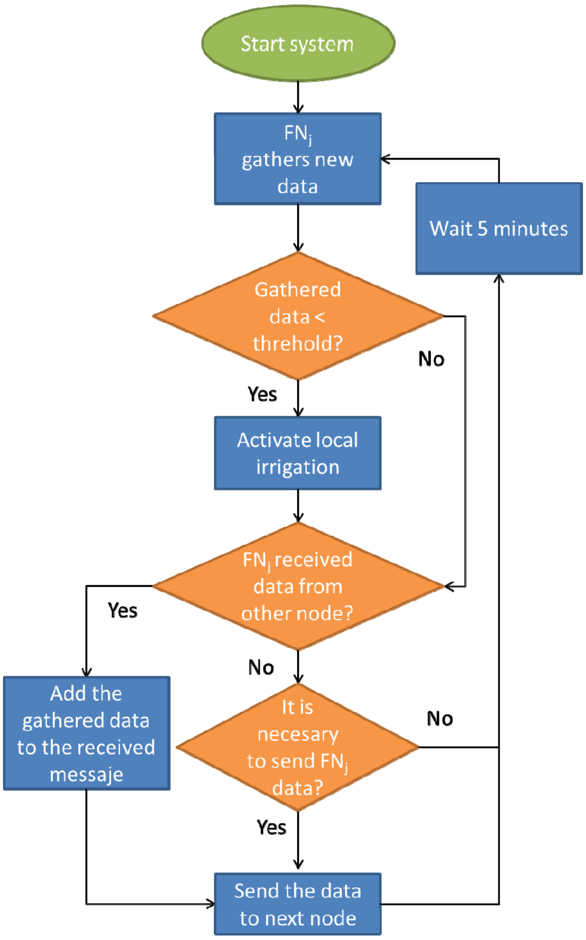

Figure 5. Operation algorithm of FNs

3.4. Fault tolerance algorithm

Figure 6 presents the fault tolerance algorithm for the nodes deployed throughout the crops. The nodes employed are Arduino Mega provided with WiFi connection employing the ESP8266 module. Firstly, the connection is stablished between the nodes. Nodes detect their neighbors and ask for the metrics to determine the shortest path to the base station. When the node determines the next hop, it starts performing its sensing activities. Then, the forwarding decision algorithm presented inthe next section of this paper is applied. When necessary, data is forwarded to the next hop. If the ACK is received, the node continues with its normal functioning. If an ACK is not received, the data is forwarded again. If after three tries an

ACK is not forwarded, the process of detecting the neighbors and selecting the one closest to the base station is performed again. Then the data and a warning are forwarded so as to inform that there is a broken node.

