Abstract - This paper presents a wireless sensor network (WSN), which were designed for application in industrial measurements with the use of low-cost commercial components. The concept of the WSN is presented, as well as hot-topics concerning its implementation, in order to make the communication between the nodes and the base-station as reliable as possible. The architecture, protocols and the reasons that governed the choice of the components are also discussed.

Keywords - WSN, protocols, microcontrollers, PIC16F628.

I. INTRODUCTION

Wireless communication microsystems with high density of nodes and simple protocols are emerging for low-data-rate distributed sensor network applications such as those in home automation and industrial control [1]. It is available a huge range of solutions, concerning the implementation of wireless sensors networks (WSN). A few companies [2-4] are offering solutions such as radios (motes) and sensor interfaces. The motes are battery-powered devices that run specific software. In addition to running the software networking stack, each mote can be easily customized and programed, since it runs open-source operating system which contain low-level event and task management. Mote Processor/Radio module families working at 2.4 GHz ISM band and supporting IEEE802.15.4 and ZigBee are available. However, the implementation of a wireless b us us in certain applications requires compact and miniaturized solutions. Moreover, a chip-size antenna included in the RF microsystem will be crucial, as is the case presented in [5] for raplication in wearable. However, in cases such as these, the use of low-cost and ready-to-deploy solutions are much expensive for use in industrial networks. Moreover, low-cost and ready-to-deploy solutions are more attractive for many others such as restaurants and snack-bars, where it is mandatory to make the temperature record and logging of the frizzing cameras on periods not more than an hour. If the is a not respected, the ASAE (Autoridade de Segurança Alimentar e Econômica) organism acts in conformity, and penalties going from monetary due to the close of the facilities are some of the consequences to work out of the law. This requires the use of an automated and efficient process to make the record and logging. One of the possible solutions relies in a wireless network. However, this can be a problem, specially in older facilities, where holes must be made in the wall to pass the cabs. Another way is to install on a wireless infrastructure, in which a low-cost multi-hop networks can be installed without making sure changes in the facilities with the advantage to be easy to increase the number of network nodes.

Moreover, other nodes with other type of functions can be installed. To finish this paper presents a wireless sensor network, where there are several options for industrial applications with a low-cost in a ready to use fashion. The next section presents some WSN aspects that were behind this network.

II. IMPLICATIONS OF THE RADIO SYSTEM

In the majority of the applications, the contributions of the electronics in a node has a low contribution in the total power consumption of this node. In fact, the fact of the available technologies being more and more low-power, this does not relieve the fact the transceiver be the block with the bigger power consumption [6]. The co-investigation of new architectures and algorithms of control, is a topic of increased interest, e.g., it is even more important to know the detailed implication of radio-frequency (RF) system in the power consumption [7]. The first step to save power, is to guaranty that the network work the lowest usage periods, e.g., the working time of the network is $T_s$ [s], for a total living time, $T_f$ [s], is the smallest. The next step, is the use of the more suitable clock frequency, e.g., if the transceiver is not transmitting neither receiving, the use of a low frequency clock will help to save power. Moreover, to save more power, after finish the processing, the node can enter in the sleep mode [8]. The next two key-factors to reduce the power consumption, are the start-up and the transmission times. The first one is the time that lasts between an enable order and the instant the electronics starts to work. The second, is the time to send a complete packet of data. The optimization of these gives a big contribution in the power consumption [9]. The next two key-factors to reduce the power consumption are the start-up and the transmission times. The first one is the time that lasts between an enable order and the instant the electronics starts to work. The second is the time that the node can enter in the sleep mode [8]. The next two key-factors to reduce the power consumption are the start-up and the transmission times. The first one is the time that lasts between an enable order and the instant the electronics starts to work. The second, is the time to send a complete packet of data. The optimization of these gives a big contribution in the power consumption [9].
very limited, because this one can't know exactly when a data transmission is targeted to it, thus, the receiver must always be activated and receiving data [11]. The only solution, is to use the RSSI circuit to detect the presence of a carrier with a significant power and use this event to wake-up the network node. Even the used modulation can be a limiting factor, due to the power consumption. A reminder must be made in order to say that compared with a simple narrow amplitude modulation (AM), the use of a direct sequence spread spectrum (DSSS) technique available in the IEEE 802.15.4 has the advantage to make the data transmission more reliable, with the cost of an increasing in the power consumption [13,14]. To finish, the wireless communications, the antenna must be small enough to comply with size constraints of the microsystems. The investigation of new frequency bands [15] and new geometries [16] will make possible to have smaller antennas to integrate in wireless microsystems [5,17]. This makes the choice of the most suitable frequency, one of the more decisive aspects in the design of RF transceivers. Normally, the desired range, baud-rate and power consumptions are key-aspects in the design to take in account, when the frequency of operation is to be selected. At a start-up, the range limits the maximum usable frequency, because the loss suffered by the radio waves in the free-space increases with the distance. However, to keep or even increase the useful life of the batteries, such a variation in the transmitted power is not possible to do. Moreover, in the case of applications requiring higher baud-rates, the transmitted bandwidth must also be higher, in order to support these applications. However, the frequency can't be arbitrarily increased, because this have implications in the power consumption, e.g., at high frequencies, the transistors must switch faster, thus the energy dissipation will be bigger.

