A DASH7-based WSN Node with IEEE 1451 Compatibility for Precision Farming Applications

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ABSTRACT

Recent advances in information, control, and communication technologies greatly influence the progress in modern Agriculture. In particular, in the last decade, wireless sensor networks technology has dramatically changed the ways of measurement, communication and control in precision farming. Moreover, the evolution in the microelectronics allows for easy smart sensors and actuators implementation. Reliable, low energy low cost and easy to deploy wireless sensor networks is a challenge for precision farming towards sustainability. In addition, methods for unification of sensors and actuators interfacing and handling can lift off the development of ICT applications in sustainable precision farming. In this paper, the architecture of a wireless sensor network relying on the DASH7 protocol that uses the 433MHz frequency is proposed, together with the design of a node device compatible with the smart transducers according to IEEE 1451 standard as a means of unification of the physical layer of interfacing with sensors and actuators.

Keywords: Wireless sensor networks, DASH7, IEEE 1451, TEDS, Transducers, Precision Farming, ISO 18000-7.

1. INTRODUCTION

Wireless sensor network (WSN) technology progress in last decade enables precision farming to meet its aims for better site-specific management and variable-rate control.
Many research effort has been put for WSN applications in agriculture. Irrigation, fertilization, pest control, climate monitoring are some of the most populart applications where WSN technology can be effectively used. Among the various WSN tecnologies are those based on IEEE 802.15.4/ZigBee, IEEE 802.11x, and less freqiently the IEEE 802.15.1 known also as Bluetooth (Ruiz-Garcia et al., 2009; Aqueel-Ur-Rehman et al., 2011). Such application require sensors and actuators to be employed to measure and control various physical and functional properties related to precision farming. These sensors and actuators have to be interfaced with wireless nodes to send data to a remote sink node and receive data and commands from it.

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The sensors for agricultural applications available in the market today are characterized by reduced functionality and poor systems integration capability. Different disciplines, know-how and skills among sensors and actuators manufactures, systems designers and applications integrators is a barrier for systems interoperability and deployment.

National Institute for Standards and Technology (NIST) and the International Electronics and Electrical Engineers (IEEE) organisation have jointly produce the IEEE 1451 standard for snart transducers (sensors and actuators) (NIST, 2010). The scope of this standandard is to provide common functions and rules for interfacing and control of transducers. According to this standard there are two types of control devices, namely the Transducers Interface Module (TIM) and the Network Capable Application Procesor (NCAP). A TIM device can be interfaced with up to 255 different transducers. A NCAP device is able to communicate with several TIMs through wired or wireless interfaces and it can also act as a gateway to popular data communication networks (LAN, Web, CAN, etc). In order to ensure interoperability, IEEE 1451.0 (Batista et al., 2012) defines the rules for the Transducers Electronic Datasheet (TEDS) which is a stuctured way for a transducer to identify itself, to be self-calibrated, and to store and read measurements data. TEDS is stored in and maintained by TIMs. NCAP devices copy and store the TEDS information from each one of the TIMs it communicates with. During the last two decades IEEE 1451 standard has been the subject of research for distributed measurement and control systems for industrial use. Recently, IEEE 1451 standard catched the interest of some researchers to s use it for design distributed measurement and control systems in agriculture. Water quality monitoring (Dinq et al., 2010), pH measurements (Tai et al., 2011), for precision agriculture (Wei et al., 2005), soil moisture (Wobschall and Lakshmanan, 2005), and greenhouse control (Yang et al., 2007) presents how to adopt IEEE 1451 standard in agriculture ensuring low-cost implementations with effectiveness and reliability.

In this paper an alternative method of NCAPs and TIMs interface is proposed based on DASH7-enabled WSN technology and a DASH7-based WSN node compatible with IEEE 1451 standard design is presented. The following sections include the DASH7 protocol description and its comparison to other WSN protocols (section 2), the benefits of using DASH7 for precision farming (section 3), the presentation of a DASH7 IEEE 1451 compatible WSN node design (section 4), and the conclusions (section 5).

2. THE DASH7 PROTOCOL

DASH7 is the trade name of the ISO/IEC 18000-7 standard which describes items management via radio frequency identification (RFID) using the frequency of 433MHz for the air interface (ISO/IEC, 2004). DASH7 is mandated by the U.S. Department of Defense (DoD) and NATO alliance. It has more than twenty years of life and it was used in the Gulf War for military material tracking and management. It is a long range, ultra-low power, low data-rate, and low latency WSN technology using the globally available frequency band of 433MHz, and designed to operate according to the BLAST

(Bursty, Asyncrhronous, and Transistive) concept (Norair, 2009). According to DASH7 there are three types of devices, that is the Gateway (the Interrogator), the Subcontroller (the transceiver), and the Endpoint (the transponder). The main characteristics of DASH7 are presented in contrast with other common WSN protocols in Table 1.

