Design and deployment of a WSN for water turbidity monitoring in fish farms

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***Abstract*— Fish farms pretend to be the sustainable option to provide fish. The water quality is very important to ensure the fish performance. Thus, the monitoring of the water quality is crucial in order to automatize different process in facilities. In this paper, we present a system to monitor the turbidity in fish farms. First, the sensors and wireless nodes are defined. We use an optical sensor for turbidity monitoring and a Flyport as a node. Then, the topology and operation process are detailed. An extended star is proposed as network topology with a wireless connection between Flyports and the Access Points. Finally, the network performance is tested. The main issue is that in the fish farms there is a harsh environment and it is needed to minimize the number of Access Points employed, but maintaining good network performance. With 5 Flyports sharing one Access Point there is a packet loss rate close to 0.5%. Moreover, the appearance of the windows to visualize the data in the server and the alarms sent are shown. It is possible to select different tank types and tank numbers on the server to see the data. In the alarm message, it is possible to see the type of alarm, the affected tank and the timer of this alarm.**

Keywords—wireless sensors networ; fish farm; water quality network performance; data server

I. INTRODUCTION

Currently, there is a diminution of fish capture without there being a diminution of the means for their capture [1, 2]. This is because the overfishing reduces the amount of fish in the sea that can be caught. With the future growth of world population, it will be necessary to increase the quantity of food to ensure food security. Since we cannot extract more fish from the sea we will have to increase the aquaculture production to satisfy the fish demand [3]. The practice of aquaculture is performed in the sea or ashore. In the ashore installations, the water is received in the reception tank, where it will spend some time before being distributed to different production tanks.

The water quality monitoring is important because the physical-chemical water parameters can have negative effects on the growth of fish or their sale later on. The suspended solids can have abrasive effects, reduced the vision of fish and produce problems in the gills [4, 5] The high temperatures also can have negative effects, because it reduces the O2 dissolved in fish water [6]. Moreover, the temperature affects the amount of feed that fish need [7, 8].

For monitoring the different physical-chemical parameters of water in aquaculture wireless sensor networks (WSN) for taking measurements are used. When water parameters are not suitable for fish, the fish farm workers can take corrective actions. Nevertheless, it can be interesting to detect the water problem before water reaches the production tanks. If we can monitor water quality in reception tanks, then it is possible to isolate the tanks with more sensible individuals or in which we are applying a special treatment. The WSN have been widely used for water monitoring [9 – 17]. The main issue on WSN is to control the energy usage [18 - 22]. The main issue specific for underwater WSN is the signal transmission [23]; however, in this case the signal transmission is over air environment.

In this article, we are going to present the design of a WSN for water quality monitoring in a fish farm on the mainland. The system is based on two sensors that are placed inside a waterproof box. There is a turbidity sensor and a temperature sensor. This box is crossed by a glass tube where the water passes. A humidity sensor inside the waterproof box is installed to detect the entrance of water inside the box. If the humidity sensor detects water in the box, it will turn off the sensors, so as to prevent any damage to the electronics. Each group of 3 sensors will be connected to a Flyport that will be connected to an access point (AP) via a Wi-Fi connection. The different APs of the plant will be connected to a Switch with an Internet connection via a Router. The data collected by Flyport are sent to a Server. This data will be accessible both locally and remotely.

This article is structured as follows. Section 2 explains some works related to the networks of WiFi sensors and their use for the monitoring of water parameters. Section 3 explains the parts of our system, both the sensors used and the communication architecture to be used in the network. Section 4 explains the performance of the RSI. Finally, in section 5 we will show the conclusions of our work.

II. RELATED WORK

In this section, we present a selection of papers where different WSN are used. Many of them propose water monitoring to obtain real-time information about parameters such as quality and component analysis.

The use of WSN is very useful these days. Bri et al. [24] in their article names the different use of this technology. Such are the monitoring of human health, industrial monitoring, military applications, environment monitoring, etc. in this article it also explains the architecture of these networks.

