Network Supplemented by Wireless Sensors. 1. Overview.

Gediminas Žukauskas [a] , Vytautas Jonkus
Machine-to-Machine laboratory, Department of Radiophysics, Faculty of Physics, University of Vilnius
Saulėtekio al. 9, korp. 3, Vilnius, Lithuania

Received 10 October 2015, accepted 15 December 2015

Abstract. As new wireless technologies become more and more advance so does their expanse of applications. Among other new and innovative wireless network, 802.15.4 standard has emerged as highly flexible and dynamics facets that are being deployed in almost wireless sensors networks. The Zigbee technology has the powerful integration degree of society habits. We must be clear when talk about "smart" definition otherwise we can't understand what is "smart" sensor or network. Review represents smart things which describe wireless sensors network.

Citations: Gediminas Žukauskas, Vytautas Jonkus. Network supplemented by wireless sensors. 1. Overview. – *Innovative Infotechnologies for Science, Business and Education,* ISSN 2029-1035 – **2(19)** 2015 – Pp. 17-22.

Keywords: wireless sensors; Zigbee.
Short title: Wireless Sensors. 1. Overview.

Introduction

Rapid improvement of silicon technology in the nineties led to the development of especially favourable conditions for the installation of a greater variety of digital solutions in mobile communication systems. These solutions include the creation of low noise transistors which are able to receive very weak signals, as well as creation and development of new fully digitized, low power standards for mobile communication systems. The usage of digital signals in the radio channel allows to efficiently use time-division and code multiplexing. Such technological step provides the conditions for the development of M2M technological progress, which in these days is very significant and has exciting prospects. M2M includes technologies, which are linked with electronic devices by wireless and cable communication.

The analysis of wireless networks of sensors reveals that the technological process is not advanced. It is distinguished for high energy consumption, capability limitations, short operational range, control reachability and versatility, and the price which is especially relevant in the Lithuanian market. Many producers rely on their own patented technology or franchise; therefore, artificial barriers for electronic device flexibility are created and the competition is distorted.

IEEE 802.11x radio communication family of exceptional success provides new possibilities not only for the fulfilment of individual needs, but also creates the grounds for the appearance of radio communication systems that work on the same high frequency and are oriented towards energy minimisation and simple design of wireless networks. This technology, which is defined by IEEE 802.15.4 standard, is known as *Zigbee*.

Review represents smart things which describe wireless sensors network.

1. Overview of IEEE 802.15.4 standard

Zigbee technological concept defines the lowest levels that are defined by IEEE 802.15.4 standard, which was approved in 2003 [1]. During the decade, it was adjusted and supplemented. However, the specifics of physical and MAC level formation technique did not change. Twenty-five international companies initiated the creation and development of IEEE 802.15.4 standard [2]. Looking at the prospects of 2015, the electronic devices of IEEE 802.15.4 standard will be accessible to 50Low price and especially low energy consumption are the main drivers of developing infrastructure. Highly specialized *Zigbee* standards are already being distinguished and perform certain functions [2]: "ZigBee Building Automation", "ZigBee Remote Control", "ZigBee Smart Energy", "Smart Energy Profile 2", "ZigBee Health Care", "ZigBee Home Automation", "ZigBee Input Device", "ZigBee Light Link", "ZigBee Retail Services", "ZigBee Telecom Services", "ZigBee Network Devices".

When detailing *Zigbee* technology, the following specifications can be distinguished [1]:

i) depending on frequency used, the speed can be 20 kbit/s, 40 kbit/s, 250 kbit/s, with a possibility to increase it up to 625 kbit/s;
ii) the devices communicate with each other directly or by using the principle of ring topology;
iii) 16 bit or 64 bit addresses are formed;

[a]Corresponding author, email: gediminas.zukauskas.1989@gmail.com

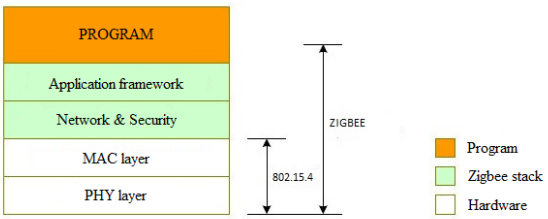

Fig. 1. "Zigbee" protocol.

iv) CSMA-CS algorithm is executed;
v) standardized response protocol;
vi) battery longevity function;
vii) channel quality identification;
viii) energy authorization;
ix) 27 channels are utilized to operate in three frequencies;
x) the devices could be described as fully or partially standardized;
xi) network hierarchy levels are formed accordingly.

