

Sensor Network in the Wireless UHF Band

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Abstract. Biological research in agriculture needs a lot of specialized electronic sensors in order to fulfill different goals, like as: climate monitoring, soil and fruit assessment, control of insects and diseases, chemical pollutants, identification and control of weeds, crop tracking, and so on. That research must be supported by consistent biological models able to simulate diverse environmental conditions, in order to predict the right human actions before risky biological damage could be irreversible. In this paper an experimental distributed network based on climatic and biological wireless sensors is described, for providing real measurements in order to validate different biological models used for viticulture applications. Firstly the experimental network for field automatic data acquisition is presented, as a system based in a distributed process. Then, the design of the wireless network is explained in detail, with a previous discussion about the state-of-the-art, and some measurements for viticulture research are pointed out. Finally future developments and conclusions are stated.

1 Introduction

The experimental wireless network is deployed in a peninsula surrounded by two large sea arms called “rias” in Spanish language. In that peninsula, located in the northwest of Spain (near the northern border of Portugal), on the autonomous region called Galicia, the vineyards have four main productive zones called: Meaño, Cambados, Ribadumia and Meis (Fig. 1).

Currently differences in productivity and quality of grapes are broadly related with relative heights and sea proximity from each of four zones but nevertheless more rigorous biological and climatic research [1,2] must be done, in order to provide accurate biological models for ecological simulations applied to viticulture. The relevant pests of vineyards to be detected by such models are: *Botrytis Cinerea* (noble rot), *Plasmopara Viticola* (downy mildew) [3] and *Uncinula Necator* (powdery mildew) [4]. For that reason multidisciplinary work must be done among electronic engineers, biologists and ecologists.

Each zone has an electronic zonal station (EZS), in order to bring differences (microclimates), in measurements like: temperature, relative humidity, leave humidity, soil temperature, solar radiation, rain gauge (tipping bucket), and other biological sensors. A data logger and a radio modem is included in each EZS in order to sense, process and transmit the data, enabling the development of an automatic wireless sensor network (WSN), which nodes (the EZSs) are accessible from a wide area. These wireless communication capabilities allow that

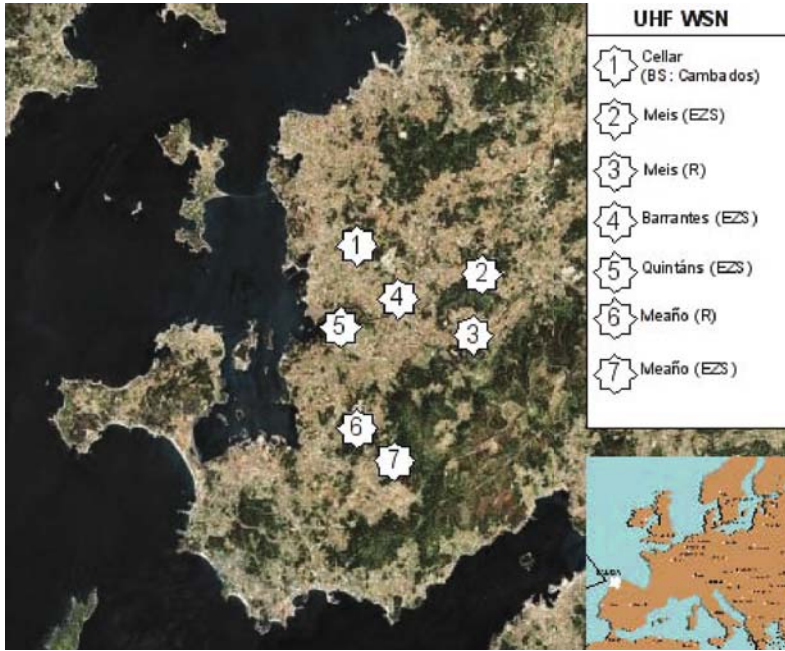


Fig. 1. Peninsula photograph

data could be remotely monitored. The implementation of a warehousing approach, allows the data to be stored in a centralized database that is responsible for query processing. The stored data will be used for biological and ecological models.