An example of the use of sensor networks is presented by Sendra et al. [10] a sensor network used to protect sheep from wolf attacks. This system works by measuring the body temperature and the heart rate of the goats (or sheep) and in the case of an attack, these parameters increase and therefore an alarm will jump in the system. Regarding sensor networks to monitor water O'Flynn et al. [11] explains the project Smartcoast a project that aims at the development of WSN that allows the observation of the sensors' data remotely. The system is based on "Plug and play" sensors that allow the integration of sensors with "Transducer Electronic datasheet" interface. These sensors will use a communication system based on Zigbee. The results of the study indicated that the use of these networks with low-energy consumption was viable.

Another example of WSN is developed for Sendra et al [12] developed a system with low-cost sensors to control the areas that present Posidonia grasslands. These sensors were mounted on a buoy and control different water parameters and measure meteorological parameters. The buoy has a system of solar panels for its operation. The data obtained are processed by a microcontroller and sent via wi-fi to the central server. From this, they are sent via the internet to the mobile or PC of the person in charge of surveillance. The WSN is also used for monitoring the tides. Parra et al. [13] designed a WSN for this purpose. In the proposed system each node sends the information to a central computer where the data is stored. The sensor used for monitoring the salinity is based with two coils of copper.The information obtained is useful for understanding changes in flora and fauna in an estuary.

The measure of water quality with WSN was studied by Simbeye et al. [14] and Rasin y Abdullah [15]. They proposed in their articles a WSN for monitoring different water parameters. The systems consist of sensor nodes, coordination nodes, and a PC. The sensor nodes control the different parameters and transmit the information to the coordinating node using the Zigbee protocols and this information is sent to the PC where it will be displayed visually. The use of open-source hardware and software was used by Rao et al. [16]. They presented a low-cost WSN to detect physicochemical parameters, which operate autonomously. Different sensors were connected to an Arduino Mega 2530. These sensors included temperature, pH, and oxygen content. According to the author with the correct calibration, it can establish a reliable monitoring system, with better resolution than current systems. It helps to understand the behaviour of aquatic beings. Lastly, Santoshkumar and Hiremath [17] proposed a system based on the measurement of pH, salinity, and temperature for the monitoring of aquaculture using an Arduino microcontroller and a Zigbee protocol.

III. WSN PROPOSAL

In this section, the WSN proposal is presented. First, the development of the employed turbidity sensor is shown. Then, the deployment and some real time measures are detailed. The details of the node used in the WSN are shown. Finally, the architecture is presented.

A. *Turbidity sensor development*

In this section, the development of the optical sensor employed for turbidity monitoring is presented. To create this sensor, an infrared (IR) light emitter and detector have been used. The sensor is based on the design presented by Sendra et al. [12]. As a light emitter, an IR LED with peak wavelength of 850nm is selected. As a detector, an IR photodiode with a sensitivity range from 790 to 1050nm is used. The IR LED is placed at 180º from the IR photodiode. The emitter and the receiver are separated by 6.5 cm. From those 6.5cm, 2.7cm are occupied by the water.

In order to calibrate the sensor, different turbidity samples, composed of water and sediment, are used. The sediment is formed by silt. The reason to use silt is because usually in fish farms the coarse materials and sands are stopped. Only the fine sediments can arrive to the cages. For the calibration of the sensor, 5 different turbidity samples are generated. The sample with less turbidity contains 0mg/L of silt. On the other hand, the sample with the highest turbidity contains 378.55 mg/L. All the samples were homogenized before performing the measures. The results of the calibration process can be seen in Fig. 1. The mathematical model that related the response of the photodiode (MΩ) with the turbidity (mg/L) is shown in equation (1). It presents a correlation coefficient of 0.99918159 and a mean absolute error of 3.8651793. In the equation (1): *Turb.* represents the turbidity and *IR* makes reference to the response of the IR photodiode. After the calibration, a verification process is carried out. For this verification process, two new samples were generated and measured. Then, the equation (1) is applied to evaluate the goodness of the mathematical model. In Table 1, the results of the verification process are presented. The maximum absolute error is 4.76 mg/L and the highest relative error is 4.37(%). The verification process shows that the calibration has been performed correctly.