Table 1. Characteristics of DASH7 and other common WSN Protocols

	DASH7	ZigBee	Low Energy Bluetooth	WiFi
Associated Standard	ISO/IEC 18000-7	IEEE 802.15.4	IEEE 802.15.1	IEEE 802.11.x
Frequency Range	433.04 – 434.79 MHz	2.402 – 2.482 GHz	2.402 – 2.482 GHz	2.402 – 2.482 GHz
Number of Channel	1 to 8	16	3	3
x Channel Bandwidth	0.6 - 1.76 MHz	6 MHz	8 MHz	22 MHz
Modulation	FSK or GFSK	QPSK	GFSK	CCK/QAM 64 (b/g)
Nominal Data Rate	27.8 Kbps	250 Kbps	1 Mbps	1 Mbps
Max Data Rate	200 kbps	500 kbps	1 Mbps	54 Mbps
Nominal Range	250 m	75 m	10 m	25 m
Average Power for ten 256-bytes per day	42 μW	414 μW	50 μW	570 μW
Materials Penetration	High	Low	Low	Low
Co-existence with IEEE 802.11	High	Low	Low	High

Unlike other WSN protocols, DASH7 is not session-oriented but an event-driven one and its devices support a wake-on mechanism. Therefore, a deterministic data latency (2 sec in worst case) and the lowest power consumption is ensured. Alike the other WSN protocols, DASH7 has its own alliance, the DASH7 Alliance, established in 2010, with more than 50 members from industry and academia from more than 23 countries (DASH7 Alliance 2012). DASH7 Alliance aims to ensure interoperability among different vendors through compliance tests and certifications, and its main milestones include integration of IPv6 and NFC. The physical layer of DASH7 was primarily defined by Mode 1. A new set of specifications under the name of Mode 2 is being developed by DASH7 Alliance and has been submitted for adaptation to the ISO/IEC 18000-7 standard since 2011 (Indigresso, 2012).

OpenTag is the protocol stack of the DASH7 Mode 2. This is the only open source WSN protocol stack and it is available from a single source. In this way the maximum interoperability and reliability is ensured (Norair 2011). The size of OpenTag stack is as little as 16kB compared to almost 90kB of ZigBee stack (Indigresso, 2012). OpenTag has the necessary functions for the physical layer, the network layer, the transport layer, the data layer, and the application layer. Regarding the networking, peer-to-peer and multi-hopping is supported. OpenTag supports four types of communication, namely broadcasting, anycasting, multicasting and unicasting. Over-The-Air-Upgrade (OTAU), 128 AES and public key security, and IPv6 are some of the supported functions of the DASH7 Mode 2 OpenTag stack.

3. THE BENEFITS OF DASH7 FOR PRECISION FARMING

The global ISO/IEC 18000-7 standard combined with the globally allowable frequency of 433MHz make DASH7 globally applicable. Due to the usage of the 433MHz frequency, DASH7 has the longest range and the best materials penetration. This performance is very important for precision farming applications. With DASH7, wireless sensor networks can operate without facing problem in harsh environment with water, humidity, snow, rain, chicken wires, or even ice. The role of the low frequencies application is not new but unlike proprietary protocols, DASH7 is a standardized and easy to implement protocol. Wireless Underground Sensor Networks (WUSN) can also be benefited from the DASH7 adoption. With DASH7 there is no need for nodes' poles taller than foliage because canopy and wet plants are penetrable. Table 2 illustrates the communication requirements of two WSN nodes located 0.5 km away one from the other using DASH7 at 433MHz, ZigBee at 868MHz, and ZigBee at 2.4GHz. Each node has 1 mW of power transmission.