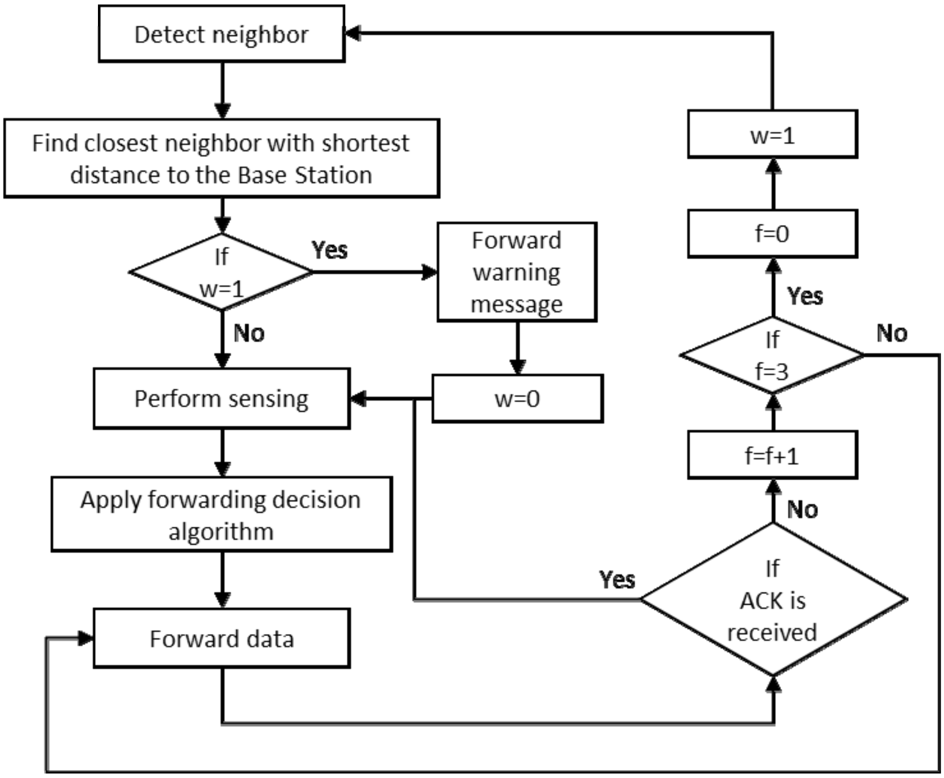

Figure 6. Fault tolerance algorithm.

Figure 7 presents the message exchange between the components of the architecture of our proposed system. Firstly, the connection establishment process is performed where nodes send a broadcast message to reach the nodes. Then, the nodes send the metrics indicating the distance to the base station. When the nodes perform correctly, the data is forwarded to the next hop and an ACK is received. Then the information is forwarded from node to node to the router in the base station, where the information from the nodes is received employing WiFi and 3G is employed to forward the information to the database. When there is a failure in a node, the data is forwarded three times in order to ensure the error was not caused by interferences. The neighbor discovery process is performed again and when the next hop is selected, the data is forwarded as usual including a warning to alert of the broken node.

