A new Wireless Sensor for Intravenous Dripping Detection

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Abstract— **Nowadays the use of wireless technologies provides a great benefit to the society. This article shows a wireless sensor network for Intravenous Dripping System, which can detect when an intravenous liquid, provided to patients in hospitals, run out, as well as detecting obstructions in the catheter. This way, the attention in sanitary centers is more efficient and immediate, as the observation of the state of the container will not need human supervision. Also a novel algorithm has been simulated in order to improve the network with its own mobility.**

Keywords- Wireless Sensor, Dripping, Network, Device, low power consupmtion.

I. INTRODUCTION

The reduction of costs that the wireless technology is experiencing has incremented the number of applications which are able to implement this technology, in which medicine is one of the fields and is also known as "eHealth". This has caused many companies to dedicate their research into the development of wireless sensor platforms for generic use, which entails having complex operating systems, meaning a high consumption of energy.

The sensor network we are proposing has been developed focusing on the application, the detection of the intravenous dripping, for which the cost and the energy consumption have been optimized.

This sensor network is formed by different wireless devices, which are placed in the drip chamber of the patients, and by a central device located in every room of the sanitary center. The wireless device consists of four modules: the sensor module, the radio module, the feeding module and the microprocessor.

It is possible to emphasize that this article includes the study of the dripping detection techniques, as well as the development and implementation of the sensor and the base station. In this moment, the project is focused on the implementation of the location and routing algorithms of the sensor network.

A. State of art

There are different techniques for dripping detection; therefore a practical study on the effectiveness of these techniques has been carried out, in order to detect the dripping within the intravenous drip chamber. This will allow us to choose the most suitable method for our sensor.

As a reference of the different detection methods, several patents dealing with all the ways of dripping detection have been consulted and tested. These methods can be divided in the following sections: ultrasounds[1][2], piezoelectric materials [3], applying capacitive electrodes [4] and optical methods [5][6][7], which can be described follow.

1) Ultrasonic method

This dripping detection method consists of the detection of the tension variation produced by a drop that crosses a beam of ultrasounds. The ultrasound emitter generates a wave at a frequency of 25 KHz, which is detected by the receiver. The effect produced by the crossing of a drop between the emitter and receiver has been analyzed. The scheme of the assembly is shown in Figure 1.

Figure 1 Ultrasonic method

It has been observed that the amplitude of the tension in the receiver varies depending on the obstacles that are between emitter and receiver.

This method may present some more disadvantages, like the fact that when the patient moves, moving the dripping chamber at the same time, the ultrasonic detection may be inaccurate, or even not work.

2) Piezoelectric method

Sheets of piezoelectric material have been used for the implementation of this method (see Figure 2). The piezoelectric material has the characteristic of varying the voltage between its tips due to some mechanical deformation

to which it is exposed. Thus, external vibrations will be able to be detected by a minimum deformation in this material.
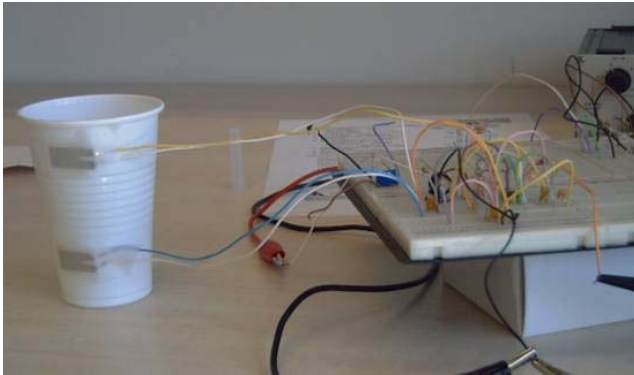

Figure 2 Measurement assembly with piezoelectric material

The technique of using piezoelectric materials can be optimized in order to obtain the dripping detection. However, we can see that the external vibrations affect the measures, thus making this method invalid for the mobile dripping systems.

