Wireless Smart Sensors Networks Overview

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Abstract

Wireless smart sensors are becoming very attractive devices in tele-monitoring, tracking moving objects, home automation, telemedicine and other industrial applications. They are small devices that gather information such as speed, humidity, pressure and temperature with high resolution and have very useful functions on the software level such as signal processing and data logging. They do measurements from different channels and adjust the data to support distributed processing and decision making. Wireless smart sensors provide clear advantages in power, size, cost, mobility and flexibility. The movement towards wireless smart sensor network technology has been established through applying different protocols such as IEEE 1451 standard. This paper describes the use of smart sensors in forming an integrated wireless network. That includes the sensors architecture, their standards, network topologies, protocols, implementation issues, and information about the wireless sensor solutions.

Index Terms — Smart sensors, wireless sensors, IEEE 1451 Standard, distributed sensors networks, wireless communications, network capable applications processor.

I. Introduction

With the ever evolving telecommunications, computer networks, Internet and industrial informatics technologies, a great development in networked wireless smart sensors technology has occurred. Wireless smart sensors networks have many advantages such as power consumption, size, low cost, scalability, mobility, and flexibility. They have gained high ground in the late decade but incompatibility issues that arise in the interface of smart sensors with wireless network systems have become a major concern. To overcome this problem, in the late 90's, the IEEE came up with a set of standards: the IEEE 1451 [1]. The objective of these standards is to define an architecture that allows sensors to be connected into any live distributed control network in a "plug-and-play" manner.

Wireless smart sensors networks have two basic architectures: the hardware and the software. The basic hardware architecture consists of a cluster that contains sensor nodes and a cluster head that acts as processing unit and gateway to a local area network via a command node. Figure 1 shows typical hardware architecture of a wireless smart sensors network.

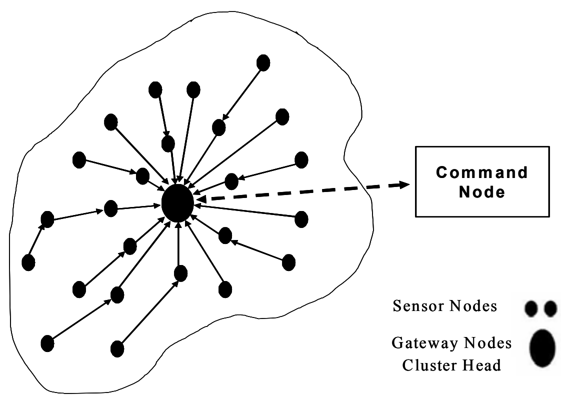

Fig.1. wireless smart sensors network Architecture [2].

The software architecture consists of four modules: smart transducer interface module (STIM), transducer electronic data sheet (TEDS), transducer independent interface (TII) and a communication protocol. Figure 2 shows the basic layout of the software modules [3-8].

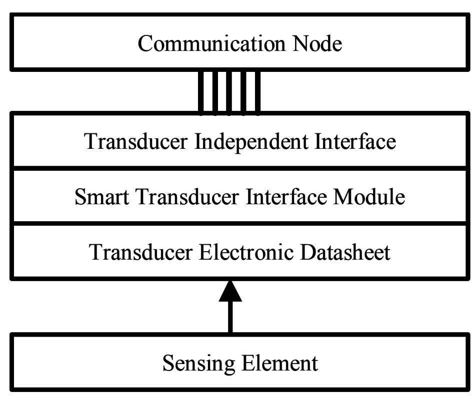

Fig.2. Software Architecture

This paper presents a comprehensive overview for each of the hardware block and the software module in wireless smart sensors networks and their implementation according to the IEEE 1451 standards.

II. Smart Sensors Architecture

Sensors can be grouped into two different categories: ordinary sensors, and smart sensors [6]. Ordinary sensors are those that require dedicated external circuitry to perform analysis on signals, on error compensation, and filtering. If lots of data are generated in the same time, buffering may also be required; while smart sensors integrate the sensor with the required buffers and conditioning circuitry in a single enclosed space. They have on-board circuitry that allow sensors to be programmed to satisfy specific system requirements but could be later re-programmed by the user when needed. A digital interface can be used to add a smart sensor to an embedded hardware, and thus a single chip could be used, called a System-On-Chip (SOC).

