Learning network protocols through WSN based games

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Abstract—**Learning network protocols is not an easy task. We use them every day, but they have become transparent, as they are integrated in the Operating System. Its use also implies the interaction between different devices, including aspects like concurrency, noise and multi-threading. As a result, the student sees this subject as not necessary, and difficult, easily loosing his interest in the matter. This document is a summary of the work developed in an undergraduate course, where Wireless Sensor Networks (WSN) based on Sun SPOTs have been used to improve the comprehension and interest of the students. In the undergraduate course Network and Communications, a Game based lab has been developed. The results show the improvements from previous years.**

Network protocols; Wireless Sensor Networks; Game based learning

I. Introduction

Computer networks is an interdisciplinary subject that covers fields between electronic engineering and computer engineering. It is the base of our actual communication systems, going from the telephone, to the Internet, and, in a more subtle way, modern digital TV.

It is commonly assumed that network protocols are integrated in the Operating System (OS). They are seen as a commodity, as the OS itself[1]. The result is a student not too much interested in learning its implementation. Moreover, network protocols usually imply multithreading and concurrency, which are seen as complex by many students. Summing up, the students usually are not too motivated in the subject.

An experience has been made on the undergraduate subject "Networks and Communications" (NC). This subject includes a lab, whose objective has been implementing a small protocol with a basic stack, including:

- Frame definition
- Addressing
- Error control through an Automatic Repeat Request (ARQ)[2] mechanism

The definition of an ARQ implies the development of a sender and reception buffer, the control of the frame sequences, and the use of timers to detect possible timeouts.

Initially, the protocol was designed using an RS-232 null-modem physical layer. The introduction of noise and errors had to be made artificially by the professor. As a result, the students saw the protocols as an overreacting solution to an improbable problem. We wondered if our lab was a turn-off[3]. For this reason, since 2005, we have started to use Wireless Sensor Networks (WSN), with the objective to improve the students understanding and motivation regarding the subject.

The WSN alternative has been confirmed by an increasing number of experiences as an educational tool. Some use them as a tool for other purposes, like a system for kids to browse Internet[4] or for undergraduates to control the environment[5]. Others use them to teach network protocols [6]-[10], as is our case. In this work we present our experience in this field.

II. Networks and Communications

Networks and Communications is an introductory course to the network protocols. It is the first time in their curriculum that the students see the characteristics of a network and its protocols. The base of the subject is the OSI reference model, the main local and wide area network protocols, and the TCP/IP stack.

A. OSI Reference Model

There are different ways to approach to the networks (bottom-up[11], top-down [12]…), but the base is usually the Open Systems Interconnection (OSI) basic reference model [13] from the International Organization for Standardization (ISO). It defines seven different layers, which are stacked. Every layer provides services to the upper layers and is client of the lower one. The layers are:

- Application: Provides access to the OSI stack.
- Presentation: Gives the representation of the data transferred between the applications.
- Session: Its purpose is to provide means to organize and synchronize the dialog and manage the data exchange.
- Transport: Transfers data transparently, relieving the upper layers from any concern with the detailed way in which reliable and cost effective transfer of data is achieved.

- Network: Provides routing and relay solutions to the transport layer.
- Data Link: Provides means to transfer data over a specific physical layer.
- Physical: Defines the way the bits are transmitted through a medium. It usually implies the definition of connectors and cables, antennas… depending on the kind of transmission.

Taking into account the real implementations, sometimes the OSI stack is divided in three environments, considering the layers interaction [14]:

- The network environment: includes the lower three layers, and it is dependent on the characteristics of the network itself (medium, codification, format…). The interaction is between layers of adjacent nodes.
- The OSI environment: its services are more oriented to the applications. The four higher layers compose it. The communication in this case is between the layers at the end of the communication.
- The Real Systems environment: are the applications itself (browsers, word processors, terminals…).

A representation of both, the OSI reference model stack and the associated environments are shown in Figure 1.