IEEE 802.15.4 standard is defined by physical and MAC levels that define technical architecture of the device. The remaining three levels digitally complement "Zigbee" protocol, see Fig. 1. The network and safety and the program construction levels are oriented towards digitization processes that supplement the part of the protocol with specific *Zigbee* parameters. The other part is freely improvised in the creation process, i.e. the mechanics of the program. Namely, the mechanics of the program, i.e. the program of the higher level, provides *Zigbee* technology with flexibility and innovative inclusive solutions. It also should be mentioned that such standard is developed only in low rate wireless personal networks, where the need for minimal energy and low price are emphasized. Mostly the devices operating in such network are less capable of specific transfer and have limited power. Yet they are perfectly suitable to be used for longer intervals of time.

1.1. Physical Level

The physical level of IEEE 802.15.4 standard is responsible for the performance of certain tasks, which are as follows [1]:

i) coordination of transmitter's status;
ii) energy detection;
iii) evaluation of the accepted package channel quality;
iv) application of CSMA - CA algorithm;
v) selection of channel frequency;
vi) data transfer and reception.

Physical channel can operate in the following three frequencies [3]: 868 MHz, 915 MHz and 2.4 GHz. The whole physical level is divided into 27 channels that are sequentially allocated according to the operational frequency - see Fig. 2.

The so-called *Binary Phase Shift Keying* (BPSK) is used for channels [0÷10] [3]. The *offset Quadrature Phase Shift Keying* (O-QFSK) is used for the remaining channels working on 2.4 GHz operational frequency [3]. According to Ref.

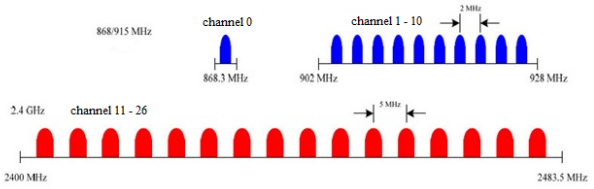

Fig. 2. Layout of radio channels in IEEE 802.15.4 standard.

[1], if you need to calculate the central frequency of operational channel (so called F_c value) you need to use simple equation.

868 MHz: only the channel zero is used,

$$F_c = 868,3 \quad [MHz]. \tag{1}$$

915 MHz: one of ten channels [1 ÷ 10] needs to be selected for the k value:

$$F_c = 906 + 2(k-1) \quad [MHz]. \tag{2}$$

2400 MHz: one of sixteen channels [10 ÷ 26] needs to be selected for the k value:

$$F_c = 2405 + 5(k-11) \quad [MHz]. \tag{3}$$

In order to detect the receivers, 0÷10 signal channels of IEEE 802.15.4 standard have to be provided with sensitivity, which is no less than 92 dBm [4], and for the [11÷26] channels, the sensitivity has to be no less than 85 dBm. The weakest signal transfer strength could be 3 dBm, and that is actually 0.5 mW [4].

$$dBm = 10 * \log_{10} \frac{P}{1mW} \tag{4}$$

The largest signal transmission radius is up to 75 meters. However, there are negative aspects as well, since the maximum length of physical level useful package is restricted to 127 bits. Moreover, specific parameters are set for each region, and they are defined by standards described in Ref. [1] - see Table 1.

1.2. MAC Level

The MAC level of IEEE 802.15.4 standard is defined as logical interfaces and acceptance controls [1]. When analysing IEEE 802.15.4 standard, data reception control shall be equal to data interface level, since the logic control of the interface is defined by IEEE 802.15.4 standard [4]. The level of access control is responsible for the structure of the signal. It controls access signal, transmission of confirmations, etc. The reception level of IEEE 802.15.4 standard is suitable to implement the low power operations and safety mechanisms.

The main tasks of MAC level could be formulated as presented below.

Table 1. Basic physicals parameters of IEEE 802.15.4 standard for several regions. Adapted according to Ref. [6].