The equation (2) shows the relation between turbidity and the received signal in volts in the Flyport after the conditioning circuit. The objective of this conditioning circuit is to ensure that the receiver signal in volts is lower than 2V, a voltage divisor is used with a secondary resistance of 2.5 MΩ. The input voltage employed has 4.5V. The resultant output voltage or signal is between 1.24V and 1.65V.

$$Turb.\left(\frac{mg}{L}\right) = 377.36 + \frac{81.14}{\mathrm{IR}\ (\mathrm{M\Omega}) - 3.90} - 46.66 * \mathrm{IR}(\mathrm{M\Omega}) \quad (1)$$

$$Turb.\left(\frac{mg}{L}\right) = 2.46 \times e^{3.22 \times Signal\ (V)} - 136 \quad (2)$$

Tabla I. VERIFICATION OF THE CALIBRATION PROCESS

Real Turbidity *(mg/L)*	**Response of IR photodiode** *(MΩ)*	**Calculated turbidity** *(mg/L)*	**Absolute Error** *(mg/L)*	**Relative Error** *(%)*
108.86	6.36	113.618032	4.76	4.37352042
373.14	4.32	369.784656	-3.36	-0.89997734

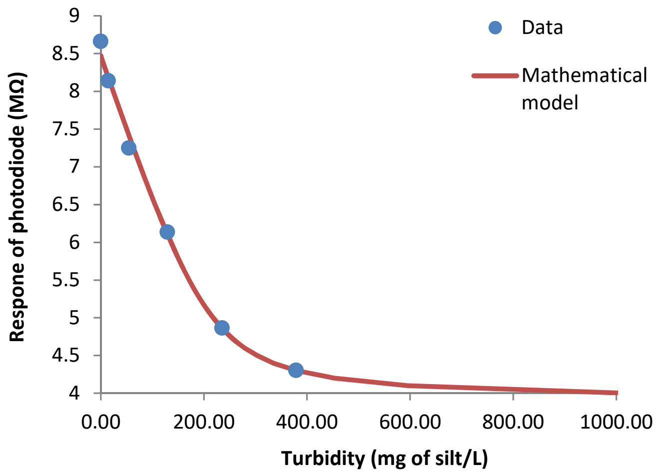

Fig. 1. Calibration of the optical IR sensors

B. Employed Node

Next, the node employed in our WSN is presented. The chosen node is the Flyport module [25] with the USB Nest (see Fig. 2). It is based on the openPicus platform with open code.

The node includes a 16 Bits processor, the PIC24FJ256, with 256K of flash and 16K de RAM. It supports the wireless connectivity of standards 802.11 b/g/n. The size of this node is 35x48x7 mm and a weight of 11g. It can be powered at 5 or at 3.3V. The node can be seen in Figure 2. The main reason to select this module is its flexibility with its several inputs and outputs. The possibility to use analogic or digital inputs is also suitable for our purposes. Finally, the possibility of programming it for different applications is crucial.

C. WSN deployment

In this section, the sensor deployment is described. First, the isolation of the sensor and the node are shown. Then, the location of the sensors in the box is detailed. Finally, the .distribution of nodes along the fish farm is explained.

Considering that our objective is to monitor the water turbidity, it will be needed to locate the sensors in the water. Thus, it is necessary to ensure the sealing of the receptacle where the sensors and the Flyport will be placed. The maximum depth where the sensors must be located is lower than 1 m depth; O-rings will be used to ensure the sealing. A sealed box made of thermoplastic is used for this purpose. The size of the box is 17,5x11,5x7cm. The closure of the box has been modified and tested to ensure the sealing at 1.5m depth in an aquaculture tank. Before to perfome the test, two holes have been done in the box to allow introducing a crystal pipe. The pipe has a diameter of 2.7 cm. It will permit to take the turbidity measures by allowing the water pass along the box. To seal the gasket between the tube and the box a special silicone has been used.