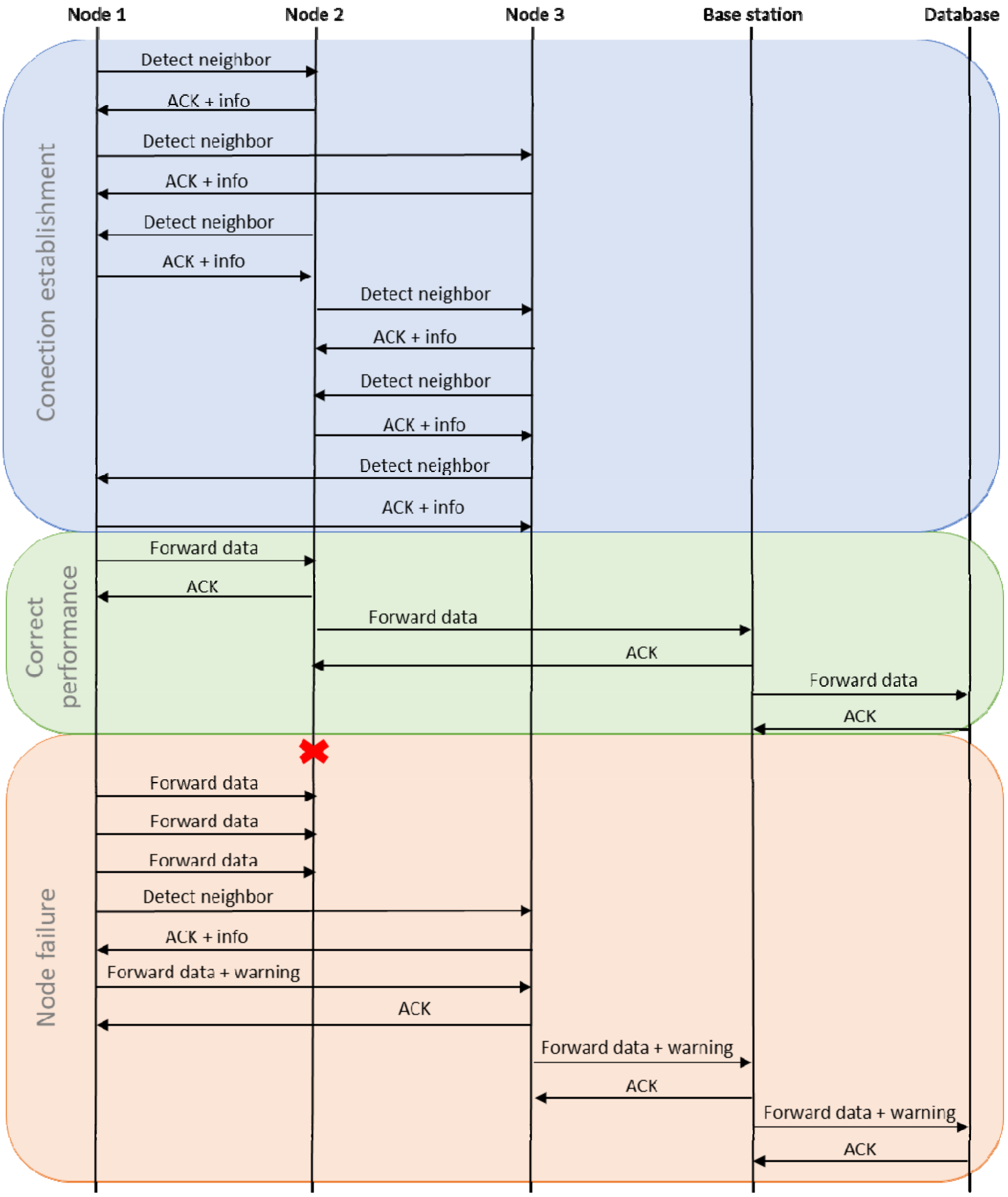

Figure 7. Message exchange among the elements of the system.

3.5. Energy saving algorithm

In this section we are going to describe the use of the energy saving algorithm. Many algorithms appear in WSN to diminish the energy usage in the last years. The majority of those algorithms are based on the selecting different transmission settings, use different routing protocols, or use specific protocols with less communication requirements or less packet size. However, the best way to save energy is to avoid unnecessary packet exchanges. In WSN, when the sensors are measuring a parameter the node usually sends the gathered data without considering the relevance of this data.

It is extremely important to consider the relevance of the gathered data to know if it is important to forward the data because if the node sends this data a high energy consumption in this and other nodes will be generated. The data transmission is considered as the procedure that requires more energy [30]. Thus, the rest of processes as processing, coding, and decoding the data can be despised. In other papers [31] authors have proposed a smart algorithm that decides if the gathered data must be transmitted or not. Basing on their algorithm we propose a simplified version adapted to our proposal.

The adapted algorithm is shown in Figure 8. In our case the decision algorithm is applied to all the nodes during its operation algorithm, Figure 4 and 5. This algorithms starts with the new gathered data and must decide if send it or not. The gathered data corresponds to two variables *m* and *n*. The new gathered data is set as *Xm* and *Xn.* Those variables are, in case of WNB and WNA the conductivity and the turbidity and in case of FN soil moisture and temperature. Then, the algorithm searches in the node memory the established thresholds for each variable (*Δm* and *Δn*). These thresholds represent the minimum variation in the parameter that is must be overcome to consider the new information relevant. Next, the algorithm searches in the node the previous transmitted values. If there were no previous transmitted values the new values are set as the last transmitted values (*Ym* and *Yn*), and the values are transmitted. If there were *Ym* and *Yn* in the node memory, the algorithm compares the *Xm* and *Xn* with the *Ym* and *Yn.* If the difference exceeds the *Δm* or the *Δn* the gathered data is transmitted. Otherwise, the data is not transmitted because it is considered that the gathered data does not content relevant information.

3.6. Protocol description

Nodes communicate emplpoying IPv4. For this proposal we present a modification of the TCP protocol that incorporate on the TCP datagram the fields presented in Figure X. In the data forwarding message, the TCP header is followed by the W Node ID field. This field is employed if there is a warning. The W Node ID indicates the ID of the node that is malfunctioning. Node 1 ID indicates the ID of the first node that wants to forward information, which has a size of 1 Byte. The next field is sensor ID and has a size of 1 bit. The Sensor data field is where the data gathered from the sensor is possitioned on the datagram. There are two types of sensor. For WNA/WNB sensors, the size of the data field is 6 bits whereas for FN sensors, it is 8 bits. Sensor 2 ID has a 1 bit size and indicates the ID of the second sensor. Lastly, Sensor 2 Data is employed to transmit the information gathered from the second sensors. Its size is 4 bits for both types of sensors.

