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# A RECONFIGURABLE FPGA-BASED ARCHITECTURE FOR MODULAR NODES IN WIRELESS SENSOR NETWORKS

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## ABSTRACT

A reconfigurable platform for sensor networks is presented. This platform has features that allow easy reuse of the node in several applications avoiding redesigning the system from scratch. The node includes an FPGA which is the core of the reconfiguration capabilities of the node. Several hardware interfaces for sensor standar protocols like I2C or PWM have been developed and implemented in the FPGA. Remote reconfiguration is an important feature and sensor networks can take advantage of it in order to improve the global performance.

## 1. INTRODUCTION

Sensor networks have become more and more important during last years [1][2]. Several challenges are imposed by this technology like low power consumption, low cost and low size, among others. In this context, hardware design of the network nodes represents a crucial matter. Modularity is a key factor in order to adapt the node to different sensors and applications and several groups develop modular platforms with different targets [3][4][5]. In this way the node is divided in several physical parts or layers, which fulfill different functionalities within the node.

Modularity implies that the node can be adapted to different situations and applications with a minimal redesign effort. Usually, changing of application drives to redesign from scratch the node, adapting it to the new requirements.

Usually, the platforms in the state of the art avoid the use of reconfigurable hardware (as FPGAs) due to the power consumption of these devices. However, the evolution of the technology drives to new low power reconfigurable devices as [6] and [7].

In this paper a modular platform for sensor networks is presented, in which an FPGA has been included to give as much flexibility as possible to the node. The FPGA allows reconfigure the node in order to process signals from sensors with very different interfaces. It must be taken into account that each sensor has its own signals, which implies

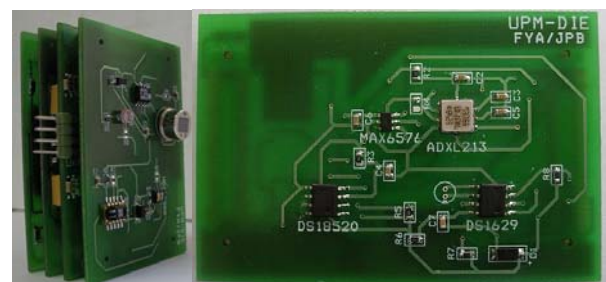


Fig. 1 Modular platform for wireless sensor networks and sensor layer with ADXL213 accelerometer, MAX 6576, DS18S20 and DS1629 temperature sensors.

hardware changes. Moreover, the FPGA gives much flexibility to the system, and the node can be modified without changing the processing hardware.

## 2. THE RECONFIGURABLE PLATFORM

A first implementation of the node platform includes four layers, which are physical PCBs (Fig. 1). Each one represents a fundamental functionality within the node: communication, processing, power supply and sensing. The processing layer is the heart of the node and here lies the reconfigurability and the modularity capabilities of the node. This layer (Fig. 2) includes a microcontroller (an

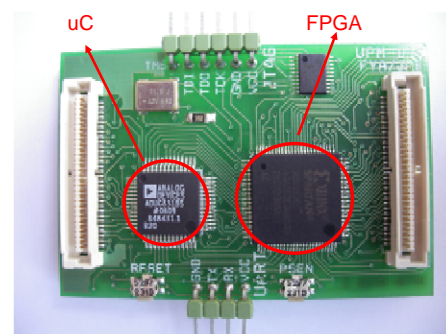


Fig. 2. Processing layer.

ADuC831 from Analog Devices which integrates a 12-bit ADC) and an FPGA (a XC3S200 Spartan III from Xilinx). Because of the versatility of this layer, the rest of the platform can be interchanged with a minimum redesign effort. In the following sections, this modular reconfigurable architecture is explained in detail

### A. Communication

Sensor networks can require multiple nodes depending on the application. Because of this reason it is desirable to eliminate the cables that interconnect the nodes. Therefore, a wireless approach is chosen to communicate nodes in the network.

Many technologies exist in the market, with different data rate and power consumption. Bluetooth technology is one of the considered solutions due to its data rate (723.2 kb/s in one direction), low power consumption, low form factor and operation in the 2.4 GHz unlicensed ISM band. Bluetooth has been chosen as a first approach because it is a quite developed technology and there are a huge variety of commercial modules with the full protocol stack implemented. Furthermore, Bluetooth allows creation of wireless networks in a dynamic way, in which network nodes can vary along network life. This is an important feature, permitting network to work even if a node breaks down.

However, ZigBee technology has been integrated in a new communication layer, in order to reduce power consumption and make easier network setup. This technology is more suitable for the purposes of sensor networks, due to its very low data rate and its very low power consumption. This is a new demonstration of reconfigurability of the platform in the physical side

All the communication tasks are carried out by the microcontroller, which controls the Bluetooth module through comads using the UART port.

### B. Processing

This layer is the one that provides the smart sensor with intelligence and expand the reconfigurability of the platform, thanks to the FPGA. Here, the signals from the sensors are converted into appropriate digital and processed signals. Moreover, the control of the communications is carried out in this layer. Searching for neighbour nodes, setting and breaking links, and management of all the tasks related with the network are controlled here by generating commands to the Bluetooth module, and interpreting commands from the Bluetooth module and other network nodes.

