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An Overview of Industrial Wireless Sensor Networks

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Abstract: **Development in the technology of wireless sensor network (WSN) has contributed a large transformation in all sectors of our daily life from homes to industries. In particular, industrial WSN (IWSN) has attracted more attention due to its large benefits. Nevertheless, the implementation of WSN by the industrial community has faced a number of challenges. In fact, several research efforts have been conducted in this area. However, a number of issues are still open for further investigation. This paper provides an extensive survey on IWSN technologies, standards, products, protocols, applications, challenges and opportunities. Thus, it compares common wireless network technologies, presents specifications of some IWSN standards and products, describes a group of proposed routing protocols, highlights some real applications, and addresses major challenges to be considered when designing the IWSN.**

Keywords: **Wireless Sensor Network, ZigBee, WirelessHART, ISA100.11a.**

I. INTRODUCTION

A wireless sensor network (WSN) consists of a set of nodes. A typical node contains a microcontroller, data storage, sensor, analogue-to-digital (ADC) converters, a data transceiver, and an energy source. The nodes connect to each other using different architectures depending on the applications and surrounding environment [1]. The sensor nodes have some resource limitations which are constrained by the limited physical size of the sensor node. Consequently sensor nodes have limited battery energy supply, limited transmission range, limited memories, and restricted computational capabilities [2], [3]. However, they are many advantages that enable the wide use of WSNs in both surveillance and civil applications. Some of these features can be summarized as follows: densely distributing nodes in working field with random location and self-organization ability; locally processing data collected from natural world; adaptively collaboration between nodes for data routing and transmission [4].

Industrial WSN (IWSN) technologies, standards and products have been studied by a group of researchers [5], [6], [7]. A survey of routing protocols for WSN with their strengths and limitations can be found in [2]. Implementation of IWSN is increasing in the areas of: system control and monitoring, real time data collection, mobile and stationary robots, rare event detection, and periodic data collection [8]. Although the deployment of IWSN is more attractive for many various potential application areas, the problem of implementing reliable wireless communication in real-life industrial environment is still very complicated and requires further research [9]. A number of researchers have figured out a lot of challenges [1], [2], where the network designers and application developers should balance the tradeoffs among the different parameters when designing protocols and architectures for IWSNs.

Thus selecting an IWSN requires evaluation of communication protocols, device availability, and present and future user needs. In fact a variety of technical comparisons of IWSN can be found on technical publications and websites, but many potential end users may not have resources for evaluation [10].

The remainder of the paper is organized as follows. Section II studies and compares sensor network technologies and standards. WSN architecture and protocols are presented in Section III. Section IV gives an overview of WSN based applications in industry. Section V highlights opportunities and challenges for WSN deployment in industry. Section VI concludes the paper with remarkable comments.

II. WSN TECHNOLOGIES AND STANDARDS

Extensive review of wireless sensor networks technology and evolution can be found in [6]. In [11], [12] different wireless systems have been compared as shown in TABLE I, where any can have various advantages and disadvantages over another depending on its use. Recently, IWSN technologies and standards have been described in [5], [13].

ZigBee as an IEEE802.15.4-based standard was designed to include features, like reliability and self-healing, support for a large number of nodes, fast and easy deployment, very long battery life (5-10 years), security, low cost, global interoperability and vendor independence. For instance, Wireless Highway Addressable Remote Transducer (WirelessHART), an open-standard wireless networking technology developed by HART Communication Foundation. ISA100.11a is an open-standard wireless networking technology developed by International Society of Automation (ISA).

TABLE I: COMPARISON BETWEEN BLUETOOTH, ZIGBEE AND WLAN TECHNOLOGIES

Technology	Bluetooth (IEEE 802.15.1)	ZigBee (IEEE 802.15.4)	WLAN, WiFi (IEEE 802.11a/b/g)
Frequency band	2.4 GHz	2.4 GHz	2.4 GHz
Radio transmission technology	frequency hopping spread spectrum (FHSS)	direct sequence spread spectrum (DSSS)	direct sequence spread spectrum (DSSS)
Range	10m	70m	50-100m
Nodes per master	7	64,000	32
Slave enumeration latency	up to 10 s	30 ms	up to 3 s
Data rate	1 Mbps	250 kbps	11-54 Mbps
Throughput max.	723Kbps	<=125 Kbps	30.6 Mbps (Ethernet); 2.6Mbps (60 bytes payload)
Power consumption	low-medium	very low - low	medium -high
Battery life	1 week	>1 year	hours
Data type	audio, graphics, pictures, files	Small data packet	video, audio, graphics, pictures, files
Periodic data	yes (depending on polling algorithm)	Yes	DCF: no; PCF: yes (with some jitter); HCF: yes
Retransmissions	Yes	Yes	yes
FEC	Available	No	no
Extendibility	No	Yes	roaming possible
Cost	Medium	Low	high
Security	64 or 128 bit	128 bit	128 bit
Complexity	very complex	simple	complex

