A 169 MHz Wireless M-BUS Based Advanced Meter Infrastructure for Smart Metering

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***Abstract*— Nowadays, the use of wireless technologies provides a great benefit to the society. One particular example is the shift towards smarter, more advanced meters. While this trend first started off with the electricity meter market, the adoption of smart meters within the gas and water meter market is also gaining momentum. This article presents an architecture, design and implementation of an advanced meter infrastructure based on 169 MHz, which is suitable for critical deployments as basements, courtyards, etc. The article includes the design and implementation of a wireless sensor node and a gateway for Gas Smart Metering, which can coordinate the network and connect the metering to the "Cloud". This way, the acquired data could be used to improve the measurement systems avoiding human errors.**

Keywords— Wireless Sensor Networks, Advanced Metering Infraestrucutre (AMI), wireless M-Bus, Cloud Computing service

I. INTRODUCTION

The cost reduction for the wireless technology has raised the number of applications, in which the remote monitoring and metering are included. This has caused many companies to dedicate their research to the development of wireless sensor platforms, known as *Smart Meters*, aimed at this purpose.

The Smart Meters are defined as advanced energy, water, or gas meters which measure the energy consumption of a consumer and provide added information to the energy provider companies. Smart meters can read real-time energy consumption information including voltage, phase angle and frequency values and securely communicate that data. The smart meters are part of a bigger system where, in addition to the smart meters a bidirectional communication infrastructure and the remote control of the devices are included.

The meter network platform we are proposing is based on the 169 MHz frequency band. This band has been reserved in Europe for meter reading purposes. Along the paper a standard platform and its gateway to the Internet is proposed, developed and tested. The platform is able to read meters or sensors remotely through typical communication protocols such M-Bus, Modbus, I2C, SPI, UART, etc., and also it has been optimized for low cost and low energy consumption.

The meter network is made up of different wireless sensor nodes linked to a master node which is connected to Internet via the mobile network. The sensor nodes are placed near the meters or sensors located in places where a robust communication system is needed, due to the attenuation. Examples of these kinds of places are basements, courtyards, rooftops, etc.

The rest of this paper is structured as follows: in Section II, details are provided concerning the related work including the identification of the main commercial platforms and its characteristics. In Section III, the system architecture is described. Section IV explains the implementation of the different parts of the Advanced Meter Infrastructure. Section V shows both the test done to the system and the results obtained. And finally, conclusions and future work are drawn in Section VI.

II. RELATED WORK

Currently, the commercial available WSN platforms in use are very similar in terms of their hardware architecture, which are based either on the 16-bit MSP430 microcontroller or the 8-bit ATmega128 MCU, in combination with a network architecture based on IEEE 802.15.4 standard. Examples of this type of platforms are TelosB, MicaZ and IRIS. The popularity of the use of the MSP430 and ATmega128 processors is due to several reasons, such as the ultra low power energy consumption, the community support, the open source compilers based on GNU-GCC, and the different embedded operating systems support, such as TinyOS or ContikiOS [1][2]. The limitations of the platforms for the IEEE 802.15.4 based networks have led us to develop a new hardware platform for the 169 MHz frequency band.

Other meter infrastructures are presented in the literature. These meter infrastructures are based on the platforms mentioned above. For example in [3] an AMI is created in the city of Goteborg, based on the ZigBee technology using the 2.4 GHz band. Another example is ZAMI [4], which proposes a ZigBee based infrastructure for automatic meter data collection and energy auditing and management.

In relation with the 169 MHz frequency band, a variety of protocols compete to extend the use of their proprietary approaches. Protocols such as ZigBee [5], EnOcean Routing Protocol [6], KNX-RF [7] and wireless M-Bus are the major

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contenders. Currently, the wireless M-Bus has a special importance, as it has been selected by the metering industry, which is organized in associations (i.e. the Open Metering Group).

Wireless M-Bus is based on the Metering bus (M-Bus) which is specialized in transmitting data from the different meters. The wireless M-Bus is specified by the European Norm 13757 [8] and covers the communications from the OSI model hardware layer to the application layer. Although wireless M-Bus does not specify the network organization, leaving it open, gives all the necessary tools to implement it. Wireless companies have developed modules which are in compliance with this norm, having most of them a preprogrammed embedded stack. For this reason, these modules are not suitable for research purposes.

III. System Architecture

The system architecture addresses buildings in a neighborhood, creating a 169 MHz wireless network, in which the meters and the sensors are the network sensor nodes. The communication between each node and the data mining services is carried out via Internet. The interconnection is provided by a special node, the gateway Node. For the connection to the WAN, the mobile communication networks have been selected, using a GSM/GPRS [9][10] module. Due to the fact that some sensor nodes can be out of range with the gateway node, all of the nodes perform message routing.

