Design lab work in telecom

Definition, design and test of a wireless sensor network

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***Abstract*— This paper describes a teaching experience where Master 2 students have to solve a telecommunication problem without having specific theoretical required knowledge but using an experimental hands-on approach.**

Keywords-Telecom networks, Architecture and Protocol, Tests

I. INTRODUCTION

A. *Problematic*

Various issues can be considered during a lecture on wireless sensor networks [1], [2]: electronic design, risk for the human being, management of the energy, technologies of telecommunication, signaling and communication protocols… The education experiment described in this paper essentially aims at making future graduates to acquire the basic knowledge needed to choose between several software and hardware telecommunication architectures more or less adapted to a context, and to help them to evaluate the consequences of their choices on the software development associated to the each device. In that context, various telecommunication technologies used in personal networks (*PAN* for *Personal Area Network*) are nowadays potentially answering such needs such as remote monitoring of buildings, care of the elderly, structural health monitoring [3]…

B. *Paper structure*

The paper is structured in the following way. Section 2 presents the context and the objectives of a teaching experiment dealing with the implementation of a platform dedicated to test of several wireless sensor networks. Section 3 details the various technologies considered for telecommunication devices. Section 4 describes the methodology used by the teachers so that the students manage by themselves to find an answer to the question: "for a given configuration, what device is the most appropriate and what is the associated software development?" The concluding section gives the first conclusions on this teaching experiment as obtained from the student feedback.

II. IMPLEMENTATION

A. *Context and objectives*

In the AE (Automatic Control and Electronics) curriculum of the INSA Toulouse [4], considering issues related to the sensor networks, the students attend lectures about analog and digital electronics, communication networks (e.g. Internet) and telecommunication principles. There is no specific lecture on sensor networks. The objective of the experiment described in this paper is to get students acquiring software and hardware skills in heterogeneous wireless sensor networks. The goal is reached following an auto-training pedagogy such as the ones detailed in *Problem-Based Learning* [5], [6]. The students have to develop an experimental platform to test different telecommunication devices usually employed for personal area networks on one hand and to test different protocols involved in communication between wireless sensors and remote customers on the other hand.

B. *Application description*

The students have to develop an application of remote monitoring of several parameters of a room (luminosity, temperature) and of movements (intrusion in the room or displacement of one object inside the room). This application is based on terminal nodes made up of a sensor, a microcontroller and a telecommunication module. Several buildings can be inter-connected while the sensors inside each building must keep interacting, as illustrated in Fig. 1. Three families of nodes are used. These families have been chosen according to the data they have to transmit. Those data are different by their:

- Nature: some are binary (e.g. detection of a threshold), others are analogical ones;
- Criticality: processing data can be more or less critical;
- Periodicity: some data must be sent periodically, while other transmissions are event-triggered…

As far as their transfer is concerned, these data have different needs concerning the quality of service. These needs must be taken into account for the choice of a specific telecommunication technology and during the development of appropriate communication protocols.

The network is constituted of terminal nodes, gateways embedding various telecommunication devices and of a main station able to maintain communication with a remote user.