TABLE II briefly describes these standards in terms of operating frequencies, access methods, network topologies and routing strategies. Recently in [14], [15] the authors have simulated these standards and conclude that the ISA100 is better than HART and far better than Zigbee in terms of energy consumption, packet loss and SNR. Also in [10] it has been argued that ISA100 differs from WirelessHART in supporting Internet Protocol version 6 (IPv6). In [7] some examples of WSN process monitoring and control products and their specifications have been presented as shown in TABLE III.

TABLE II: IWSN STANDARDS

Standard	ZigBee	WirelessHART	ISA100.11a	OCARI
Group /Reference	ZigBee Alliance – [16]	Highway Addressable Remote Transducer (HART) Communication Foundation -[17]	International Society of Automation (ISA)-[18]	Optimization of Communication for Ad hoc Reliable Industrial networks [19].
PHY layer	IEEE 802.15.4-2003 with 868 MHz/915 MHz or 2.4 GHz radio.	IEEE 802.15.4-2006 with 2.4 GHz radio.	IEEE 802.15.4-2006 with 2.4 GHz radio.	IEEE 802.15.4 with 2.4 GHz radio. Very robust.
MAC layer	IEEE 802.15.4-2003 with a slow frequency hopping schema.	IEEE 802.15.4-2006 with TDMA+ Channel hopping or Token-passing method.	IEEE 802.15.4-2006 with an extension shim for frequency hopping and slotted hopping.	Global MaCARI Protocol: deterministic, energy-efficient.

	No deterministic access methods.		No deterministic access methods.	
Network topology	Star, Mesh, Tree.	Star, Mesh.	Star, Mesh.	Star, Tree.
Network routing strategy	Mixed mechanism composed of AODV and tree routing. No energy-aware routing strategy.	Graph routing (link state routing). No energy-aware routing strategy.	Graph routing (link state routing). No energy-aware routing strategy.	Energy-efficient strategies: topology control, aggregating information, energy-efficient routing, scheduling node-activity.

TABLE III: IWSN PRODUCTS

Company	**Accutech**	**Honeywell**	**Emerson**
Example application	Pressure, temperature, level measurement, discrete input	Pressure, temperature, level, position measurement, discrete input/output	Pressure, temperature, level, position, vibration measurement, discrete input
Communication Technology	Star Point to Point Communication - Base station that transmits and receives data from multiple field units	Star Mesh Network - The Honeywell One Wireless network is formed with multi-protocol communication nodes, called multinodes, which support both 802.11 and field sensor-based transmissions.	Mesh Network - The Dust Mesh network with self healing and self organization features.
Transmission Technology	900MHz Frequency Hopping Spread Spectrum (FHSS)	2.4 GHz Frequency Hopping Spread Spectrum (FHSS)	2.4 GHz Direct Sequence Spread Spectrum (DSSS)
Maximum Transmit/Receive Range	Up to 5000ft (~1500m)	Up to 6 miles (10 km) multinode to multimode communication; sensor to multinode designed for over 2,000 ft (600m)	200m
Fastest Update Time	1 second	1 second	4 second
Wireless Standard	Uses proprietary protocol	ISA100.11a	WirelessHart
Number of Field Units per Network	Up to 100 wireless field units per base radio	Each multimode accepts signals from up to 20 wireless transmitters reporting at 1 second, and up to 400 transmitters reporting at slower rates.	Up to 100 devices for a single wireless gateway
Gateway Interface	Modbus	802.11 Wi-Fi	Ethernet, Modbus

III. INDUSTRIAL WSN PROTOCOLS

Industrial WSN protocols are necessary for implementation of IWSN. The following requirements were considered by researchers in the development of effective industrial WSN protocols [1]: *real-time and reliable communication* in heterogeneous networks [20]; *coping with transient interferences*: guarantee deterministic and timely data delivery in case of temporary link failures [21]; *resource-constrains* of the WSN such as low processing power, limited energy and small memory; *energy-efficiency* [22]: operate at low duty cycles, maximizing shutdown intervals between packet exchanges; *deterministic node lifetime* [22]; *scalability* [22]; *capability for localization, synchronization and energy management* [23]; and *safety and security* [24].

