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DASH7 Mode 2: A Promising Perspective for Wireless Agriculture

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Abstract: In search of robust wireless standardized solutions for the harsh agricultural environment, the 433 MHz based DASH7 Mode 2 technology is proposed as the enabler for a new perspective of the wireless sensor networks in Agriculture. In particular, DASH7 foundation background and its technical characteristics are reported. A comparison between DASH7 and its main competitive technologies such as the ZigBee, the Low Energy Bluetooth, and the WiFi is quoted as well. DASH7 advantages for the wireless Agriculture are classified according to environment, systems development, systems deployment, cost, integration and reliability. Subsequently, the development tools ecosystem as well as the typical architecture of a DASH7-based wireless sensor node has been presented. A systems architecture focusing on DASH7 inherent ability for different wireless systems domains unification in Agriculture is proposed. Finally, as a proof of concept, a DASH7-based WSN node implemented to host applications such as IEEE 1457 smart transducers interface and radio frequency identification is presented.

1. INTRODUCTION

Wireless sensor network (WSN) technology admittedly is considered as a valuable tool for Agriculture. From environmental monitoring to precision agriculture, data gathered from a network of sensors can effectively contribute to agricultural products of higher quality and quantity, lower in cost, and produced according to controlled time schedules. The most common standards used in WSN are the IEEE 802.15.4 (ZigBee and 6LoWPAN), the IEEE 802.11 (WiFi), and, rarely, the IEEE 802.15.1 (Bluetooth) (Suhonen *et al.*, 2012). Despite the enormous research on every aspect of the WSN field (e.g. routing, power consumption, range, etc), WSN technology has not yet been applied in the extent that it was expected (Wang *et al.*, 2006). Additionally, in Agriculture where WSNs meet several physical constraints, the existing WSN technologies cannot guarantee the reliability and effectiveness in applications performance. Factors such as the foliage, the rain, the canopy, the ice and snow, and the water content of plants, are some of barriers of the wireless signals propagation in Agriculture (Meng *et al.*, 2009; Liang and Liang, 2010; Wang and Sarabandi, 2007; Richter *et al.*, 2005). According to radio signals transmission fundamentals, lower frequencies have bigger wavelengths. The frequencies that are currently used by the dominant WSN standards are basically that of 2.45 GHz, and the 868-915 MHz bands. Lower frequencies, such as the 433 MHz, have been successfully used in several cases (Yu *et al.*, 2013; Bochtis *et al.*, 2011; Dong *et al.*, 2012; Hu and Qian, 2011), but on the basis of proprietary communication protocols, thus compromising the overall performance in most cases. In addition, the existing high frequency WSN standards seem to impose a lot of development effort and cost in case where the integration of WSN to RFID applications is required (Wang *et al.*, 2006; Ruiz-Garcia and Lunadei, 2011; Ruiz-Garcia *et al.*, 2012). From such systems integration, the concept of *from the field to the shelf* (Blackburn and Scudder, 2009) can be realized in practice.

In this paper, the DASH7 standard is described and it is compared with its competitive technologies. Then, the benefits of DASH7 usage in Agriculture are presented. Next, the tools available today for DASH7 systems development are reported. Finally, the DASH7 typical node's architecture and the potential overall systems topology deployment are proposed. As a proof of concept the design of a DASH7 Mode 2 WSN node is presented as well.

2. THE DASH7 STANDARD

2.1 DASH7 Background

DASH7 has a history background of more than twenty years. The International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) have published the ISO/IEC 18000 standard which defines the items management via radio frequency identification (RFID). This global standard is comprised of several parts that each one of them covers the operation in different frequencies. ISO/IEC 18000-7 is the particular part that describes the air interface among active RFID tags through the usage of the 433MHz industrial, security and medical (ISM) frequency band (ISO/IEC 2004). The rest parts of the ISO/IEC 18000 standard are associated with frequencies as 135 kHz, 13.56 MHz, 860-960 MHz, 2.45 GHz, and 5.8 GHz. DASH-7 actually, is the trade name of the ISO/IEC 18000-7 standard, similar with what the WiFi is for the IEEE 802.11 standard. DASH7 was devised by Savi Technology (Schneider 2010) and its first application was in the Gulf War for military

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material tracking. Since then, DASH7 has been mandated by the U.S. Department of Defense (DoD) and NATO alliance. In 2009 U.S. DoD awarded $429 million to private industry for DASH7 further development. That was the milestone for the commercialization and standardization of the DASH7.

