ELSEVIER
CrossMark
Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 50 (2014) 270 – 276
Energy Procedia

The International Conference on Technologies and Materials for Renewable Energy, Environment and Sustainability, TMREES14

Wireless Sensor Networking architecture of Polytropon: An open source scalable platform for the smart grid

P. Papageorgas[1]*, D. Piromalis[2], T. Iliopoulou[1], K. Agavanakis[1], M. Barbarosou[1], K. Prekas[1], K. Antonakoglou[1]

[1]*Department of Electronic Engineering, Technological and Educational Institute of Piraeus*
[2]*Department of Automation Engineering, Technological and Educational Institute of Piraeus*

Abstract

This article presents the overall design methodology followed for an open source Wireless Sensor Networking platform that aims at the remote energy monitoring of home appliances in real-time using web technologies. This platform can be a paradigm for building open source devices for smart metering and home energy management by controlling electric loads, thus contributing to the development of the smart grid infrastructure. The Polytropon platform is designed as a research tool for experimenting with the various hardware and software components that can be integrated in the nodes, by following the open source hardware and software guidelines for development.

Selection and peer-review under responsibility of the Euro-Mediterranean Institute for Sustainable Development (EUMISD)

Keywords: Wireless sensors networks; Smart grid; Internet of things; Smart metering; Automated Meter Reading; Open Source Hardware; Open Source Software; Arduino; Launchpad

1. Introduction

The electric power grid in most countries has been designed during the previous century using a centralized architecture with minimum feedback between the consumers and the electricity generation companies. Today, strict restrictions about the emission of carbon dioxide and greenhouse gas emissions demand for policies that will enable the energy production through distributed renewable energy sources and encourage the ecologic behavior of the consumers. Information and Communication Technologies advancements like the Internet of Things combined with the worldwide usage of Internet technology will result to the total redesign of the electric grid, the smart grid [1,2]. The envision is that the consumer appliances will be interconnected using Machine-to-Machine technologies with the distributed production units in an efficient manner enabling the optimal usage of the produced energy and the overall

* Corresponding author. Tel.: +30-210-538-1405; fax: +30-210-538-1405.
E-mail address: ppapag@teipir.gr

Selection and peer-review under responsibility of the Euro-Mediterranean Institute for Sustainable Development (EUMISD)
doi:10.1016/j.egypro.2014.06.033

planning of energy consumption. Moreover, the introduction of electric cars will accelerate the entrance of smart grid technologies providing an efficient distributed energy storage system that can filter out the electric energy outages that are common today and cost to USA only, about 180 billion of dollars annually.

The usage of mobile telephony and Internet technologies follows an exponential curve worldwide. The introduction of smart phones that integrate Internet communication and computation capabilities enable the deployment of low cost machine to machine interconnection in a safe way with advanced capabilities. Wireless sensor network technology when combined with the Internet communication infrastructure enables the development of the backbone of the modern smart grid [3].

Ad-hoc Wireless Sensor Networks (WSNs) are defined as a large number of self-sufficient nodes, with embedded sensors and processing capabilities, in conjunction to wireless communication between them in the form of a self-deployed multihop communication network. In the last decade, the research in WSNs was very intense starting from Berkeley University with the envisagement of smart dust [4-8] and continuing today with the Internet of Things [9]. The main research interest in WSNs has been focused in the development of devices with embedded microcontrollers, sensors, actuators and short range wireless communication capabilities (10 – 100 m) with emphasis in low-power operation [10-13]. But, even though a large number of research and commercial wireless sensor node platforms are available today, the development of an open-source code platform that could be used for scientific and educational purposes still remains attractive, especially for the associated hardware.

In this paper the description of the Polytropon platform is given together with a brief description of the core software that is developed for integrating web capabilities for supporting Data aggregation for Automated metering as well as control of appliances with specific actuators. In the following sections an overview of the developed sub-system modules is given concerning the hardware and software design with focus in the scalability of using such a platform for developing the smart grid infrastructure for the Home Area Network (HAN).