Sensor network architecture has been discussed in [25] in conjunction with OSI model, where three cross layers planes have been added to the five OSI layers. Thus, the overall layers of the WSN can be listed as shown in Fig. 1. TABLE IV summarizes the functions of these layers.

5.6.7. Application Layers	Power	Localization	Synchronization
4. Transport Layer			
3. Network Layer			
2. Data Link Layer			
1. Physical Layer			

Fig. 1: WSN protocol stack

In [25] it has been argued that these planes are used to manage the network and make the sensors work together in order to increase the overall efficiency of the network. For instance, a certain node can sense, transmit, receive and route tasks. When the power level for this node reaches the threshold value the cross planes will make this node to stop doing the routing task and inform all the neighbours that this node will save the remaining power for sensing and transmitting tasks in order to stay alive as much time as possible.

TABLE IV: WSN ARCHITECTURE

Layer	**Description**
Application layer	Supports the same functions as proposed in the OSI model.
Transport layer	
Network layer	
Data link layer	
Physical layer	
Power management plane	Controls the power level for all nodes.
Mobility management plane (localization)	Detects sensor nodes movement. A node can keep track of neighbors and power levels (for power balancing).
Task management plane (synchronization)	Schedules the sensing tasks to a given area. Determines which nodes are off and which ones are on.

Recently, an adaptive protocol for industrial control applications using WSN has been proposed in [26], called Breath, to ensure a desired packet delivery and delay probabilities while minimizing the energy consumption of the network. In [27] a study on the existing middleware approaches for wireless sensor networks are presented. Comparative studies of WSN routing protocols have been presented in [2], [28], [29]. Industrial Control using WSN has been discussed in [30]. A scheduling algorithm has been proposed for implementation in a typical industrial sensor node [31]. Security and quality of service (QoS) perspectives have been investigated by the authors in [32] for supporting the deployment of WSN in industry. A survey on routing protocols for WSN based industrial monitoring applications has been presented in [29], where limitations and weaknesses are discussed according to the industrial requirements. TABLE V presents strengths and weaknesses of some routing protocols for the industrial WSN.

TABLE V: IWSN ROUTING PROTOCOLS

Protocol	**Strengths**	**Weaknesses**
ARQ: energy aware routing for real time and reliable communication in wireless industrial sensor networks [20].	- Provides reliability, reduced delay, and energy efficiency.	- Requires global accurate positioning information to perform the routing. - Results in control message overhead and does not consider the buffer size limitation of the sensor nodes.
A reliable routing protocol based on deterministic schedule for wireless industrial networks [33].	- Provides reliability, energy saving, low complexity, and data aggregation.	- Results in data redundancy. - Does not consider delay. - Does not mention how to measure routing metrics and does not consider the buffer size limitation of the sensor nodes.
A reliable and energy	- Provides reliability and reduces the	- Uses a single path for routing the data

efficient routing protocol in industrial WSNs [34].	number of control packets.	packets and does not consider energy and buffer size limitations of sensor nodes.
A light weight routing protocol for industrial wireless sensor and actuator networks [35]	- Provides reliability, low latency, and low complexity. - No duplicates and no outdated data packets. - Guarantees packet progress towards the sink.	- Requires accurate positioning information to perform the routing tasks. - Not energy efficient and does not consider the buffer size limitation.
InRout: a QoS aware route selection algorithm for industrial WSNs [36].	- Provides reliability, low latency and service differentiation. - Considers energy and buffer limitations.	- Does not adopt an effective method for delay calculating; it only considers, the minimum number of hops towards the destination. - Needs some time to converge.
POCTP: Pareto optimal collection tree protocol for industrial monitoring WSNs [37].	- Provides reliability and low latency.	- Results on control messages overhead. - Does not consider energy and buffer size limitations.
Enhancing real time delivery of gradient routing for industrial WSNs [38].	- Provides real time performance and energy efficiency.	- Uses a single path for routing data packets. - Does not consider reliability. - Does not consider the buffer size limitation.
SPIN: Sensor Protocols for Information via Negotiation [2].	- SPIN-l uses a negotiation mechanism to reduce the consumption of the sensors. - SPIN-2 uses a resource-aware mechanism for energy savings [2].	- Implosion caused by duplicated messages and overlap when two or more nodes sense the same area.
Direct diffusion: a data-centric routing protocol for sensor query dissemination and processing.	- The sink broadcasts a query, the nodes reply by broadcasting data to the neighbors, and then the sink chooses the best route and forces others to turn off [25].	- Large waste of resources when a number of nodes broadcast data to all neighbors.
LEACH: Low-Energy Adaptive Clustering Hierarchy.	- Solves routing and energy problems by dividing the network into clusters, each selects a head node to do the routing from the cluster to the sink after data aggregation [25].	- It is not applicable to networks deployed in large regions. - Dynamic clustering brings extra overhead [2].
PEAS: Probing Environment and Adaptive Sleeping.	- Designed to have a high performance in harsh environments by dividing sensors in three modes: sleeping, probing and working [25].	- Misses the point of power balancing, where edge nodes stay wake up most of the time, which leads to quickly consume energy at the edge sensors.
GAF: Geographic adaptive fidelity [2].	- Produces a grid map to save energy by determining the unnecessary sensors and turning them off [25].	- Does not address QoS or data aggregation.
GEAR: Geographic and Energy –Aware Routing [2].	- Reduces the energy consumption, increases the network life time and provides better performance of packet delivery [25].	- Does not address QoS or data aggregation.
CLD: Controlled Layer Protocol.	- Combines good features from PEAS, MTE, and LEACH [25], which result in a very efficient protocol.	- Needs a tremendous number of sensors in order to provide a full coverage.
SAR: Sequential Assignment Routing.	- Produces routing trees according to QoS metric and energy resource [25].	- Does not make use of hierarchy or data aggregation.

