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10th IEEE EAST-WEST DESIGN & TEST SYMPOSIUM (EWDTS 2012)

Kharkov, Ukraine, September 14-17, 2012

The main target of the **IEEE East-West Design & Test Symposium** (EWDTS) is to exchange experiences between scientists and technologies of Eastern and Western Europe, as well as North America and other parts of the world, in the field of design, design automation and test of electronic circuits and systems. The symposium is typically held in countries around the Black Sea, the Baltic Sea and Central Asia region. We cordially invite you to participate and submit your contributions to EWDTS'12 which covers (but is not limited to) the following topics:

- Analog, Mixed-Signal and RF Test
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- Built-In Self Test
- Debug and Diagnosis
- Defect/Fault Tolerance and Reliability
- Design for Testability
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- FPGA Test
- HDL in test and test languages
- High-level Synthesis
- High-Performance Networks and Systems on a Chip
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- Network-on-Chip Design & Test
- Modeling and Synthesis of Embedded Systems
- Object-Oriented System Specification and Design
- On-Line Testing
- Power Issues in Design & Test
- Real Time Embedded Systems
- Reliability of Digital Systems
- Scan-Based Techniques
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- Signal and Information Processing in Radio and Communication Engineering
- System Level Modeling, Simulation & Test Generation
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- Logic, Schematic and System Synthesis
- Place and Route
- Thermal, Timing and Electrostatic Analysis of SoCs and Systems on Board
- Wireless and RFID Systems Synthesis
- Digital Satellite Television

The Symposium will take place in Kharkov, Ukraine, one of the biggest scientific and industrial center. Venue of EWDTS 2012 is Kharkov National University of Radioelectronics was founded 81 years ago. It was one of the best University of Soviet Union during 60th - 90th in the field of Radioelectronics. Today University is the leader among technical universities in Ukraine.

The symposium is organized by Kharkov National University of Radio Electronics and Science Academy of Applied Radio Electronics http://anpre.org.ua/ in cooperation with Tallinn University of Technology. It is technically co-sponsored by the IEEE Computer Society Test Technology Technical Council (TTTC) and financially supported by Trades Committee of Kharkov National University of Radioelectronics and Trades Committee of Students, Aldec, Synopsys, Kaspersky Lab, DataArt Lab, Tallinn Technical University.

CONTENTS

Internet of Things: A Practical Implementation based on a Wireless Sensor Network Approach

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Abstract

In this paper we present an introduction and an overview of the Internet of Things concept and its possible realization of an infrastructure based on a Wireless Sensor Network. Our proposed solution aims for memory and power consumption efficiency. Similarly, our proposed implementation is informed by (1) open technology standards; (2) accessibility and reachability; and (3) multi functionality and modularity. In addition, we place emphasis on the use of very low power devices and communication protocols.

1. Introduction and background

Internet of Things (IoT), a term first coined by Kevin Ashton in 1999 [1], is used to refer to uniquely identifiable objects (or more broadly things) and their virtual representations, similar to the network of websites in an internet. The idea is to have all things tagged and, if that were the case, they could be identified and inventoried by computers [2]. If this could be implemented, it will transform drastically our way of life [3]—waste will be reduced significantly; stores will not run out of stock; and stolen items could be easily located.

A main component of IoT infrastructure is "*smart objects*" which are objects that hold a unique identifier. The identifier will allow the objects to be located, enable them to interact with their surrounding environment, and let them communicate with each other for data exchange and collaboration. Within the IoT paradigm, *smartness* is not only for objects but includes the nature of the networks that connect them. To build smart objects, we need sensors, actuators, radio-frequency identification (RFID) tags, etc. Applications of IoT include domotics, industrial application, nature and environmental monitoring.

Even after more than a decade since it was first coined, the implementation of a system of IoT has yet to become a reality. In this paper we proposed a plausible implementation of an IoT system or infrastructure based on a wireless sensor network (WSN) approach. We propose hardware and software possibilities to support such an infrastructure. Our approach emphasizes on three main guidelines (see Figure 1).