This article is organized in seven parts including this introduction. Part II describes the Data Acquisition System. Part III outlines the global data management. Part IV provides a state-of-the-art in wireless sensor networks. Part V details the implementation of experimental WSN. Part VI explains the propagation measurements made by an emulated WSN. Finally, parts VII and VIII present the future developments and conclusions.

2 Data Acquisition System

The electronic zonal stations (EZSs) are connected with the base station (BS) by the UHF band (not licensed) between 869.4MHz to 869.65MHz, and the BS is also connected through Internet to the Data Base (DB), the biological and ecological models (BEMs), and to the Web access (Fig. 2). Each zonal station comprises an UHF radio modem that transmits the sensors information to the BS through a data connection. A powering solar panel (PSP) is located near each EZS for feeding its circuits. In order to reduce the amount of data stored in the EZs, the BS establishes a data communication to all the EZSs every hour by means of a polling procedure [5]. During these calls the EZSs send all the

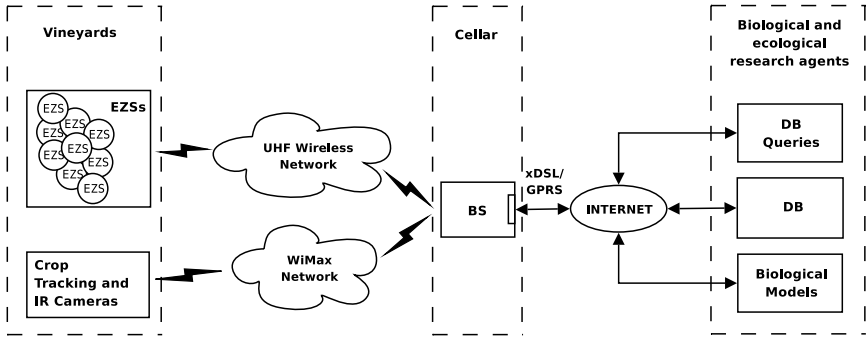


Fig. 2. Network architecture and database interfaces

information that has been stored on that period. Therefore the BS periodically executes the reading data process and later database storage of the received information, through an Ethernet local area network.

2.1 Data from Sensors

An electronic zonal station (EZS) is the basic acquisition equipment of the distributed system, which carries out the data registration (measurements and processing), and the communication with the base station (BS). In this way, each EZS comprises an automatic measurement unit with data transfer capability. The data acquisition process is made inside the EZS by the sensors and the data logger. Each EZS comprises the following sensors: temperature, relative humidity, leave humidity, soil temperature, solar radiation, rain gauge (tipping bucket), and other biological and ecological features depending on running models [6].

All that sensors are integrated in the data logger. The data logger is the EZS nucleus; it captures the data from each sensor, automates the measurements, synchronises the data and manages the communications. The data transmission is carried out by means of the data logger and the UHF radio modem connected to it. Next, the data captured by the EZS is sent to the database (DB), through the base station (BS), where they are saved. The communication process setting, through the UHF radio modem connected to the data logger, allows the control and programming of several tasks as well as the acquisition of stored data.

The data captured by the data logger are organized in registers. The registers comprise the sensor outputs as well as the time and date. These registers are then sent to the storage system where they are saved for a future access. The data logger is programmed for capturing and storing the sensors information each minute. Figure 3 illustrates the data logger, the storage system, the UHF radio modem and connections with the sensors and electrical supply. All these elements are placed inside a box which protects them from the weather conditions. This box and all the sensors are fixed to a metallic base located at the site (Fig. 4).



Fig. 3. EZS data acquisition and communications system assembled in the protection box



Fig. 4. Final assembly and EZS installation

3 Global Data Management

The information obtained from the EZSs are collected by the BS and stored in the DB for later process, analysis and query. The BS requests and compiles the data from the different EZSs to store them in the DB. Also the BS is provided with an UHF radio modem to make the polling query of each EZS in the wireless network. Therefore the BS is a PC connected to a wireless network and Internet that executes the developed program to perform its operations flowchart. The figure 5 shows this flowchart.

Since all the measured data must have the same time reference for its later process, the BS obtains the system reference clock from a real time network server by the NTP synchronization protocol (Network Time Protocol). So after the data have been obtained, a time synchronization test is verified for the EZSs clocks, to determine if the collected data can be considered valid. If this is the case, the information is stored directly in the DB. Otherwise the problem is corrected (if it is possible), it is notified by e-mail and/or a message, and finally the data and the error information are stored. In this way it is possible to know exactly when and what type of errors took place and, depending on this information data can be corrected.

