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# Wireless Instrumentation: The New Frontier

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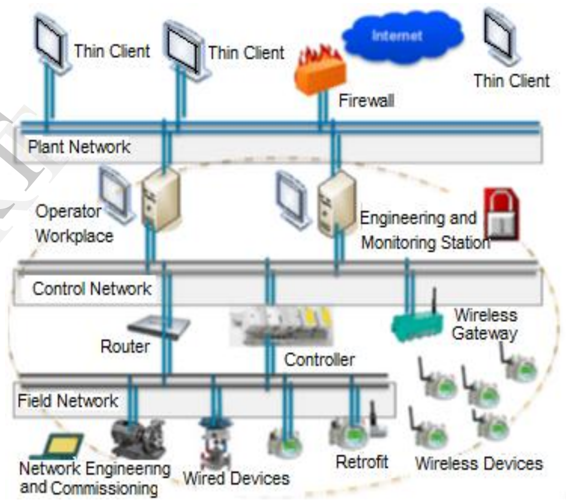
***Abstract*** **- Wireless Sensor Networks (WSNs) are an emerging technology that is being gradually adopted in industrial process automation due to its potential benefits such as increased network flexibility, mobility, and cost reduction. WSN technologies have merged with the traditional industrial field instrumentation into an exciting new technology of wireless instrumentation, which is an appealing development in industrial process since the recent approvals of the WirelessHART and ISA100.11a standards. This article gives an overview of wireless instrumentation, including the potential benefits, challenges and future research development of the wireless instrumentation as a new frontier in modern industrial automation.**

Keywords: **WSN; Wireless Instrumentation; WirelessHART; ISA100.11a; Automation, Process Control**

## 1. INTRODUCTION

Main networks for industrial control systems consist of specialised components and applications, such as Supervisory Control and Data Acquisition (SCADA) systems, Programmable Logic Controllers (PLCs), and Distributed Control Systems (DCS) [1-3]. The communication involving between and within these components and systems is the primary concern of the industrial networks. Field-level networks have been one of the key communication technologies used in modern automation systems especially in the context of effective horizontal and vertical integration of distributed devices and functions [1-4]. While these industrial networks have played a crucial role over the past two decades, they are increasingly proving to be inadequate to meet the highly dynamic and stringent demands of today's industrial applications, especially the provision of high quality of service (QoS) under ever-tightening budgets. The adoptation of advanced communication technologies, highly integrated control, and programming platforms are called for to improve operational performance of industrial automation systems.

The generic automation network is the combination of the field network and control network which make up the automation system network (Fig. 1) [5]. In a bid to improve operational efficiency, the automation industry has shown a strong interest in migrating substantial parts of the traditionally wired networks to wireless technologies to improve flexibility, scalability, and efficiency, with a significant cost reduction. The wireless technology that has recently received the greatest attention is the Wireless Sensor Networks (WSNs) [6]. A WSN consists of distributed autonomous sensor devices which collaborate to monitor physical parameters such as temperature, pressure, or vibration level. The devices in the WSNs communicate wirelessly with each other. A typical industrial WSN consists of sensors, routers (which can also have sensing capabilities) and a wireless gateway (also called network administrator) which usually has a wired connection to the backbone automation systems [6,7].




Currently, WSNs are targeting the field level where they are being integrated into the wired field instrumentation systems [7-10]. Wireless networking at the instrument level offers a cost effective option to improve the visibility of processes by allowing full monitoring of processes and asset conditions. There is an emergence of hybrid wired-wireless communication systems for the automation infrastructure [10-12].