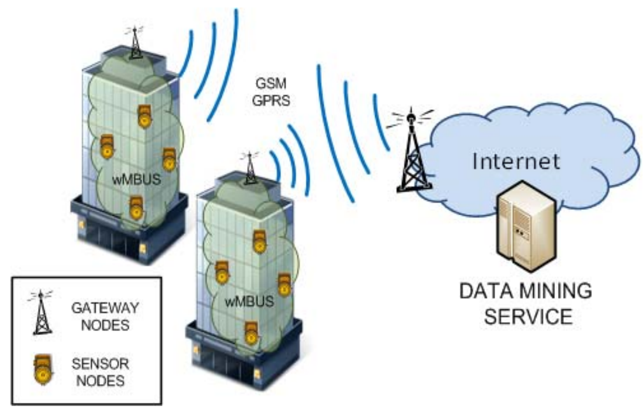

Fig. 1 Advanced Meter Infrastructure (AMI), based on wireless M-BUS networks

Fig. 1 presents the most important components of the system, where each sensor node is able to report data values and respond to external request in an autonomous and independent way. These nodes require small computational power but memory can be an important issue, depending on the time interval the measured values have to be stored.

Usually the sensor nodes are run by batteries; although in some cases they could be run by the electric grid. In the case of the gateway node, it requires significantly higher energy resources for collecting and storing together the data received from the sensor nodes, and to be sent to the data mining services. This node is also responsible for sending the software updates, the configuration commands and test commands to the nodes. As it has been mentioned, this node is connected to the Internet via a GSM/GPRS module. The current consumption of these modules could reach peaks of 1A. This is the reason why the gateway node is powered by the electric grid.

IV. Implementation

A. Hardware implementation of Sensor Node

The objective of developing a new wireless M-Bus platform was to have a base layout design that can be easily controlled and modified. It could also be used in various applications with different interfaces for meters and sensors. Fig. 2 shows a scheme of the proposed Sensor Node.

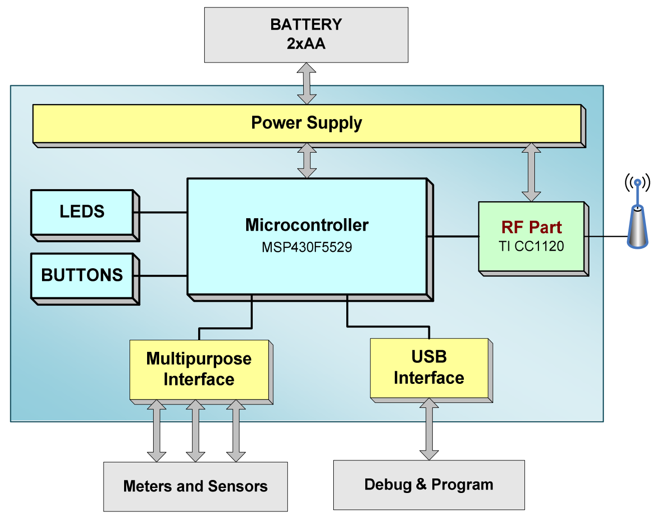

Fig. 2 Sensor's Node hardware scheme

The hardware architecture of the wireless device has been divided in different modules: the microprocessor module, the multipurpose sensor interface, the 169MHz RF module and the Power supply module.

The microcontroller module is the core of the system. It receives the sensor information through the multipurpose interface and also controls the battery level and the radio communications. For this module we chose a MSP430 based microcontroller used in the main commercial platforms such as TelosB, TinyNode, Tmote Sky, etc [11]. The selected one is the MSP430F5529 microcontroller with 8KB+2KB RAM, 128KB Flash and with integrated USB and PHY supporting USB 2.0, four 16-bit timers, a high-performance 12-bit analog-to-digital converter (ADC), two universal serial communication interfaces (USCI), hardware multiplier, DMA, real-time clock module with alarm capabilities, and 47 utilizable I/O pins. The MSP430F5529 is a 16-bit RISC microcontroller equipped with different low power modes between Off Mode (RAM Retention) and Standby mode (1.9µA from 1.8V to 3.6V).

