A Low Cost and Flexible Power Line Communication Sensory System for Home Automation

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***Abstract*—This work focuses on the definition of a home automation system based on power line communication. A low cost and non invasive system has been developed and tested with successful results. It is based on the Cypress CY8CPLC10, an integrated power line communication chip which embeds both a PHY modem and a network protocol stack. The information management and data generation processes are demanded to a microcontroller, in this first prototype, being implemented with a standard commercial board. Combining the use of a microcontroller with a power line modem and a dedicated software application it is possible to manage sensors and actuators in the neighbors through the power grid and without modifying the existing electrical and network systems.**

***Index Terms*—Actuators, automation system, microcontroller, power line, sensors**

I. Introduction

Nowadays, electricity is the main resource for both human wellness and productivity. In this sense, home and urban automation are benefiting of great efforts from the designers with the dual aims of improving the quality of life and preserving the natural resources. For this reasons, the presence of Home Automation systems are becoming widespread in everyday life [5], as they are all expected to comply with user requirements (e.g., basic comfort, security, energy conservation). Some of these are Heating Ventilation and Air Conditioning (HVAC) control systems [6, 7], lighting [8], safety and security (e.g., video surveillance, fire/smoke detection, intelligent alarm systems) and so on. Also communication systems are widely increasing themselves thanks to a variety of interests, from safety to information purposes. In this scenario, the mix of different skills and knowledge is straightforward and leads to the definition of innovative applications [1–16] and systems for human wellness [17–28]. In the context of Smart Home, there are many home automation technologies available on the market that are useful to fulfill user requirements, but very often users need to choose the best one, as presented in [9]. Home automation systems are enhancing the convenience, safety, comfort, and energy efficiency of a growing number of homes around the world. Smart homes are realized by means of sensors, advanced appliances, actuators and user interfaces that communicate by means of interconnections. Usually, they are realized with dedicated, physical networks or by means of RF and wireless links [29, 30]. Anyway, both the solutions experience some drawbacks that rely on the necessity to modify or expand the electrical system for wiring solutions or to occupy useful bandwidth in the local wireless network. To avoid this problems, the embedded designers want to find a solution that combines the characteristics of a wired connection without having to modify the home system or spend money to cable the system with additional physical wires. Since houses already have a network of wires that connect each room (the electrical line), and these wires are used only for one task (to supply each room with electricity), it is possible to transform them to transmit data like any other wire, and this is what a power line network does. By using the network adapters connected to the electric sockets throughout the home building it is possible to use the existing electric cables as a kind of replacement Ethernet cable. This has no effect on the normal operation of the electrical cables. Furthermore, power line networks work as standard wired connections in terms of security and performance, since there is no possibility that the home network will be hijacked or used by an unauthorized person (unless someone sneaks in private home). On the other hand, performance is not as fast as an Ethernet connection, but generally you get transmission speeds between 40 and 80 Mbps, depending on the adapters you use.

In this scenario, the solution here presented and based on power line communications represents an adequate and feasible alternative to implement efficient and non-invasive automation systems. In particular, the proposed solution embeds different key points valuable for home applications and environmental monitoring, allowing to achieve simplicity, ease of installation, reliability, and robustness requirements. It combines a commercial microcontroller and the Cypress CY8CPLC10 [32], an integrated power line communication chip which embeds both a PHY modem and a network protocol stack, allowing a robust communication between different nodes. In this work we present an efficient hardware architecture that combines the use of a microcontroller with a power line modem making possible the management of sensors and actuators in any place in the neighbors through the power grid and without modifying the home existing electrical and network systems. In addition, the choice of the Cypress chip gives further advantages in terms of available features, since it allows a bidirectional half duplex communication, Frequency-Shift Keying (FSK) modulation and error correction codes.

All these characteristics improve the overall quality of the system permitting robust communications also on old electrical systems.

The remainder of the work is organized as follows: Section 2 describes the hardware architecture of the proposed system. Section 3 presents the device prototype and relative tests. Section 4 illustrates the PLC configuration software which allows to set the system parameters. Finally Section 5 closes the paper with some conclusions and future works description.