2. Hardware Architecture of the Polytropon platform

An integrated wireless sensor platform has been designed and developed (named hereafter Polytropon) suited for applications that can be integrated in the backbone of the smart grid. Two successful open source platforms, the Arduino [14] and the Texas Instruments Launchpad [15] have been utilized for the extraction of the final specifications that follow the open source standards for the distribution of the developed software and hardware. The main parts of this platform are a wireless sensor node and a gateway node. The gateway is based on a Polytropon wireless sensor node that has the role of the coordinator of the WSN realized combined with the Beaglebone Black [16] open source platform that integrates a high processing power microcontroller and a single-chip solution for TCP/IP networking.

A block diagram of the Polytropon platform is given in Fig.1. The important characteristics that this platform integrates can be summarized to the following:

- Two Ultra low power consumption microcontrollers
- New non-volatile RAM based on FerroElectric technology (FRAM) that provides robustness combined with extremely high speed and power consumption compared to the common FLASH technology
- Embedded electric power metering using a dedicated IC
- Unique 64-bit EUI identification for the MAC address
- Embedded encryption capability based on AES128/256
- Embedded Real time clock peripheral
- Embedded backup power source
- Sub-GHz RF modem with IEEE802.15.4 for the MAC layer of the wireless network
- Capability for 6LowPAN networking protocols
- Compatibility with board extensions for the Arduino Platform-Shields
- Compatibility with board extensions for the Launchpad Platform-Boosterpacks

In Fig. 2 the overall system architecture is given. A three-tire architecture has been followed for the monitoring and characterisation system, with the first level referenced to the Polytropon wireless sensor. The POLYTROPON gateway is used as the gateway for Cloud services (Fig. 2). This node is based on an ARM core for high processing capabilities in order to support a first level of data aggregation while it integrates the appropriate communication peripherals for interfacing with the wireless sensor nodes wirelessly and the cloud.

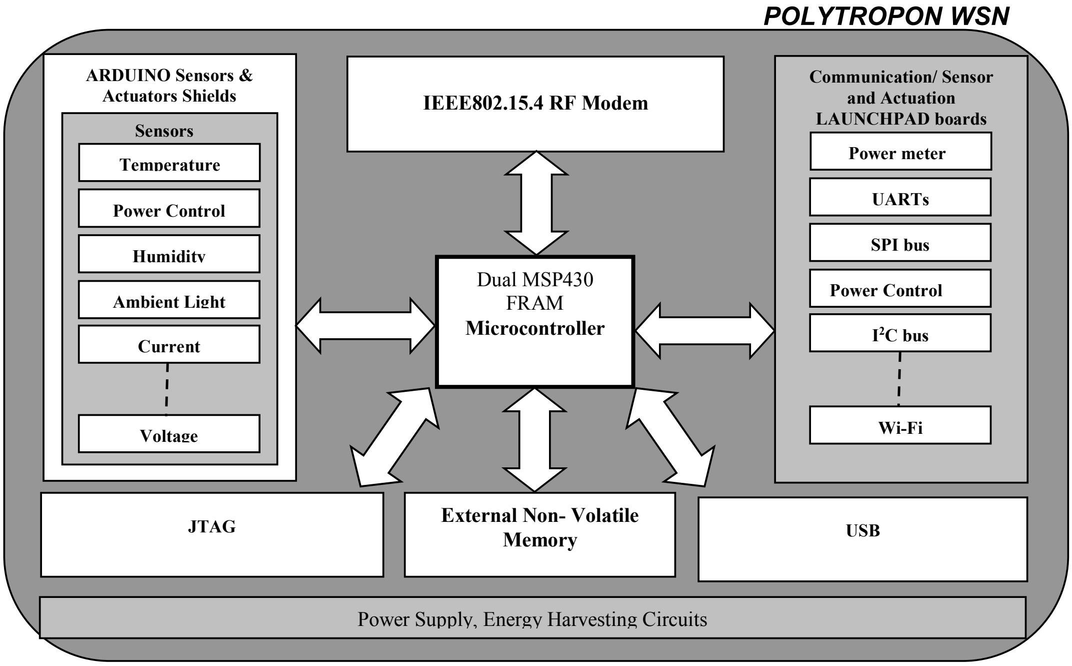

Fig. 1. A simplified diagram of the proposed wireless sensor node.

The architecture proposed will enable the Machine-to-Machine interface between the sensors and actuators of the HAN and the Power Electricity generation substations. A wide area peer-to-peer (P2P) network can be supported with the developed platform, enabling: the transfer of data, the remote monitoring and management of the WSN, as well as publishing the data collected from the embedded sensors using web-based technologies.