When a node receives information from other nodes in order for it to be forwarded, the information is placed on the datagram following the data from the other nodes. As it can be seen in Figure 9, where Node 1 Data is followed by Node 2 data and so on depending on the number of nodes that are forwarding data at the moment. The W Node ID field is only employed when there is a warning. Finally, the ACK message is composed of only the TCP header, without adding any more data.

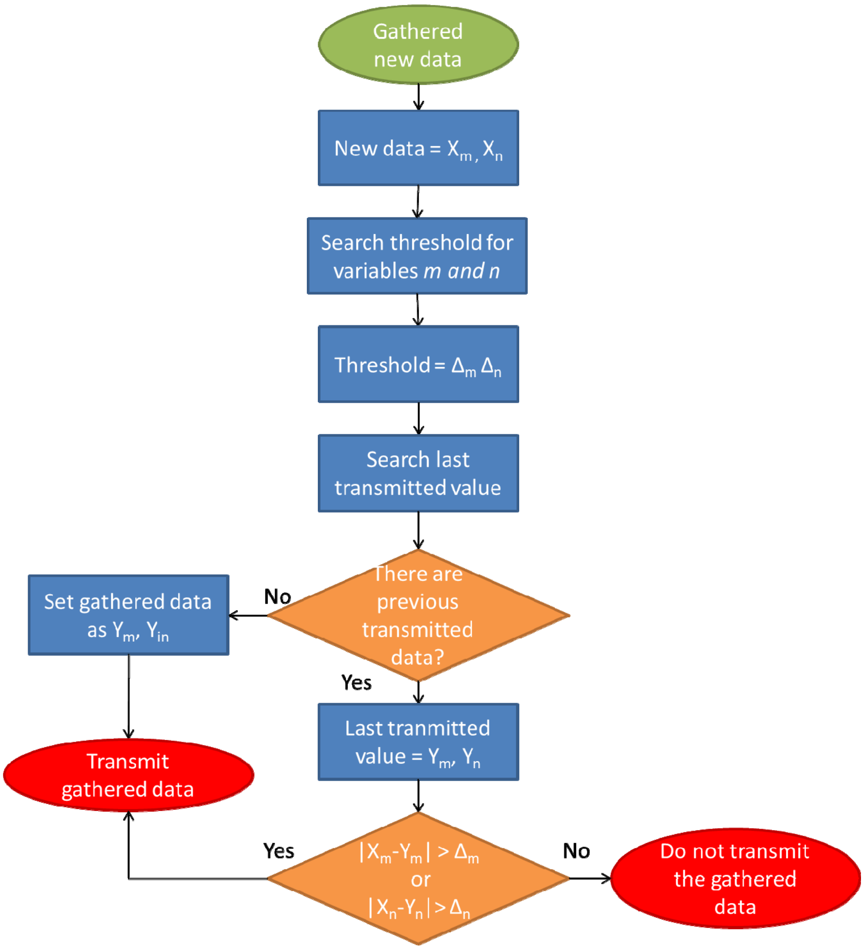

Figure 8. Energy saving algorithm.