Region	Organization	Specification
Europe	European Telecommunications Standards Institute (ETSI)	ETSI EN 300 328-1 [B11] ETSI EN 300 328-2 [B12] ETSI EN 300 220-1 [B10] ERC 70-03 [B13]
Japan	Association of Radio Industries and Businesses (ARIB)	ARIB STD-T66 [B14]
USA	Federal Communications Commission (FCC)	FCC CFR47, Section 15.247 [B14]
Canada	Industry Canada (IC)	GL36 [B15]

Frequency, MHz	Spectrum width, MHz	Quantity of channels	Maximum speed, Kbps	Modulation type	Region
868	868 ÷ 686,6	1	20	BPSK	Europe
915	902 ÷ 923	10	40	BPSK	America, Australia
2400	2400 ÷ 2483,5	16	250	O - QPSK	Cover all regions

i) to ensure network functionality when the device acts as a coordinator;
ii) to synchronize communication between devices;
iii) to maintain the functions of network allocation and disconnection;
iv) too ensure security of transferred packages;
v) to implement unique functions and algorithms (such as CSMA-CA, GTS...) of 802.15.4 standard;
vi) to ensure uninterruptible connection between other levels, services.

Most of the processes that take place at the MAC level will be discussed in the later sections that deal directly with the higher levels, since the service which is running at this level has to link the transitional processes that take place at the levels. We are not only talking about the checking of the package, but about formation, security and other important parameters and processes as well.

2. Zigbee network

Fig. 3 represents topology diversity of *Zigbee* network. By analysing the electronic devices that comply with *Zigbee* protocol, the following two types that are suitable for the implementation in the networks of such type can be distinguished:

1. Reduced functionality devices (RFD). Such devices have limited memory, low energy capabilities and perform elementary processes. The main condition for the devices of such level is as follows: they cannot perform the functions of the coordinator or router.
2. Full functionality devices (FFD). In the *Zigbee* network the devices of such type have the resources that can perform complex tasks; therefore, they usually have coordinator's or router's role. They are fully capable of performing all procedures of IEEE 802.15.4 standard.

During design of *Zigbee* network, i.e. when implementing "Zigbee" protocol, it is possible to insert the definitions of different hierarchy devices that perform a certain role in the network.

1. *Zigbee* coordinator. This device is responsible for the performance of the main functions, such as network creation, address allocation to the devices that exist in the "Zigbee" network, control during the network formation and while performing the operations. Only one device of such hierarchy can be in the network.
2. *Zigbee* router. The device of this type is equipped with resources with which it performs the route algorithms and advance messages to and from network devices.
3. *Zigbee* reliance centre. This is the core component in *Zigbee* security architecture. It is entrusted to the other devices that exist in the network. The main task of this centre is to provide reliability, device and network control with proper services. Such device is not used in local personal network, since all the needed infrastructure is implemented in higher levels of "Zigbee" devices.

Zigbee device. The simplest unit of *Zigbee* network hierarchy structure. Such electronic device barely meets *Zigbee* standard and is able only to accept and receive necessary data and information;

Zigbee bridge. The device of this type does not participate in the network processes and is only an interface for *Zigbee* network to transit to a network of another type. It often performs the protocol transformation for necessary network.

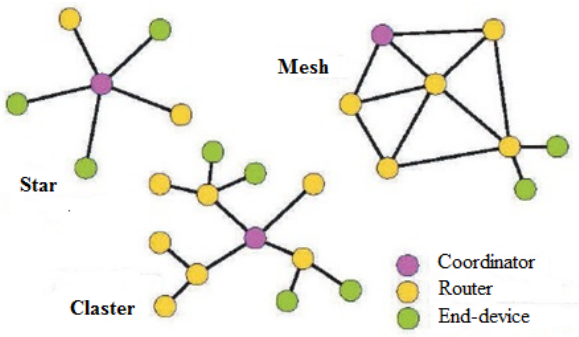

Fig. 3. Topology diversity of *Zigbee* network.

Table 2. Star, cluster, node topology according to Ref. [4].

Properties	Topology		
	Star	Cluster	Node
Advantages	Easy synchronization	Low routing costs	"Energetic", multi-hopping communication
	Low energy operations	Super-package formation	Flexible network structure
	Short time of delay	Multi-hopping communication	Short time of delay
Disadvantages	Small scale network	High costs of alternating routing	Inability to form super-packages
		Long delay time could occur	High costs of route finding
			Storage vault is required to store routing addresses

It should be noted that "Zigbee" network could have the star topology or be linear (the so- called node topology). Combining both topologies together, we could create structurally more complex network which usually is deemed as having a cluster topology. Every topology of "Zigbee" network has its specific advantages and disadvantages. Usually the network topology features different parameters and unique network formation algorithms.