Power saving modes are managed here too in order to prolong battery life. This is an important question in wireless sensor networks because it is required that the network works autonomously for a long time without human intervention.

A mixed microcontroller/FPGA design is proposed in the first implementation in order to satisfy different

requirements for several applications. Versatility and reconfigurability are the targets of this election, existing other possibilities such as using only the microcontroller, or only the FPGA.

In the current implementation of the platform, both microcontroller and FPGA are present in the processing layer. A handshake protocol manages the communication between both devices. The microcontroller and the FPGA share 16 pins, which are two ports of the microcontroller (ports 0 and 2 of an 8051 compliant architecture). The FPGA receives triggers from the microcontroller, and a channel selection number which represents a specific sensor or actuator (transducer). The FPGA takes the measure from the sensor specified or send orders to the actuators. If a value from a sensor is taken, the FPGA sends a trigger to the microcontroller and puts the data (two bytes) in one of the ports shared by both devies. This two bytes are sent separately, because one of the two ports shared is used to send the control signals (channel selection, triggers, etc.).

This implementation implies a great reconfigurability of the node depending on the different transducers that have to be used in a specific application. In the other side, for the microcontroller is very easy to take measures from the sensors, because it only has to put triggers in different ports, and all the work is accomplished by the FPGA. In this context, the FPGA can be seen as an accelerator of the microcontroller, but with reconfigurable capabilities, which gives much flexibility to the design.

### C. Sensing

This is the layer that includes sensors and/or actuators (transducers). According to the use of the smart sensor network, multiple combinations are possible. Multiple kinds of sensors can be included in this level, and actuators may be incorporated too, in order to act according to parameters measured from environment.

As a first step in modularity for the reconfigurable platform, two sensor layers have been developed, including

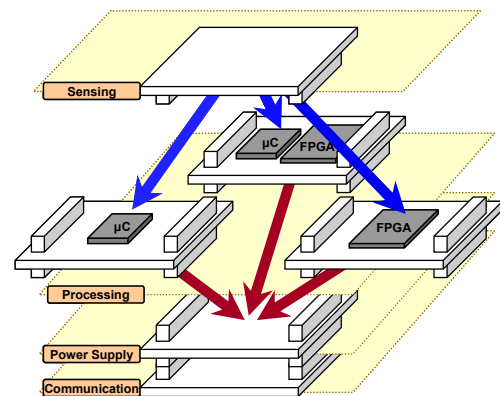


Fig. 3 Reconfigurability of the modular platform

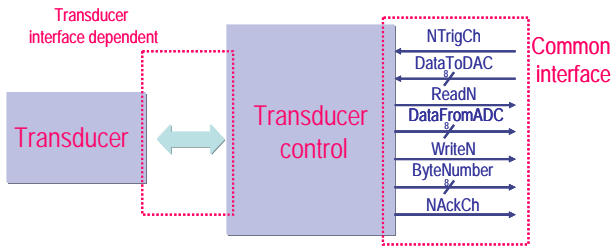


Fig. 5 General structure chosen for the control of a transducer.

temperature, humidity, acceleration, threshold light, light intensity and infrared sensors.

The digital sensors are connected directly to the FPGA which process these digital signals and sends the processed data to the microcontroller. The microcontroller takes the data and makes the last processing before sending the information to the network.

Analog sensors are connected to the ADC of the microcontroller, which processes the analog signals directly (Fig. 4)

With this configuration, the reconfigurability of the platform is maximum, and it is possible to change the sensors without changing any of the rest of the platform layers.

#### D. Power Supply

The main objective of this layer is giving the necessary power for the rest of the modules, which can be extracted from a battery or a converter connected to the power line, for instance. In this way, it is possible that a node takes the energy from a source with an unlimited lifetime like the power line, or takes it from a battery. In the latter case, low power would be an important requirement for the rest of the modules in order to increase the system lifetime. Again, versatility is an important feature of the design being possible different power approaches depending on

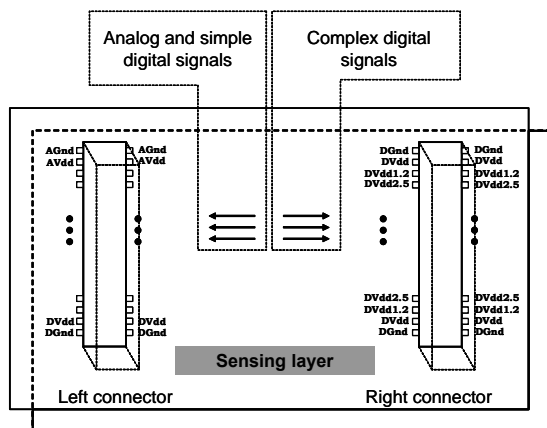


Fig. 4 Sensor signal distribution

the application.

This layer is also in charge of generating the appropriate digital voltage levels for the rest of the modules. Here, voltage regulators are included because different elements of the node (FPGA, microcontroller, Bluetooth module...) operate at different voltage supplies. This layer generates voltages of 5 V, 3.3 V, 2.5 V and 1.2 V or any other voltage level, depending on the application.