### Wireless communication technologies

<table>
<thead>
<tr>
<th>Radio-frequency (RF)</th>
<th>Magnetic field</th>
<th>Optical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standardised</td>
<td>Standardised</td>
<td>LASER</td>
</tr>
<tr>
<td>DECT</td>
<td>RFID</td>
<td></td>
</tr>
<tr>
<td>Bluetooth</td>
<td>Standardised</td>
<td></td>
</tr>
<tr>
<td>ZigBee</td>
<td>Infrared</td>
<td></td>
</tr>
<tr>
<td>WLAN 802.11</td>
<td>Standardised</td>
<td></td>
</tr>
<tr>
<td>LR-WPAN 802.15.4</td>
<td>IrdA</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1: Available frequency bands and respective applications.

Figure 1 shows the available frequency bands for the different technologies used in wireless communications. The most suitable frequencies are those belonged to the so-called ISM band (Industrial, Scientific and Medical), which are not subjected to standardization and can be freely used, since the emitted power are maintained below the maximum levels imposed by the legislation. Such a flexibility lead to the rising and spreading of interesting applications.

### III. IMPLEMENTATION OF THE WIRELESS SENSORS NETWORK

#### A. System architecture

The fabricated network nodes has sensors readout, which are constituted by analog-to-digital converters (ADCs) of eight bits, digital circuits both to control the read-outs, by the Microchip's PIC16F6628 microcontroller, which provides basic services for communication purposes. The core services also makes possible the external service of additional services. The Figure 2 shows the block diagram of network nodes, which contains the supported sensors read-out, the RF interface and an optional RS-232 interface to transfer data towards an external laptop computer, a PDA or a mobile phone.

![Figure 2: The block diagram of the wireless sensors network nodes prototype.](image)

The prototype uses a commercial RF transceiver, which operates at 433 MHz. The microcontroller PIC16F6628 was select, due to its frequency clock of 20 MHz, which corresponds instructions with an execution speed of 0.2 μs. Using this clock, and the maximum baud-rate of 40 kbps imposed by the RF transceiver, a total of 500 instructions are executed for each transmitted bit. However, and as will be discussed further, the implemented code reduces the effective baud-rate to half, e.g., doubling the processing time for each transmitted bit.

#### B. Frame formatting

As shown in Figure 1, two types of frames were defined: the general use and the command frames.

![Figure 3: Existing fields in a) the general use and in b) the control frames.](image)

The general frames have two purposes, one is to carry information in the payload field between the nodes and the base-station, in a coordinator fashion. The second function is to send commands from the base-station to the network nodes. The command frames are used by the base-station to send commands to the network nodes. These command frames are identified by the base-station, which need to identify it, is not needed. These frames are sent in a quick manner, which are identified, such as configurations of good AC...
Acknowledgements) or bad reception (NACK - Nacknowledgements) of previously received data. In the first frames, the payload length is variable. In the case of this frame be used to send commands, the field type is 01h (00 00 00 01h), its length is minimum and is equal to 16 bytes. The default case is when the frame carries data, e.g., the value in the Type field is 00h (00 00 00 00b). In the future, additional types can be defined, for values in the Type field of 02h (00 00 00 10b) of higher. These frames, allows to identify the destiny (the receiver), to number the network and to check with the help of the CRC field, the existence of transmission errors. This is also allowed in command frames.

C. Line coding

This is perhaps the most important issue in the WSN. Very long sequences of ones or zeros can result in a data imbalance, which can cause the loss of carrier and bad symbol synchronisation. To have a good data balance, e.g., one level transition for a set of two consecutive data bits, a sequence of two symbols are transmitted at twice the effective baud-rate (the data-rate). The symbol sequences '10' and '01' are transmitted, when the information bit '1' or '0' is to be sent. Moreover, this scheme also helps to synchronise the clock of the receiver with the clock of the transmitter [18].