Advantages and disadvantages of star, cluster and node topology [4] are presented in Table 2.

3. MRF24j40 chip. Overview of properties

MRF24J40 chip is a receiver of 2.4 GHz frequency that complies with the technical requirements of IEEE 802.15.4 standard. The lowest "Zigbee" levels, physical and MAC, are integrated in this receiver [6], see Fig. 4.

Such semi-conductor chip is described in the market as cheap wireless local personal network device which consumes little energy and transfers and receives data at low speed [250÷625] Kbit/s. This device is the product of "MICROCHIP" corporation, designed for the series of PIC microcontrollers. MRF24J40 is controlled with four SPI and three additional outlets: "RESET" (the outlet of chip's initial parameters), "INT" (chip events outlet) and "WAKE" (chip's awakening outlet) [6]. Not only all lowest levels of IEEE 802.15.4 standard are included in the solution of one chip, but also are technologically implemented solutions that describe "Zigbee" technical protocol [6]:

i) energy detection;
ii) function of channel sensitivity setting;
iii) three CCA models;
iv) implementation of CSMA-CA algorithm;
v) automatic organization and transmission of confirmations;
vi) automatic forwarding of sent package;
vii) technological solutions that enable the super-package mode were created;
viii) security engines that provide the possibilities of coding and decoding not only at the level of data transferring but at the higher ones, too.

Such multi-functionality of the chip reduces the load on the microcontrollers, due to which the energy costs diminish in the controlling semiconductor devices as well. MRF24J40 chip is ideally suitable to be used not only while creating *Zigbee* network, but also implementing the technological solutions of "MIWI" (the strain of *Zigbee* standard) or "MIWI P2P".

Fig. 5 represents the topology of MRF24J40 chip [6]. The external 20 MHz oscillator is the synthesizer of the required frequency. It ensures 2.4 GHz operational frequency. The signal reception circuit is created by using conditional architecture which is comprised of a low noise amplifier, recalculation mixer, multiphase channel filter and the basic stripe restriction amplifier with the received signal strength indicator (RSSI). The signal transmission circuit architecture is based on the 0 dBm maximum output and 36 dB range power controller [6]. Both transmission and reception circuits are combined by switching method and controlled by two chip outlets: RFN and RFP. The outlets of shared usage are used smartly: the access and transfer logics are being controlled (switched) through PA/LNA circuits.

The voltage regulator (LDO) is integrated into the whole energy management architecture to ensure the suitable conditions for the purposeful operation of the chip while receiving and transmitting the signals. Due to the internal 100 kHz or external 32 kHz tactical frequency generators, the MRF24J40 chip can switch into sleep mode, where the current needs are only 2μA. It should be noted that the structure of this chip's memory is comprised of short 8 bit and long 16 bit registries. Short registries are used for the parameters of MRF24J40 chip. Long registries are used not only to control the parameters, but also to upload security keys, store received and transferred information. This semiconductor device has 4 different 128 byte transfer buffers, depending on the selection of IEEE 802.15.4 standard type, and one 144 byte

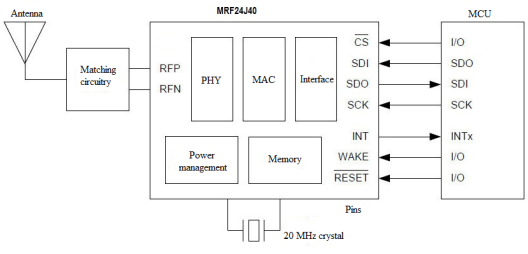

Fig. 4. MRF24J40 chip block diagram. Adapted according to Ref. [6].

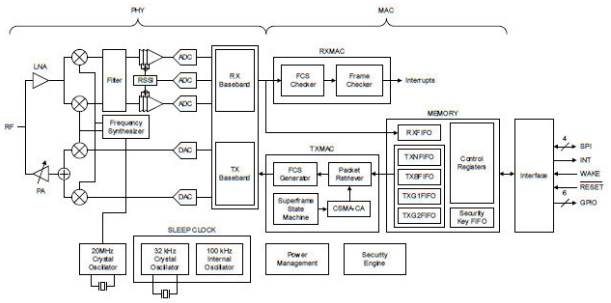

Fig. 5. Topology of MRF24J40 chip. Adapted according to Ref. [6].

reception buffer [6]. As it was mentioned before the registries are accessed via SPI bus.