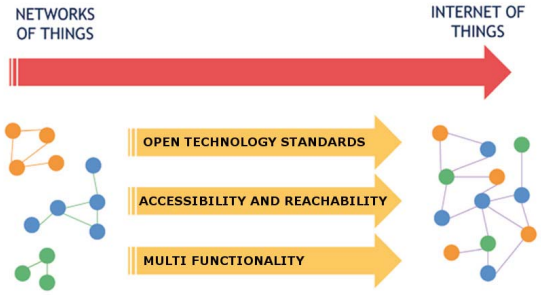

Figure 1.Three main aspects to implementing IoT [4].

1.2 Internet of Things: Three perspectives

Broadly speaking, IoT can be explored from three perspectives: (1) *Object*-oriented; (2) *Internet*-oriented; and (3) *Semantic*-oriented.

(1) *Object-oriented perspective*. This perspective sees IoT to be a collection of nodes, with every single node representing each object. Within this collection every node should be: very simple; characterized by a unique ID (e.g., EPC or RFID); and equipped with components (such as sensors, actuators and wireless capabilities) which allow the nodes to link the real world to the digital one. In addition, the ID will enable every object to be traced in space and time during their existence.

(2) *Internet-oriented perspective*. This perspective focuses on the reduction of the complexity of the IP protocol stack. This is needed as usually the motes that compose a wireless network hold very limited resources. An IPSO paper [5] describes an interesting

IP adaptation, realized with an incorporation of IEEE 802.15.4 into the IP architecture. In this conception the objects has to be addressable and reachable from anywhere.

(3) *Semantic-oriented perspective*. There will be an enormous amount of data coming from the many objects distributed everywhere. Bearing this in mind, this perspective deals with the use of semantic technologies to exploit models and obtain useful, relevant information from the enormous amount of incoming data. To achieve this, there is need for a semantic execution, scalable storage system and an adequate network infrastructure.

The realization of an infrastructure supporting an IoT network will need to bring these three perspectives together, and if this can be achieved, then the final result will be an infrastructure which can integrate *anything*, at *anytime*, in *anywhere*, and for *anymedia*. We will focus our solution on very low power devices where all the nodes will have to consume little power so as to reduce cost, but without losing performance.

2. Enabling technologies

Wireless Sensors Networks (WSN) are composed of a number of nodes which can communicate with each other wirelessly. Every node should have high power efficiency, and the network should be scalable and reliable. The most widespread protocol for the physical and MAC level is the IEEE 802.15.4 [6]. Some of the issues at the higher level of this protocol stack are: (1) lack of IPv4 addresses availability; (2) small frame size in the MAC level (the maximum size is 102 bytes); and (3) constraints in the sensors (e.g., they usually have a sleep mode, something not common in ordinary IP networks).

IPv4. The number of available IPv4 addresses is rapidly decreasing. To face this problem the adoption of IPv6 seems to be the right choice because IPv6 addresses are 128 bits long.

Other network-related issues. Another networking issue is the mobility of nodes. This problem could be solved for example with Mobile-IPs or solutions based on the Home Location Register (HLR) and Visitor Location Register (VLR) as used in networks of mobile phones. The way the object address is obtained represents another issue. One of the proposed solutions is ONS (Object Name Service) which maps and provides an RFID Identifier with an URL containing all the information of the object.

3. A 4-Level IoT framework

Any framework usable to guide the implementation of an IoT infrastructure will need to take into account 4 levels.

(1) *Physical and MAC level*. IEEE 802.15.4 is a widely adopted protocol. It is designed to lower the cost of hardware and software, is enhanced for low-latency, and is suitable for energy critical WSN applications. There are two types of devices that can benefit from this protocol: (1) *Full* function devices (FFD) and (2) *Reduced* function devices (RFD). FFD can communicate with each other and also with other RFD, and one FFD is to be chosen as the PAN coordinator of the network. In addition, 802.15.4 provides two operation modes: (1) Beacon Enabled (Slotted CSMA/CA) and (2) Non Beacon Enabled (unslotted CSMA/CA).