In this paper, Section II discusses the main requirements for successful implementation of wireless instrumentation technology in industrial automation. Then Section III presents the benefits of wireless instrumentation in process industries. Section IV gives the challenges and future research directions on the development of wireless instrumentation. Finally, the conclusion is given in Section V

## WIRELESS INSTRUMENTATION IN INDUSTRIAL NETWORKS

### A. *Wireless Instrumentation*

The application of WSNs in traditional instrumentation has resulted in a new breed of wireless instruments. A wireless instrument is essentially a traditional instrument equipped with radio communication which is tailor made for specific wireless measurement and data acquisition applications. With the dramatic advance of highly integrated microcontrollers, sensors and now low-power, cost-effective, high-quality CMOS radios, these instruments can be treated as wirelessly networked devices serving physical information for purposes of monitoring, analysis and control. A typical network for wireless instrumentation is shown Fig. 2. The traditional field instrumentation in the process automation and manufacturing industries is dominated by the standard wired (4 to 20 mA or fieldbus) installations [10,13]. These systems, while having limitations of their own, have to a large extent satisfied the industrial requirements such as safety, security and quality of service (QoS). Instruments, meters and gauges were once sparsely connected, often with humans serving as the only means of transporting the information they gathered [14]. Thus, until such a time when the wireless instruments are considered to adequately meet the same industrial requirements which exist in wired systems, it is highly unlikely that wireless instruments will overwhelmingly replace the existing wired fieldbuses. Purely wireless systems, such as in the case of WSNs with huge numbers of nodes and strongly indeterminate time-varying topologies, are an extreme example not typical for automation applications in whatever form [10,15-17]. Instead, the realistic and sustainable approach is the deployment of wireless instruments to complement traditional wired systems by offering an economical solution for difficult applications [8,10,11]. Thus, a typical automation network will likely consist of wireless field level network and a wired backbone network. Hybrid wired/wireless automation networks are promising to be the dominant configuration of choice for the near future, particularly when it comes to the inclusion of wireless devices, because wired segments still have dependability advantages, particularly if used as the backbone. Typically, initial deployment of wireless instruments (or industrial WSNs) targets the monitoring processes and management of industrial assets. Wireless instrumentation is a competitive technology in cases where there is need to remotely monitor instrument condition, remotely reconfigure instrument and monitor process data to optimize performance. While there is a demonstrated interest in wireless instrumentation, there is a general slow adoption of wireless technology perhaps due to the perception that the wireless technology is not mature enough to compete with the tried and tested wired fieldbus systems [17,18].



Nevertheless, the continued need to improve productivity and safety while at the same time reducing costs means that generally, more measurements need to be made. The most effective way to add these measurements is with wireless instruments that use the existing process control infrastructure. Ultimately, the benefits of wireless access to field instruments will finally outweigh the risks and uncertainties of rolling out a wireless network to the field devices

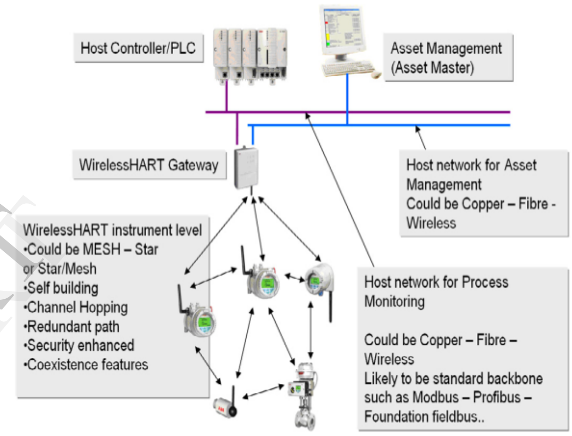



Figure 1: Simplified architecture of a typical wireless employing WirelessHART – ABB [12]

### B. *Standards for Wireless Instrumentation*

Currently WirelessHART and ISA 100.11a are the IEEE 802.15.4 [19] based standards that are most promising for high reliability wireless networking of industrial sensors in very difficult RF environments.