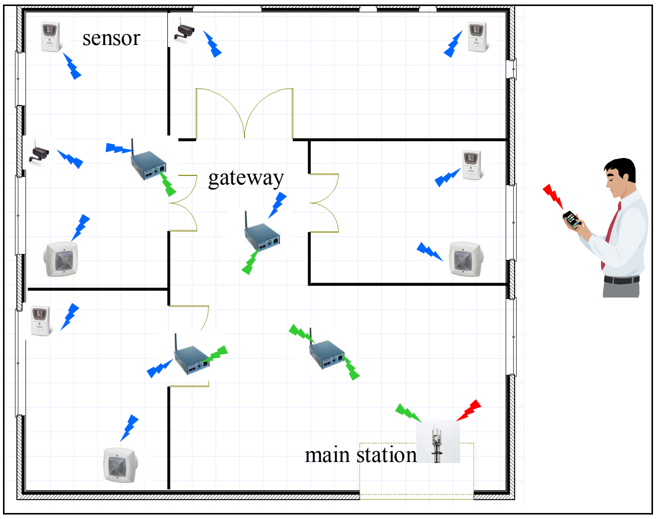

Figure 1. Example of a wireless sensor network

III. A SELECTION OF TECHNOLOGIES TO BE INVESTIGATED

This section presents the various telecommunication devices involved in the network as well as the various protocols which the students have to set up. Devices are connected via customized boards to the evaluation board of a microcontroller (MCBSTM32 [7] of *Keil*, processor ARM / ST). This configuration represents a "less embedded" solution than a dedicated electronic board which would have specifically been developed but it offers a high flexibility of use and of debug to the students by supplying a multi line LCD screen for display, free zones for oscilloscope test points, series connections to a terminal PC, diodes... The communication and signaling protocols are implemented on the microcontroller by means of the environment *µVision3* of *Keil* [8] which offers functions of simulation and transfer towards a microcontroller.

A. Telecom devices

Three technologies of devices are selected for this teaching lab work:

- A half-duplex transmitter using FSK modulation at 433MHz manufactured by Telital;
- An IEEE 802.15.4 transmitter manufactured by Microchip;
- A GSM / GPRS modem manufactured by Sagem.

The choice of these technologies is driven by the diversity of the services that they offer and by the diversity of their service access. The presentation of these services is the object of section B. The presentation of the service access is given below. Table 1 roughly summarizes the characteristics of these modules, the objective of the student lab work being to refine and to extend this table. The symbol "O" means an average performance, the symbol "+" a performance superior to average, and the symbol "-" a performance below average.

TABLE I. MAIN DEVICE CHARACTERISTICS

Device	Characteristics			
	Cost[a]	***Range***	***Access***	***Energy***
802.15.4	O	O	SPI	O
FM 433MHz	+	-	RS232	+
GSM/GPRS	-	+	RS232/AT	-

a. Initial and use cost

The column "Access" indicates the bus which must be used between the telecommunication device and the microcontroller to reach the communication services. Two buses are available: the RS232 bus which is implemented by a connection USART (*Universal Synchronous and Asynchronous Receiver Transmitter*) of the microcontroller, and the SPI (*Serial Peripheral Interface*) bus which is implemented by a connection MSSP (*Master Synchronous Serial Port*) of the microcontroller.

Three scenarios thus appear:

- The FM device is directly usable through RS232. That means that the device directly transmits the binary data flow on the medium;
- The IEEE 802.15.4 module using the SPI bus requires to set or to read registers to configure and use the service of telecommunication;
- The GSM / GPRS modem is used in the same way as any wired modem. The RS232 connection allows the use of the applications implemented on the device through “AT” commands like a classic PSTN modem.

B. Signaling and communication protocols

Each module studied in section A has specific communication and signaling services which can be extremely basic or may include complex embedded applications. The implementation of these services also differs a lot from one device to another. To develop the application of remote monitoring, students must initially understand the interest of these services, and then extend them if necessary. The following of this section details various aspects of the standard communication services offered by each module.

1) Half-duplex FSK/FM 433MHZ device

The FM 433MHz transmitter only offers a simple service to access the medium. It offers none of the classic services usually present on communication networks (based on the TCP/IP protocol stack for example) initially known by students during lectures about Internet basics: there is no addressing map, neither cyclic redundancy check, nor frame sequence number… The offered service is assimilated to a “simple” *broadcast* of data without other functionalities.

The student wishing to transmit information should follow the procedure below:

- Set the line TX of transmission;
- Write information on the microcontroller USART connection;
- Release the line TX of the device.

The instrumentation of this device is very easy; it is also possible to check a frame structure by capturing the RS232 frame with oscilloscope, both in sending and receiving modes.

This communication service is thus extremely simple to use (but also poor in functionality!); however students have to understand the need to release the line TX at the end of transmission if several transmitters alternately want to transmit (otherwise the receiver is unable to receive the data of transmitters emitting simultaneously).