3) Capacitive electrodes

The capacitive electrodes method consists in the detection of the capacity variation between two copper sheets produced by the dielectric change generated by the crossing of a drop through the generated field. In Figure 3 the assembly can be seen.
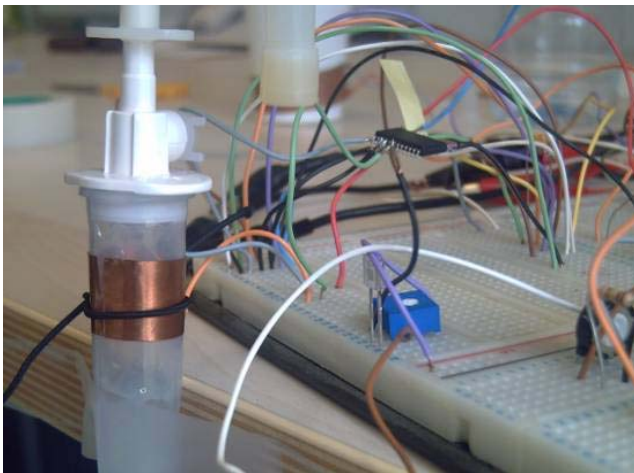

Figure 3 Measurement assembly of capacitive electrodes

The capacity between electrodes follows this equation:

$$C = \frac{k.\varepsilon_0.A}{d} \qquad (1)$$

Where:
C = capacity in Faradays.
A = area of copper sheet in m2.

d = distance between sheets in meters.
k = dielectric constant of the inter-sheet material.
ε0 = permitivity in free space (8.85x10-12 F/m).

In order to ease the calculations when the materials between the plates are different, the capacity also could be defined as:

$$C = \varepsilon_0 \frac{A}{l_e} \; \alpha\nu\delta \; l_e = \frac{l_1}{\varepsilon_1{}'} + \frac{l_2}{\varepsilon_2{}'} + ... + \frac{l_n}{\varepsilon_n{}'} \qquad (2)$$

Where l_e is the equivalent thickness, ε_n' is the relative permitivity of the material and l_n the length. If we consider that the media is isotropic, homogenous and linear $k = \varepsilon'$.

Having in mind the material of the drip chamber (polyurethane) and making the suitable operations, the capacity between the electrodes varies a bit with the passage of the drop, which makes the detection circuits more complex.

4) Optical method

The optical methods try to detect a variation in the tension level in a phototransistor or photoelectric cell, produced by the deflection of the beam of light generated by the passage of the drop. To achieve that, visible LEDs (Light-emitting Diode) of diverse colors, infrared LEDs and lasers have been used as emitters, whereas, phototransistors and photoelectric cells have been used as receivers. In Figure 4 one of the assemblies of the optical method can be seen.
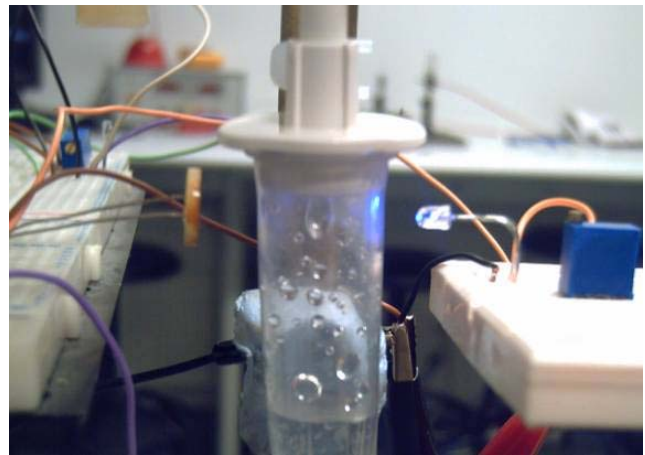

Figure 4 Method of optical measurement

Using these optical methods the dripping detection through the intravenous drip chamber is possible. The use of this method for the implementation of our sensor has been chosen, which has fundamentally lower cost, minor circuital complexity and low energy consumption, because the sensor will be battery-fed.

B. Aims of the system

The overall objective of the system is the dripping detection of all the patients in a sanitary center and to contact with a control center, so that the personnel in charge

attending to the patients will be more efficient. To do that, the system is equipped with wireless sensors for dripping detection and central devices in charge of receiving and redistributing the signals received by the wireless sensors.

Besides, the system is optimized to minimize the energy consumption as well as the cost. The energy consumption optimization is done in each module, achieving a considerably long battery life.

There are other similar thematic articles which are not centered in the energy consumption [8].