The data from the EZSs are centralized in a relational database. This DB presents one interface with the BS through which all the system information is introduced, and three interfaces to access this information: general data access, access to interesting data to analyze viticulture features, and query of data for providing models (Fig. 5). The interface between BS-DB and queries-DB are executed directly by means of ODBC (Open Database Connectivity).

The general data access will directly take place through an Internet accessible Web page. Whereas for queries related to the analysis of viticulture features and models, the access is made through specific views for each type of study [7]. Figure 6 shows an example of the EZS data management. This picture illustrates the structure of communications among equipments, interfaces and layers.

4 The State-of-the-Art and the Implemented Network

Past decade has been very fruitful in the development and application of several standards for mobile, nomadic and fixed wireless networks related with sensors [8,9,10]. Some specific problems about this kind of networks have been well studied, like: energy efficiency due to collisions, overemitting-receiving, control of packets and idle listening; scalability and changes adaptation in network size, node density and topology; communication paradigms like node-centric, data-centric and position-centric; and many others.

Nevertheless this great researching effort over wireless networks for sensors, there is no any accepted Media Access Control (MAC) for them, because this kind of sensor networks has a very big dependence of the application. Recent surveys about the most advanced wireless networks like MANETs [11,12] show poor real results in front of expected ones, because the great complexity involved