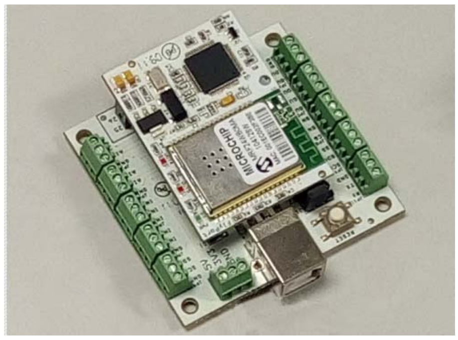

Fig. 2. Flyport module

Three sensors have been placed in the sealed box. First, the turbidity sensor is located next to the crystal pipe. The second employed sensor is the temperature sensor. It is based on a Zener diode with 2 terminals. The sensor is already calibrated with an error of 1ºC. The temperature sensor is located ensuring the contact with the crystal pipe. This location has been selected because the crystal is better temperature conductor than the plastic. The main reason to use this sensor is due to the temperature is a crucial parameter for fish bioenergetics performance. The last employed sensor is a humidity sensor. This sensor is located in the bottom of the box. The function of the humidity sensor is an early detection system. The system will detect an increase of humidity in the box in order to prevent damages caused by water. To power the sensors a 9V battery is employed. To power the Flyport a 5V external battery is used.

The nodes are located in different points of the fish farm, in the production tanks and in the reception tank. In the production tanks one node is located in the middle of the tank, next to the wall. In the reception tank two nodes will be located one at the water entrance and the other at the water exit.

D. Architecture

In this section the topology and operation system of our proposal are shown.

The employed topology for our proposal is based on an extended star. The Flyport devices are connected to an AP by a WiFi connection. The APs are connected to a Switch, by Ethernet connection, which is connected to a Router to have internet access. The network topology is shown in Fig. 3. There are two APs where the Flyports are connected and another AP where the other devices are connected. These devices include computers, smartphones and a server. The server collects all the information gathered by the sensors. The rest of devices can access the server to visualize the data. The information can be accessed in local mode or in remote mode.

The physical topology is conditioned by the fish farm structure. In this paper, we use the structure of the majority of the fish farms without recirculation system (See Fig. 4). Those infrastructures have a big reception tank, which is generally placed on a higher floor than the production tanks. Moreover, there are one or more rooms in both floors designated to offices. The environmental conditions in the tanks zone include high humidity and a huge amount of water flowing. In some facilities they employ saline water. Those conditions favour the corrosion. For this reason, it is important to minimize the network devices included in this zone. Thus, the Switch and the Router are placed in the offices. In the tanks zone only the APs needed are placed.

At the water entrance and exit of each tank there are valves that can turn on and turn off the water. Our proposal is to monitor the levels of turbidity in the water of the reception and the production tanks. If an increase of the turbidity is detected in the reception tank, it is possible to isolate some of the tanks. Not all the tanks have the same fish and not all the fish have the same needs. By the other side, if the humidity sensor give a lecture higher than 50%, it will action a system to prevent further damages in this node.

Finally, the algorithm that regulates the operation of the proposed system is detailed (See Fig. 5). Initially, the tanks rows (*TWi*) are defined as Row 1 (*TW1*), Row 2 (*TW2*) and Row 3 (*TW3*). Each row has each own water quality requirements attending to the fish type that is in each tank row.

Once the Flyport receives the sensor signal identify each signal as *Turbidity*, *Humidity* or *Temperature* according to the analog input. After that, those signals are converted into digital values and transmitted to the server and to the users over HTTP. Only the values of *Turbidity* and *Temperature* are transmitted. The data of *Humidity* is only used as a security mechanism to prevent physical damages in the Flyport.