4. What is a sensor?

Usually the sensors are the part of electronic equipment which converts certain changes into the signal known to the receiver. The function of the sensor is informational, since the main process is to identify the changes of temperature, motion, pressure, humidity and other parameters. Many electronic devices are full of various sensors that ensure proper functionality of the device. Nowadays smart phones, security systems and other processes that surround us simply will not be technologically implemented without sensors.

The main sensor need is of the thermal nature, when the thermal energy is converted into electric, or when due to the thermal change the signal or current or voltage values change. It should be noted that the whole electronic circuit which generates the scope of influence is being considered as a sensor - see Fig. 6. Fig. 7 represents the principal design of sensor in the network chain.

However, nothing is ideal in nature; therefore, the holes and electrons in the electronics act differently, as such creating sensor deviations [5]:

a) theoretical sensitivity differs from the real one - linear deviation is called the error of sensitivity;
b) stability of measurement result interval;
c) zero value of input sensor;
d) instability of sensitivity throughout the range - non-linear deviation;
e) dynamic tolerance;
f) output signal slowly changes despite the outside influence;
g) long term drift;
h) noise influence;
i) occurrence of hysteresis;
j) digital tolerance;
k) dynamic errors due to repeatable frequencies;

All these deviations are divided into systemic and random errors [5]. Systemic errors can be corrected with calibration methods, while the random errors can be corrected by using various filters or other components that reduce noise.

All sensors are divided into two groups: natural and biological [5]. The following items can be considered as natural sensors:

i) sensors of external setting effects: temperature, motion, humidity;
ii) sensors of internal setting effects: tension, movement of organism;
iii) environmental molecules: toxins;
iv) interaction of biomolecules and kinetic parameters;
v) internal setting of metabolism;
vi) internal signalling molecules: hormones...;
vii) differences between proteins in the organisms and the formation of protein structure groups.

5. Sensors network

Networks of wireless sensors are the systems of new type. The interest in such networks rapidly increases due to the independence and smartness of the network. It has great potential for the processes, like smart electricity networks, energy conserving buildings, smart house concepts that require large programs. Despite big demand for smart services, there still is a lack of suitable analysis and calculations - practical knowledge, energy conserving schemes and autonomous algorithms in the networks of wireless sensors. Recently the progress of dynamic spectral access was achieved. Cognitive radio, wide and cooperative communications will perform an important role in the structure of advanced wireless networks. The following requirements that properly describe the networks of wireless sensors are distinguished [7]:

i) smart protocols of design and organization;
ii) energy consumption issue;
iii) smart zone of implementation/visibility;
iv) security and privacy issue;
v) smart applications that include appropriate network functionality logic;

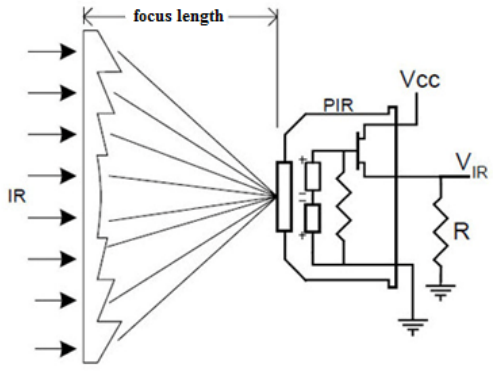

Fig. 6. IR sensor.

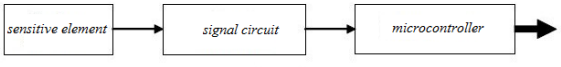

Fig. 7. Principal design.

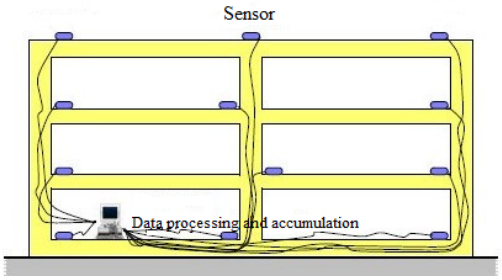

Fig. 8. Basic sensors network.