Similar to the well-known WSN standards, DASH7 has its own alliance, namely the DASH7 Alliance, established in 2010, with more than 50 members from 23 countries today (DASH7 Alliance 2012). Cross-vendor interoperability, promotion, education and certification are the main directions of DASH7 Alliance activity. In terms of the DASH7 development, Table 1 quotes the most important technical milestones (DASH7Alliance 2009).

Table 1. Main DASH7 Alliance milestones

IPv6 Integration	IPv6 addressing and services (e.g. ICMP, UDP) to the DASH7 endpoint
Security	Via ISO 29167-7 development public and private key cryptographic authentication methods for data and air-interface security.
Passive & NFC Integration	HW proof-of-concept & product development combination of passive RF communication with DASH7, including usage of NFC+DASH7 over a single antenna
DNA	SW specification development and implementation DNA = "DASH7 Network Access" a common open-source API for connecting DASH7 network infrastructure

2.2 DASH7 Characteristics

DASH7 is an ultra-low power, low data-rate, long range, and low latency WSN technology. The main characteristics of DASH7 are presented in Table 2.

Table 2. DASH7 main characteristics

Parameter	Value
Standard	ISO/IEC 18000-7
Range	10m – 10km
Frequency	433.92MHz
Propagation	Water, Walls, Concrete
Latency	Max. 2 seconds
Data Rate	28kbps – 200kbps
Multi-Hop	Yes
Pear-to-Pear	Yes
Communication	Broadcast, Multicast, Anycast, Unicast
Security	128 AES, Public Key
IPv6	YES
Battery Life	Up to10 years

DASH7 has been designed to operate according to the *BLAST* concept. This acronym comes from the words Bursty, Light-data, Asynchronous, and Transitive (Table 3) (Norair, 2009).

There are three types of DASH7 device profiles, namely the Gateway (the interrogator), the Subcontroller (the transceiver) and the Endpoint (the transponder).

The devices stay idle until an event to occur. DASH7 is not a session-oriented protocol but an event-driven one. All the devices support a wake-on mechanism ensuring this way a deterministic data latency (2 sec in worst cases) and the lowest energy consumption.

Table 3: The *BLAST* concept of DASH7 operation

Bursty	Data transfer is abrupt and does not include content such as video, audio, or other isochronous (i.e.streaming) forms of data.
Light-data	In conventional applications, packet sizes are limited to 256 bytes. Transmission of multiple, consecutive packets may occur but is generally avoided if possible.
Asynchronous	DASH7's main method of communication is by command-response, which by design requires no periodic network "hand-shaking" or synchronization between devices.
Transistive	A DASH7 system of devices is inherently mobile. Unlike other wireless technologies DASH7 is upload-centric, not download-centric, so devices do not have to be to be managed extensively by fixed infrastructure (i.e. base stations).

The transmitted signals consist of the wake signal, the preamble and sync fields, as well as the data payload and a 16-bit CRC field. The dialog among the devices includes Requests and Responses and optionally Follow-Up Requests. There are three types of data payload as presented in Table 4, while there are four types of communication, namely Broadcast, Multicast, Anycast, and Unicast.

Table 4. DASH7 Data Types

Packet Type	Comment	Packet Size
Synchronizer Packet	Wake-on method	6 bytes
Normal Packet	Request/response	up to 256 bytes
Data Packet	Long frame series	up to 65k bytes

Under the name Mode 1, the physical layer specifications of DASH7 was ratified in the first ISO/IEC 18000-7 standard. Today, there is a new specifications framework, named Mode 2, that aims to fulfill the markets requirements for the next ten years. Mode 2 is compatible to Mode 1, it is developed by the DASH7 Alliance, and it has been submitted for adaptation to the ISO/IEC 18000-7 standard since October 2011 (Indigresso, 2012). The evolution of DASH7 is shown in Table 5.