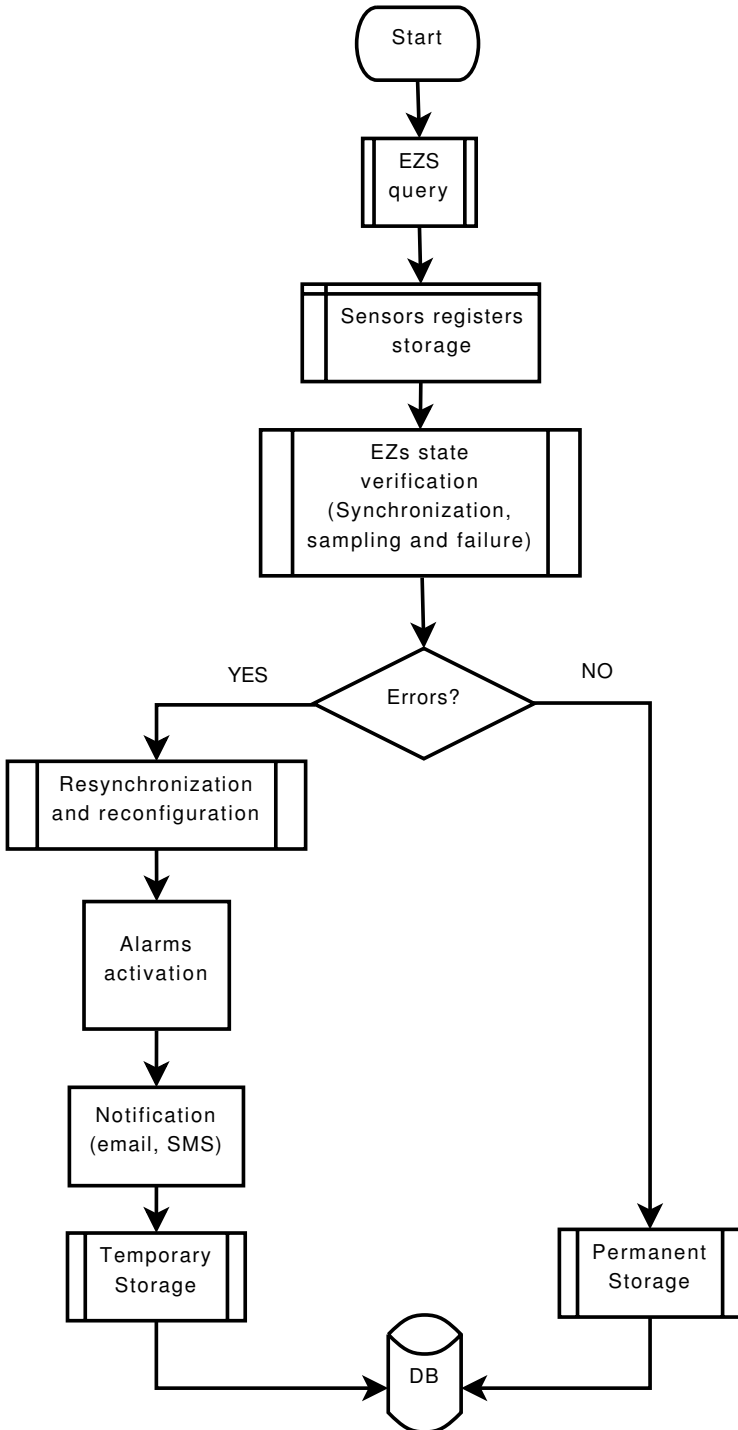


Fig. 5. BS operations flowchart

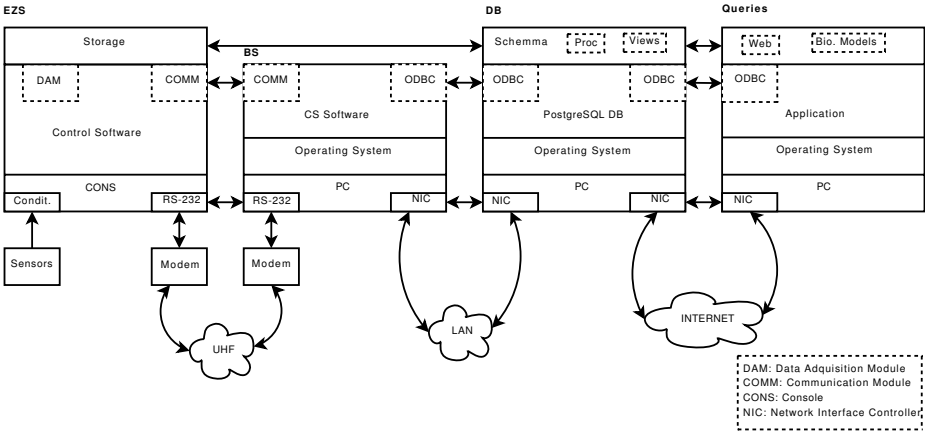


Fig. 6. Communication example between equipments, interfaces and layers

in simulated MAC protocols [13], on big programming tools, was not after validated with implementation, integration and experimentation over real equipment (chips, microcircuits, modems, antennas, and others). In this way, a particular field of application, called “wireless sensor networks” (WSN) is proposed for environmental monitoring, industry [14] and precision agriculture, among other sectors of activity. The WSNs are featured by a stronger interdisciplinary collaboration for creative projects, and a change in the communication paradigm from node-centric to data-centric one, because the main point is the transfer of data from the application field, and not the communication between all the network nodes.

4.1 The Wireless Sensor Network (WSN)

Several comparatives among general wireless standards like ZigBee [15,16], Ultra Wide Band (UWB) [17], Bluetooth [18] and WiFi [19] have been made in order to evaluate some examples of application included industrial wireless sensors [20]. Also, more specific WSN applications could be found about environmental research like: hydrology [21], fire monitoring [22], deep ice [23], climate monitoring [24] and others [25].

Given the hilly nature of the vineyard zones, the coverage challenges for linking the EZSs with the BS were founded in power, data speed and acceptable error ratio. For example, in the Meis zone the coverage area was over 5km, with difference in heights about 200m, very prone to interpose obstacles in the line-of-sight (LOS) among EZS-BS. In order to achieve a wireless network with very low cost and reduced power consumption, because static nodes are transmitting infrequently (low duty cycle) only two-way small data packets, the European ISM band (868-870MHz) was selected, where one channel with a data rate of 20kbps is available [18]. In this ISM band the used radio modems for linking EZS-BS, have the following features: 10-500mW of transmitting power, 25kHz of channel spacing, half-duplex communication, 10% duty cycle and 36 seconds