II. Hardware Architecture

The architecture of the proposed power line module is shown in Fig. 1. The electrical grid is used for bi-directional communications between different nodes, which in home environments can represent control units, user devices or appliances. The overall functionality is guaranteed by the use of a microcontroller (uC in Fig. 1) combined with the communication chip. The microcontroller interprets the user requests and generates the corresponding message to transmit.

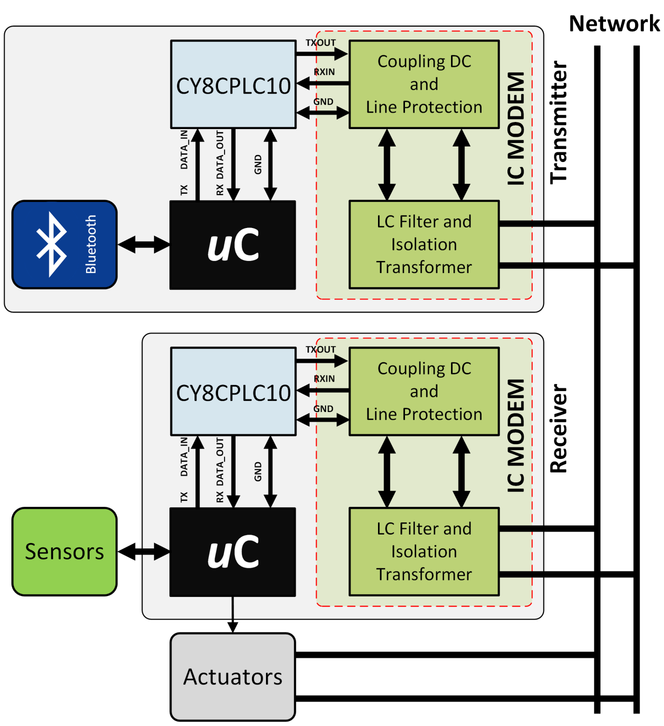


Fig. 1. Basic scheme of the communication system for home appliances.

The information reaches the power line device through an I^2C serial bus and the Cypress CY8CPLC10 [32] is responsible of the data transmission, since it embeds both a network protocol and an FSK modem providing the following characteristic to the overall system:

- PHY Modem
- 2400 bps Frequency Shift Keying modulation
- Optimized power line network protocol
- Half-Duplex bi-directional communication
- 8-bit CRC Error Detection code
- I^2C communication protocol at 50, 100 and 400 kHz
- Full compatibility with 110V-240V AC and 12V-24V AC/DC network voltages
- Fulfillment of CENELEC EN50065-1:2001 and FCC Part 15 rules
- Minimum RX input sensitivity 125 μVrms
- 8-bit logical addressing supports up to 256 Power line nodes, 16-bit extended logical addressing supports up to 65536 Power line nodes and 64-bit physical addressing supports up to 2^{64} Power line nodes

The Cypress CY8CPLC10 internal architecture is shown in Fig. 2. Finally, the receiver node demodulates the network signal in the reverse way and transfers the information to the control unit so to perform the requested action with a user configured system sensitivity.

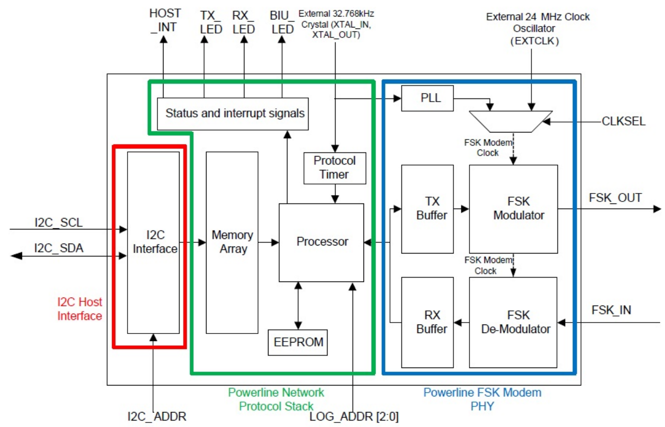


Fig. 2. Cypress CY8CPLC10 Hardware Schema.