IV. INDUSTRIAL WSN APPLICATIONS

Due to the diversity of the industrial applications the International Society of Automation (ISA), SP100 workgroup, has classified them into three categories and six classes. TABLE VI shows these categories and classes for different industrial automation applications [39], [40], [41].

TABLE VI: CLASSIFICATION OF INDUSTRIAL APPLICATIONS

Category	Class no	Application	Description
Safety	Class 0	Emergency action (safety systems)	Always critical. E.g. fire alarm systems.
Control	Class 1	Closed loop regulatory control systems	Often critical. Periodically and based on events, measurements are sent to the controller.
	Class 2	Closed loop supervisory control systems	Noncritical. Measurements are not expected periodically but can be based on certain events. E.g. a supervisory system that collects statistical data and reacts only when certain trends are observed.
	Class 3	Open loop control systems	Intervention of human in control, where a WSN is responsible for data collection and the operator makes analysis and undertakes any measures if required.
Monitoring	Class 4	Alerting systems	Systems with regular/event-based alerting. E.g., a WSN for continuous monitoring of temperature in a furnace and alerting at different stages, to indicate part of the work done.
	Class 5	Data logging (Information gathering systems)	System used for data collection and data forwarding to a server. E.g., WSN nodes deployed to gather data, such as temperature, for a specific duration of time, which can be used to decide on long term plans for managing temperature.

Implementation of wireless sensor networks have been highly recommended for industry with the primary emphasis on the following areas [39]: *Field instrument maintenance*: accessing maintenance information in smart modules, in addition to measurement values, such as settings, operational status and so on. *Temporary installation*: temporary installations are desirable to get some process data before permanent installations. *Flexible engineering*: cabling engineering costs much money and time as well as it is inconvenient for many applications, such as rotations and big tanks. *Monitoring*: monitoring applications are easier to adapt wireless networks than control applications since reliability and latency are not critical for monitoring process data.

In [42] the authors have summarized advantages of WSN in industrial process plant as follows: *Automatic collection of data from hazardous or non-accessible area, Reduction of cost of data acquisition, Flexibility in installing/upgrading network, Low deployment and maintenance costs, Decentralization of automation functions, Drastic improvement of fault localization and isolation and hence improvement in maintenance efficiency*.