One of the definitions that could describe a smart sensor is given by the IEEE 1451.2-1997. It clearly differentiates between a smart transducer and a smart sensor, which in fact is a "sensor version of a smart transducer" [7]. A clearer definition was also cited in a research concerning the progress of smart sensors. It states that a smart sensor is a sensor that "provides functions beyond those necessary for generating a correct representation of a sensed or controlled quantity. This function typically simplifies the integration of the transducer into applications in a networked environment." [8]. The basic building blocks of a "smart sensor" are: Sensing device, signal conditioning circuits, high performance multiplexers Analog-to-Digital Converters (ADCs), and Digital-to-Analog Converters (DACs), microcontroller with built-input resources such as flash memory, interrupt driven input capture and output compare timers. The on-bard microcontroller performs online auto-offset and auto-null mechanize. The sensor is equipped with built-in wireless access point (transceiver) [3]. Figure 3 shows standard smart sensor architecture.

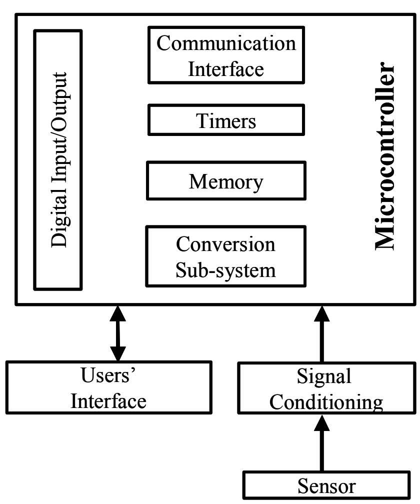

Fig.3. Smart sensor basic architecture

In addition to the hardware, the smart sensor has application software that performs the following tasks [8]:

- Manages the real-time parameters acquisitions from physical environment, process the data based on predefined algorithms and commands actuators.
- Memory: It is a digital data storage for the sensor information (configuration information, identification of the sensor), for calibration data, and any other important information that the sensor need to store.
- User interface: It is the presentation of the correct data, ready and processed, to the end user in the user language and specific to an application.
- Communication: It is the interface which allows the communication to the medium, for a remote access sensor. It is used for the setup stage, the calibration, the data capturing, and other functions needed by the sensor.

III. SMART SENSOR NETWORKS

A network compatible smart sensor node must be equipped with the network interface capability so that sensors can be clustered together. A cluster is a set of sensor nodes that surround the target phenomena and are capable of detecting and processing the data required by the users [2, 8, 9]. Clustering techniques are used to reduce and optimized the data traffic through out the sensor nodes and the network. It can also be used "for hosting the data-centric processing paradigm from both geographical and system design perspectives" [9]. Cluster networking techniques are dynamically formed depending on different criteria such as communication range, number/ type of sensor used and the geographical locations.

Multiple clusters may share the same sensor nodes and overlap with each other without any deficits. In each cluster a node is dedicated to be the cluster head which is "responsible for control and coordination of sensor nodes within the cluster" [9].

Each cluster selects one of its nodes as cluster-head. It is also called network capable application processor (NCAP). It manages the sensor's nodes in the cluster and provides communication gateway to a center node. In multi- clusters smart sensors wireless networks, the central node coordinates and manages the activities between the cluster heads in the networks. Cluster heads can communicate with each other directly or via the central node.

Multi-gateway clustered wireless network architecture is shown in figure 5 [2].