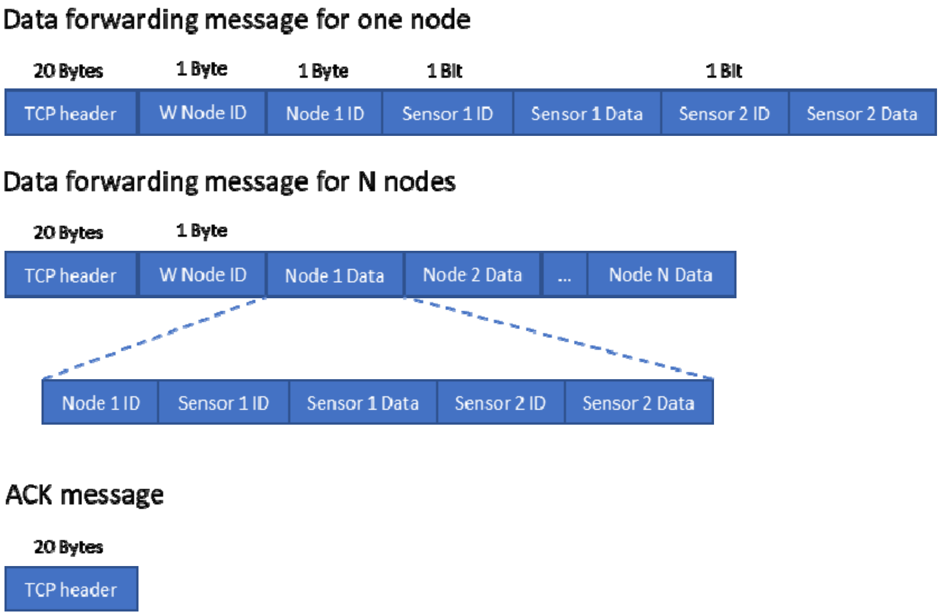

Figure 9. Message strucutre.

4. Simulation description

In this section we are going to describe the simulation performed with the proposed protocol and algorithms.

First, we describe the number of employed nodes and its topology. In our simulation we include a total of 23 nodes. From those 23 nodes, there are different types of nodes such as WNA (1 node), WNB (1 node), FN (20 nodes) and FNS (1 node). In Figure 9 we show the location and type of the nodes. In blue we can see the WNA and WNB placed in the Jucar River and in the channel used to transport the water to the orchards. The FN are represented in red dots and are numbered in letters, from "a" to "u". The node "k" is the FNS, which will collect the data from the rest of the nodes.

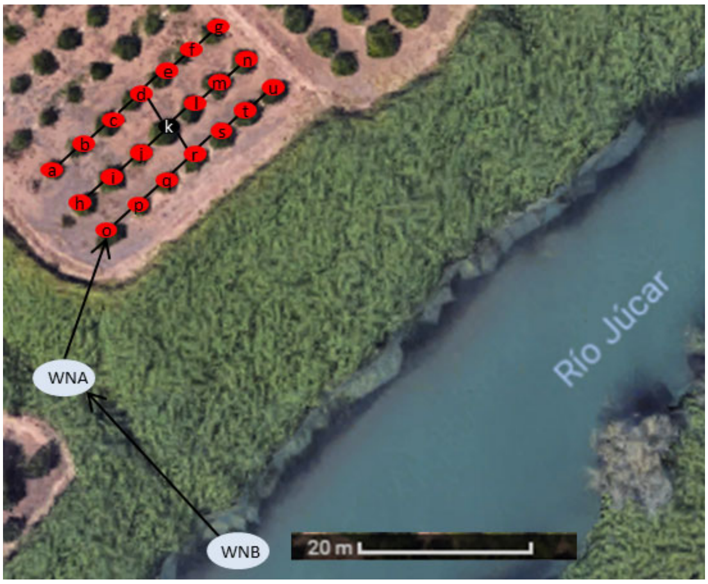

Figure 9. Topology for the simulation

According to [30, 31] we assume that the energy used for transmission and reception is 50nJ/bit, and 100pJ/bit/m2 considering a distance of 3m between FNs. In our simulations we are not going to use any type of encryption to avoid the energy use. The initial battery of the FNs is 0.1J and the FNS has a different battery with 0.5J Jules. We consider that the nodes gather data each 5 min. The data is sent only if the gathered data is relevant, see Figure 1. For the simulation we consider a 10% chance that the gathered data is relevant and must be sent.

When one node sends information, according to Fig 1, 2, the following nodes in the topology have to add their gathered data to the received information and send it. The length of the TCP header is 160 bits. The length of the data gathered by WNA or WNB is 20 bits. The length of the data gathered by FNs is 22 bits. The ACK packet length is 160 bits.