II. HARDWARE IMPLEMENTATION

The hardware architecture of the wireless device has been divided in four modules: the sensor module, the radio module, the feeding module and the microprocessor. In Figure 5 the scheme of this new platform can be observed. As it is possible to see, in order to save energy, the sensor module, in the left part of the figure, is fed by a switch, which is activated by the microprocessor when it is desired to make a measurement.
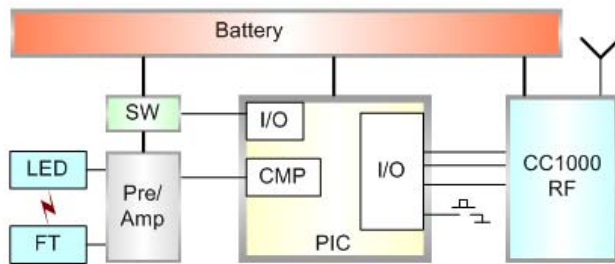

Figure 5 Sensor Scheme

The hardware design, at electronic scheme level as well as at PCB "layout" level, has been made using the OrCAD tool [9].

In the next paragraphs we will do a brief description of the functionalities of each module:

A. Sensor module

This module consists of two stages: on the one hand we have the sensorial stage, composed by the emitting LED and the phototransistor, and on the other hand is the stage of preparation and amplification of the detected signal.

The study of dripping detection techniques has determined that the beam of light used for the sensor is the optical one. The passage of the drop turns aside the beam and the light intensity that arrives at the phototransistor decreases, so a small fall of tension takes place.

That tension difference is the signal we will have to prepare and amplify for its insertion into the microprocessor. For that purpose, a double operational amplifier is used; one of them is used to stabilize the reference tension and the other to amplify the variation of tension produced by the drop. In Figure 6 the block diagram of this module can be seen, where the comparator part is done inside the microprocessor, which have two comparators.

On one hand, the reference level is introduced to one of the pins of the internal comparator of the microprocessor and on the other hand, the reference signal plus the amplified signal is introduced in the other pin.
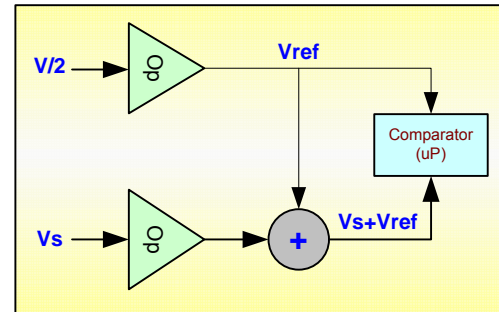

Figure 6 Signal Preparation

B. Radio module

The radio used for the wireless communication is the CC1000 of Chipcon [10]. The handling of the radio is carried out by the microprocessor of the serum sensor, to that purpose, we connect 6 pins of the microprocessor to PALE, PDATA, PCLK, DCLK, GAVE and CHP_OUT/LOCK pins of the CC1000 radio.

In order to achieve the objective of low power consumption of the wireless device, the radio remains in low consumption mode most of the time, only changes to TX mode to transmit strictly necessary messages, as they are the warning of dripping end and low battery.

The sensor has a button to activate the configuration mode of the wireless device. In that configuration mode the wireless sensor communicates with the central device asking for one unique ID. This way, the central device assigns one unique ID to the sensor, and it is known what room it belongs to. Thus, the switch insertion problems are avoided and any sensor can be operative under any central device of the different rooms.

C. Microprocessor

The microprocessor module is the core of the system. It receives the dripping signal and determines if the intravenous infusion system is dripping or not. The microprocessor also controls the battery level of the device.

However, the microprocessor changes the operation mode into configuration mode if it detects an interruption produced by the configuration button.

The microprocessor also controls the radio communication; in such way that the first routine it must do is configuring the radio, which means, to choose the correct frequency, the correct power and so on. Another process is to check the information of the received signals, and to send the corresponding message to the central device using the designed communication protocol.

The energy saving is very important in the wireless sensor device, so the microprocessor also is in charge of increasing the energy saving using a listening algorithm. To do that, it is able to switch-off the sensor module when the

dripping monitoring is not important. This software saving obtains a great increase of battery life.

For the design of the wireless device, the microprocessor PIC16F688 of Microchip has been used [11], which is made with the new nanoWatt technology, so it has a very small consumption in "running" mode, around 300uA with 4 MHz clock, and in "Sleep" mode it consumes near 80nA.