***WirelessHART***: Wireless Highway Addressable Remote Transducer (WirelessHART), is an open-standard wire-less networking technology developed by the HART Communication Foundation, which was introduced to the market in September 2007 [20]. WirelessHART com-plements the ever so successful HART field devices by providing the possible means for communicating via wireless channels. The WirelessHART standard is con-sidered the first open communication standard designed for wireless industrial monitoring and control applica-tions. The WirelessHART is based on the physical layer of IEEE802.15.4 but implements its own link layer. It is based on the 2.4GHz ISM band but adopting only 15 channels, because channel 26 is not allowed in some countries [21]. Instead of using CSMA/CA as defined by the IEEE 802.15.4 standard, it implements an MAC layer with Time Division Multiple Access (TDMA). Frequency hopping spread spectrum access (FHSS) is used as proven technology to provide further improvements in-terms of link gain compared to direct sequence spread spectrum (DSSS) option. The adoption of TDMA technology with precisely network-wide time synchronization is the key technology that makes WirelessHART different from other industry standards [22].

***ISA100.11a***: An open-standard wireless networking technology developed by International Society of Automation (ISA), the ISA100.11a was released on September 2009. ISA100.11a aims to provide secure and reliable wireless communication for noncritical monitoring and control applications [22,23]. Like the WirelessHART, the ISA standard is based on the IEEE 802.15.4 physical layer but defines its own MAC layer. The MAC layer characteristics are very similar to the characteristics presented on WirelessHART. It also applies TDMA and frequency hopping to improve reliability. The network layer is a bit different, since it uses header formats based on the IP protocol [22]. Although the logical link layer of ISA100.11a standard has a similar structure compared to WirelessHART, the standard specifies configurable timeslots with variable durations from 10ms to 12ms on a super-frame base

### *C. Requirements for Wireless Instrumentation*



The ISA SP100 workgroup classified the industrial processes into three broad categories and six classes of WSN usage (from Class 0 to Class 5) [23] (see Table 1). Applications such as data logging and equipment maintenance and inspection where real-time quick responsiveness and high data arrival reliability in communication are not required correspond to Classes 3 through 5. In the more critical applications, sensor/process data need to be transmitted to the destination in a reliable, timely and accurate manner. The wireless communication for the process control applications that require real-time responsiveness and robustness correspond to Classes 1 and 2.

TABLE 1: INSTRUMENTATION CLASSES [23]

| | |
|---|---|
| Safety | Class 0: Emergency action (always critical) e.g. instrument protection systems/safeguarding systems |
| Control | Class 1: Closed loop regulatory control (often critical) e.g. regular control loops |
| | Class 2: Closed loop supervisory control (usually non-critical) e.g. set point manipulation for control optimization |
| | Class 3: Open loop control (human in the loop) e.g. manual actions on alerts |
| Monitoring | Class 4: Alerting/Flagging (Short-term operational Consequence) e.g. event based maintenance |
| | Class 5: Logging & downloading/uploading (No immediate operational consequence ) e.g. history collection, preventative maintenance |

At the field level, wireless instruments form a wireless network (WSNs) and it is at this level that the most restrictive requirements appear. The instruments should be designed to work continuously in an industrial environment which has high mechanical and electromechanical noise. Thus the wireless device must be robust and allow for flexible operational options, and highly maintainable. The equipment must be industry-grade with respect to mechanical quality and robustness. Very strict requirements are expected of some sectors, especially in explosive atmospheres, such as Oil & Gas and mining. Special provisions such as the ATEX directive in Europe is meant to enforce these requirements [24]. Table 2 summarises some of the critical requirements to be met by the wireless instrumentation