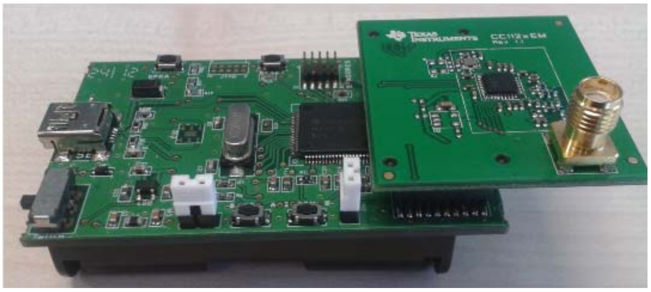

Fig. 3 Picture of the developed sensor node

For the 169 MHz frequency band, the CC1120 chip from Texas Instruments was chosen. This RF module was selected due to the fact that it offers the possibility of changing parameters related to the communication protocol, a feature not provided by the commercial ones.

The Printed Circuit Board (PCB) was designed addressing signal integrity issues for digital circuits such as loop inductance, crosstalk, and Power Distribution Network (PDN) issues. A FR4 2-layer PCB was used with all the components in the top layer. For crosstalk reduction, all empty routing space was filled with cooper and connected to ground plane. In the case of the PDN decoupling capacitors are placed near the IC's power pins minimizing the effect they have on the rest of the circuit. Traces were kept as small as possible and splaying corners are used, to avoid transmission line reflections. In order to have the best performance against the EMC the smallest component packages were used to ensure low equivalent Series Inductance (ESL). The result of the developed sensor node is shown in Fig. 3, where the dimensions are 80mm x 40mm.

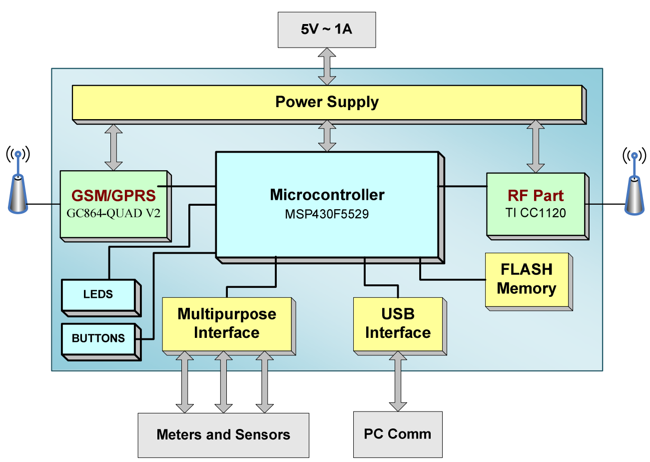

Fig. 4 Gateway's hardware scheme

B. *Hardware implementation of the Gateway Node*

The gateway node is designed as an extension of the previous node with added modules and features. In this case, a GSM/GPRS module and a FLASH memory are added to the hardware architecture, and the USB interface is used to have a direct connection to the PC. It is used as a command line for debugging and programming. Another remarkable change is the power source which is obtained from the electric grid. A graphical scheme of the gateway node is shown in Fig. 4.

The PCB was designed similarly to the one of the sensor node. The result of the gateway node implementation is shown in Fig. 5, where the dimensions are 85mm x 54 mm.

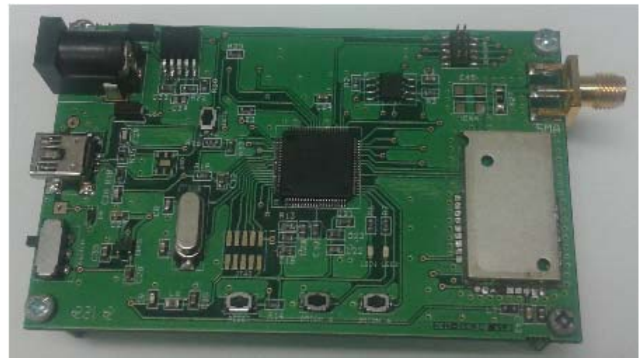

Fig. 5 Picture of the developed wireless M-BUS Gateway

C. *Software implementation*

The developed software is a key point of the system and has a modular scheme. It also created from scratch and built with the open msp430-gcc compiler. The design allows the different modules to be independent from the hardware as long as the same standards and definitions are used. Fig. 7 shows the software architecture and the interactions between its components. The major components are:

- **Sensor node software:** reports information about the sensors and responds to requests.
- **Gateway node software:** includes the following functions: request data, aggregate nodes to the network, manages communications and provides information about all the nodes to the "cloud".
- **Data mining service:** exploits the data and introduces them into the database.
- **Web interface:** displays the data and allows the user to send commands to the network or to an individual node.