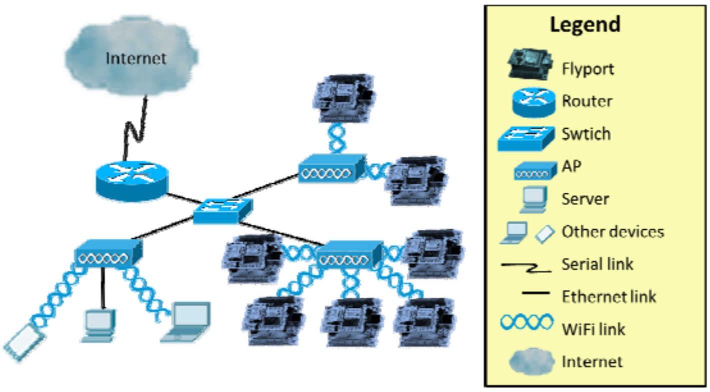

Fig. 3. Network topology

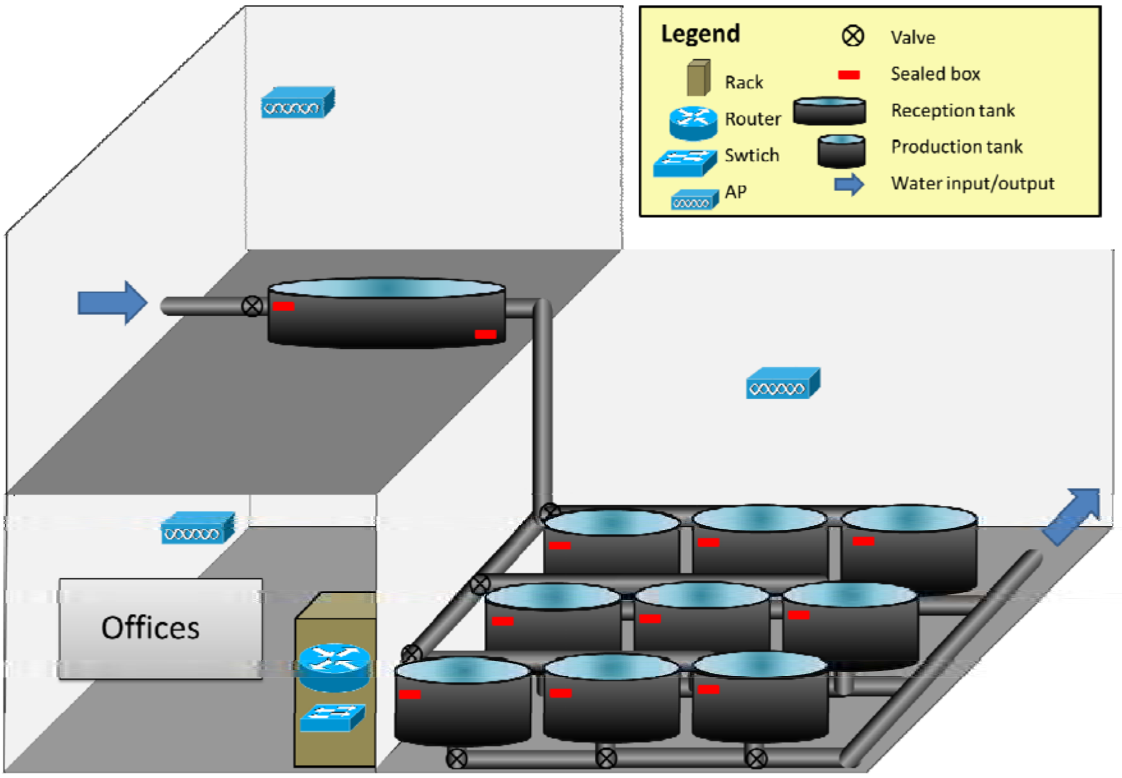

Fig. 4. Physical topology

If this value exceeds an established threshold (50% of relative humidity), a process is triggered. This process will send an alarm to the maintenance workers and will initiate an emergency shutdown in order to avoid electronic damages. In the alarm message it is indicated the number of the tank where the alarm is generated and a worker will change the sealed box with all the components for a new one. The old sealed box is taken to maintenance to check is there are damages or not and to reboot the system.

On the other hand, if the level of *Turbidity* exceeds the established thresholds of water quality, the system will proceed to stop the water flux to some of the tanks. Previously, the person in charge on the production has established the thresholds according to the fish species and stage of development that are being kept in the tanks. Thus, he will establish a threshold to each tank row. In the moment that a row of tanks is isolated from the water flux a timer will be turned on. This timer will record the time that this tank row has been isolated. This information will be used by the person in charge of the production to restart the water flux even that the water quality remains lower in order to avoid low oxygen concentration in the tanks. Likewise, the alarm that a row has been isolated will be sent also to the workers. The workers must pay special attention to those tanks.