In the next figure, Figure 7, an image of the prototype of the wireless sensor device can be seen.
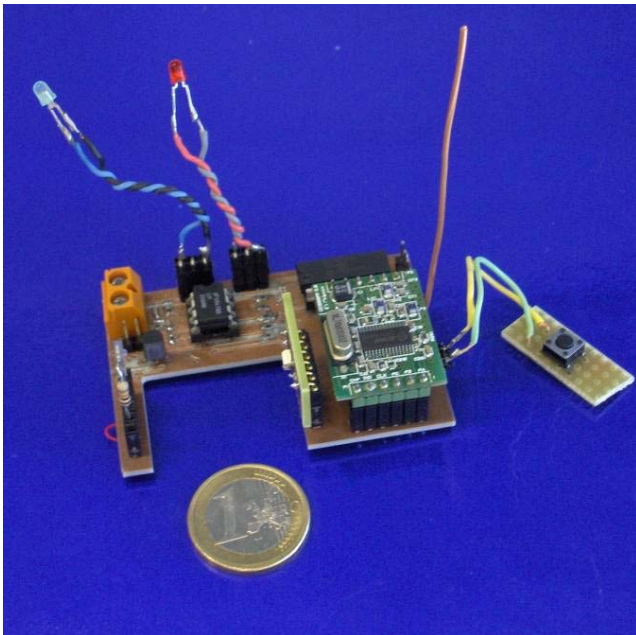

Figure 7 Wireless sensor device prototype

D. Feeding module

The feeding module is in charge of providing adapted tensions to each part of the sensor and also controls the battery level. When the battery level is low, it warns to the microprocessor so it sends an alert signal of low battery, then the corresponding person changes the battery of the device.

The battery life in a wireless sensor is the key for its acceptance in the market, so here is a study of the lithium battery load duration of the CR2 of Panasonic; its rated load is 750mAh.

Figure 8 shows the obtained results of the evaluated battery during 100 hours with a continuous unloading current of 10mA. It is observed that both voltages in the graph agree at any moment. During the first 80 hours the voltage provided by the battery is stable and superior to 2.5V. With the applied unloading cycle, around 30.000 unloading cycles each 24 hours are considered, which supposes about 100.000 cycles in 80 hours. These consumption maximums have been of 25mA during 25ms and 10mA during 2.5s. Therefore, the energy consumed in these 80 hours is of 730mAh approximately, which is equivalent to a battery yield of 93%.
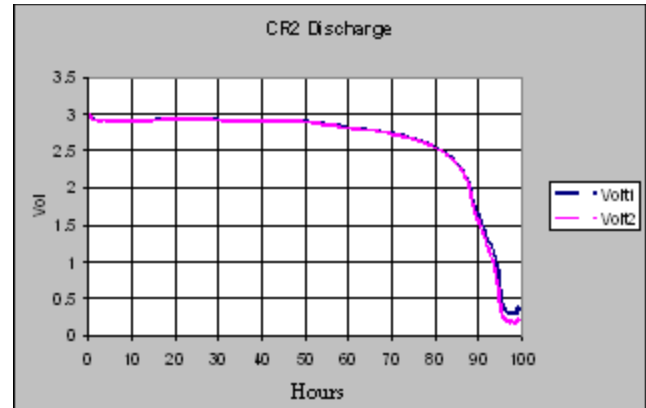

Figure 8 Curve of unloading of the battery

III.   SOFTWARE IMPLEMENTATION

A. Software implementation of the Wireless Sensor Device

The correct implementation of software is a key point when communicating all the modules described in the hardware section. The chosen language to program the microprocessor is C.

The software developed to be embedded in the platform has a modular scheme. This design allows the software being independent from the platform and also gives flexibility.

The whole software structure is divided in 4 layers as it is depicted in Figure 9. The layers are separated by dotted lines and a short description for each one is given below:

- *Physical level*: is the lowest level and it depends on the hardware directly. The modules present in this level are corresponding to the physical modules of the node; these are analog and digital sensors, Serial Parallel Interface (SPI bus), Timers, Memory Access, etc.
- *Controller level*: this layer is the interface between controller and application. The functions developed in this level permit the application level to invoke controller functions. The ADC (Analog Digital Converter) module converts analogical signals from the analog sensors to digital, and the SPI allows communications of the CPU with the CC1000 RF chip. In this layer are also included the set of RTC (Real Time Clock) functions.
- *Interface level*: this layer contains the main functions that the sensor node performs during its duty cycle. These functions range from reading ADC channels or communicating through the SPI interface, to sending and receiving data from RF chip and access to the comparator module. Programmed interrupt routines functions are also developed in this layer.
- *Application level*: this is the top level layer and executes related actions according to interruptions received (external switches or internal interruptions).
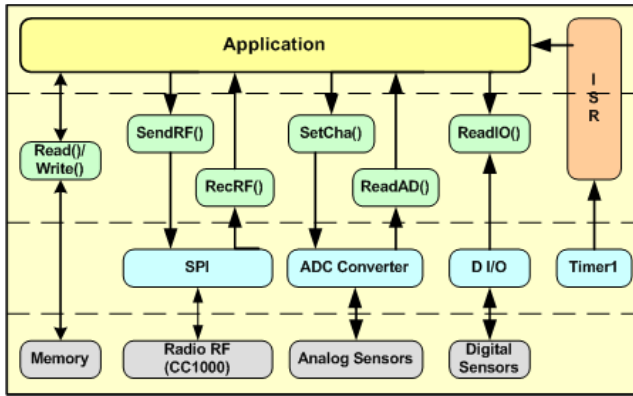
Figure 9 Embedded Software