Table 5. DASH7 specifications Evolution

	Mode 1	Mode 2
Channel Size	500kHz	216kHz
Channels	1	8
Modulation	FSK ±50 kHz	GFSK ±50 kHz
Encoding Options	Manchester	PN9. FEC
Symbol Rate	55.6 kHz	Normal: 55.6 kHz Turbo: 200 kHz
Data Rate	27,8 kbps	Min: 27.8 kbps Max: 200 kbps
Packet Sync	Pulse width	Sync word

DASH7 Mode 2 is implemented in a stack named OpenTag (Norair, 2011). OpenTag is an open-source stack and its size is as low as 16 kB (Indigresso, 2012; Sourceforge, 2012). Fig.1 shows the DASH7 Mode 2 layers (according to OSI model) together with the OpenTag stack components. Regarding the nodes addressing, DASH7 OpenTag supports unique identification numbers (UID) of 64 bits long.

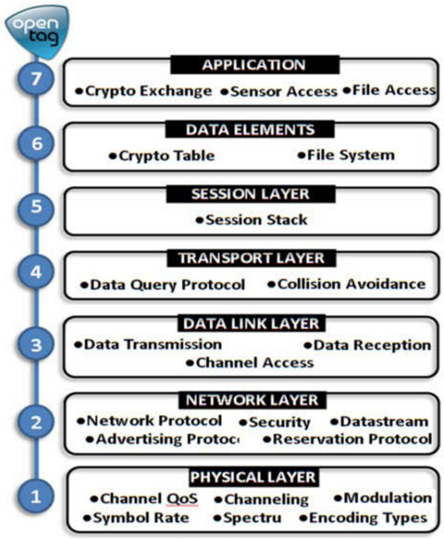

Fig. 1. Layers and functions of the DASH7 OpenTag stack

3. DASH7 VERSUS OTHER WSN STANDARDS

Amongst the most well-established technologies for wireless sensor networking there is ZigBee, Low Energy Bluetooth, and the WiFi. All of them are based on IEEE standards and use 2.45 GHz band for their operation. ZigBee can also use sub-1-GHz frequencies (868 MHz - 915 MHz). DASH7 is not an IEEE standard but an ISO/IEC global standard operating at the globally available and free ISM band of 433 MHz. The usage of the 433 MHz band is the most important difference between DASH7 and its competitors. In Table 6 we quote the main technical features of DASH7 and its competitive technologies in order to have a technical comparison basis of them.

Table 6. Technical Features of WSN Technologies

	DASH7	ZigBee	Low Energy Bluetooth	WiFi
Frequency Range	433.04 – 434.79 MHz	2.402 – 2.482 GHz	2.402 – 2.482 GHz	2.402 – 2.482 GHz
Number of Channels	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 Potential 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

To cover a given distance and with a certain transmission power, DASH7 needs an infrastructure with less nodes. With DASH7 there is no need for extensive multi-hop requests and responses compared to its competitors. This benefits the application's overall cost of ownership. In Table 7 we quote a comparison for the data transmission between two wireless nodes that are 500 m far away from each other. For this example DASH7 is compared with 868 MHz and 2.45 GHz ZigBee technology. All the nodes have identical transmission power (4 mW).

Table 7. Communication of two 0.5km distant nodes at 4 mW

Requirements	DASH7 433 MHz	ZigBee 868 MHz	ZigBee 2.45 GHz
Number of Hops	1	2	6-7
Infrastructure	1 Node	10 Nodes	100 Nodes

Fig.2 illustrates how certain critical system parameters are influenced according to frequency value.

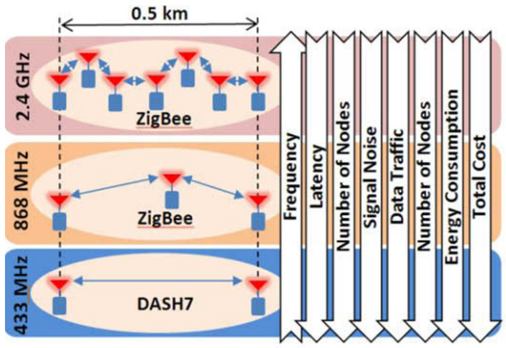

Fig. 2. Outdoor communication between two distant nodes.