This device is commonly and frequently used in the industry because of its low consumption and of its moderate cost. There are a lot of wireless sensor systems based on this technology; the most widespread examples are for home automation or for weather stations using wireless sensors. In spite of the simplicity of the services and the poor qualities of transmission offered by these devices, they offer a real interest in this lecture, essentially for two reasons. The first one is that the students have to ascertain that at a given moment, the risk of collision between two frames resulting from various sensors is unavoidable and even increases, obviously, with the quantity of simultaneous traffic. The second reason to study this device is related to the lack of reliability of this connection due to this risk of collision, but also to the loss of the signal quality when the receiver is far away from the transmitters or when it is not in direct vision.

Then, if it is required by the application, students have to consider additional mechanisms to make the connection reliable. Three solutions, that have different effects, can thus be envisaged:

- Set up a mechanism of detection and resumption of error;
- Make systematic redundancies of information, for example transmit the same frame several times to decrease the risk of collision and so decrease the risk of loosing a piece of information;
- Set up a mechanism of emission coupled with a mechanism of acknowledgement of the data that have been effectively received by the receiver.

The study of advantages and drawbacks of these solutions goes beyond the framework of this paper. However, the main consequence of the third solution is that the transmitter must also be able to receive data (to process acknowledgement)!

2) IEEE 802.15.4 device

The IEEE 802.15.4 device offers all the services defined in the 802.15.4 standard [9] via a *ZigBee* [10] stack. These services concern as well the communication and signaling protocols.

From the communication point of view, the device offers OSI/Transport level services, for example:

- The establishment of connection;
- The management of acknowledgments;
- The automatic retransmission mechanisms if data are lost…

There is also an advanced medium access control service which avoids the transmission of data through an already busy channel. The hardware offers various transmission channels; this allows a more accurate management of the bandwidth and reduces the risk of collision.

From the signaling point of view, *ZigBee* integrates many configurations of network topology: star, tree or mesh. For each of these topologies, it defines specific equipments, coordinator, and router in charge of the signaling mapping. To optimize the space memory on a microcontroller, *ZigBee* envisages a partial establishment of the signaling stack according to the targeted device. In this lecture, all the devices implement the totality of the *ZigBee* services.

From the student point of view, it is important to understand the interest of these services when the network topology becomes more and more complex. Indeed, *ZibBee* offers a management of the helpful services when the application targets aggregated traffics by data resulting from various sites. Services also offer a management of the communications (indifferently *unicast* or *multicast*) implying the crossing of several equipments: i.e. multi hop communications. The configuration of nodes, when an equipment fails or when the topology changes, is automatic if the appropriate services are activated. Fig.2 illustrates these various cases.

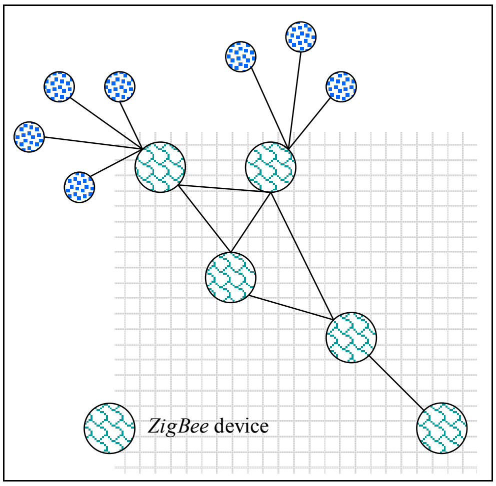

Figure 2. *ZigBee* suitable topology

3) GSM/GPRS device

The services offered by the GSM/GPRS device are different from those offered by the previous devices. They are more oriented towards embedded applications (voice, text, data, picture, video, music). From the user point of view, services like configuration of a topology, management of collision, etc. are hidden … If the appearance of these telecommunication devices may be seen out of the lecture scope, they are nevertheless very interesting. Indeed, the GSM remains a widely spread mean to transfer all kinds of information between an equipment with strong mobility and information server (typically "machines to machines", *m2m*, applications) or a user. The parameter analysis on a vehicle fleet (position sensor, consumption measurement) is an industrial example. To keep a communication link between the sensor network and a mobile remote user, the students set up an application of SMS processing. This application allows to make the reporting of periodic events towards the user or to process a specific request of the user wishing to interact with the remote monitoring system (system deactivation, state of a sensor request…).