Table 2. Communication requirement of two 0.5km distant nodes at 1mW

Requirement	DASH7 433 MHz	ZigBee 868 MHz	ZiGbee 2.45 GHz
Number of Hops	1	2	6-7
Response in Hops Number	1	2	6-7
Required Infrastructure	1 Node	10 Nodes	100 Nodes

DASH7 requires less nodes infrastructure allowing in this way the reduction of application ownership cost, the easiness in the networks deployment and management, and the reduction of the energy consumed by WSN nodes. In addition the "sprint and sleep" session-less style of communication along with the wake-up mechanism ensure the maximum battery life which is vital for agricultural applications with unattended remote WSN nodes. Concluding the benefits of DASH7 for precision farming, it is worth mentioning the easy integration of WSN applications with RFID systems used in supply chain due to the inherent ability of this protocol to collaborate with passive and active RFID systems.

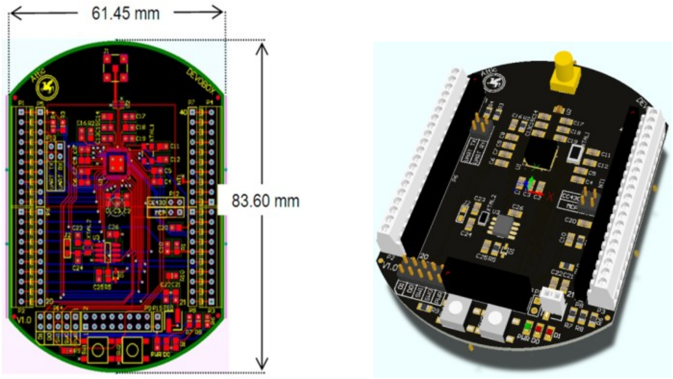
4. DESIGN OF A DASH7-BASED WSN NODE

Designing a WSN node for precision farming, the key points included the exploitation of a 433MHz standardized networking protocol in order to ensure long range and high materials penetration, and the capability of hosting IEEE 1451 applications for smart transducers. With such a node, any common sensor or actuator could be managed as a IEEE 1451 compatible smart transducer (STIM). DASH7 protocol is adopted for networking and communication for reasons explained in previous sections. For hosting IEEE 1451 applications, the node must be equipped with a microcontroller with a certain amount of program and data memory, communication ports, and digital and analog inputs and outputs.

OpenTag is the only stack available for DASH7 Mode 2 protocol. It is written in C language and it is freely available. After the stack compilation, it can be written to a microcontroller's program memory. Suitable microcontrollers for OpenTag are those who have at least 16kB of Flash program memory and a direct access memory (DMA) embedded peripheral. Persistent data RAM memory is not required. Thus, any 16-bit or 32-bit microcontroller can be used. Regarding the radio communication, a radio frequency (RF) transceiver must be employed. Market solutions include single-chip RF transceivers as well as system-on-chip (SoC) which embed microcontroller and radio transceiver in a single chip. In case of DASH7, RF transceivers must support operation at 433MHz band, and FSK/GFSK modulation with 200kbps data rate. Typical examples of RF transceivers are the CC11XX family from Texas Instrument and SX12XX family from Semtech for single-chips, and CC430FXXXX family from Texas Instruments for SoC respectively. Depending from the application, the RF antenna can be either half-wave dipole, helical, loop antenna or even printed in the circuit board or chip antenna. Development tools for DASH7 are available for microcontrollers such as MSP430 (Texas Instruments) and ST32 (STMicroelectronics). OpenTag can also be ported to any ARM architecture microcontroller.

The DASH7-based WSN node presented in this work is based on the CC430F5137 microcontroller from Texas Instruments. This is an ultra low power microcontroller with a embedded a CC1101 RF transceiver on chip. This selection simplifies the RF design process significantly. CC430F5137 is 16-bit microcontroller with 32kB of Flash program memory, 4kB of RAM, and several analog and digital peripherals. Also, an external low power Unique Identification (UID64-MAC Address) chip with Real-Time-Clock (RTC) functionality is added to the node. The integrated chip used for this is the MCP79412 from Microchip. For the design of the printed circuit board (PCB) we used microstrip calculations to connect the antenna's connector to the microcontroller. In total we used four PCB layers, two for signals (top and bottom layers), and two for the power supply planes (power plane and ground plane). All the components except the pass-through headers are surface mounted to the PCB. Figure 1a gives an overview of the PCB. Figure 1b shows the DASH7-based WSN node in 3D view. This node can host IEEE 1451 applications acting as a Smart Transducers Interface Module (STIM). Implementation of such application requires 1kB up to 8kB of program memory (Microchip, 2000; Wobschall and Lakshanan, 2005). The CC430F5137 microcontroller has 32kB of Flash program memory that is enough to facilitate both OpenTag stack and the IEEE 1451 TIM implementation. Figure 2a illustrates the block diagram of the DASH7-based IEEE 1451 STIM implementation in the CC430F5137 microcontroller.