Thanks to the Bluetooth module, the full system can be controlled and monitored with any Bluetooth application, as for instance, the “Arduino Bluetooth Control Developer”, freely available for Android devices. In this way, a smartphone or tablet can be enough to check and change the status of any appliance connected to a power line node. In this work, an ATMEGA microcontroller has been selected for several purposes; the most important issue related to this scenario is the register configuration. This problem enhanced the settings of device parameters that should fulfill with the input/output requirement of a specific automation environment. This situation has been solved with a software interface between final user and electronic device and has been shown in the next paragraph. In addition, a front-end to be used between the power line chip and the electrical network is also necessary and has been designed for filtering and amplifying the generated signal, in compliance with the CENELEC and FCC standards. The transmitter filter is a pass-band network realized in the Chebyshev topology with operational amplifiers and showing a center frequency of 133 KHz. It has a gain of 16.5 dB with an in-band delta gain of 1.5 dB and an out-of-band attenuation that allows to obtain -20dBc at 150KHz and -50dBc at second harmonic. The transmission chain ends with a further op-amp-based amplification stage that provides an additional gain of 12 dB and is designed with a push-pull output stage, useful to drive the low-impedance loads of the power line. The receiver chain instead, has an input, pass-band filter realized in the Butterworth topology, with an insertion loss of 1 dB and a 3 dB bandwidth of 60 KHz.

III. Prototype and Test

The hardware architecture described above has been implemented (see Fig. 3) and tested in home environment. The TX/RX module, which embeds the selected Cypress device, the Bluetooth module and the signal conditioning circuitry, has been realized as a standalone board and a photo of the top side of the prototype is shown in Fig. 3.

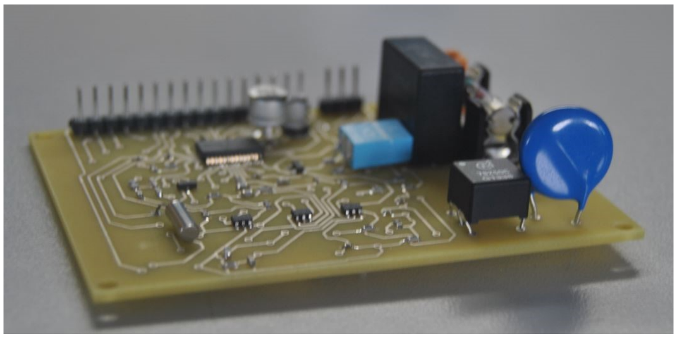


Fig. 3. Prototype of the TX/RX transmission module.

The socket strip in the lower side of the *Printed Circuit Board* (PCB) allows to connect the board to both the external microprocessor board and the electrical grid. The microcontroller has been programmed accordingly to provide the full functionality of the system. In this application, the breadboard prototyping board has been used for testing purposes to check the node features and the transmission modes. Also the actuator and a typical appliance or user device have been simulated on the bread-board with a generic load . As an example of application, in Fig. 4 a measured typical modulated transmission signal is plotted.

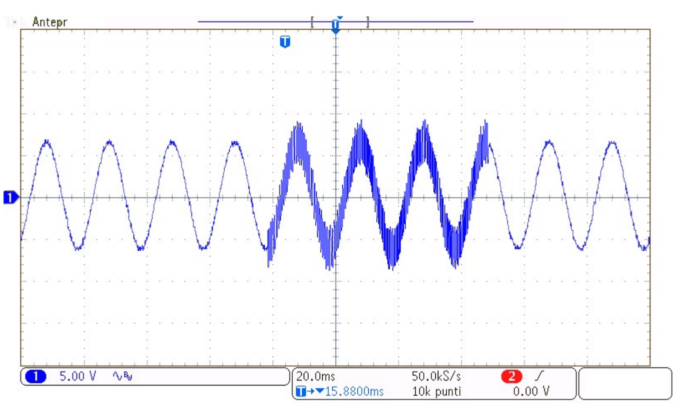


Fig. 4. Example of measured 50 Hz signal with a FSK modulated transmitted information.

In this case, the electrical grid signal is simulated with a sinusoidal signal at the frequency of 50Hz and a 12 V peak-to-peak amplitude. This carrier is used to transport the information through an FSK modulation and the modulated signal is superimposed to it. It is important to note that both the generation of information and data conversion of the communication signals have been demanded to the microcontroller and have required the development of dedicated algorithms and code to correctly interpret the used needs and aims.