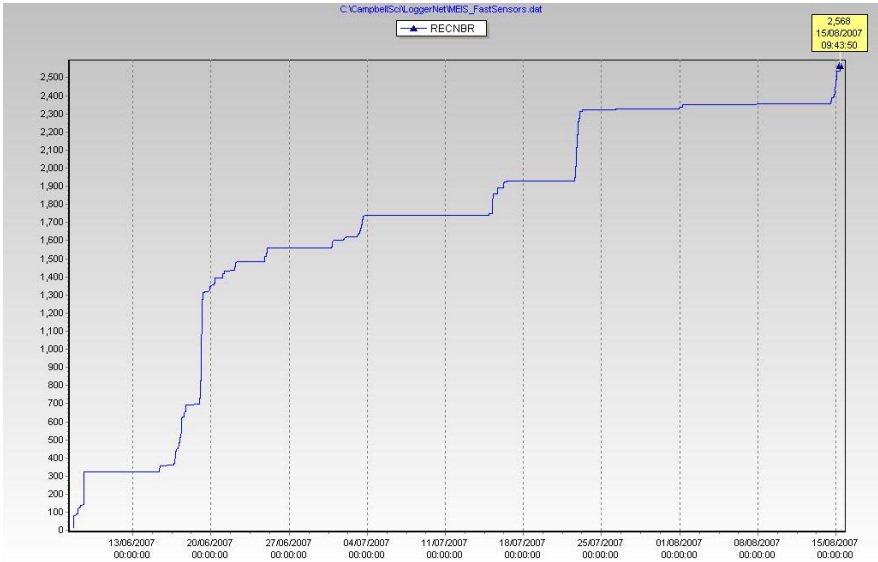


Fig. 7. Measured rain plot

of maximum emission time (must be controlled by the data logger). To avoid an obstacle in the LOS between the BS and the EZS, a repeater station (RS) is inserted with other ISM radio modem and a directive antenna, linking the EZS (2.1km) with the BS (5.17km). Figure 7 shows an illustrative example of measured rain series carried out between EZS-RS-BS in the Meis zone.

5 Implementation of the WSN in the UHF Band

The wireless network has been implemented using dataloggers from Campbell (CR1000 series) linked by radio modems (Satellite 3AS). Those radios are working in the UHF band (869.400-869.650 MHz) that is unlicensed in Spain. Power emission is limited until 500mW and the data speed is about 19,200 bps for a 25 kHz half-duplex channel. Without obstacles (LOS) the coverage can be more than 5 km at the maximum allowed power [26].

One of the advantages of those radio modems is the capability of routing data packets among them, making more or less complex networks of nodes depending on the wireless applications. For configuring this kind of networks a unique address is assigned to each radio modem, and all possible routes must be declared on the node where the polling procedure is controlled (BS). Therefore this network configuration is only valid for centralised architectures, where a central station makes periodically the queries to all nodes of the wireless network [27].

Each EZS is made by a data logger and its corresponding radio modem both connected by a serial port with a bit rate of 9,600 bps (RS232). In most cases dedicated repeaters are not necessary given that every radio modem, how has

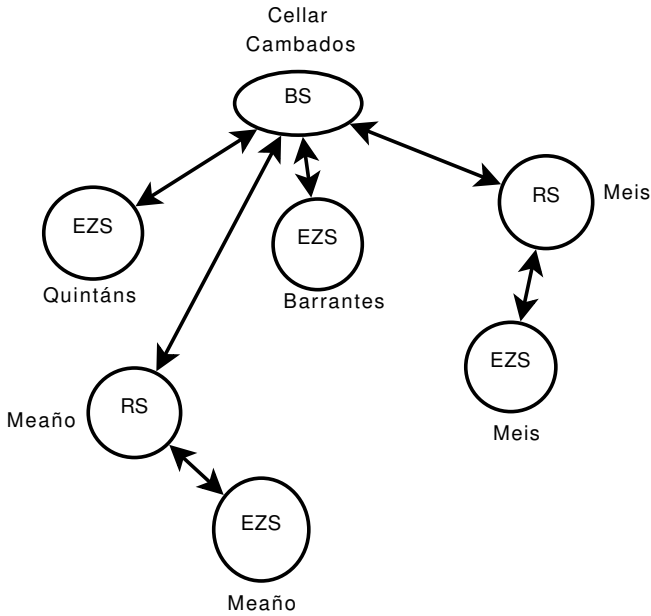


Fig. 8. WSN configuration

Table 1. Routing and addresses of stations

WSN	Address	Route	Hops
Cellar (BS: Cambados)	1	—	—
Meis (EZS)	2	3-2	2
Barrantes (EZS)	4	4	1
Quintáns (EZS)	5	5	1
Meaño (RS)	6	7	1
Meaño (EZS)	7	6-7	2