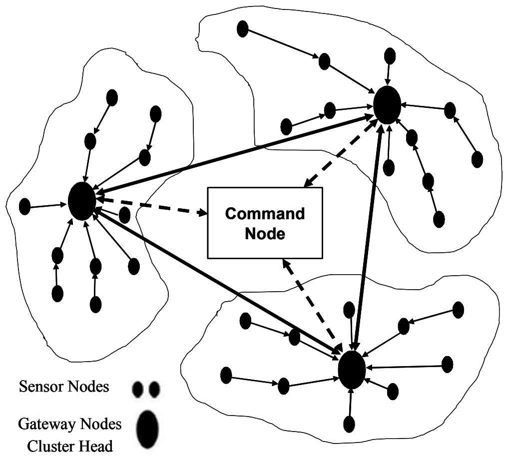

Fig.5. Multi-gateway cluster networks

Each cluster has a middleware software architecture that provides standardized system services for different applications, runtime environment that can support and coordinate multiple applications, a mechanism to adapt and use the system resources efficiently.

The cluster-based software architecture may be divided into two layers: cluster layer and resource management layer [2, 9].

The cluster layer is responsible for the following tasks:

- Forming clusters from the various sensor nodes that are around specific target phenomena. The criteria used in dividing the sensor node into different clusters are the node capabilities and network connectivity.
- Distributing commands issued from the cluster head for resource management and cluster control purposes.
- Interface with the network

The resource management layer is responsible for following tasks:

- Allocation and adaptation of resources
- Cost models
- Resource description
- Resource management
- Quality of service interpreter Q o S
- Interfacing with the physical sensor node

IV. Wireless Technologies for Smart Sensors Networks

As mentioned in section III, each cluster head communicates with peer cluster head, and with the command node. Different technologies are used to implement a short-range wireless communication between the cluster heads as well as the command node. The most popular technologies are HomeRF, Bluetooth, IEEE 802.11x, and IrDA [5].

The adaptation of one of the above technologies is based on several factors such as maximum distance covered, data rate, frequency, application, power consumption and modulation. Table 1 shows a summary for the four mentioned technologies based on the above mentioned factors [5].

Table 1. Various Wireless Technologies

Criteria / Technology	**Max. Distance Covered**	**Data Rate**	**Frequency**	**Applications**	**Power Consumption**	**Modulation Scheme**
HomeRF	150 feet	1 – 2 Mbps	2.4 GHz ISM Band	Home Networking Solution	100 mW	FHSS, 2FSK, 4FSK
IrDA	3 feet	9600 bps - 16Mbps	1.8 MHz	Between adhoc data access points (handheld computers)	100 mW	Line of Sight (LOS) with 30°
IEEE 802.11x	300 feet	1, 2, 5.5 and 11 Mbps	2.4 GHz	Industries, Home use	1 W	FHSS, DSSS
Bluetooth	30 feet	1 Mbps	2.4 GHz ISM Band	Cable Replacement, Exchanging Objects, Peripheral Communication, Audio Communication	1 mW	FHSS, Gaussian frequency-shift keying

V. Smart Sensor Standardization

The smart sensors technologies and applications are growing and becoming integral part of some industrial and commercial products. As any emerging technology, incompatibility problem is one of the challenges that smart sensors face and is becoming an issue. The IEEE came up with a set of standards for a smart sensor interface to overcome the incompatibility issues that arise when interfacing sensors to different control networks and microprocessor-based systems. The main objective of theses standards is to declare an architecture that allows smart sensors to connect into any live network in a “plug-and-play” manner. IEEE 1451 defines a common sensor communication interface which means having network-independent smart sensors. In other words, IEEE 1451 standard means sensor re-usability and portability; the same sensors can be used on different networks [10].

IEEE 1451 standard has four sub-standards that are:

– 1451.1 - Network Independent Model
– 1451.2 - Smart Transducer
– P1451.3 - Multi-drop Transducer Bus
– P1451.4 - Mixed Mode Transducers

The 1451.1 and 1451.2 have been adopted by the IEEE standards committee whereas P1451.3 and P1451.4 (where ‘P’ = proposed) are still being developed. Each one of these sub-standards focuses on a specific area of the smart networked sensor signal path. These sub-standards can be used separately or together as part of the entire network solution as illustrated in figure 6 [5].