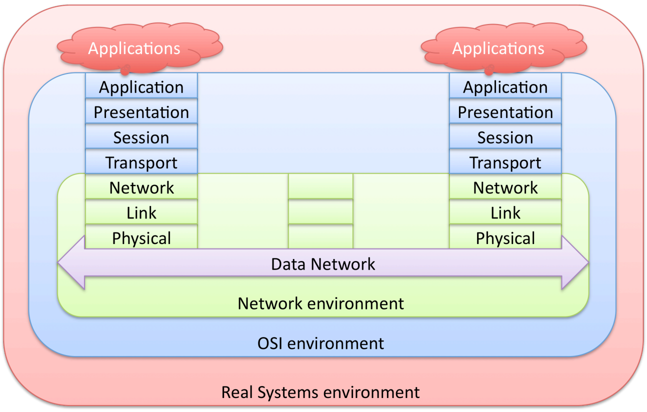

Figure 1. OSI reference model and associated environments.

The Networks and Communications subject (NC) is oriented to the network environment, with a brief vision of the OSI environment.

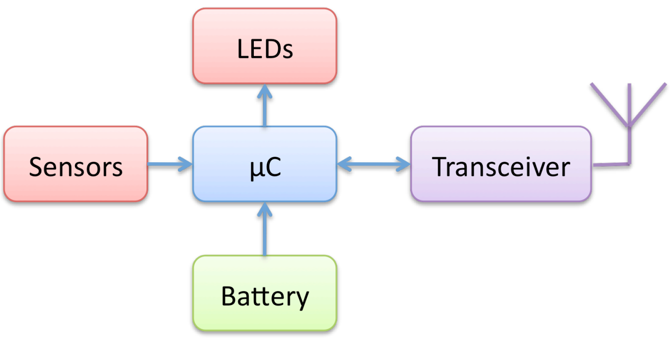

Figure 2. Block diagram of a basic WSN node.

B. *Wireless Sensor Networks*

WSN is a relatively new technology, which is based on the improvements of wireless communications, low power consumption and sensor size reduction. The results have been devices the size of 2 AA batteries, able to get information from their environment. Every device becomes a node of a network that allows transmitting data among them [15]. The block diagram of a basic device is shown in Figure 2.

The simplest WSN node includes a microcontroller, a transceiver and a battery. Usually it also includes some sensors and depending on the application, LEDs or other display to provide some information to the user. Initially the communication was using proprietary transceivers. Since 2003, the IEEE 802.15.4[16] protocol is available for this kind of networks.

IEEE 802.15.4 is a simple protocol, designed to work with little resources and power[17]. It uses three different bands, but the most common is the ISM 2.45 GHz band. This band is shared with Bluetooth and Wi-Fi, meaning that it has to include strategies to avoid interferences with these and other protocols. This is accomplished using an offset quadrature phase-shift keying (O-QPSK) modulation.

One of the first solutions for WSN was the TinyOS framework[18]. It provides a language (NesC), an Operating System (TinyOS) and the blueprints for different devices. One of the firsts commercially available was the tMote(Figure 3.). These motes were based on a Texas Instruments (TI) msp430 microcontroller. It also included an IEEE 802.15.4 transceiver from Chipcon (now TI), and some sensors and LEDs to get data and provide some feedback.

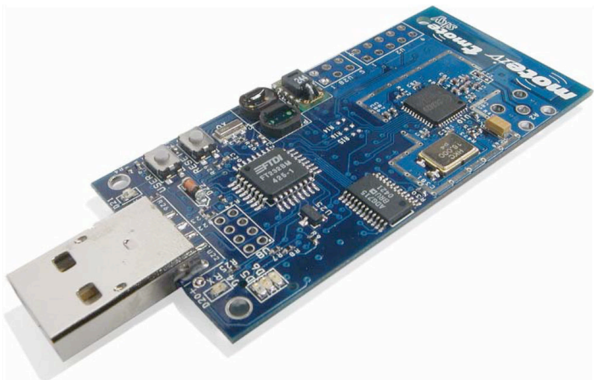

Figure 3. tMote photograph.

This alternative seemed interesting as more nodes could be included in the network, and no cable was necessary. For this reason, we started in 2004 to work with these devices. The organization of the labs was:

- Introduction to NesC programming.
- Introduction to the tMote sensors.
- Interchange of data between motes.
- Development a simple weather station based on the tMotes and using an ARQ protocol to transfer data between them.

The main difficulty was the change of point of view. When a student implements a program, usually thinks in solving a problem with an algorithm, easy and simple. He is the only user, and he knows how to work with it. As a result, the program works perfectly. In other words, if the algorithm is good, the results are warranted.

In computer networks, the situation is different. The algorithm can be perfect, but if errors are not taken into account, the system will work with bad performance, or simply it will not work. This implies that the student has to start to think about the inputs and outputs as something that can introduce errors. These errors have to be detected to take the necessary actions.