been said, can be a repeater. Where NLOS must be supported then a radio modem will be used only as a dedicated repeater (RS). In the figure 8 the current designed WSN is shown, where four EZS's are linked with the BS, with two of them through one repeater (RS) each one. The table 1 specifies the routing map for the BS, and the table 2 justifies the relative positions and heights involved in the EZS's coverage.

The assignment of network addresses is the same as the data loggers CR1000. Those data loggers are connected using the proprietary protocol from Campbell called PakBus, which frames are composed following the figure 9. The starting configuration of routes and available wireless nodes is made in the BS. For each available EZS an unique address is assigned included the repeater address, if any, linked to its route. How has been said, a routing map is stored in the BS radio modem (Table 1). All EZS's and repeaters (RS) know the routing configuration

Table 2. Location of EZSs, Repeaters (RS) and BS

UHF WSN	Length (Km)	Area (m2)	Altitude (m)	Latitude (N)	Longitude (W)
Cellar (BS) Cambados	—	—	50	42°31'11.60"	8°47'33.28"
Meis (RS)	5.17	—	202	42°29'31.69"	8°44'13.13"
Meis (EZS)	2.1	15000	176	42°30'28.33"	8°43'31.3"
Barrantes (EZS)	2.6	5300	13	42°30'17.98"	8°46'5.36"
Quintáns (EZS)	3.31	4000	34	42°29'28.35"	8°48'14.53"
Meaño (RS)	7.64	—	135	42°27.3'3.42"	8°47'40.89"
Meaño (EZS)	8.61	5000	20	42°26'36.27"	8°47'8.99"

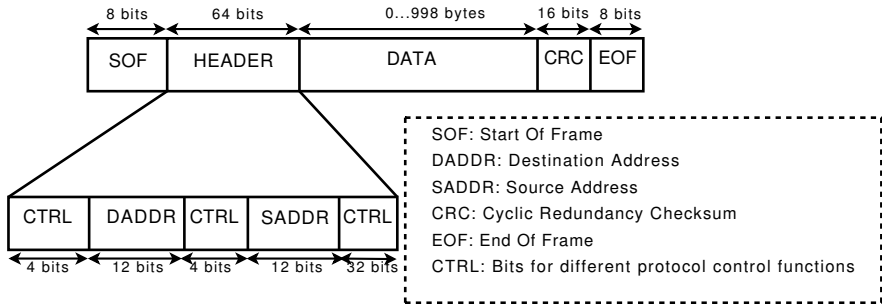


Fig. 9. Pakbus frame

when a frame comes through them, in order to send correctly the back data packet as response to a first query from the BS.

The PakBus frames used by the EZS’s are composed by a Start-Of-Frame (SOF), a header, the body of message, a Cyclic-Redundance-Check (CRC) and an End-Of-Frame (EOF). The header includes the destination address and the origin one. Using those data the radio modems are configured so that they can find the address within the packet. This is achieved setting the offset and the address length in the radio modem configuration, to indicate where to get the corresponding address inside the received frame from the serial port.

The configuration of the radio modems is accomplished using a serial terminal program, such as Hyperterminal in Windows or Minicom in Unix. The figure 10 shows the configuration menu.