In the first implementation, both the microcontroller and the Bluetooth module operate at 3.3 V, while the FPGA needs three different supplies: 3.3 V, 2.5 V and 1.2 V. The most consuming device is the FPGA and power save modes must be implemented.

### 3. THE RECONFIGURABLE TRANSDUCER INTERFACES

Several sensors with very different interfaces are available in the market and it would be desirable not to change the hardware every time the application changes. The use of ASICs optimizes power consumption and reduce platform size but limits the adaptability of the node. Several sensor interfaces can be implemented in the FPGA, to deal with the myriad of potential sensors for a determined application. Reusability is another key factor, because multiple different sensors use the same interfaces, and every interface has to be designed only one time. The interface can be used in other application, with perhaps a few modifications.

Several interfaces have been developed and implemented in the FPGA in order to manage signals from digital sensors. These interfaces and some examples of commercial sensors included in the sensor palayer of the platform are, among others:

- PWM (ADXL213 accelerometer from Analog Devices).
- Signals with variable period/frequency (MAX6576 and MAX6577 temperature sensors from Maxim).
- I2C (DS1629 de Dallas-Maxim)
- I2C modified (SHT11 Humidity and temperature sensor from Sensirion).

All these signals may overload the processing capabilities of the microcontroller, which is busy with communications and analog signals from sensors. The management of the network is very important as well as treatment of signal from sensors. In this way, the FPGA releases the microcontroller from the digital sensor processing. The FPGA can deal with these sensors optimizing the node performance.

The interface structure follows the IEEE 1451.2 standar, with a common interface for every transducer and an interface dependent of the transducer (Fig. 5). This standar pursues to make the sensor transparent for a user, independently of the interface.

New interfaces are being developed (1-Wire, SPI), because several sensors include this kind of standards. The purpose is to create a library of hardware interfaces for sensors and actuators interfaces and to generalize the interfaces in order to make easier redesigning the system when new sensors are included in the platform. The generalization of the interfaces will make the platform almost transparent for a user that have to modify the intergaces for a specific application. The FPGA allows this approach, and make possible to reconfigure the platform in a fast and easy way.

#### 4. REMOTE RECONFIGURATION

The application scenario of wireless sensor networks can imply hundred or perhaps thousands of nodes. In such situation, reconfiguration of the nodes becomes unfeasible, if the nodes must be reconfigured independently. In this case, it is possible to take advantage of dynamic and partial reconfiguration of the FPGA.

An application scenario could be an environmental one, for example a forest, where a lot of nodes take measurements from the environment and communicate the data to a base station. It can be possible to change the algorithm used to control the sensor signals, in order to reduce power consumption or to accelerate processing because the application demands. Wireless communication can be used to send the new bit stream to the FPGA, reconfiguring it partial o totally, depending on the new requirements.

There are previous experiences carried out in this working group, in reconfiguring FPGAs from wireless links, like those reported in [8].

#### 5. POWER CONSUMPTION

Power consumption is always a critical issue in wireless sensor networks. The situation usually presents several autonomous nodes sensing physical parameters in inaccessible places, which must save the most energy they can.

FPGAs are not the best candidates in order to reduce power consumption, but it is known that it is possible to reduce the global energy consumption by managing resources in the right way. In this context, processing the information using the configurable hardware can be more economic in terms of energy, than a microcontroller for example.

Moreover, manufacturers work hard in order to achieve new goals in power consumption of reconfigurable devices, like Eclipse II FPGA from QuickLogic or Igloo FPGA from Actel (Fig. 6). In the future FPGAs will be an option for the processing in wireless sensor networks, and the nodes will be more versatile, reusable, interchangeable and

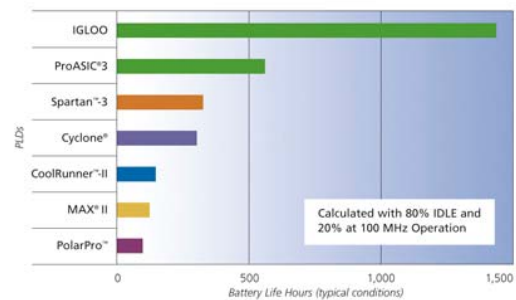


Fig. 6 Battery life depending of the FPGA family (source: Actel [6]).

reconfigurable. The present work focuses this solution today, thinking in the future.

It must be said that in applications where the node take the energy from the environment, taking advantage of energy harvesting techniques, the remote reconfiguration can be an alternative in order to reuse hardware, which drives to reduce the cost.

#### 6. CONCLUISONS

A reconfigurable platform for sensor networks has been presented. The reconfigurability is possible in different ways, since the node physical structure until the reconfiguration of the processing hardware thanks to the FPGA.

Reconfigurability can reduce the cost of the system. In this context it is possible to take advantage of reusability of interfaces for transducers and physical layers.

The result is a platform that can change in every aspect can be imagined adapting it to very different scenarios with minimal redesign effort and cost.

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