The same scenario will be tested with different energy configurations. The first configuration is the previous one, with 0.1J in all the FN nodes and 0.5J in the FNS. The second configuration gives 0.5J to FNS, 0.25J to nodes d and r. In the last configuration the node d and r have 0.425J, the nodes c, e, j, l, o, p, q and s have 0.15J, the FNS 0.5J and the rest of the nodes 0.05J. The number of iterations will be 20000. A total of 9 simulations will be performed for each configuration.

5. Results

In this section we present the data obtained from the aforementioned simulation, including the total bandwidth consumed from the FNs and the remaining energy after 10000 iterations.

First, we are going to present the results from the consumed bandwidth by the network. Figure 10 presents the consumed bandwidth during 5000 iterations. The mean consumed bandwidth is 1938 bits. The maximum consumed bandwidth is 7252 bits at iteration 4165. The minimum consumed bandwidth is 0 bits, this occurs many times in the 5000 iterations.

Next, the remaining energy in the nodes are shown, see Figure 1. The node represented by a k in Figure 1 is the FNS and have 5 times more energy than the rest of the nodes. In Figure 11 we are representing the energy use related to the data transmission and reception. The nodes j and f consumes the energy much faster than the other normal FNs. The node with less remaining energy is the r node, with 0.028J. The average remaining energy in the FN is 0.081J. The FN with higher remaining energy is the h node with 0.95J. The FNS has a remaining energy of 0.36J.

Now we are going to evaluate the different energetic configurations. Table 1 shows the iterations before first node dies. In the first configuration, the first node that dies is the node r. The first node dies between iterations 6762 and 6919. The mean lifetime of the network is 6841 iterations. For the second configuration, the first node that dies is the node q. This happens between iteration 1306 and 13609. The mean lifetime of the network is 13300 iterations. For the last configuration, the fist node that dies is the k node. The mean lifetime of the network is 18126 iterations, the minimum and maximum are 18079 and 18189. In Figure 12 we can see the maximum remaining energy in one node and the mean remaining energy in all the nodes for the different configurations. The configuration that uses less efficiently the energy is the configuration 1, where there is one node with up to 3J when the first node dies. The second and third configurations have almost the same maximum remaining energy in one node. However, the configuration 2 has higher mean remaining energy in the nodes, 0.06J while configuration 3 has only 0.04. In additions the configuration 3 is the one that presents longer lifetime.