A final comparison of the main characteristics of the proposed solutions with respect to other solutions from the literature is reported in Table I. In particular the proposed system shows very long communication range with respect to other proposed solutions with reasonable high data rate. This proves that our solution has a high sensitivity respect to other works, providing the possibility to put multiple addressed nodes and to use them with repeater configuration in order to reach distances of over 1 km. In addition, this solution does not suffer from obstacles like walls or buildings, as happens with wireless solutions, because the power line is distributed through the whole building. Finally, unlike other solutions that use more robust modulations [31], it has the advantage of being simple to implement and low consumption, as presented below.

TABLE I
Comparison between different solutions from the literature.

	Solution A [1]	Solution B [2]	Solution C [3]	Solution D [4]	**This work**
Transmission Mode	Bluetooth	ZigBee	X10	ASK Modulation	**FSK Modulation**
Communication Node	RF	RF	PLC	PLC	**PLC**
System-On-Chip Solution	Yes	Yes	Yes	Yes	**Yes**
Encryption	128-bit AES	128-bit AES	No	No	**No**
Energy Usage	Medium	Medium	High	High	**Medium**
Data Rate	3Mbps	$>$ 20kbps	20-200bps	1200bps	**2400bps**
Two-way Communication	Yes	Yes	No	No	**Yes**
Ability to work as Repeaters	Yes	Yes	No	No	**Yes**
Transmission Range	$\approx$ 350m	$\approx$ 60m	$\approx$ 30	$>$ 10m	**$\approx$ 100m (1000m with repeaters)**
Easy of Installation	Medium	Medium	Difficult	Medium	**Easy**

IV. PLC Configuration Software

A proper software application has been developed to configure the memory mapped power line communication device parameters. These parameters can be accessed by external host applications and controllers. Several PLC commands are issued from power line network protocol and, depending on them, several memory locations are read and/or written [32]. A typical scenario allows users to set device register parameters and save them in the local microcontroller (uC) EEPROM memory. This step is useful to reload the starting configuration at the uC booting stage and improve sending and receiving data in the power line network without direct involvement of the final operator.

Fig. 5 shows the software architecture related to the PLC configuration, based on a *Model-View-Controller* (MVC) pattern. Java was chosen as development programming language for its cross-platform benefits, its object-oriented paradigm (OOP) that helps the programmers to develop their software with focus on code reuse and business evolution (using specific software development process and exploiting properly design