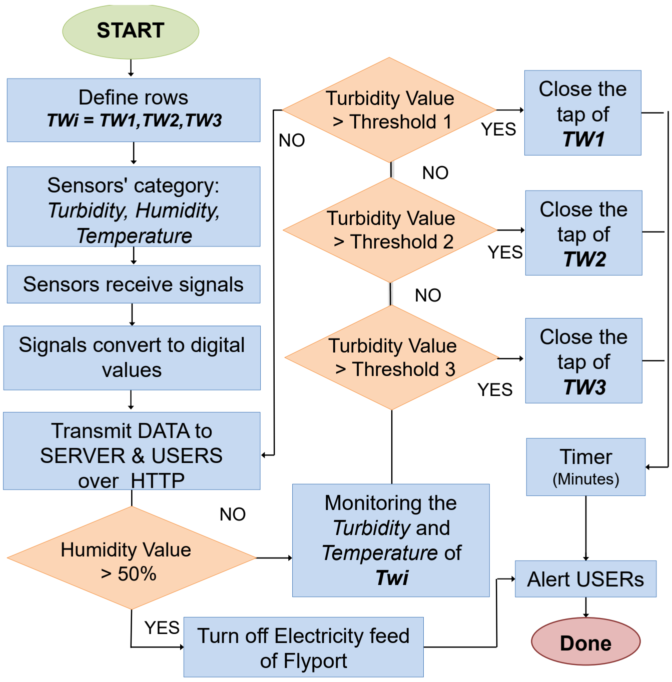

Fig. 5. System operation

IV. WSN Performance

In this section, the performance of the WSN is analyzed. Our main objective is to ensure its performance, obtaining low packet loss rate. We need to minimize the number of AP deployed in the tanks zone. For that, we develop several tests connecting a different number of Flyports to an AP. The network performance will be evaluated next.

The studied network parameters included the transfer packets per second, the rate of packets loss and the retransmitted packets per transmission. Different scenarios have been studied with a different number of wireless nodes connected to an AP. In the scenarios, various wireless nodes will be used which enumerate from 1 Flyport to 10 Flyports connected to the same AP. First, is analyzed the results of the packets per second transmitted in the different scenarios (See Fig. 6). It is possible to see how as the number of nodes increase the number of packets per second received in the AP increase. The average of packets has been transferred per second throughout the AP with connected 3, 5 and 10 Flyports in period of 60s is 70.33, 86.47 and 95.42 pps respectively.

The standard deviation for 3, 5 y 10 wireless nodes is 6.28, 4.55 y 3.43. The results demonstrate that how number of few connected Flyports use less throughput of packet transmission with high fluctuations.

As shown in Fig. 6. To have more information about those fluctuations the maximum and minimum amount of packets per second are determined. With 3 Flyports connected the maximum rate is 80 pps and the minimum is 60 pps. For the configurations with 5 and 10 Flyports the values are: 80 and 95 pps for 5 Flyports and 90 and 100 pps for 10 Flyports.

Next, the packet loss rate during 60 sec. is analyzed. In this test, several experiments have been used, from 1 Flyport per AP to 10 Flyports per AP. The results can be seen in Fig. 7. We can observe that less than two Flyports no packets have been lost in the tranmission period. Between 3 to 7 Flyports less than 1% of the packets are lost. Nevertheless, with more than 8 Flyports per AP the packet loss rate rockets, reaching the 3.5% with 10 Flyports.

As the Flyports supports TCP, it is capable of retransmitting the lost packets. The information related to the retransmitted packets can be seen in Fig. 8. It is shown the retransmitted packets at intervals of 10 sec. when there are 3, 5 or 10 Flyports connected to the AP. We can see that with 3 Flyport, only in 2 intervals is needed to retransmit packets. In both cases 1 packet was retransmitted. For 5 Flyports, in 4 of the intervals packets were retransmitted, the amount of retransmitted packets goes from 1 to 3. In the scenario with 10 Flyports, during 4 intervals retransmitted packets were detected. The maximum number of retransmitted packets was 5. As higher is the number of packets higher retransmission is needed and higher is its variability. In global terms, the scenery with 3 Flyports present 2 retransmitted packets, the number increases to 7 and 14 for 5 Flyports and 10 Flyports respectively.