In Figure 10 the flow chart of the Application layer can be seen, which shows the wireless device operation, summarized in the following lines: once the device is ON, the program sets up the radio to operate at 868.3 MHz and also sets up other conditions like power output, etc. Later the wireless device asks for the unique ID to the central device and keeps it in memory. This unique ID will identify it throughout the session. It would be possible to change the unique ID in the same session by pressing the configuration mode button.
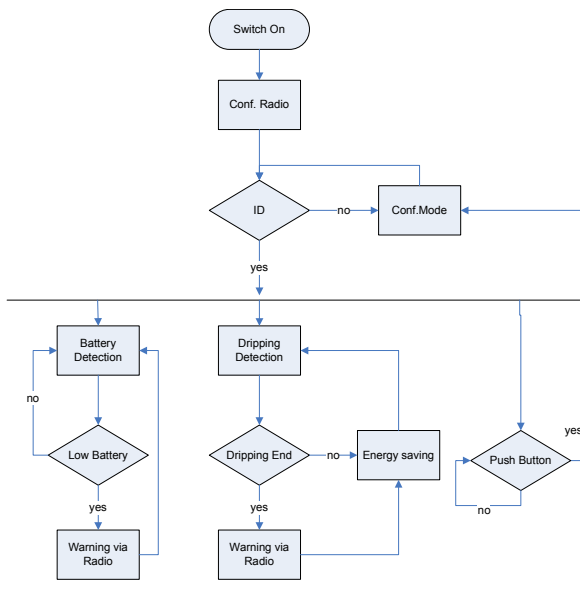

Figure 10 Software diagram

When the whole set up is done the microprocessor is pending of three tasks. One of the tasks is the dripping detection and warning of the end of dripping in case it is necessary.

Apart from that, the microprocessor is pending to see the battery state to warn about the need of change if it is low.

Finally, the microprocessor is pending of the external interruption generated by the configuration mode button pulsation.

B. Energy saving algorithms

The end of the dripping detection in the intravenous systems is not essential to be immediate, so a margin period from the end of the dripping to the renewal exists. This margin makes it possible to accomplish a listening period to verify if the intravenous system is dripping or if it has stopped.

The listening periods make that the time when the sensor module is ON to be minimized, which implies an energy saving.

Figure 11 shows that the energy consumption can be reduced to 50% (or less), making listening and extinguished periods equitable o minors.
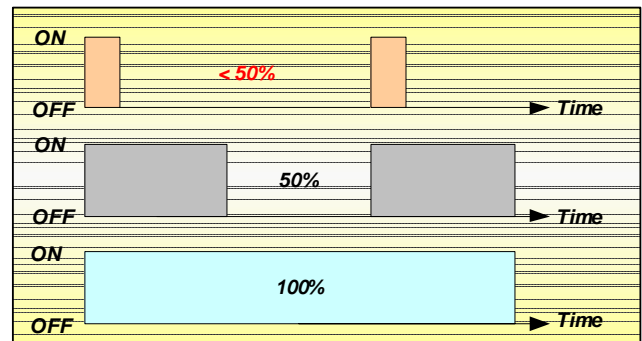

Figure 11 Energy Saving algorithm

Making studies had determined that more energy can be saved if during the listening periods we count the number of drops. Thus, if during listening we count a fixed number of drops, for example 3, we already can know that the dripping exits, so we do not have necessity to continue listening the dripping the rest of the listening period, then the saving is increased in more than a 50%, depending on the dripping frequency (first graphic in Figure 11).