The packet routing can be correctly executed if no fragmentation is assured over the frames from data logger, easing a correct location by radio modems of the message destination address. In that way it must be avoided that the received frames from diverse network nodes, could exceed the maximum allowed size limit per frame in the radio modems. In the implemented WSN this limit is 1 KB, because an overhead is imposed to the frames by the routing protocol of the radio modems. The configuration software of data loggers allows limiting the maximum size of sending frame, assuring no fragmentation in that way. It is worth to say that if a fragmentation occurs data will be lost, or even worse, no communication can be possible because only the first fragment of the frame

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***** SATELLINE-3AS *****
SW version x.yz / HW TC4x
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Current settings
-----
1) Radio frequency 468.5000 MHz ( CF 468.2000 MHz, spacing 25 kHz )
2) Radio settings  Tx power level 10 mW / Signal threshold -110 dBm / FCS OFF /
TX start delay 0 ms / Diversity RX OFF / EPIC PWRsave OFF
3) Addressing      RX address OFF / TX address OFF /
RX address to RS port OFF / TX address autoswitch OFF
4) Serial port 1  ON / 19200 bit/s / 8 bit data / None parity / 1 stop bit
5) Serial port 2  OFF / 19200 bit/s / 8 bit data / None parity / 1 stop bit
( RS-485/422 )
6) Handshaking    CTS Clear to send / CD RSSI-threshold / RTS Ignored
7) Additional setup Error correction OFF / Error check OFF / Repeater OFF /
SL-commands OFF / Priority TX
8) Routing        OFF
9) Tests          OFF
A) Restore factory settings
E) EXIT and save settings
Q) QUIT without saving

Enter selection >

```

Fig. 10. Radio configuration by the software tool

would be correctly received, given that radio modems would route erroneously the remainder fragments.

Even when the right configuration for avoiding the fragmentation is chosen, some problems can still arise. The radio modem splits data flow into frames based on the time delay between bytes. Normally the bytes of one packet are sent together but sometimes due to the operating system management of the serial device in the BS, a delay can happen in the middle of the frame sent leading to the fragmentation. Something similar can be found in the EZS. These errors are occasional and not fatal and they only cause a retransmission in the data.

The routing of frames is possible through the unique network addresses and inner tables of routing stored in the radio modems. Although the routing tables are only firstly configured in the BS, the intermediate wireless nodes hold actualised their own tables because the routing information is included in the frames sent by all radio modems. When the BS receives new data from the serial port, the radio modem gets the address network from received data. If that address is in their routing tables, this information is added at the beginning of the new frame to send close the original encapsulated frame and checking codes (CRC), and send it to the following hop in the route. Each radio modem receiving this message learns from headers the routes, and actualises correctly their own tables for getting aware of routing back messages.

The queries from the BS are implemented by a Campbell software tool called Loggernet. This tool discharges periodically data from data loggers (EZS's) configured in its database. For each data logger is configured an unique address and a station name with which data are stored. The Loggernet tool allows registering a lot of communication parameters such as: data speed of serial port, starting of

serial port, dialing of numbers for communications by GSM modems, etc. One of parameters with great interest is the time between retransmissions. This time should be great enough to allow that a data query could arrive to the destination data logger and return with requested data. Depending on network topology and the number of hops until destination, this elapsed time could be higher than a second.

It is very important that the computer, where the Loggernet program of data discharges is executed, had a dependable time reference. For that reason the NTP protocol is used [28], synchronizing the computer time through Internet with servers offering stable and dependable time references. Each time that the BS queries an EZS, it checks the time differences and if are relevant an adjustment is made in order to get a temporal coherence among data from all EZS's.

6 Future Developments

Experimental work over the implemented WSN is being made in the following lines:

- Addition of new climatic and biological sensors to the EZSs.
- Change of UHF proprietary modems for new RF modular technologies integrated by the authors, in order to enhance the WSN's capabilities.
- Deployment of new EZS over the four different vineyard zones for providing more spatial resolution to biological and ecological models.
- Design of a wireless broadband (20Mbps) network in order to provide crop tracking by real time images, and infrared cameras (zonal isotherm maps), by WiMax (IEEE 802.16) equipment [29,30,31] over the 5GHz ISM band (Fig. 2).
- Integrate those images in the global data management system, for giving to the biological and ecological researchers new knowledge for future enhancement of models.
- Propagation simulations with geographical data for the WSN deployment [32].

7 Conclusions

The authors have developed an experimental distributed network based on the WSN paradigm for wireless sensors. This WSN is based on the European ISM band for providing a low cost and low power consumption network, bringing real measurements to validate different biological and ecological models used for viticulture applications. Also a global data management system is designed to integrate consistently the measured data in the models. New developments in the experimental wireless network are being tested to add real time images and infrared cameras information, by means of broadband network standards.

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