The Polytropon platform integrates two MSP430 microcontrollers with FRAM memory, one dedicated for the compatibility with the open source ARDUINO platform and the other one dedicated for the compatibility with the LAUNCHPAD platform. With the dual-microcontroller configuration extensions for both open source

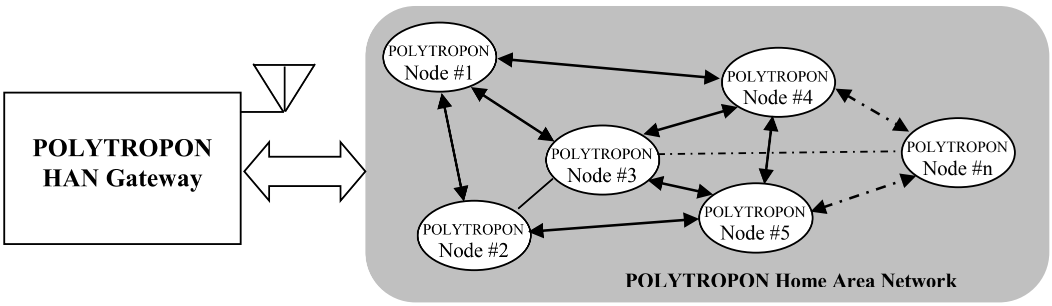

Fig. 2. The interconnection of the proposed Polytropon Wireless Sensor Network Platform with the Cloud via the network's gateway

platforms are directly supported, that is the Arduino shields and the Launchpad Boosterbacks. A unique EUI 64-bit address has been embedded in order to give the capability for direct IPV6 Addressing of the board, thus enabling the use of protocols as the 6lowPan for Web accessibility [18]. The real-time measurement of the power consumption of the Polytropon board as well as of the extension boards used is supported with a dedicated Integrated circuit. In addition the Polytropon board integrates the capability for direct control of the power of the various card extensions thus reducing the overall energy consumption. A number of RF transceivers can be utilized with the Polytropon platform through the RF extensions directly supported. A specific RF board has been designed in the Sub-GHz frequency range for achieving maximum range inside the buildings and supporting simple topology networks for accessing the gateway. The MAC and PHY layers of the realized WSN network are based on the IEEE 802.15.4 protocol, while the MQTT-SN protocol realizes a publisher for the specific type of the collected data.

3. An Open Source Publish-Subscribe protocol for efficient deployment of WSAN for the smart grid

The distributed power management of the electric power produced from small renewable source generators demands the use of new technologies for monitoring. For the design of the communication mechanisms between the WSN sensors and actuators and the applications that "need" access to the data for analysis, presentation, modelling and forecasting a flexible topology is required as presented in the following Figure. Aggregators in our case are the WSN nodes that collect data either locally or preferably in remote Servers, while the reception service references to remote servers that implement various functionalities using cloud services as is the mass-storage of the topics that are published (collected data) and the configuration data for the WSN nodes, as for example the addressing details and the sampling rate of the sensors and actuators. The access functionality refers to the security aspects of the Wireless Sensor and Actuator network as is the administration of the encryption public keys.

With the Publish/Subscribe approach each client makes subscriptions to the topics of its interest. The Message Queuing Telemetry Transport (MQTT)[19..23] is an open publish/subscribe protocol for telemetry. Moreover, the MQTT protocol is open source, and the adaptation to a variety of messaging and communication needs is very easy. In the design of the system architecture the MQTT (Message Queuing Telemetry Transport) has been adopted and especially MQTT-SN, which is an extension for WSNs that are not implementing the TCP/IP layer.