This section highlights a group of IWSN applications from the literature. A closed loop energy evaluation and planning system with the WSN architecture was proposed in [43]. A wireless real-time system dedicated for remote sensor/actuator control in production automation was presented in [44]. Wireless industrial monitoring and control using a smart sensor platform was proposed in [45] targeted for instrumentation and predictive maintenance systems. A number of research areas for wireless industrial networking have been addressed in [46]. In [47] the authors surveyed WSN applications in general as well as classified the problems into three different categories, namely internal platform and underlying operating system; communication protocol stack; and network services, provisioning, and deployment. Implementation of WSN in petrochemical industry was presented in [48]. Application of WSN for safety monitoring in coal mines has been discussed in [49]. Implementation of WSN for remote online automatic meter reading (AMR) system was described in [50]. A detailed survey on major developments in industrial WSN applications can be found in [51]. Application of WSN for real-time distant energy monitoring and fault diagnosis in industrial motor system was presented in [52]. In [53] a WSN based approach has been developed for detection of faults in metal cutting process. The authors in [54] demonstrated a digital system based on WSN for evaluating energy usage, condition monitoring, diagnosis and supervisory control for electric systems with dynamic power management (DPM). A WSN security system for a power plant using human motion sensor was discussed in [55]. Technical and design challenges were introduced in terms of hardware, system architectures, protocols, and software development [3]. In [19] the authors were presented an industrial development of a wireless sensor network technology called: optimization of communication for Ad hoc reliable industrial (OCARI) networks. In [56] an overview of the state-of-art of real-time sensor networks for industrial applications was presented. Overview of the application of WSNs for electric power systems has been presented in [57]. In [58] a WSN system for measuring and monitoring water quality was designed. Major achievements have been accomplished for supporting wireless process monitoring and control systems [7]. Research issues in industrial applications have been recently discussed in [59]. A review on WSN applications for process monitoring in oil and gas industry can be found in [60]. In [61] the authors have extensively discussed the available WSN solutions for industrial applications, open issues and future trends for different types of industrial applications in environmental sensing, condition monitoring and process automation.

V. OPPORTUNITIES AND CHALLENGES OF IWSN

There is a great opportunity of deploying WSN in industry as compared to the deployment of the traditional wired network. These opportunities are enhanced by a number of advantages which can be summarized as follows [1]: *Flexibility in installing/upgrading* network. *Reduced deployment and maintenance costs*. *Decentralization* of automation functions. *Better coping with regulatory and safety obstacles* in running cables in dangerous areas. *Applicable for moving and rotating equipment*. *Improved fault localization and isolation*. *Incorporating short-range technologies* to automation system forms a heterogeneous network, which may improve automation system efficiency. *Exploitation of micro-electromechanical systems*: integrated wireless sensors with built-in communication capabilities offer a more robust design.

On the other hand, adopting WSN facing a number of real constraints due its unique characteristics as compared to the traditional wireless communication networks such as mobile ad hoc network (MANET) and cellular systems. The authors in [2] have discussed in details the characteristics and constraints of WSN, which can be briefly described in the following: *Dense sensor node deployment:* sensor nodes are usually densely deployed in IWSNs. *Battery-powered sensor nodes:* sensor nodes are usually powered by battery and are deployed in a harsh environment where it is very difficult to change or recharge the batteries. *Severe energy, computation, and storage constraints:* sensors nodes are having highly limited energy, computation, and storage capabilities. *Self-configurable:* sensor nodes are usually randomly deployed and autonomously configure themselves into a communication network. *Unreliable sensor nodes:* since sensor nodes are prone to physical damages or failures due to its deployment in harsh or hostile environment. *Data redundancy:* in most sensor network application, sensor nodes are densely deployed in a region of interest and collaborate to accomplish a common sensing task. Thus, the data sensed by multiple sensor nodes create redundancy. *Application specific:* a sensor network is usually designed and deployed for a specific application. *Many-to-one traffic pattern:* in most sensor network applications, the data sensed by sensor nodes flow from multiple source sensor nodes to a particular sink. *Frequent topology change:* network topology changes frequently due to the node failures, damage, addition, energy depletion, or channel fading.

In addition to that network constraints the design of routing protocols for WSNs is challenging with scalability, i.e. routing protocols should be able to scale with the network size. Also, sensors may not necessarily have the same capabilities in terms of energy, processing, sensing, and particularly communication. Hence, communication links between sensors may not be symmetric, that is, a pair of sensors may not be able to have communication in both directions.

Most IWSN designs have different requirements and priorities on design objectives, for instance common challenges that should considered when designing a WSN control systems can be summarized as follows [1]: *real-time requirements*; *band-limited channels*; *network delay*; *data consistency*; *network architectures*; and *multipath fading*. While real-time operating systems require the following properties [1], [24]: *multitasking*; *interrupt handling*; *task scheduling* using priority-based event scheduling and/or time sharing using clock interrupts; and *dynamic memory allocation*.

To deal with the above-mentioned challenges as well as to meet the diverse IWSN application requirements, the following table addresses the major WSN challenges with some proposals as alternative solutions for the arise problems (TABLE VII).