The sensor node software implements a wireless M-Bus stack besides a power saving algorithm, designed to manage all the power modes of the modules. It puts the modules in the best mode, considering the tradeoff between their functionality and the minimum power consumption.

```
<device>
  <id>01:02:0A:0B:0C:0D:01:01</id>
  <measure>
    <var>
      <varid>1</varid>
      <value>2</value>
      <time>2013-04-16 12:20:53</time>
    </var>
  </measure>
</device>
```

Fig. 6 XML file description

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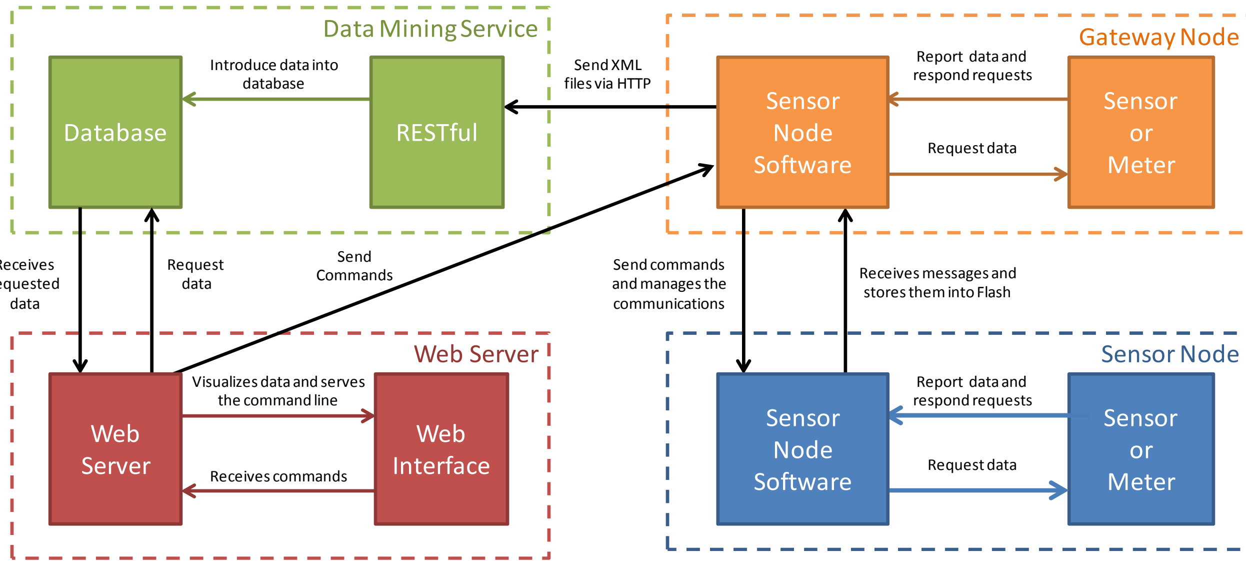

Fig. 7 Software Architecture

The embedded software running in the gateway node also implements the wireless M-Bus stack, but in this case it is not worth implementing the power saving algorithm. Furthermore, this software implements the gateway functionality, which translates the data between the wireless M-Bus network and the Internet. However, another protocol translation occurs prior to this one. Data obtained from the wireless M-Bus network is translated into a custom XML, and is sent to the data mining service by the HTTP protocol over TCP/IP via the GSM/GPRS module. In addition, the gateway node has a USB interface with a console for configuration. An example of a piece of code from a generated XML file is shown in Fig. 6.

The data mining service is composed by a RESTful web service API, a MySQL database and a web server service. The RESTful service receives the XML file generated and sent by the gateway nodes and introduces it into the database. The web server service is used as a web interface that handles the data visualization and is able to configure some parameters of the nodes and also to send commands to the gateway.

V. TESTS AND RESULTS

In this section, the most relevant results and tests have been evaluated. First, a power consumption study of the main operations of the sensor node is shown. Then the evaluation of the gateway communications front-end is exposed. Finally, the whole system with Internet connection is evaluated and analyzed.

A. Sensor Node

The energy consumption of the developed sensor node has been studied by analyzing the voltage drop across a 10Ω resistor placed in series with the power source. Then the current consumption is obtained by applying the Ohm's law.

Fig. 8 shows the current consumption profile obtained for different typical operations.