The implementation of the protocol in the microcontroller's program memory, the so called firmware stack, it is commonplace for every WSN standard. The ZigBee stack is provided for free from many silicon manufacturers but each one of these vendors has developed its stack tailored to fit only within its microcontrollers. Thus, for a given standard, e.g. ZigBee, there are many different implementations of its stack targeting to particular microcontrollers of particular manufacturers. Systems designers face many difficulties to assimilate all these stack variants and for this reason they stick to a particular family of microcontrollers. From the other hand, DASH7, is the only standard that has an open source stack (OpenTag) that is provided through a single source (Sourceforge, 2012). Additionally, DASH7 stack size is the lowest in size, just 16 kB, compared to 90 kB of ZigBee stack. Such a low size stack is also difficult to be achieved by proprietary protocols. The size of the stack influences the cost and performance of nodes systems. Also, the lightweight stack together with over-the-air programming function inherent in DASH7 makes the over-the-air upgrade (OTAU) an easy operation. Another two advantages of DASH7 is its inherent strength for real-time localization systems (RTLS) due to its RFID nature, and its ability for energy harvesting based power supply due to its ultra-low power consumption. There are two seemingly weaknesses of DASH7 compared to its competitors, namely the low data rate (28 kbps in Mode 1) and the 433 MHz antennas sizes (λ is around 69 cm). Mode 2 ensures data rates up to 200 kbps, but even in case with 28 kbps data rate, DASH7 compensates the low data rate with its wider area coverage using less nodes and producing less network traffic. As it regards with the antennas dimensions, there are several options for 433 MHz bandwidth with small form factor and very good performance, e.g. chip antennas. In Table 8 we present a comparison between DASH7 and other well-known technologies.

Table 8. DASH7 versus other WSN standards

	DASH7	ZigBee	Low Energy Bluetooth	WiFi	Low Power UWB
Range	●	○	◐	○	◐
Battery Life	●	◐	●	○	○
In Building Coverage	●	○	○	○	○
Low Latency	●	○	○	○	○
Multi-Hop	●	●	○	●	○
Co-exist with IEEE 802.11n	●	○	○	●	○
Penetrates Concrete	●	○	○	○	○
Penetrates Water	●	○	○	○	○
"Bends" Arround Metal	●	○	○	○	○
Tracks Moving Things	●	○	○	○	○
Security	◐	●	◐	●	◐
Globally Available	●	●	●	●	◐
Small Protocol Stack	●	○	○	○	●
Data rate	○	◐	●	●	●
Major Market Proponents	●	●	○	●	○

● *High,* ◐ *Medium,* ○ *Low*

4. DASH7 BENEFITS FOR AGRICULTURE

The benefits accruing from DASH7 Mode 2 technology in wireless sensor network applications in Agriculture are many. The use of 433 MHz frequency ensures the best materials penetration and long range. Wireless sensor nodes energy consumption can be kept in minimum due to the "sprint and sleep" session-less concept together with the wake-on functionality of the DASH7 and the minimization of multi-hop fashioned mesh networking topologies.

Due to the fact that the DASH7 natively cooperates with passive and active RFID systems, it is the most suitable technology to integrate applications existing in farmlands and greenhouses, feedstock facilities, warehouses and refrigerator facilities, wholesale and retail supply chain, and consumers. DASH7 WSN nodes interface easily with RFID readers and passive Tags in applications such as animal tagging (ISO/IEC11784 RFID for animals), proximity cards and tags applications (ISO/IEC 14443 RFID proximity cards, ISO/IEC 15693). In addition, DASH7 interfaces with smart wireless transducers which use TEDS (Transducers Electronic Data Sheet – IEEE 1451.7, ISO/IEC 24753).

Thus, DASH7 can bridge the RFID with the WSN and smart sensors and actuators domains. This is the main reason that DASH7 seems to be the enabler technology for the longing of realizing the concept of *From Field to Shelf*. This feature, combined with the ability of DASH7 to encapsulate IPv6 protocol for *the Internet of Things* (IoT), makes DASH7 very beneficial for the measurement, communication, and control applications in Agriculture.

In Table 9 a summary of DASH7 main advantages for Agriculture is presented in major categories.