TABLE VII: WSN CHALLENGES, PROBLEMS AND SOLUTIONS

Challenges/Limitations	Consequences/Problems	Solutions/Proposals
- *Harsh industrial environmental conditions*; where sensors may be subjected to: radio frequency (RF) interference, low signal due to lack of power, long path	- Lack of data reliability and real-time guarantee. - A portion of industrial sensor nodes may malfunction.	- *Radio transmission technology*: DSSS or FHSS technology has been utilized to significantly reduce noise interference. - *Diversity technique*: different radios may be utilized for operation of various ranges.

lengths or obstacles, multipath fading, highly caustic or corrosive environments, high humidity levels, vibrations, dirt and dust, or other conditions that challenge performance.	- Packet errors and variable-link capacity, which make QoS a challenging task.	- *Multi-path technique*: where signals may be routed/relayed through multiple wireless nodes to guarantee reliability. - *Synchronization and identification technique*: time synchronization techniques are used to synchronize all the nodes by time-stamping the data with a global clock. - *Evaluation and estimation technique*: a WSN self-test technique is introduced to deal with the dynamic RF environment in order to adapt the operational characteristics of the WSNs to meet the specific application goal. - *Redundant technique*: components in WSN can be redundant to increase its reliability.
- *Dynamic topologies*: the topology and connectivity of the network may vary due to link and sensor-node failures.	- Problems in connectivity, adaptability, mobility, and scalability.	- *Mesh topology*: self organizing and self healing features make the network highly adaptive to node failures/relocation and easily scalable for network expanding.
- *Multiple resource limitations*: processing power and memory limitation, bandwidth limitation, and constrained energy capacity.	- Performance limitation as a result of limited memories and restricted computational capabilities.	- Overcome *hardware limitation*: by utilizing powerful processor and large memory in sensor nodes. - Solve *bandwidth limitation:* by data aggregation [62]. - Reduce *energy limitation*: by adopting energy efficient transmission; variable transmission range [63], [64]; energy aware protocols [65], [66]; energy harvesting techniques [67].
- *Quality-of-service (QoS) requirements:* since sensor data are typically time-sensitive, it is important to receive the data at the sink in a timely manner [3].	- Data with long latency due to processing or communication may be outdated and lead to wrong decisions in the monitoring system.	- Enhancing the accuracy by developing techniques to get the data reported at the sink node which is the same as what is actually occurring in the industrial environment.
- *Link and network layer protocols*: have less emphasis on energy conservation.	- Inefficient consumption of power.	- MAC protocols for WSN focus on reducing the idle power consumption by setting the sensor radios into a sleep state as often as possible [7].
- *Security attacks*: it is an essential feature in the design of IWSNs to make the communication safe from passive and active attacks.	- Traffic analysis, modification, fabrication, and interruption of transmissions [70].	- Security services are well addressed by WSN standard technologies [68], [69].
- *Large-scale deployment and ad hoc architecture:* most IWSNs contain a large number of sensor nodes, which might be spread randomly over the deployment field.	- Hard to manage data redundancy because of the high density in the network topology. - Difficult to maintain network connectivity autonomously.	- Development of protocols that support data aggregation with intelligent routing mechanisms, where only necessary information is transported to the end-user and communication overhead can be significantly reduced. - Modular and hierarchical systems can enhance the system flexibility, robustness, and reliability [3].
- *Implementation issues*: coverage, interoperability, compatibility, serviceability, longevity, coexistence, availability, delivery and price.	- Reluctance of end users in deploying WSN products. - Integration with Internet and other networks.	- Lots of efforts have been put into standards development by considering these issues to enhance the deployment of WSN in industry [71], [72]. - Current sensor-network platforms use gateways for integration between IWSNs and the Internet.

VI. CONCLUSION

Deployment of IWSN has attracted more attention due to its large benefits. In particular, this paper has reviewed the state of the art of recent research results on IWSNs. Special focusing has been devoted to technologies, standards, products, protocols, applications, opportunities and challenges.

Thus, the review compares wireless network technologies, namely Bluetooth (IEEE 802.15.1), ZigBee (IEEE 802.15.4) and WLAN WiFi (IEEE 802.11a/b/g). Also, it presents specifications for a group of IEEE 802.15.4 standards, and it gives some examples of IWSN products. It highlights requirements of designing routing protocols for industrial wireless sensor networks as well as summarizing the strengths and the weaknesses of some proposed routing protocols. Also it classifies and lists a group of IWSN applications with primary emphasis on monitoring and control processes.

Finally, the review addresses the major challenges and their consequences together with some proposals as alternative solutions to be considered as goals when designing the IWSN.

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