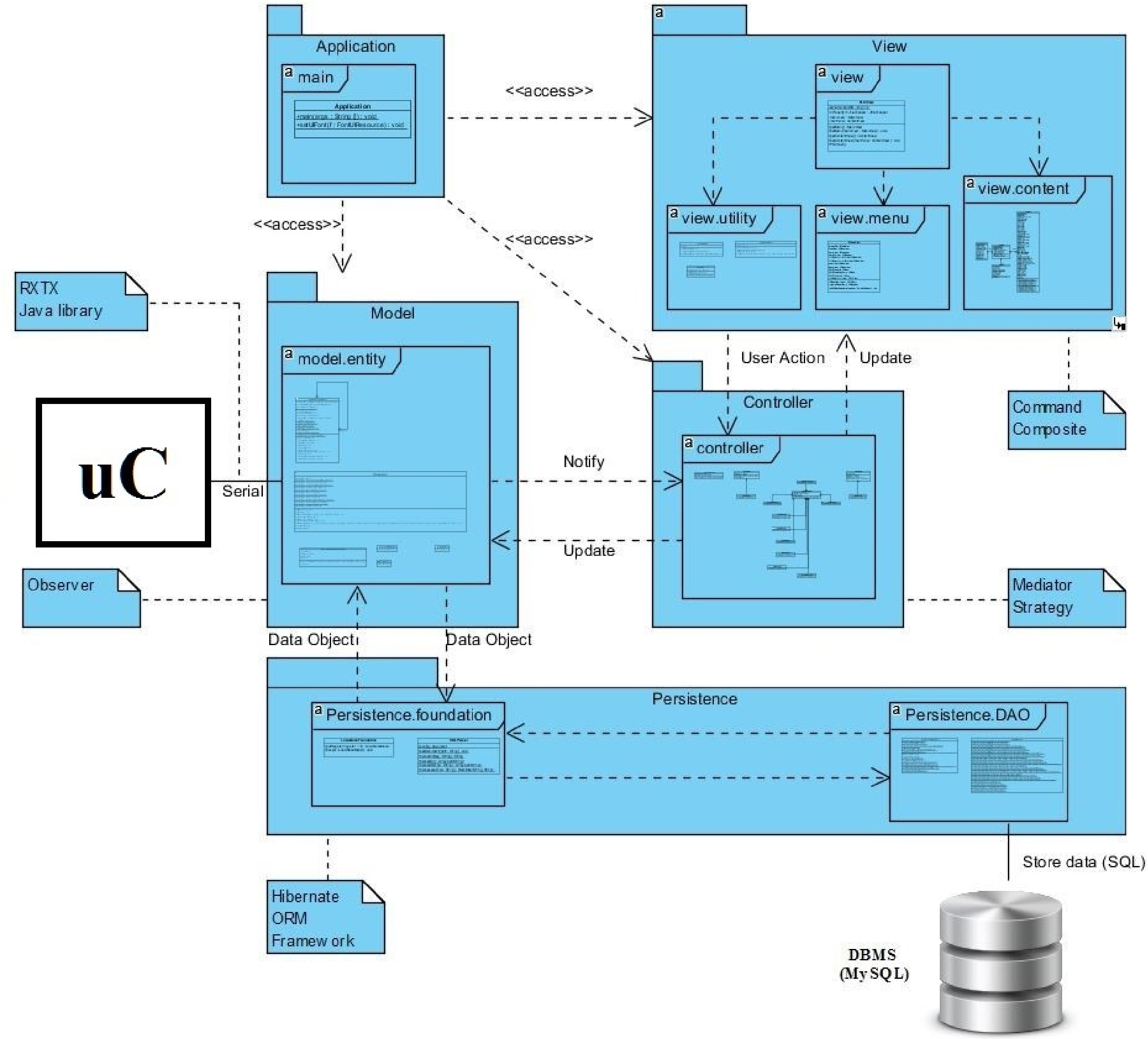
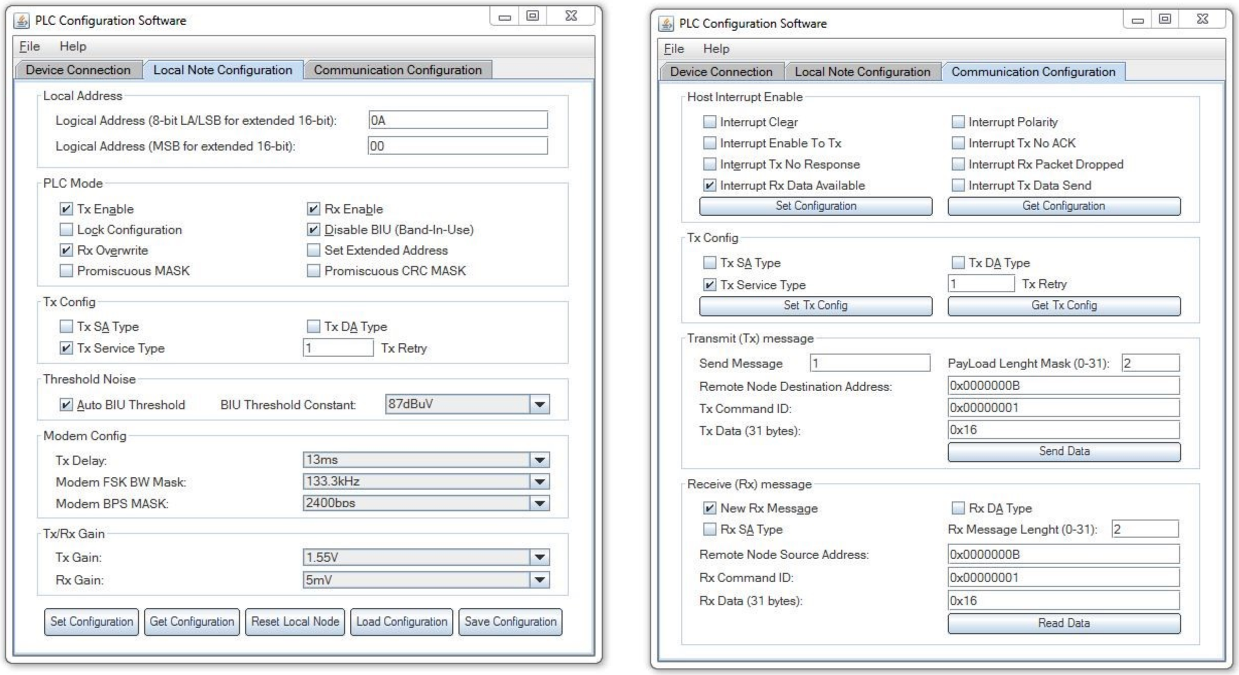