Using an RS-232 cable, this concepts where hidden as the communication was nearly ideal. With WSN the students started thinking for an ideal environment, more or less equivalent to an RS-232 cable. However, the situation was fully different. The networking concepts appeared naturally. Frames from one group were received by another (addressing), or some frames were lost when two motes transmitted data at the same time (collisions).

Another major issue was the difficulty of the students to learn the NesC language. Although it is similar to Java (the base language in Computer Engineering), it took between 10 to 14 hours to learn it, which was half the laboratory time. This time could not be easily reduced because there was not a simple simulator to continue the work at home, as TOSSIM[19] was not a good educational tool.

In any case, the difference between the use of an RS-232 cable and this tMotes was clear. Only the possibility to light a LED changed the face of the students. The lab results were better, but we continued to think about possible improvements.

Figure 4. Sun SPOT photograph.

C. *Sun SPOTs*

In 2004 Sun Microsystems started to work on a WSN device including an IEEE 802.15.4 transceiver and an embedded Java Virtual Machine. The devices were finally available in Europe in 2007. They created a grant for universities to use these devices in labs. This way we started to work with them.

A Sun SPOT (Figure 4.) is a device similar to a tMote, but more fancy. The first difference is its box, made of transparent plastic, which allows seeing the electronics. It includes sensors for acceleration, temperature, humidity and switches. It also includes eight tri-color LEDs, to provide information to the user. Last, but not least, it has a microcontroller with enough memory to run an embedded Java Virtual Machine.

From our point of view, the main improvements were:

- The platform is based on the Java programming language. This means that the students do not have to learn a new language, just a small API.
- There are more sensors and LEDs available, which allows more interaction with the device. The students see these devices like toys, and their interaction as a game.
- An Integrated Development Environment based on Netbeans, which simplifies the code development.
- A “console output” is available, which can display messages.
- Finally, a simpler simulator[21] has been developed, which allows the students to continue the work at home, without being necessary to have the device itself.

The result was an increase of the lab available time. For this reason, we started to think about new alternatives to improve the labs taking into account this increase of resources, and some requirements:

- The objective of the lab had to be an application, not a protocol
- The protocol had to become a tool to solve the applications requirements
- The target had to be adequate to the time available for the subject.

With these conditions in mind, we thought that the best objective was to develop a small game based on two Sun SPOTs.

D. *Laboratory modules*

The lab is organized in four modules and one presentation of results. The students are organized in groups of three people. We have chosen three to have at least two students of the group in the lab, as sometimes one has a “job emergency”. The exercises are solved as a group, but the documentation is presented individually. The modules are based on the tutorials and documentation from Sun Microsystems[22]. These modules are:

1) First steps using a Sun SPOT (1 session)

The purpose of this module is to introduce the student to the Sun SPOTs. Taking into account that we want the student to have the IDE and simulator installed at home, we explain them how to do it in the class.

After that, they learn how to update the Software Development Kit (SDK) and the Sun SPOTs. This task has to be done every year, as new stable tools are available.

Finally, they start to use the IDE to develop a simple demo application that blinks a led. The students usually end up feeling that the labs can be done.

2) Sun SPOTs anatomy (1.5 sessions)

The objective of this module is to introduce the different elements of the Sun SPOT to the students. They start to use the tri-color LEDs making counters and sliders to present the information.

The second step is to use the buttons to get information from the user. The students have to develop a program that changes the LEDs behavior depending on the buttons.

The third is to use the accelerometer, and then the fun is guarantied, as they see a quick feedback to their movements. They have to show the angle in the three axes on the LEDs. As a result, they see that it is not possible to get the horizontal angle using and accelerometer.

Finally, they start to work with the radio just measuring communication strength. They can see that if they separate the modules, the power is reduced. This experience also allows explaining the physics behind the transmission of data.

3) Sun SPOTs communication (1.5 sessions)

This module was the introduction to the way a Sun SPOT communicates. The difficulty of this lab is not the code itself, but the problems that the students have due to the concurrency of different devices sending information at the same time. As said before, in a few minutes the students perceive the need of addressing and error control.