The best option to minimize the number of AP without losing network performance is to select 5 Flyports per AP. Moreover, the observed results show scalability of the proposed system, which able to accept increased volume of high connected Flyports. Thus, sleep mode of flyports scalable with respect to reduce high-energy consumption and reduce cost effective from damages.

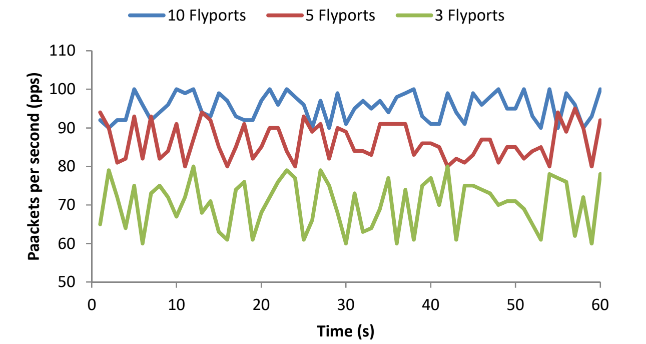

Fig. 6. Packets per second in different scenarios

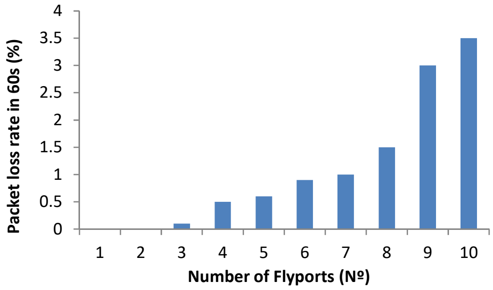

Fig. 7. Packet loss rate in different scenarios

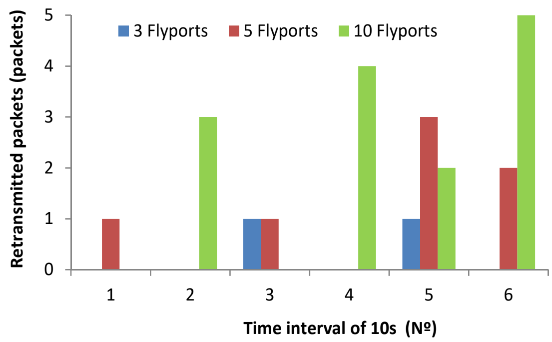

Fig. 8. Number of retransmitted packets in different scenarios

Finally, we show the appearance of the different visualization systems. First, in Fig. 9 we can see the aspect of the data shown in the server after select one node. In the main window of a node that belongs to the reception tank the server presents the data of the last 60 minutes from turbidity and temperature. In the graphic of turbidity it is possible to see the currently established thresholds in different colours. In the bottom we can see if there is any alarm due to turbidity values and the duration of each alarm. From this window it is possible to select another node to see its data. When the selected node belongs to a production tank the appearance of the window is shown in Fig. 10. In the upper part, it is possible to see the graphics of temperature and turbidity with the threshold of the selected tank. In the bottom is presented the alarms generated in the last 60 minutes in this tank. Moreover, we can see the timer of the alarms in the last 60 seconds and the timer of the accumulated alarms in this tank in the last 24 hours. The Fig. 11 presents the information received in a smartphone from two different alarms. On the left is shown the information of one alarm triggered by humidity. The information includes the type of affected tank (production or reception) and the number of the tanks. In the case of a production tank, the alarm will show the number of the tank. In the case of reception tank, it will show if is the node at the entrance or at the exit of the tank. Moreover, a figure with the exact location of the node is presented. At the right is shown the information of a turbidity alarm. It contains the information of the affected row (Row 1, Row 2 or Row 3). Besides, it contains information of the timer or this alarm.