Fig. 5. PLC Configuration SW architecture. The application uses Rx-Tx Java Library, Hibernate ORM framework and DB technologies to offer to the end users a GUI suitable to configure in the right manner the network node that use the Cypress CY8CPLC10 chip.

pattern solutions), and for the big library and community environment that drive and help the software developer to avoid problems in the software implementation. In such a context, the *TxRx Java Library*, that provide serial and parallel communication for the *Java Development Toolkit* (JDK) with external devices, and the *Hibernate* Object-Relational Mapping (ORM) framework, an object-relational mapping framework for mapping an object-oriented model to a relational database, have been used in the software implementation to guarantee a correct serial communication between host PC and microcontroller devices and to make the configuration and communication messages persistent using a Database (DB) solution (in this case *MySQL*, but the ORM system is independent respect to the DB technology).

The *Graphical User Interface* (GUI) is shown in Fig. 6. The software allows to set the register parameters to properly configure the PLC commands protocol to guarantee a correct communication among network devices. Users can change the default configuration to match their requirements, send and read the messages exchanged by the devices (connecting the host with the specific network node at each time) and save/load both old configuration and messages to have a view and statistics of the whole network, testing the communication among nodes to avoid problems and errors at run-time. A



(a) Local Node Configuration Interface.

(b) Example of communication using PLC Cypress, Arduino devices and host PC.

Fig. 6. PLC SW configuration GUI.

configuration example is shown in the Fig. 6 (b). In this scenario, the host is connected to a specific node (0x0A). The scenario involves two devices (device 0x0A and device 0x0B). The device A sends a message to device B (0x16, a value related to temperature sensing), B reads the message and re-sends the same message to device A. When the user pushes the ReadData button, the software instance attached to device B shown the value 0x16 in output in the right text form and this demonstrates that the value has been correctly received. This example presents a real use case in which two devices try to communicate each other using the PLC network and the Cypress chip.

Considering the possibility to change the PLC Cypress chip with a different circuit, the algorithm and software can be easily adapted to manage new protocols parameters for a different node communication. Furthermore, this approach guarantee the adaptability of this power line architecture with different microcontroller types without changing the power line *Integrated Circuit* (IC) modem solution. Furthermore, to change the microcontroller platform with a programmable logic solution that involve, for example, FPGA technologies [33], most useful design flow methodologies and tools [34–36] could be used to perform the development of the communication protocol and the resource management, also considering, for example, heterogeneous/homogeneous multi/many-core architectures [37], and/or profiling and monitoring systems [38] to manage at run-time possible errors, bus and memory utilization. These solutions can be used to improve the resource of the specific network node in order to consider more complex systems and more complex tasks that each node could compute in different environment conditions and domains.

V. Conclusion

In this work a home automation system based on power line communication has been presented and discussed. The proposed system, if compared with other solutions from the literature, allows an improved range communication capability with a 2.4kbs data rate making it suitable for any kind of home actuators and appliances control and management. Future and further works will consider the developed PLC configuration SW connected with different hardware devices such as other microcontrollers, System-on-Chip (SoC), Single-Board Computer (SBC), etc., to improve and enhance prototype performance, also considering different metrics and requirements (such as in energy consumption monitoring case study).

Acknowledgment

This research was partially funded by the ECSEL-RIA 2017 FitOptiVis grant number 783162 and ECSEL-JU 2018 COMP4DRONES grant number 826610 projects.

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