- Interval 1 and 5 shows the device in the best power down mode, where the average current consumption is 0.223mA.
- Interval 2 corresponds to the microcontroller in active mode and the transceiver in idle mode, where the total current consumption average is 2.529mA.
- Interval 3 relates to the receive operation of the transceiver in the channel "1a", defined in the wireless M-Bus standard. In this interval the device is waiting for a packet and receives it, in which case the current consumption average is 25.002mA.
- Interval 4 presents a transmit operation of a wireless M-Bus packet in channel "1a", composed by 23 bytes without taking into account the preamble. In this case the current consumption average is 40.075mA during 45.5ms.

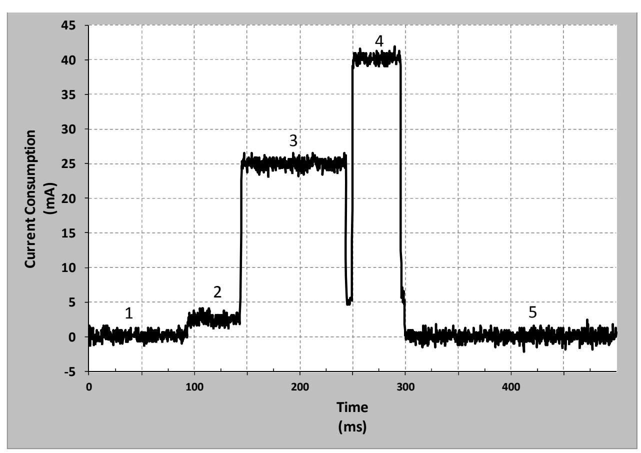

Fig. 8 Node´s Energy consumption

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B. Gateway Node

The gateway node was built and tested similar to the sensor node. Upon the electrical test was done, the connection to the PC through the USB was tested, creating a command line in the USB and configuring the USB line as a serial CDC emulation. The GSM/GPRS module was tested by sending AT commands via the command line and observing the responses, sending some text messages to some phone devices.

C. Advanced Meter Infraestrucutre

The system was prepared by setting-up a wireless meter network with 2 sensor nodes and 1 gateway node. As the sensor nodes do not have connected any sensor or meter, the sensor nodes were configured to send periodical messages every 2 minutes with the "On time" value to the gateway node. The data mining service and the web interface was configured as it is presented in the implementation.

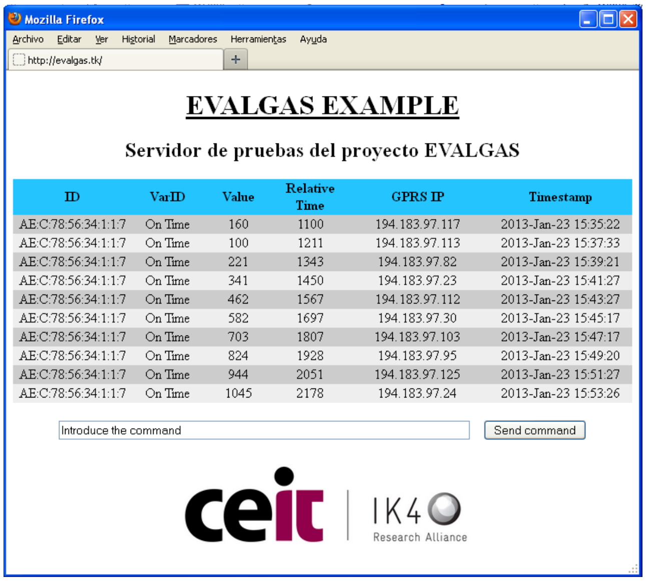

Fig. 9 Web interface screenshot

The infrastructure was tested analyzing the results obtained in the web interface, which shows the "On time" values configured to be sent on sensor nodes. A screenshot of the web interface is shown in Fig. 9. The developed wireless M-Bus stack was checked by requesting data of a sensor node. The results obtained validate the network functionality and the suitability of the wireless M-Bus for the AMI.

VI. Conclusions and Future Work

This paper proposes an architecture, describes the implementation of the required hardware and presents the design and the implementation of the software for an Advanced Meter Infrastructure. We successfully build a small low power sensor node platform and a gateway node platform.

Wireless M-Bus demonstrated to be a good solution to implement the communications for the Advanced Meter Infrastructure. The software architecture has been validated and allows bidirectional communication between the web interface and the sensor nodes.

In addition, a power consumption analysis has been performed and the obtained value will be used to determine the periods of transmission for a specific lifetime.

Currently we are working on improving and enlarging the knowledge of the meter infrastructure in several ways:

- Defining a new generic XML file.
- Studying the transmissions from a physics point of view.
- Introducing the *Internet of Things* to the system, allowing TCP/IP communications.
- Release the Hardware and Software as an open Hardware Platform for Metering purposes.

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