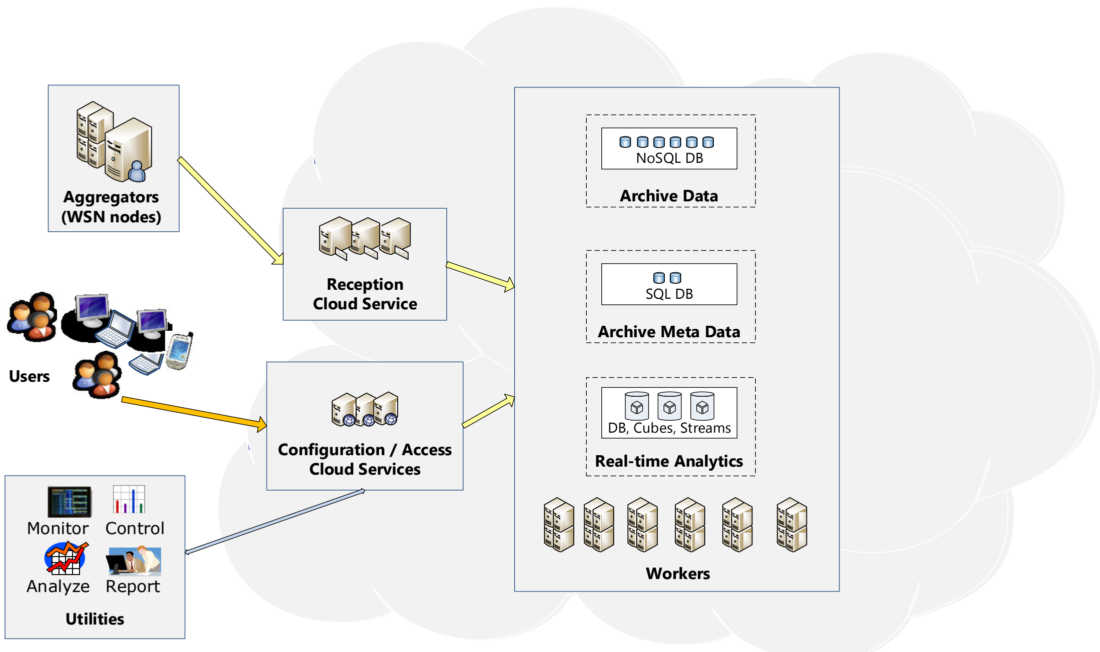

Fig. 3. The overall structure of the Cloud Services for accessing the sensor data from the Polytropon WSN

In each Polytropon WSN node the MQTT-SN protocol for publishing data is realized while in the Polytropon Gateway transparent functionality is performed that connect all the Polytropon WSN publishers to a common Server (broker) by simply forwarding the specific requests. MQTT-SN is lightweight and can be realized with 2kB of memory making it the ideal choice where energy and memory resources are critical, as is the case in most wireless sensor nodes that use a low-power microcontroller [24, 25]. With the Polytropon gateway a bridge is realized

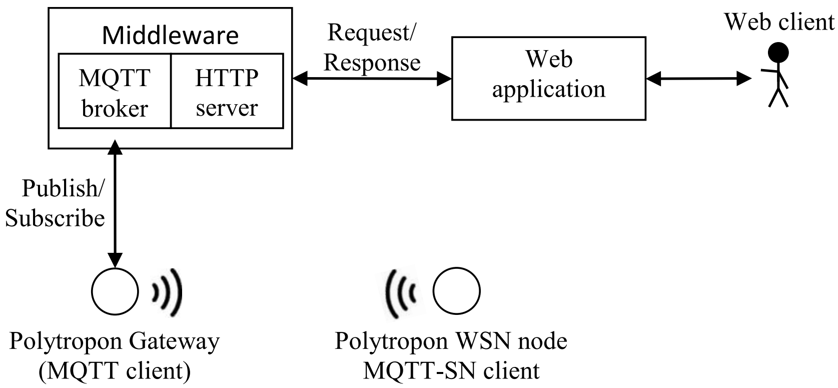

Fig. 4 The MQTT-SN Publish/Subscribe Protocol for Wireless Sensor Networks

between the MQTT-SN domain (WSN) and the MQTT domains (traditional TCP/IP based networks).

The Data producers called "Publishers" (as for example the WSN nodes used for Automated Meter Reading) are not aware of the addresses of their subscribers that can be a remote located server or a simple HTTP application or any kind of Agent (software application) that can have access to the collected data. In the specific Polytropon platform the MQTT-SN protocol has been realized in every WSN node for publishing the collected data.