4) Sun SPOTs game (8 sessions)

The last module is a small project. They have to design and develop the game that is the objective of the labs. For this purpose, they have to propose a game that can be developed using two Sun SPOTs that communicate. The action and results have to be shown with the LEDs. The students can use any sensor in the device. Examples of these games are:

- Bowling: The movements of the hand and arm are measured, when one button is pushed on a Sun SPOT. This is equivalent to throw the ball. Depending on the angle and acceleration, more pins are knocked down in the second Sun SPOT.
- Shake master: Two players have to shake as fast as possible two Sun SPOTs. The one that shakes the Sun SPOT quicker wins.
- Power master: Two players make the quickest movement that they can. The one that gets the highest acceleration wins.

From this small sample, it is easy to see that the preferred sensor is the acceleration one. The reason is the quick feedback that it provides. However, sometimes, the response is not as fast as desired.

All the games require interchange of data. This implies that they require developing some kind of network protocol, including an ARQ mechanism. Although the IEEE 802.15.4 provides an acknowledge mechanism, it is not used in the lab. This way, the students could define their own frames and its behavior.

The students also understand the frame control field and its contents. The required flags come from the functionality. They also, become conscious of the necessity of a sequence number to have a reliable link.

The main drawback was that some student relied on the simulator, which has an ideal behavior. This means that no noise is created. In this case, these students were unable to interchange data. A workaround was to include a node that sent random data. This created network noise, providing a more realistic scenario.

5) Presentation (1 session)

Finally, there is a session where students present their games, showing their behavior. Usually their focus is on the application itself, forgetting about the communication aspects of the project. For this reason, the evaluator has to ask questions regarding the protocol implemented and how they solve different problems.

The approaches presented by the students from the application point of view, can be classified as:

- Basic Client-Server: There are two different programs, one for every Sun SPOT. One behaves as client and a second as server. The start-up sequence has to be followed precisely, or the system is unable to run.
- Advance Client-Server: The Sun SPOT include both programs, the client and the server, and at the start-up sequence, the protocol defines which Sun SPOTs behaves as server.

At link level, the addressing implementation is necessary as explained before. Reliability is achieved through the implementation of an inactive ARQ mechanism. The main difference with standard protocols is the text-based codification of the fields. Only a minority of groups does the leap to binary codification.

Finally, all the students present the documentation of the project. It is also difficult for them to differentiate between the documentation of the project and the comments of the code. The difference between the application, and its elements, description and the way it has been implemented. In some cases because they have relied on their partners, in others, because they really do not know how to explain what they have done.

To minimize the problem, the outline of the documentation is explained in detail at the latest session. This solution has proven to be effective, improving the documentation quality.

E. Results

The marks of the students for the last five years have been analyzed. The graph shows on one hand the percentage of students that passed the lab; on the other, the rate of students that passed over the number of students that went to the first exam (Figure 5.).

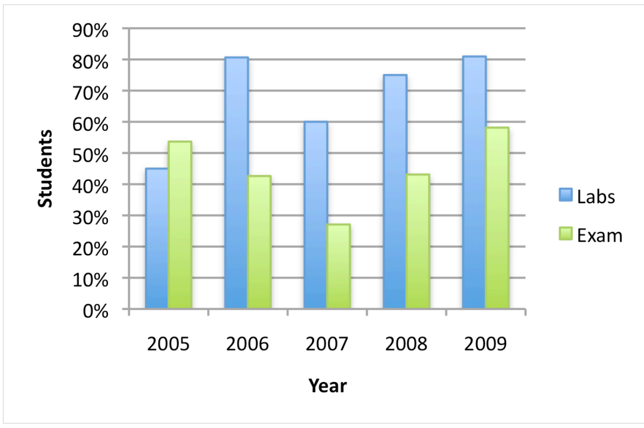

Figure 5. Percentage of succesful students in the lab and the first exam.

From the percentage of successful students, it is possible to see that there is an important change between 2005 and the rest of the years. The main reason is the change from an RS-232 based lab to a WSN one.

In January 2006 we started to use WSN in the lab. The number of students that pass the lab has its first maximum. The only drawback is a decrease of students that pass the exam. We thought this change came from the increase of difficulty of the labs, making the students change their priority from networks to learning NesC.

The number of successful students descended in the labs and the exam in January 2007. One reason was still the difficulty to learn and program NesC. Another reason was the motivation. There is a subject the same period that included the development of an application. The time required was high, and was seen as more interesting for them than WSN. At this moment, we started to think about a new change.

In January 2008 the results improved a little, although they were still worse than 2006 ones. This confirmed us that we had to rethink this laboratory.

In January 2009, with the introduction of the Sun SPOTs, both labs and the exams have had a maximum.