(2) *Network Level*. At this level there are two different solutions which deserve attention. The first one is ZigBee which implements on its devices the protocol stack from the physical to the network level. There are three types of ZigBee devices: Coordinator, Router, and End Device. The usage of these devices allows the realization of a low speed ad-hoc network. An alternative to ZigBee is 6LowPAN [7], which aims to bring IPv6 networking features to constrained networks and allows a transparent integration with the internet. Some of 6LowPAN characteristics are: an efficient header compression; support of fragmentation; network auto configuration using neighbor discovery; and IP routing. The main difference between ZigBee and 6LowPAN is the adoption of standards and the integration with well-known network protocols: 6LowPAN extends IP in the Internet of Things while ZigBee does not.

(3) *Transport Level*. The TCP protocol is connection-oriented and this means that the small motes in a WSN should always be connected, making it inefficient. Besides, there are other reasons why it is not suitable for IoT. Every session starts with a set-up phase and this is very expensive in terms of energy consumption and communication. Also, if the amount of data is small the congestion control of TCP is not that useful. Lastly, the buffer management to guarantee ordered delivery of datagrams is again very expensive for devices with batteries. For all these reasons UDP seems to be a more convenient transfer protocol.

(4) *Application Level*. The most widespread solution for the application layer is the Constrained Application (CoAP) protocol [8]. It is a specialized RESTful (Representational State Transfer) protocol to be used within constrained networks—it is very small and very easy to parse. It has support for resource discovering and works over the transport UDP level with an optional feature for reliable transmission. CoAP provides the REST Method/Response interaction model between application end-points and can be easily translated to HTTP for integration with the web. The goal of CoAP is not to blindly compress HTTP, but rather to realize a subset of REST common with HTTP and is optimized for M2M applications.

4. Proposed hardware and firmware choices for IoT implementation

We propose the EnvEve/Minteos [9] hardware platform as a potential candidate for the realization of IoT system which can satisfy the two requisites of *low power* and *modularity*. In the following sections, we give some broad details of the EnvEve/Minteos platform.

The EnvEve/Minteos platform is composed of two different modules: UTRX (small devices with RF capability and a small micro controller) and GATEWAY (a device in charge for the data collection and data sending to a central server). Field communications are handled using two independent ISM RF slots units with efficient packet-oriented hardware modems. Out of field communications with the application server are handled by GPRS/Ethernet slots interface. In terms of modularity, different slots on gateway allow to plug many types of RF transmitter (e.g., 433MHz, 169MHz, 868MHz) or mixing them together. Finally, solar or other external energy sources, whenever available, can be harvested by the gateway to replenish its energy resources. An internal backup battery is used whenever the external energy is not available or insufficient.

The GATEWAY is a mainboard where other modules can be plugged to add capabilities. EnvEve/Minteos architecture is based on the Atmel ATMEGA 1280 microcontroller scheduled to work in maximum available energy saving mode (Deep Sleep and Hibernate). The microcontroller wakes up only when it is strictly needed, ensuring very low power consumption. Different modules can be connected through a serial line to the UART at different transmission rates. A power check circuitry monitors the rechargeable battery level and takes care of power switch with a primary battery when needed.

The UTRX module is composed of a microcontroller with internal FLASH, SRAM, and EEPROM memory banks, a board-to-board connector, and a 433MHz band radio transmitter. The connector allows the microcontroller programming and the application board access to microcontroller I/O resources. The board can connect to the sensors using digital interfaces (e.g., SPI, I2C, byte-oriented TWI, UART and GPIO) and analog ones (e.g., ADC or other analog comparator channels).

Earlier in the paper, we examined communication protocols. In particular at *network* level, we briefly described the main difference between ZigBee and 6LowPAN. We want to adhere to open standards and to satisfy this we suggest that the following be used: (1) Physical and MAC level to use *IEEE 802.15.4*; (2) Network level to use *6LowPAN*; (3) Transport level to use *UDP*; and (4) Application level to use *CoAP*.