Table 9. Benefits of DASH7 use in Agriculture

Category	Advantages
Environment	• Designed ruggedized for harsh environment • Snow and Ice penetration • Water and Rain Penetration • Canopy Penetration • Wet Plants Penetration • Humidity in Cardboard Fruit Container • Chicken wires penetration • Concrete and walls penetration • Underground operation • Long Range
Systems Development	• Light-Weight Stack • Low Code Size in Program Memory • Open Source Stack • Low power • Any-Protocol Integration • Development Tools Ecosystem • Optimized for Energy Harvesting • Real-Time Localization Support
Systems Deployment	• Location Based Services Supported • High performance indoor or outdoor • IPv6 support • Addressing Flexibility • Over-The-Air Firmware Upgrade • " From Field to Shelf" Enabler • Less wireless nodes required
Systems Cost	• Cheaper Lower Energy batteries • Less Flash Memory Microcontrollers • Avoid Power Amplifiers in Most Cases • Avoid Taller than Foliage Nodes' Support Poles • Cooperation with RFID Tags and Readers
Integration	• Cooperation with Near-Field-Communication (NFC) • Interface with NFC-enabled mobile phones • Interface with IEEE 1451.7 TEDS Intelligent Wireless Sensors • Single-Vendor Stack Firmware
Reliability	• Less EMI (designed for aircrafts) • Robustness (Designed for Military Applications) • Low and Deterministic latency • No WiFi and GSM Interference • ISO/IEC 18000-7 Global Standard

5. DASH7 SYSTEMS DEVELOPMENT

Among the proponents of DASH7, there are several semiconductor manufacturers that provide silicon solutions and development tools to those who wish to design and develop DASH7-based systems. Texas Instruments, ST Microelectronics, Melexys, and Semtech are the most active solutions providers in this field. As it is expected, DASH7 wireless devices may be built either using an RF transceiver integrated chip interfaced with an embedded microcontroller (chipset approach), or using systems-on-chip (SoC approach) solutions where the RF chip and the microcontroller are encapsulated into the same package. In either case, the embedded microcontroller hosts the communication standard stack. As already mentioned, the OpenTag is an open source stack implementation of the DASH7 Mode 2 specification. Due to the facts that the code size of the OpenTag is as low as 16 kB and that no persistent SRAM variables are required, theoretically any microcontroller could be used as a DASH7 node's microcontroller. In practice, any 16-bit or 32-bit microcontroller or microprocessor equipped with a direct memory access (DMA) or some kind of FIFO (First In First Out) integrated peripheral could be used for OpenTag. Such micros are the MSP430 from Texas Instruments, the ST32 from ST Microelectronics, and any ARM Cortex M3 or M4 compatible.

In terms of wireless communication circuitry required in a DASH7-based WSN node, there are RF transceivers available such as the CC11xx from Texas Instruments and the SX12xx from Semtech. Among the basic features of the radio transceivers is the 433MHz frequency band, the FSK/GFSK modulation, and up to 200 kbps data rate, while some optional features such as hardware encoding and low power consumption are preferred in most cases.

System-on-Chip solutions are also available, i.e. the CC430 from Texas Instruments, the SX1282 from Semtech, and ADuCRF101 from Analog Devices. SoCs ensure reduction in systems physical dimensions and increase reliability.

Regarding the software development tools, the OpenTag is a C-language set of files. Designers can use either their microcontroller's integrated development environment (IDE) or other commercial solutions like the IAR code development suite.

6. DASH7-BASED WSN ARCHITECTURE FOR AGRICULTURE

Every wireless sensor network comprises of a number of nodes of different types according to a communication protocol. For DASH7-based wireless sensor networks there are three types of nodes, namely, the Endpoints, the Subcontrollers, and the Gateways. In Fig. 3 we present the architecture that includes all the required sub-systems to fulfill the vast majority of WSN applications in Agriculture. The dotted rectangle that surrounds the RF Transceiver and the MCU (microcontroller) denotes that there is also the System-on-Chip (SoC) approach in which these two sub-systems are coming together as a single integrated circuit. We suggest the use of SoC solutions when there is limitation in the node's physical dimensions and when there is no sufficient expertise in RF systems design and development.