With the new labs, the students seem more motivated, asking more questions. A questionnaire has been done in December 2009 to confirm the last information (Figure 6.).

Questionnaire

1. How well did the introductory modules prepare you for the laboratory?
2. Did you find the SunSpots installation clear enough?
3. The SunSpot anatomy module provides enough information?
4. Did you find the SunSpots communication module appropriate?
5. Do you think a game is a good application?
6. The organization of the laboratory in a small project is a good option for this subject?
7. Do you think that the lab with SunSpots is interesting?
8. Did the laboratory help you to better understand the subject?
9. Do you think that this laboratory has to continue?
10. Summing up, do you think that this laboratory has been useful?
11. Comments

Figure 6. SunSpot laboratory questionnarie.

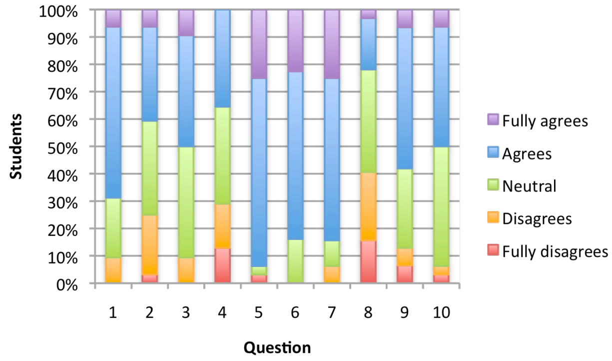

Figure 7. Questionaire results

The plot (Figure 7.) shows the results for the last cohort. In general, the students agree or fully agree on the actual organization of the laboratory. Only in questions 2, 4, 8 and 10 the agreement is below a 50%. Theses questions are analyzed deeply:

- Question 2: The installation of the SunSpots is difficult in shared environments like those that are used in a lab. Every year we have found problems with this. We are working to solve them.
- Question 4: This communications module presents how to program the SunSpots communication. To work with this module, it is necessary to understand communications and threads. From the comments, it seems that the problems come from the use of threads, so we are modifying the actual module with an extensive introduction on threads.
- Question 8: From the results of this question it seems that the laboratory is a failure, although it cannot be so bad if they think it has to continue (question 9). From our point of view, the problem is that the labs have been too centered on the game development. To solve this we will increase the stress on protocol aspects.
- Question 10: The sum is good; around a 50% see the laboratory useful, and less than a 5% disagrees. We think the alternatives presented will increase the quality of the subject, improving the number of agrees.

In summary, the use of SunSpots and WSN has proven to be a good tool to teach network protocols. However, the impact of related aspects, like the programming language or threads, has to be well calibrated.

III. DISCUSSION

The results obtained with this lab can be qualified as good. The students have shown a deeper understanding of the subject. However, we have made a deeper analysis to evaluate pros and cons:

Pros:

- The students see the Sun SPOTs as a toy, which is easy to understand and use. This reduces the concerns for a new technology.

- The developing tools are free which is an important issue in an education environment[8].
- The use of Java has minimized the time required to learn. This has allowed focusing on the subject aspects.
- The use of a game as a target in NC has introduced network protocol as a tool, not as a requirement. This has improved the perception of the students.
- The students have shown, in general, creativity and motivation.

Cons:

- The students sometimes where more interested on the game image than its functionality, increasing unnecessarily the work, resulting in unsatisfactory outcomes[9].
- Sun SPOTs IDE does not include an easy debugging tool. This implies solving problems through console messages, which is not always easy.
- It is necessary to improve the interaction between theory, problems and labs in NC. A high percentage of students fail the course, although they have passed the labs.

Many of these results are shared by [7], which also uses Sun SPOTs to teach sensor networks.

IV. CONCLUSSIONS

The introduction of WSN on NC has introduced an improvement on the learning process of students. Now they see networks as a tool and not as commodity. It has also improved the number of students that have passed the lab. The students' learning curve is steeper, giving more time to focus on the subject aspects. They have also presented a stronger interest in the network related concepts, and better understanding. Finally, it is necessary to improve the integration between the theory, problems and labs to increase the number of successful students.

V. FUTURE WORK

These results have been used to redefine this subject in the new Computer Engineering Grade, based on the European Space for Higher Education (Bologna Declaration)[23]. Now, we are preparing the material for this new course, based on the results.

ACKNOWLEDGMENT

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