4. Applications of the Polytropon platform for PV panels monitoring and Energy consumption of Appliances

Two use cases have been realized with the Polytopon platform. For both applications the same board has been used with two different extension cards for each one. For the PV panel monitoring an extension card for DC current and voltage measurement has been realized [26]. For the energy consumption of home appliances an AC current and voltage measurement extension card has been realized. The overall design of the software of the Polytropon nodes are quite the same for both applications with differences concerning only the "topics" (that is the specific text headers) for the measurements transmitted in each application. The gateway software is common for both applications as well as the server (broker) software. For both use cases the applications that "consume" the aggregated data generated from the WSNs are "subscribers" interested in the two special "topics". One "topic" named "Country/City/PVpark_1234/Panel_456/Power" references a PV Park with identification number 1234 and the Power generated from the PV panel with identification 456. This text string must be transmitted according to the MQTT protocol through the WSN gateway to the specific Broker. Similarly, for the electric power consumed from a specific home appliance (e.g. a refrigerator) a different "topic" has been created with the text header "Home/Floor_1/appliance_234/Power" where Home defines a specific home, Floor_1 references the first floor, and the appliance with identity number 234 references to the specific refrigerator that we want to extract its energy profile.

The sensor data are transferred with the text headers described above in a defined time interval from the individual WSN nodes following the MQTT-SN protocol to the Polytropon Gateway and through the TCP/IP connection are published in the cloud from a specific Broker, that is, a remotely located server. The data are published according to a specific "topic" taxonomy and can be available in real-time to a subscriber (or many subscribers) for analysis and further processing. A subscriber in our case is a simple HTTP application for presentation of the data collected in a specific "topic". The "topic" taxonomy followed enables the sophisticated manipulation of huge amount of data aggregated from multiple WSN nodes in an easy way and natural scalability according to the processing power available from the Broker. What is important to be mentioned is that there is no bottleneck in the communication with the individual WSN node with a remote server and the overall traffic is kept to the minimum. According to the previous described use cases, when an application wants to access the power generated from many panels it uses special text characters (wildcards) for processing the required set of data. For the first use case the topic "Country/City/PVpark_1234/+/Power" refers to the Power generated from all the Panels of the PV park with identification number 1234 installed in the specific "City". Similarly the topic "Home/Floor_1/+/Power" references to the electric power consumption of the first floor of the specific home. The loose architecture described enables the aggregation, storage and processing of large quantities of data generated from the sensors of the deployed WSNs. The reverse direction is also possible by using actuators in the WSN nodes for turning on or off appliances or controlling distributed power generators. The described approach can be an important component of the smart grid especially for the HAN.

5. Future extension of the Polytropon platform for realizing Virtual Power Plants

The Virtual Power Plant concept that has been evolving during the last decades in order to tackle with the problem of managing distributed medium-to-small size power generators can be an application area of the Polytropon platform with great results. Small, independent and dispersed WSN nodes, may be operating in a collective manner and finally seen as a whole of significantly bigger size and dramatically affect the grid behaviour when combined together. Indeed, the combination of the distributed measurement collection infrastructure, with the cloud services ability of online real time analytics and decision making, and finally with bi-directional communication capabilities (also covered by the proposed platform), may lead to the aggregation of hundreds of thousands small power generation units, such as domestic PV installations, wind generators, micro-CHP, etc. The orchestration of the behaviour of the dispersed consumption loads and generation units, in the benefit of the installation owners and the grid as a total, create a whole new domain of challenges and profits, in terms of grid quality, cost, and user experience.

6. Conclusions

The Polytropon Platform presented in this article integrates a number of important characteristics that can be very important for the design of the backbone of the smart grid. It follows the open source principles for the hardware and software design of the nodes and provides a versatile platform for experimentation in the design of the network protocols that can be used for the smart grid. The software components for networking through the wireless network enable the transmission of data to remote servers in an asynchronous mode using the MQTT-SN protocol realising a "publish" "subscribe" approach that seems ideal for managing very large quantities of data that can be accessed from various remote clients for storage, processing and decision making.

Acknowledgements

This research was implemented through the Operational Program "Education and Lifelong Learning" and is co-financed by the European Union (European Social Fund) and Greek national funds.