C. Protocol Implementation

Figure 12 shows the composition of the data bytes that are sent from WS (Wireless Sensor) to the Room Base Station (RBS). The number of bytes to send is 18, which can be described in the next paragraphs:

- Preamble: is composed by 32 bits and it allows to the RF chips to start the communication. I our case the double word chosen for preamble was 0xAAAAAAAA.
- ID: there are 2 bytes (16 bits) reserved for the ID, which can be unique for the devices.
- The Payload is composed of 64 bits (8 bytes) as shown in the figure. The content of the payload is the following bits:

- The Time: each sensor has a Real Time module and it serve to know the exact time at which sensor has an alarm.
- Status bits are the most relevant, and are composed for the status of the dripping system (empty or not), the status of the battery, etc.
- Reserved: there are 16 bits reserved for future applications.
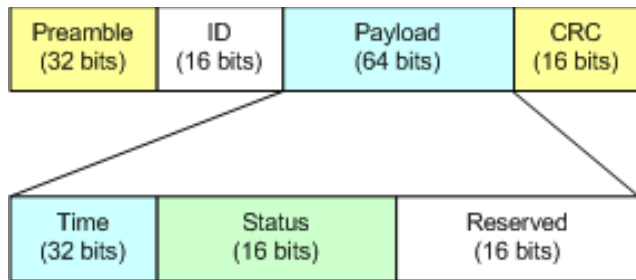- CRC: is used to control that the data that is send to the RBS station reach this target.

Figure 12 Protocol Implementation
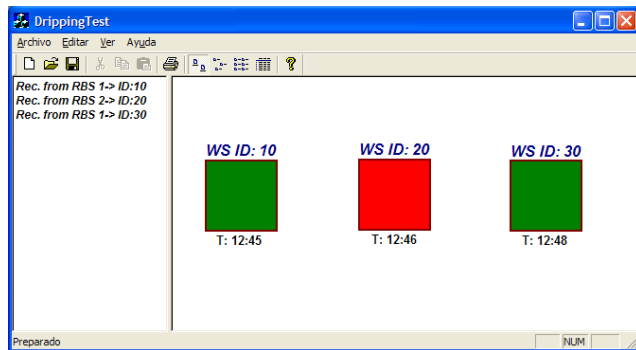
D. PC application

Figure 13 PC Program Application

The PC application is a windows based program, which was designed only to test the devices. This environment has been developed in Visual C++ platform and has the following functionalities:

- It allows knowing how many wireless sensors (WS) are in the system.
- To see when each WS is empty or not, in which case it sends an alarm to the Room Base Station (RBS) located nearer. In that case, the PC program can represent it using colors (in our case, red color), which means that the dripping chamber is empty and will be replaced immediately.
- To configure the sensors: set the date and some configuration parameters in the node, like the frequency channel for wireless communication, power of transmission, ID, etc.

- To store the information in a local database for further analysis

IV. NETWORK TOPOLOGY

Prior to describing the network topology of the dripping detection wireless sensor network, a separation between two kinds of dripping systems has to be done.

In every hospital we can find patients which cannot move and are lain down on the bed all the time. Apart from those, there are also patients which can move around and walk during the day, in any moment, and with a high degree of freedom.

Each of these patients may need an intravenous dripping system. Thus, two systems of this kind can be found in hospitals currently:

- Static intravenous dripping system: these are located in each room, next to the beds, and are used by those patients which cannot move and spend all the hospitalization time in bed.
- Mobile Intravenous dripping system: these are used by those patients who have the ability to move around, and consist of a human-height-size metallic bar, equipped with small rollers or wheels. On top of it is where the serum bag and the dripping detection system are located.

In both cases the need of automatic detection of a run put of intravenous solution is present. As a consequence, a different network topology has to be defined for each case, determined by the mobility of the patient.

A. Static network topology

As mentioned before, the static intravenous dripping systems are those which are located in each room of the hospital, next to the beds in which the patients lie down. Figure 14 shows a picture of one of these systems. And there is one for each patient, so it can be established a one-to-one equivalence between patients and dripping systems. This eases the identification of the dripping systems which need to be replaced.

Figure 14 Static intravenous dripping system

The implemented static network topology can be observed in Figure 15. The wireless sensor devices (WS) communicate via RF with the central devices of each room (RBS). RBS devices are in a LAN (Local Area Network), communicated with the central server in which the control of the dripping state of all the intravenous systems will be carried out.