a)



b)

Figure 1. The printed circuit board (a) and a 3D view (b) of the DASH7 node

Specific parts of the IEEE 1451 were included such as the IEEE 1451.0 for TEDS and the IEEE 1451.2 for the serial communication through physical layers. According to IEEE 1451.2, STIMs can communicate with NCAPs via serial interfaces (UART-based, I^2C and SPI buses) (Song, 2008). We imitated this function using an application programming interface (API) which practically acts like a serial communication peripheral. STIMs write to NCAP and read data from it through this API which in turn, sends to and receives data via DASH7-based WSN. Through this approach, the DASH7 network can be seen by IEEE 1451 STIMs as a serial port. The interface of the DASH7 node with NCAPs is depicted in Figure 2a.

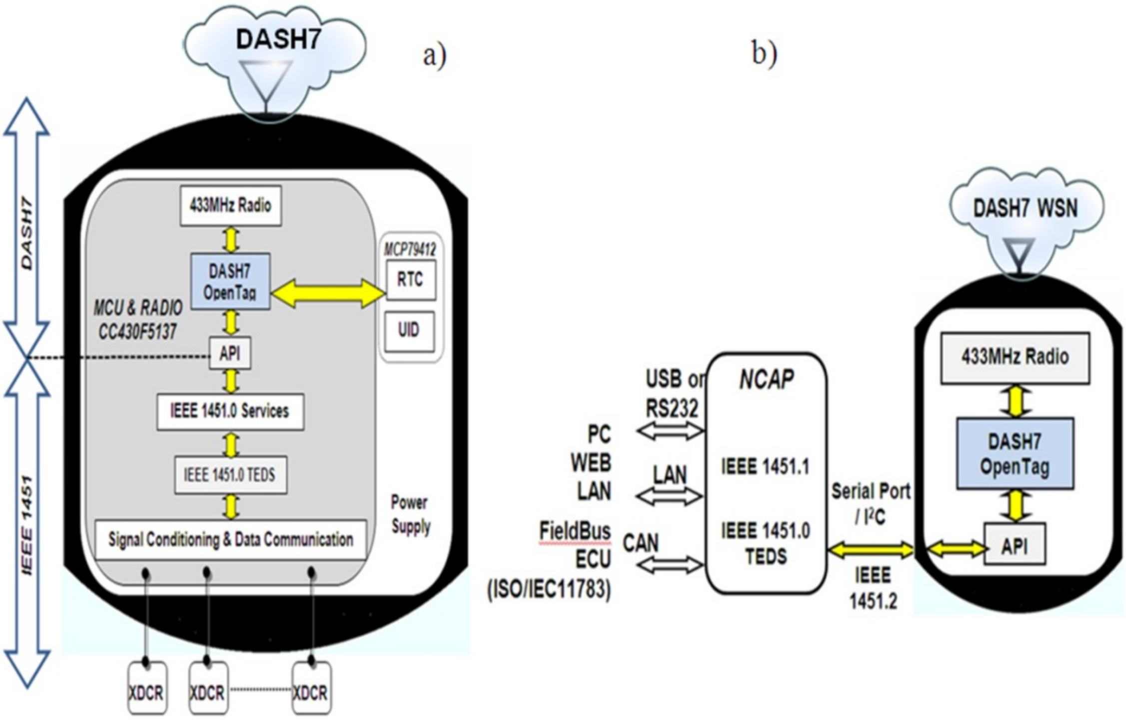


Figure 2. a) DASH7-based WSN node with IEEE 1451 STIM functionality, and b) DASH7-based WSN node interface with a IEEE 1451 NCAP.

Adopting the usage of the 433MHz frequency band for wireless sensor networks ensures more distance coverage using less wireless sensors and actuators nodes compared to other sub-1GHz frequencies as well as with the 2.4GHz frequency. The adoption of the DASH7 protocol for communication appears to be a standardized way of development of 433MHz WSN applications for precision farming. Proprietary networking protocols operating at 433MHz in agricultural applications can be replaced by DASH7 Mode 2 protocol. IEEE 1451/TEDS standard for smart transducers can be conveniently hosted by a DASH7-based wireless sensors node. The proposed wireless sensors network and the associated DASH7-based and IEEE 1451 compliant nodes can leverage the development of ICT applications for sustainable precision farming.

5. CONCLUSIONS

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