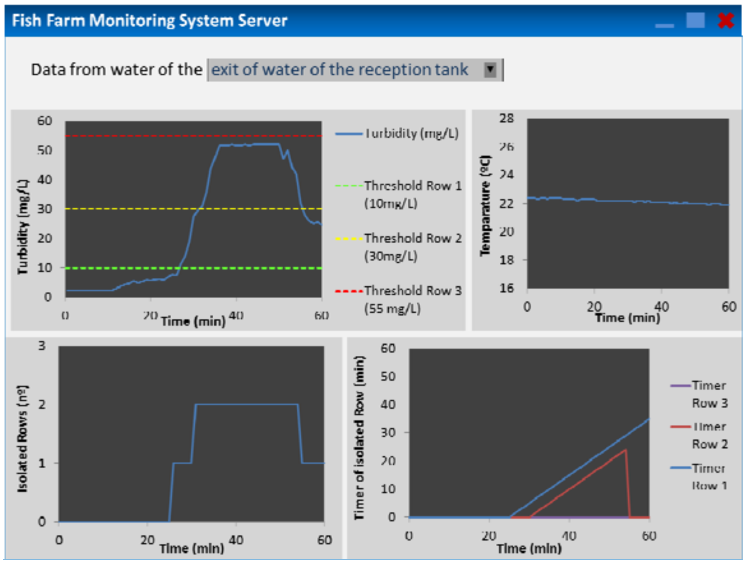

Fig. 9. Server appearance showing reception tank information

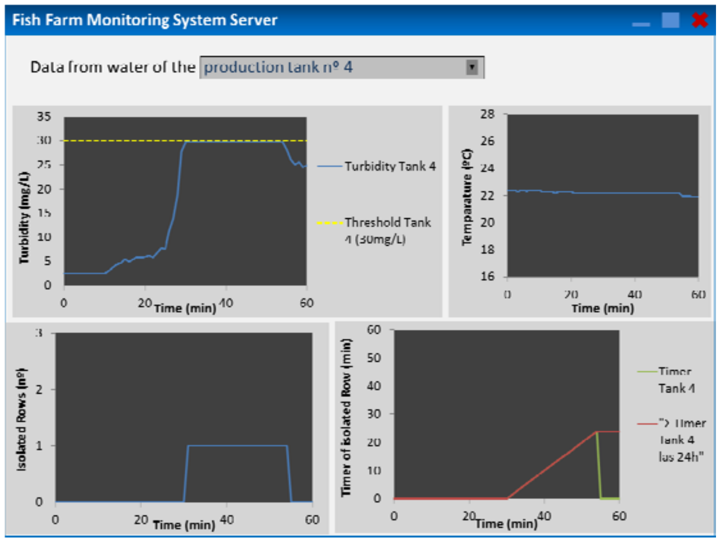

Fig. 10. Server appearance showing production tank information

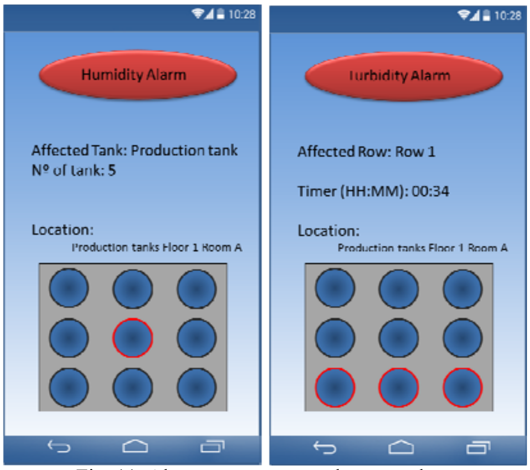

Fig. 11. Alarm appearance at the smartphone

V. CONCLUSIONS

In this paper, the design of a WSN for fish farms monitoring have been presented. First, we have shown the turbidity sensor and the employed node. Then, the operating system is presented and the sealed box is tested. Next, the topology is shown. Finally, the network performance is evaluated and the appearance of the server and the alarms are exposed. The effect of changing the number of Flyports per AP is studied.

As future work, we will introduce authentication system to access to the server and other sensors as [26] will be added to monitor the fish behaviour and other water parameters to automatize some process

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