IV. STUDENT EVOLUTION

Students of Master 2 have to set up a prototype of a sensor network. They use this network to formulate generic principles on the wireless sensor networks: choice of a telecommunication device, communication and signaling protocols suited to a targeted application. This training includes 7 supervised sessions of practical works (3 hours each); free sessions are also scheduled so that the students can have access to the technical equipment.

The starting point is the application specifications. Various items are available: software development tools, sensors (this teaching is synchronized with another one which objective is the development by the students of all the electronic part of the sensors), microcontroller evaluation boards and devices, with a detailed technical documentation and datasheets. The interface boards between evaluation board and the three telecommunication modules are also given from the start.

Students have to discover and understand the manipulation of each device taken separately before starting to completely implement the platform.

The students have to follow the following evolution:

- Step 1: discovery of devices. For that purpose, they test every device by establishing a direct and basic communication (send of an *ASCII* characters) between a single transmitter and a receiver. This step is common to every device and requires no elaborated configuration nor to add services to those already offered by modules.
- Step 2: several transmitters on the network. By testing services offered by the first device (FM technology), students understand that it is necessary to add a field "address" in any emission of information. They also note a risk of collision and loss of frames which grows with the transmitter number if they do not use a device offering suitable services or if they do not extend those basic ones proposed by the device.
- Step 3: the network spreads out. The initial range of the first two modules (FM and *ZigBee*) is not sufficient to cover communication needs on more important distances. It is then essential to set up several modules with a suitable signaling service on intermediate devices.

Gradually, the students thus take into account a more and more complex topology until they consider the complete platform of test compatible with the application of remote monitoring. The objective for the students is to refine and to complete the information contained in the Table 1 by means of a platform whose technological solution is represented in Fig. 3. Indeed, this solution appears as the best compromise if all the parameters are taken into account. Effectively, if the criteria of cost and energy saving are ignored, the platform could consist only of sensors equipped with a GSM device allowing to cover all the needs of the application. On the other hand, as long as we only consider communications inside one site, a solution based on FM device could appear as sufficient. But this solution would require a very heavy development to guarantee the same flexibility of use and the same level of services offered by *ZigBee* device when the topology becomes complex.

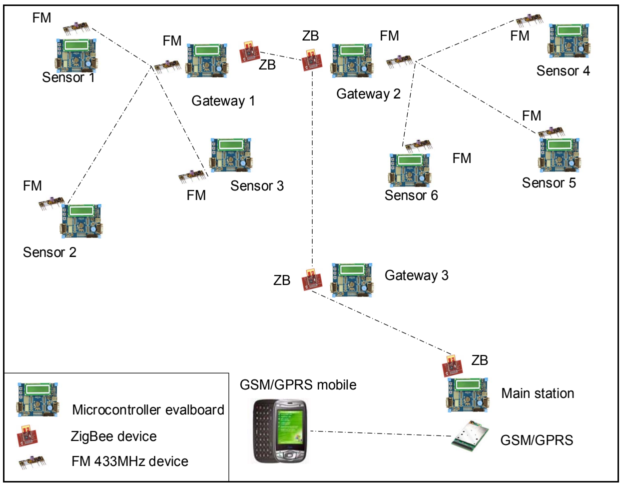

Figure 3. Platform solution

V. CONCLUSION

This paper describes a teaching experiment that addresses Master 2 students of INSA Toulouse. The scientific objective is the study of communication and signaling protocols involved in wireless sensor networks. In this course, students have to cope with a problem for which initially they don't have any technological solution; they only possess the necessary general background. They must develop and experiment an appropriate study based on tests. To make these tests possible, the students set up a platform prototype based on various telecommunication devices. This platform answers a typical application of industrial site remote monitoring by the means of wireless sensor networks. The experience is conclusive, it demonstrates that even if Master 2 students have no specific knowledge in the field of the personal area networks, a scientific approach based on tests and analysis allows discovering generic principles.

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