The configuration mode of WS sensors makes it possible to a sensor from a room to be transferred to another one and the system will continue working in the correct way, because the changed WS will contact with the new RBS in the present room.
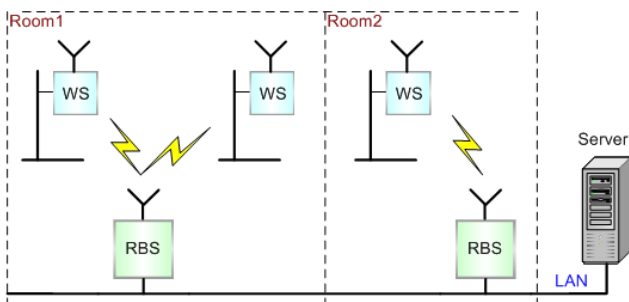

Figure 15 Diagram of the System

B. Mobile network topology

As stated before, the mobile intravenous dripping systems are those which can be carried along the hospital corridor by patients capable of moving around. Figure 16 shows a picture of one of these systems.

Figure 16 Mobile intravenous dripping system

For the case of the mobile system, simulations have been carried out. The simulated network topology for this case can be seen in Figure 17.

The diagram represents a patient carrying a mobile intravenous dripping system along a hospital corridor. The dripping system is equipped with a wireless sensor, and along the corridor, several Base Stations (BS) are located.

The mayor challenge in this case is to achieve a continuous and seamless connectivity, in order to be ale to carry out two functions:

- Send an alert of intravenous liquid replacement in any moment, and anywhere the patient is in that moment.
- Localize the patient in the hospital, using the Base Station Identifier of the BS to which it is connected in that exact moment.
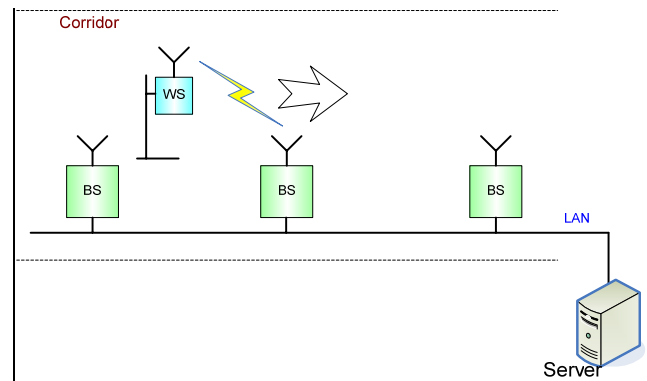

Figure 17 Diagram of the Mobile system

V. MOBILITY

This section describes the mobility algorithm designed for the mobile intravenous dripping system, as well as the simulations carried out in order to validate the system.

Traditionally, in the field of wireless sensor networks, only three types of mobility were defined:

- Node mobility: is the case in which the wireless nodes themselves are mobile. The network must be capable of reorganize itself frequently enough to be able to function correctly.
- Sink mobility: the most interesting case involving sink mobility is the one in which the sink isn't part of the sensor network.
- Event mobility: in applications like event detection and in particular in tracking applications, the cause of the events or the objects to be tracked can be mobile.

The application presented in this research work corresponds to the first type of mobility listed above.

A. State of the Art in node mobilty

Nowadays, the wireless sensor node mobility principles are studied mainly under the umbrella of MANET (Mobile Ad-hoc Network) related research work.

A mobile ad hoc network (MANET), sometimes called a mobile mesh network, is a self-configuring network of mobile devices connected by wireless links. Each device in a MANET is free to move independently in any direction, and

will therefore change its links to other devices frequently. Each must forward traffic unrelated to its own use, and therefore be a router. The primary challenge in building a MANET is equipping each device to continuously maintain the information required to properly route traffic.

The limited resources in MANETs have made designing an efficient and reliable routing strategy a very challenging problem. An intelligent routing strategy is required to efficiently use the limited resources while at the same time be adaptable to the changing network conditions such as network size, traffic density, and network partitioning.

One of the most popular methods to distinguish mobile ad hoc network routing protocols is based on how routing information is acquired and maintained by mobile nodes. Using this method, mobile ad hoc network routing protocols can be divided into proactive routing, reactive routing, and hybrid routing.

In a reactive routing protocol, routing paths are searched only when needed. A route discovery operation invokes a route-determination procedure. The discovery procedure terminates when either a route has been found or no route is available after examination for all route permutations. In a mobile ad hoc network, active routes may be disconnected due to node mobility. Therefore, route maintenance is an important operation of reactive routing protocols.

For the research work presented in this paper, a similar strategy to that used by reactive routing protocols has been chosen. As the wireless sensor moves along the coverage of different base stations, the active route or link is determined and selected reactively, based on the signal power received from the base stations.