For the antenna sub-system there are more than one available approaches, i.e. half-wave dipole antennas, helical antennas, and loop antennas. Depending on the particular application, the antenna may be implemented in the copper of the node's printed circuit board (PCB). In addition, when small form factor is required, then chip antennas that also contain the balun (BALalance-UNbalance) circuitry is a good choice. In addition, the antennas used in DASH7 nodes can communicate with the 135 KHz and 13.56 MHz RFID devices because 433.92 MHz is an even multiple of RFID frequencies (e.g. 32 * 13.56 = 433.92). Also Near-Field-Communication (NFC) (exists in many mobile phones) operates at 13.56 MHz. Thus, through NFC-enabled phones the interfacing of DASH7 WSN with the smartphones domain and the world-wide-web is realizable.

According to this architecture, the hardware can be the same for the different of DASH7 device types. The type of a device is determined by the configuration files according to the OpenTag stack file system.

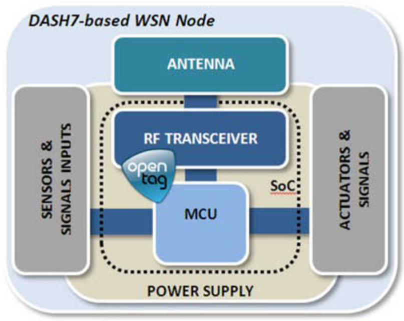

Fig.3. DASH7-based WSN node architecture

In Fig.4 we present the deployment of a wireless sensor network for Agriculture. It is demonstrated DASH7's inherent capability to interface with other domains such as the RFID domain and the TEDS-based (Transducers-Electronic-Datasheet) smart transducers, as well as the world-wide-web using GSM/GPRS and local networks. With this structure, concepts like "internet of things" (IOT) and "from the field to the shelf" can be effectively supported and enabled in real-life applications in Agriculture.

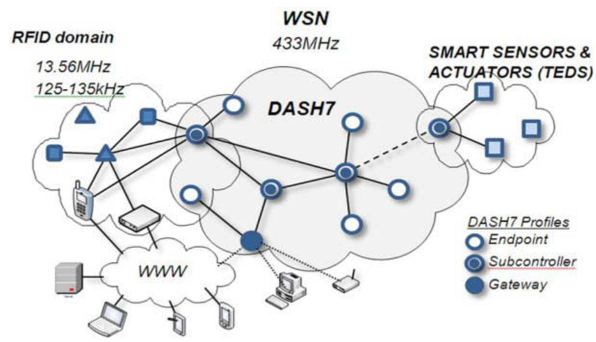

Fig. 4. DASH7 deployment architecture for Agriculture.

As a proof of concept, we designed and implemented a DASH7 WSN node to use it for precision agriculture. It is based on the Texas Instruments CC430F5137 system-on-chip which includes a MSP430 microcontroller with a CC1101 RF transceiver. The CC430F5137 is an ultra-low power device with 32 kB of Flash program memory, 4 kB of RAM data memory, several serial communication ports (UART, SPI, I2C), 12-bit analog-to-digital conversion channels, timers and comparators. As it is depicted in Fig. 5, there is a SMA antenna connector, and several terminal blocks to ease connection to every pin of the CC430F5137 device. This node requires 2.0 to 3.3 Volts for power supply and can be powered from two AA batteries.

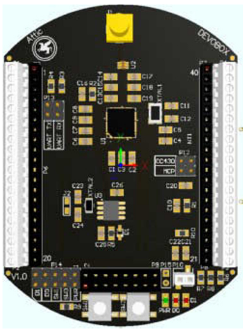

Fig. 5. Implementation of a DASH7 WSN node

The above WSN node can host applications for IEEE 1451/TEDS for building smart transducers interface modules (STIM) (Piromalis et al., 2013), and it can also support interface with RFID systems (Piromalis and Arvanitis, 2013).

7. CONCLUSIONS

DASH7 standard can cooperate with other standards for RFID, NFC, and smart transducers. Thus it could be used to integrate WSN applications to different wireless application domains in Agriculture. Existing technology can support designers by providing an almost complete ecosystem of development tools. DASH7 is a challenging technology that is here to stay and change the wireless Agriculture in the near feature.

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