We also want to develop very low power implementations. The picture (Figure 2) below shows energy required by different OS implementations of 6LowPAN. 6lowpancli and B6lowpan are solutions adopted by TinyOS; Sicslowpan, adopted by Contiki OS, seems to be the best choice.

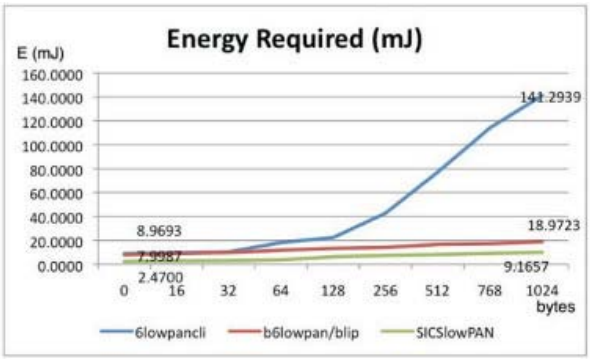

Figure 2. Energy required by 6LowPAN solutions

Based on the above requirements, the hardware architecture will need to be composed of two kinds of nodes: (1) *sentry*—a small device embedded to a sensor with 16KB flash and 1KB SRAM memory, without power harvesting capability; and (2) *gateway*—a bigger device, listening for messages coming from sentries, with 128KB flash and 8KB SRAM memory and with rechargeable battery and power harvesting capability.

Memory size and power supply features have been pointed out because we must consider the overhead added by the network protocols in terms of final packet size, which in turns affects the power consumption as the radio must be switched on for a longer period for the whole packet transmission to take place. In addition, we have to examine if the complete protocol

suite is really needed and feasible for both the gateway and sentry nodes. It appears that direct accessibility of every single node of the network may not be strictly needed. Similarly, the final size of the software library loaded in RAM and its execution by the device must be considered. With all these premises, we need to also know which part of the network stack protocol should be loaded on the sentry and which part on the gateway. A possible trade-off is to implement the complete suite on the gateway device, so that the accessibility of the network is guaranteed at this level; then the gateway can take care of connections and data routing with the rest of the sentries cloud.

5. Some practical implementation steps

In this section we provide concrete some steps for software and firmware installation on the EnvEve/Minteos hardware platform.

OS installation. All EnvEve/Minteos devices work with a broad range of firmware and application software. The first step includes the installation of an operating system for WSN. A possible choice is the Contiki OS [10] which already supports an implementation for IEEE 802.15.4, 6LowPAN and CoAP protocols. The twofold goal of this step is (1) the integration of Contiki OS with the EnvEve/Minteos hardware and (2) the programming and usage of two gateways for data exchange in 6LowPAN format.

6LowPAN emulator. We suggest that the standard protocol stack is implemented only at gateway level and this means that not all the WSN nodes can be queried directly from an external actor. In this step the gateway should act as a router and an emulator for the sentries from a source external to the WSN. The Gateway should intercept all requests to the sentries, translate them so that they are understandable for the internal communication protocol, forward the requests to the sentry, get the response, and finally send the replies.

6LowPAN on sentries. With the completion of the previous step we already have a fully working IoT Network. A further step forward is to extract only the 6LowPAN library from the Contiki OS and adapt it so that it can be integrated on the sentry firmware. In this way all the devices could be directly queried as the Internet of Things paradigm requires.

6. Summary and future work

We present a brief overview of the Internet of Things paradigm, three perspectives on this paradigm, and some main guidelines for its implementation. Similarly, we provide a framework with 4 levels. We also suggest some hardware and software choices to implement the paradigm. Finally, we outline some steps for implementation. In the future, we hope to test and compare our proposed solutions with others. Comparison will be carried out in terms of performance on long distance, message delivery reliability and power consumption. In addition, we plan to conduct a series of experiments at the *application* level in different domains.

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