B. Design of the algorithm

Figure 18 shows the flow diagram which determines how the mobility algorithm operates.

The determination of the active link is based on the received signal strength. Among all the received signals coming from the base stations, the wireless node selects that which has the higher received power.

The algorithm, after the initialization stage, measures the received power of all the signals coming from the reachable base stations, and with that it builds a data base, including the identification of the base station and the received signal strength. With that information, the algorithm is able to identify which of the base station has the highest received signal strength, which will be used by the next stage of the algorithm.

The next stage establishes the link using the information provided by the previous steps of the algorithm. The whole process is repeated every second, in order to update the status of the connection.

This algorithm allows the achievement of the two main objectives determined before:

- It allows the mobile wireless sensor to be permanently connected to the hospital LAN, and thus, send an intravenous–liquid-replacement alert anytime and anywhere the patient is.
- It allows the localization of any wireless sensor in the hospital, due to the characteristic of each of them

being permanently attached to a base station. Looking at the identifiers of the wireless node and base station that form a certain link, the task can be performed.
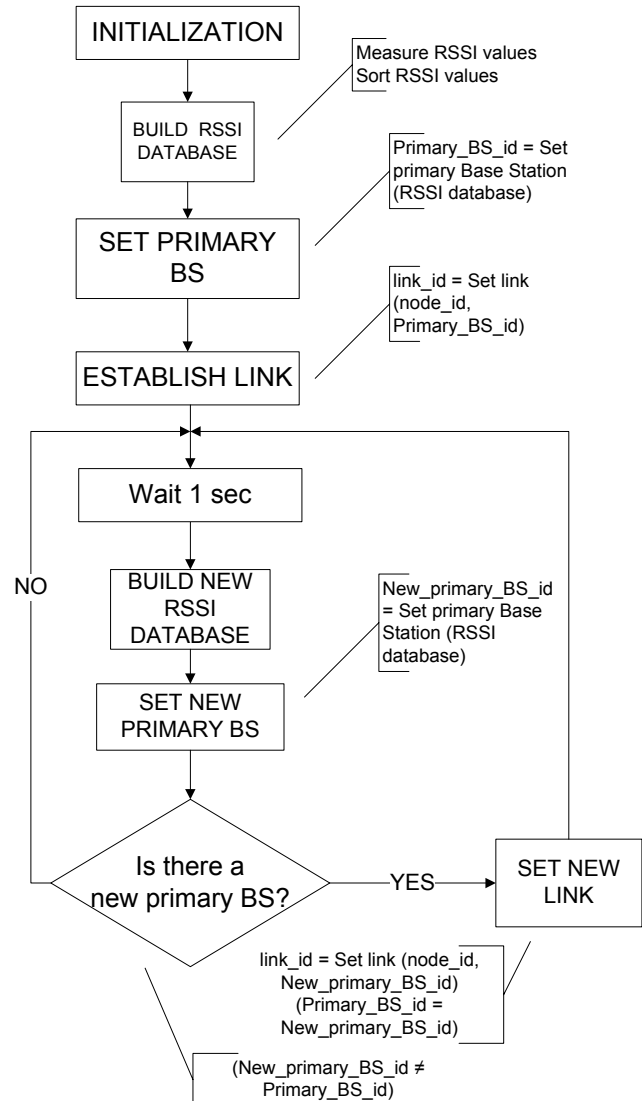

Figure 18 Flow diagram of the mobility algorithm

VI.   CONCLUSIONS

In this section we will summarize the most important conclusions which can be extracted from this project. It is necessary to emphasize the following aspects obtained with the present design:

- Reduction in consumption in comparison to other wireless devices with the same characteristics.
- Low cost of the device.
- The device size, the sensor dimensions are considerably smaller.

- Network forming flexibility, being able to use any sensor in any room.
- Great contribution in the improvement of effectiveness and security in the health care of the patients.
- Easy scalability of the system.

Regarding the mobility algorithm, there are two main tasks pending, which are planned as future work. On the one hand, obtaining concrete parameter measurements from the simulations, e.g. bitrate, number of lost packets, or switching time.

On the other hand, the implementation of the mobility algorithm is planned. It will be carried out using the sensor nodes described in this paper, and real life measurements are going to be done using a backbone network deployed along a concrete area of a building.

We also can mention the great ease of the system evolution. The future work can be focused on these topics:

- Location systems.
- Use of the wireless sensor itself as a node, therefore they could resend signals from other nodes.

- Greater advantage of the processing capacity of the wireless sensors.

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