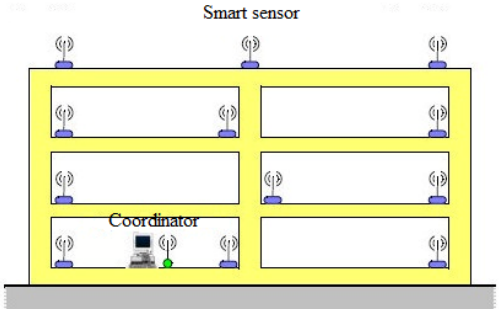

Fig. 9. Wireless sensors network.

Talking about the networks of wireless sensors, firstly we should ascertain the integral part of the network, i.e. the sensor. Sensors in wireless network systems can be only smart since such sensor has the microcontroller which can perform many digital, data transfer and other functions [7]. Basically, the appearance of microcontroller gave the start to the development of smart sensors.

In 2001, Kiremidjian presented wireless sensor network which works in real conditions. This network was one of the first systems that complied with all requirements. In addition, smart sensor self-diagnostics and self-calibration became its main innovation which allows the user to completely distance himself from the implementation of sensor functionality - the data are no longer stored on the computer, the signals are no longer processed by specific developed computer applications [8], see Fig. 8.

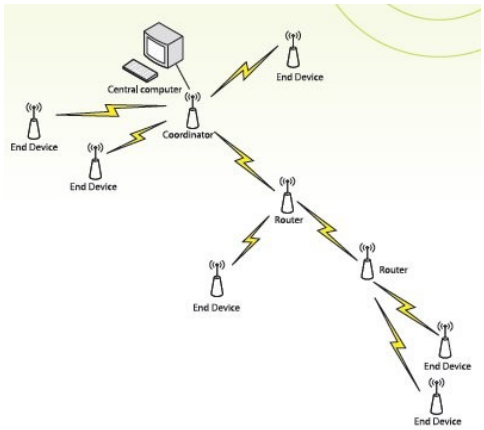

Fig. 10. Basic topology of wireless sensors network.

Usually the structure of the sensor wireless network is comprised of three types of nodes and the access to the internet or data vault [7]. The simplest network node is a smart sensor, which transfers information to the other point, until the intermediary (local data) vault is reached. From the local data vault the contact can be made with another type sensors or wireless networks. In 2001, Evans presented a set of alternatives how wireless network systems could be implemented - see Fig. 9.

The main reasons were to use free frequencies of 2.4 GHz and 915 MHz. Such reflections have determined the appearance of energy conserving wireless networks that comply with "Zigbee" technology - see Fig. 10.

Conclusions

1. The designed electronic device uses approximately 4 mW of energy.
2. The electronic device can play the role of the coordinator, router and common device without the alteration of electronic circuit board and software.
3. The energy needs of electronic device (sensor) are three times lower than those of commercial sensors.
4. After the use of energy conservation activities, it was possible to reduce energy consumption costs by six times.

References

1. IEEE Standard for Information technology. Telecommunications and information exchange between systems. Local and metropolitan area networks Specific requirements. Part 15.4: Wireless Medium Access Control (MAC) and Physical Layer (PHY). Specifications for Low-Rate Wireless Personal Area Networks (LR-WPANs). – Institute of Electrical and Electronics Engineers, Inc. 3 Park Avenue, New York, NY 10016-5997, USA. 1 October 2003. - Pp. 13-186.
2. <http://www.zigbee.org/Standards/Overview.aspx>, accessed 2014.11.22.
3. Ken Masica. Recommended Practices Guide For Securing ZigBee Wireless Networks in Process Control System Environments. – Lawrence Livermore National Laboratory. April 2007.
4. Meng-Shiuan Pan, Yu-Chee Tseng. ZigBee Wireless Sensor Networks and Their Applications –
5. <http://en.wikipedia.org/wiki/Sensor>, accessed 2014.11.22.
6. Microchip, MRF24J40 data sheet, IEEE 802.15.4- 2.4 GHz RF Transceiver – Microchip Technology Inc, 2010.
7. Yuhang Yang, Bahram Honary. Smart Sensor Networks: Theory and Practice. – Hindawi Publishing Corporation, 2012.
8. B.F. Spencer, Jr. Manuel, E.Ruiz-Sandoval, Narito Kurata. Smart Sensing Technology: Opportunities and Challenges –