![Figure 4](image-url)

Figure 4: Used masks when the Manchester code a) is applied to the frames, and b) for uncoded frames.

As shown in Figure 4, before a node sends the byte \( b_1 b_2 b_3 b_4 b_5 b_6 b_7 b_8 \), a program call must be made, to divide that byte into two parts, and a code is created two new (separated) bytes \( b_1 b_2 b_3 b_4 b_5 b_6 b_7 b_8 \) and \( b_2 b_3 b_4 b_5 b_6 b_7 b_8 b_1 \). If the older byte belongs to the header, then the exclusive or (XOR) is executed in the two new by tes, using the mask "01 00 01 10b". However, if the older byte belongs to the header, then the XOR is made with the mask "01 01 01 01b". Independently of the result of the two XORs, the two resulting bytes are transmitted at twice the data-rate of the information contained in the frame. If the user chooses to not code the frame as, then the same program is also called, but the mask is always "00 00 00 00b". In this case, a data balancing will not be ensured. Compared with the coded case, and in order to have a real double data-rate, the software must double the processing rate.

D. Synchronisation of frames

To a correct reception of frames, the receiver must evaluate with accuracy the start of the frames. As depicted in Figure 5, this is done using a window, which is no more than a FIFO with a capacity of 16 bits, which is filled with the symbol bits as they arrive. This window starts to tell the presence of the header, and as soon as the synchronisation character (FAW) is fully received and fully fills the FIFO, the receiver then recognises the frame and the data in the payload field will start to happen. Figure 5 and 6, illustrate this process taking the synchronisation character 1Bh (00 01 10 11b) as an example.

![Figure 5](image-url)

Figure 5: Window to detect the synchronisation character 1Bh (00 01 10 11b).

![Figure 6](image-url)

Figure 6: Acquired received base-band signal, where it is possible to observe the header and the synchronisation character 1Bh (00 01 10 11b), which is Manchester coded, "01 01 01 10 01 01 10 10b".

E. Error controlling

The data transmission is not immune to errors in the channel. Thus, it was defined a control block filled with a length of sixteen bits, in the footer of both frames, e.g. the CRC (cyclic redundancy check) field. The CRC is correlated with the transmitted data. After receiving the entire frame, the receiver makes the calculation of the CRC of this frame and then compares this value with the CRC contained in the footer of the frame. If both CRCs are equal, the receiver assumes that the data were received without errors. In the opposite case (inequality of the CRCs) the data has errors.

The CRC is generated according to the polynomial [19]

\[
p(x) = a_7 x^7 + a_6 x^6 + a_5 x^5 + a_4 x^4 + a_3 x^3 + a_2 x^2 + a_1 x + a_0
\]

The values \( a_i \) are zeros or ones, and imposes the existence of each of the feedback connections illustrated in Figure 7.

![Figure 7](image-url)

Figure 7: Generation of the CRC.

The CRC generation is very simple, and is based on a calculator (CALCproc) procedure, which is called the number...
of the bytes to be used. The cont ent of the shift-register (SR) of Figure 7 is cleaned and after an execution of the CALCproc, its value remains in the SR, in order to be available to the next byte to be processed. The CALCproc has an eight bits buffer to store and to make e i g h t shifts during each call. The values $CRC_3$ to $CRC_0$ give the temporary CRC number to be transmitted. This number also remains in the SR, until the last byte is fully processed, which is the CRC code or other) uncoded baud-rate, $T_{proc}$ [bps], must be at least:

$$n_t > \frac{f_s}{N_{node}} \times (9 + \max(N_{acc} + \max(N_{control} + 2N_{header}) \times \frac{2\max(d_j)}{c} - t_{proc_TX} - t_{proc_RX})]{1 - \frac{1}{f_s}} \times N_{node}$$

(1)

where $N_{node}$ is the number of bits in the header. This equation is valid for both the general type and command frames, where for $k$th node, $N_{control,k}$ is nine (#9) one (#1), respectively.

IV. CONCLUSIONS

This paper presents a practical, industrial ready-to-use WSN, which were developed with the use of low-cost commercial components. It was also presented hot-features concerning its implementation.

REFERENCES

12. AD8309: 5-500 MHz, 100 dB demodulating logarithmic amplifier with limiter output datasheet, Analog Devices.