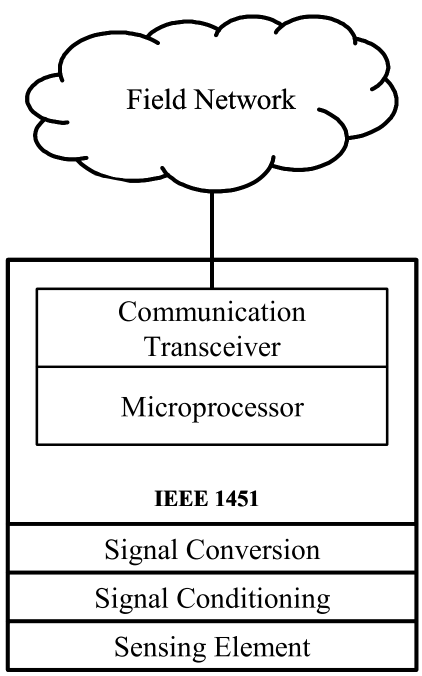

Fig.6. the 1451 standard for a smart sensor interface

The actual components of the IEEE 1451 components are the network hardware, I/O interface hardware, microprocessor hardware, transducers and the communication network. The IEEE 1451.1 standard defines a Network Capable Application Processor (NCAP) Model [10]. This model is to enable the interfacing of smart sensors to various networks. The NCAP provides the details of the sensor hardware implementation and also defines how the model is mapped to the control network.

The IEEE 1451.2 standard defines a Smart Transducer Interface Module or ‘STIM’, a Transducer Electronic Datasheet or ‘TEDS’, and the Transducer Independent Interface or ‘TII’ through communications protocols between the STIM and the NCAP.

The STIM is the networked, remote and intelligent transducer node. A STIM can connect to up to 255 channels of transducers. The STIM uses some addressing logic to distinguish between the types of the transducer (sensors) which it is connected to. A STIM contains a non-volatile memory area that describes or identifies the STIM itself. Therefore, this specific memory area is called the Transducer Electronic Data Sheet or (TEDS).

The TEDS is divided into eight fields. Each field is to describe different traits of the STIM and the Transducer channels, the attributes, operation, type and the calibration of the transducers connected to the STIM. Therefore, the TEDS provide easiness as it allows easy maintenance, upgrades and replacements. It allows “plug-and-play” operation through accurate TEDS. The Network Capable Application Processor (NCAP) controls the STIM. The NCAP intervenes between the STIM and the control network, and provides intelligence.

The STIM communicates to the network through the Transducer Independent Interface (TII) that connects it to the NCAP. The TII is a 10-wire serial I/O bus that provides a digital interface for this communication. It is a synchronous serial communication interface based on the Serial Peripheral Interface or SPI standard. The TII allows the NCAP to get the sensors’ readings. In other words, the TII provides triggering functions, byte transfer method, byte read and write protocol and data transport frames [11].

The NCAP controls the communication between the STIM and the NCAP on the TII. The NCAP initiates the connections; it initiates a measurement by triggering the STIM. The STIM then responds with an ACK once the measurement is taken. The NCAP may be interrupted by the STIM only in the case of an exception, failure, or a fatal error.

The IEEE P1451.3 standard proposes a standard digital interface called a Transducer Bus Interface Module (TBIM) connecting multiple physically separated transducers in a multi-drop configuration [5].

The IEEE P1451.4 proposes a standard interface that will allow analog transducers to operate in a mixed signal mode with analog and digital modes [10, 12]. As for the digital mode, manufacturer data will be transferred upon power-up or upon command then the transducer switches to analog mode and sends its analog sensor readings.

VI. Conclusion

Wireless smart sensors are emerging technologies and are gaining high ground in industrial applications. To mention few, we can cite the control of electrical devices, the remote patient monitoring systems, the process automation and the environment and weather monitoring. In this paper, the smart sensors' architecture and their characteristics were presented. It also described how to integrate these sensors to construct a wireless smart sensing network. In addition to that, the paper discussed the available wireless technologies for networking smart sensors, showing the advantages and disadvantages of each of them: a brief description of the IEEE 1451 set of standards was presented.

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