References

[1] Don Von Dollen. Electric Power Research Institute (EPRI), Report to NIST on the Smart Grid Interoperability Standards Roadmap. June 17, 2009 (Contract No. SB1341-09-CN-0031—Deliverable 7)
[2] http://www.smartgrids.eu/

[3] P. Baronti, P. Pillai, V.W.C. Chook, S. Chessa, A. Gotta, Y.F. Hu. Wireless sensor networks: A survey on the state of the art and the 802.15.4 and ZigBee standards. Computer Communications 30(7) (2007) 1655-1695.
[4] Akyildiz, W. Su, Y. Sankarasubramaniam and E. Cayirci. A Survey on Sensor Networks. IEEE Communication Magazine, Aug. 2002 p.p. 102-114
[5] C.Y. Chong and S.P. Kumar. Sensor networks: evolution, opportunities, and challenges. Proceedings of the IEEE, vol. 91, August 2003, pp. 1247- 1256.
[6] Mauri Kuorilehto, Mikko Kohvakka,Jukka Suhonen, Panu Hamalainen,Marko Hannikainen, and Timo D. Hamalainen. Ultra-Low Energy Wireless Sensor Networks in Practice: Theory, Realization and Deployment. John Wiley & Sons Ltd,2007, ISBN 978-0-470-05786-5
[7] Berkley Wireless Research Centre, http://robotics.eecs.berkeley.edu/~pister/SmartDust/
[8] Harvard Sensor Networks Lab, http://fiji.eecs.harvard.edu/
[9] John Buckley. From RFID to the Internet of things. Pervasive networked systems Conference organised by DG Information Society and Media, Networks and Communication Technologies Directorate, 6 & 7 March 2006, CCAB, Brussels
[10] ProSense, Promote, Mobilize, Reinforce and Integrate Wireless Sensor Networking Research and Researchers: Towards Pervasive Networking of WBC and the EU, http://www.prosense-project.eu/
[11] UbiSec&Sense (Ubiquitous Sensing and Security in the European Homeland), http://www.ist-ubisecsens.org/
[12] SENSEI (Integrating the Physical with the Digital World of the Network of the Future), http://www.ict-sensei.org/
[13] e-Sense (Capturing Ambient Intelligence for Mobile Communications through Wireless Sensor Networks), http://www.ist-e-sense.org/
[14] Arduino, http://www.arduino.cc/
[15] MSP430 LaunchPad, Texas Instruments Wiki, http://processors.wiki.ti.com/index.php/MSP430_LaunchPad
[16] BeagleBone Black, BeagleBoard.org, http://beagleboard.org/products/beaglebone%20black
[17] Andy Stanford-Clark and Hong Linh Truong, MQTT For Sensor Networks (MQTT-SN) Protocol Specification, IBM, http://mqtt.org/new/wp-content/uploads/2009/06/MQTT-SN_spec_v1.2.pdf
[18] D.D. Piromalis, K. G. Arvanitis. RFID and WSN Applications Integration using DASH7 Mode2 Standard in Agriculture. International Commission of Agricultural and Biological Engineers, Section V. CIOSTA XXXV Conference, July 3-5, 2013 Billund Denmark
[19] P. Gil, I. Maza, A. Ollero, and P. J. Marrón. Data centric middleware for the integration of wireless sensor networks and mobile robots. 7th Conference on Mobile Robots and Competitions, ROBOTICA 2007, April 2007.
[20] P. T. Eugster, P. Felber, R. Guerraoui, and A.-M. Kermarrec. The many faces of publish/subscribe. ACM Computing Surveys (CSUR), vol. 35, no. 2, pp. 114–131, 2003.
[21] Message queue telemetry transport (mqtt). [Online]. Available: http://mqtt.org/
[22] A. S. Tanenbaum and M. v. Steen. Distributed Systems: Principles and Paradigms (2nd Edition). Upper Saddle River, NJ, USA: Prentice-Hall, Inc., 2006.
[23] Richard Zurawski. Embedded Systems Handbook. Taylor & Francis Group, 2006
[24] An open source mqtt v3.1 broker. [Online]. Available: http://mosquitto.org/
[25] A. Rudd. Mqtt.js - an mqtt library for node.js. [Online]. Available: https://github.com/adamvr/MQTT.js
[26] P. Papageorgas, D. Piromalis, K. Antonakoglou, G. Vokas, D. Tseles, K.G. Arvanitis. Smart Solar Panels: In-situ Monitoring of Photovoltaic Panels based on Wired and Wireless Sensor Networks. Energy Procedia, Volume 36, 2013, Pages 535-545