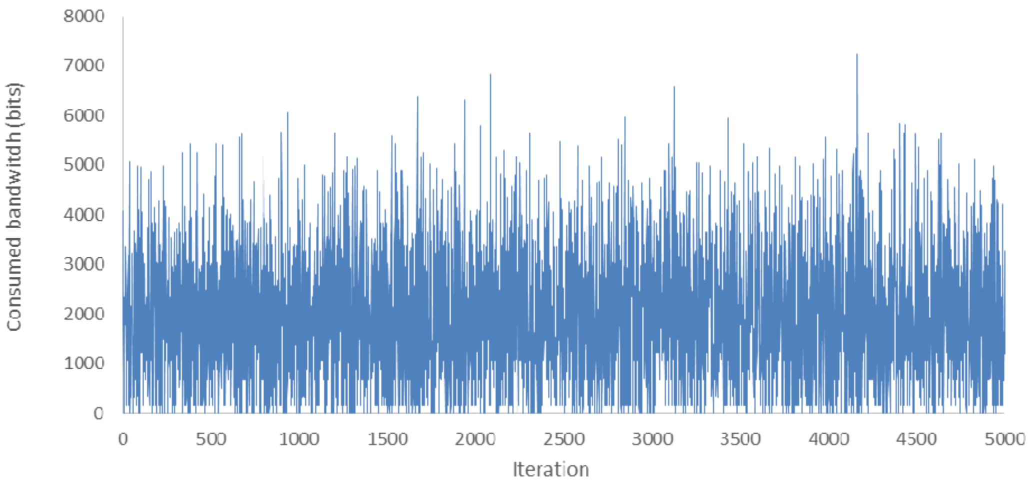

Figure 10. Consumed bandwidth

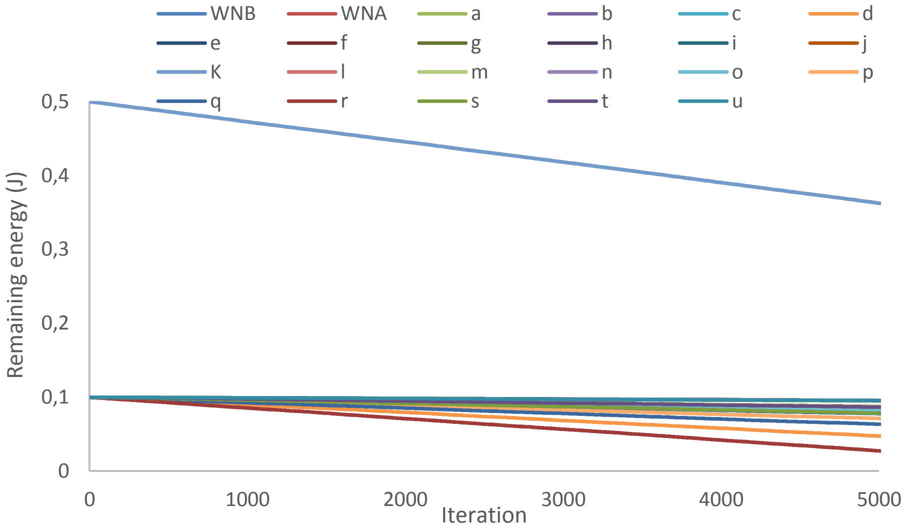

Figure 11. Remaining energy in nodes after 5000 iterations

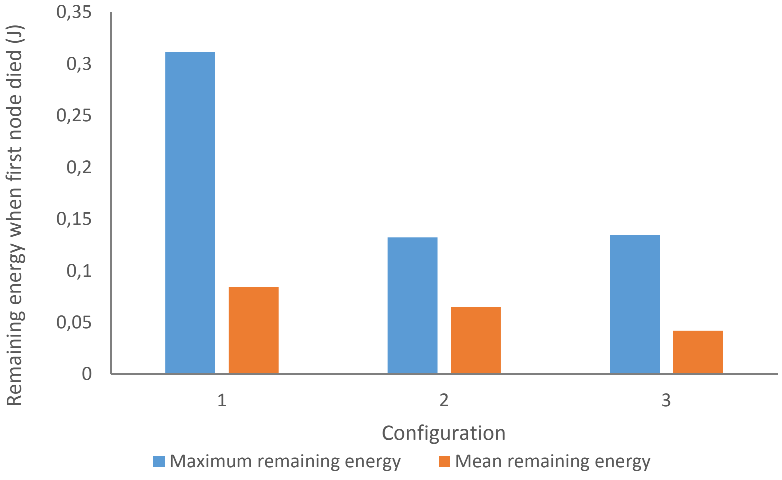

Figure 11. Remaining energy in nodes after 5000 iterations

Table 1. Description or brief title for the following table.

	Iteration first node died		
Simulation	***Conf 1***	***Conf 2***	***Conf 3***
1	6919	13236	18094
2	6862	13153	18189
3	6844	13326	18158
4	6765	13409	18129
5	6875	13343	18098
6	6762	13414	18114
7	6833	13609	18079
8	6850	13144	18146
9	6861	13065	18124
Mean	6841	13300	18126

6. Conclusion

In this paper we present the application of a smart irrigation system with a new protocol for WSN that allows a diminution in the energy consumption and have a fault-tolerance mechanism.

First we describe our proposal including the employed sensors, nodes and architecture. Then the protocols and algorithms are detailed. Finally, a simulation was performed with a topology that includes 23 nodes. We show the consumed bandwidth and the remaining energy after 5000 iterations. Moreover, we simulate the moment when the first node reaches the 0% of energy using different combinations of energy distribution in the nodes.

Our results show that the mean consumed bandwidth is 1938bits, while the maximum consumed bandwidth is 7252 bits. After 5000 iterations no one node has use all its energy. Different energy configurations show different network lifetime and different remaining energy in the rest of the nodes.

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