TABLE 2: REQUIREMENTS FOR WIRELESS INSTRUMENTATION

| Requirement | Description |
|---|---|
| 1. High Reliability | Reliability is an absolute requirement for any monitoring technology, because if the data is not reliable, the economic benefits of its low installation costs are rendered irrelevant. For general monitoring applications, reliability should be > 99.99 %, e.g. maximum acceptable data loss is 1 sample out of 10,000 samples [24,25]<br>Note that even a network with a significant packet loss can achieve 100 % reliability due to retransmissions and redundant paths [9,15,26] |
| 2. Energy Efficiency | For battery operated wireless sensors with a one minute update rate, the battery lifetime should be in excess of 5 years [24,25]. Batteries have a finite lifetime, although it is sometimes possible to prolong this lifetime by combining energy-harvesting techniques [27,28] |
| 3. Update Rate | Requirements for necessary sensor data update rate should be stated. For IEEE 802.15.4 networks, update rates down to 1 minute is practically achievable. Note the trade-offs between update rate and power consumption [25,29] |
| 4. Sensor Traffic Patterns | The type and amount of data to be transmitted is also important when considering control applications [16,30]. Control signals can be divided into two categories: real-time and event based. For real-time control, signals must be received within a specified deadline for correct operation of the system. In order to support real-time control, networks must be able to guarantee the delay of a signal within a specified time deadline . Hence, heavy traffic may be generated if sensors send data very frequently [31,32].<br>Event-based control signals are used by the controller to make decisions but do not have a time deadline. The decision is taken if the system receives a signal or a timeout is reached [33-35]. |
| 5. Integradability with existing systems | (Typically via 4–20 mA interfaces):– Wireless instruments should integrate with existing control and monitoring systems over standard industrial interfaces (field buses etc.) [24]. The wireless instrumentation systems must allow for the use of gateways to integrate both a wireless instrumentation base radio and a long range industrial radio in the same device [13,30] |
| 6. Scalability | Scalability is the ability of the network to grow, in terms of the number of nodes, without excessive overhead. The instruments or the wireless network should be such that optimal network performance is guaranteed even when the network size or rate of data generation increases [9,16,36] |
| 7. Technical/operational requirements | In general wireless devices must be able to fulfil the same performance requirements as wired instruments. The introduction of wireless instruments should not be associated with new maintenance loads. In addition, the devices should not interfere, nor disturb other systems utilizing the same frequency band [24,25,37]. |
| 8. Security | Ensure data integrity, resilience to hacking, unauthorized access and sabotage- the networks should be resilient to both active and passive security threats and attacks [9,16,38] |



## II. BENEFITS FOR WIRELESS INSTRUMENTATION

***Reduced installations cost***: Cabling and installation for a typical automation project in an existing facility can run as high as 80% of total system cost and can exceed $1,000 per linear foot in regulated environments, like a typical power plant [39]. Compared to wired systems, wireless devices have 80 % lower installation costs [40]. It costs roughly $200 per meter to install wires in an ordinary process plant and approximately $1000 per meter in offshore installations [29].

***Increased productivity***: Wireless devices can be deployed in applications that are both physically inaccessible and cost prohibitive for wired instruments. This is typically so for monitoring and control devices for rotary machinery [41-51]. Thus, wireless instrumentation allows for more intelligence to be gathered and more information availed for comprehensive monitoring of assets and machinery [26,52]. Wireless instrumentation allows for device management applications and enables easily configuration the wireless devices [53,54]. It is envisaged that the widespread deployment of WSNs in industry could improve overall production efficiency by 11 % to 18 % in addition to 25 % reduction in industrial emissions [55].

***Increased flexibility and scalability***: Wireless instruments can be easily reorganized and relocated without tedious work of removing old cables and laying out new ones [52,56]. Furthermore, the industrial process system becomes highly scalable and flexible due to the device autonomy [57,58]. Wireless systems are battery powered, newly added devices can be installed at any location without running power supply and data communication wires through concrete walls during factory expansion. On the contrary, wired systems can take days or weeks to install, whereas wireless instruments require only the sensor to be installed in the process, saving time and valuable resources [59].

***Improved Maintenance***: Wireless instrumentation offer easy maintenance since problems like corrosion, water in the conduit, burned cabling, freezing, wild animal damage, physical wear which are frequently encountered in wired systems are eliminated [8]. Process instruments need to update data at certain rates to ensure optimum performance. With wireless instruments, it is possible that instruments on the same network can update at different rates from seconds to several minutes. Fast updates will exhaust batteries quicker. The refresh rate required by many process and maintenance monitoring applications does not need to be fast [12]. A typical example of a wireless instrument that has revolutionized maintenance and machine health is the CSI 9430 wireless vibration transmitter made by Emerson Process Management [60]. The CSI 9430 vibration transmitter monitors mechanical equipment, delivering predictive diagnostics for improved reliability and plant safety. As a component of Emerson's Smart Wireless solutions, the transmitter connects quickly, easily and economically to any machine. The transmitter delivers vibration information over a highly reliable wireless self-organizing network for use by operations and maintenance personnel. Users indicate they can cost-effectively apply this device on a wide range of equipment such as pumps, motors, fans, compressors pulverizers and many other types of equipment [61]. Table 2 and 3 show summary of some reported applications of wireless instruments/WSNS in monitoring and control applications

TABLE 3: APPLICATIONS OF WIRELESS INSTRUMENTATION IN MONITORING APPLICATIONS

| Application | Description | Refs |
|---|---|---|
| ***Gas Sensing and leak monitoring*** | Application to leak detection at carbon sequestration sites | [62] |
| | Combustible gas monitoring | [63-65] |
| | Gas/Methane leak detection | [66,67] |
| | Combustible gas and early fire detection | [68,69] |
| ***Gas Pipeline monitoring*** | For outside exposed gas pipeline monitoring | [33] |
| | Industrial Pipe-Rack Health Monitoring | [70] |
| | Routing protocol and addressing scheme for oil, gas, and water pipeline monitoring | [71] |
| | Flow-induced vibrations for pipeline integrity monitoring | [72] |
| | Network for Pipeline Monitoring | [73,74] |
| ***Machine monitoring & diagnostics*** | Online and remote motor energy monitoring and fault diagnostics | [75] |
| | vibration detection of induction motors | [76] |
| | In-service motor monitoring and energy management of motors | [44,45] |
| | Local Processing for Motor Monitoring Systems in Industrial Environments | [77,46] |
| | Wireless and powerless sensing node system developed for monitoring motors | [48,81] |
| ***General industrial machinery monitoring*** | condition monitoring and energy usage evaluation for electric machines | [75,48] |
| | Condition monitoring in end-milling | [49] |
| | for machinery monitoring | [31] |
| | equipment fault diagnosis in the process industry | [80,38] |
| | experiences from a semiconductor plant and the north sea | [38] |



TABLE 4: APPLICATIONS OF WIRELESS INSTRUMENTATION IN PROCESS CONTROL

| Brief description of reported works/application | Refs |
|---|---|
| Reliable application of WSNs in industrial process control | [78] |
| WirelessHART: Applying wireless technology in real-time industrial process control | [57] |
| Cyber-physical systems in industrial process control | [79] |
| WSNs solutions for real time monitoring of nuclear power plant | [58] |
| Adaptive protocol for industrial control applications | [34] |
| Protocol design for control using WSNs | [35] |
| Distributed collaborative control for industrial automation with WSNs | [81] |
| A proposal of greenhouse control using WSNs | [82] |
| Remote sensing and control of an irrigation system using a distributed WSNs | [62] |
| Wireless process control using IEEE 802.15. 4 protocol | [84] |

## III. CHALLENGES AND FUTURE RESEARCH

### *A. Challenges*

***Harsh environmental conditions*:** Operating packet-based communications equipment in industrial environments such as offshore rigs and chemical processing facilities presents reliability challenges [4,5]. The Direct Sequence Spread Spectrum (DSSS) or Frequency Hopping Spread Spectrum (FHSS) technology has been utilized to significantly reduce noise interference. Redundant technique-dual gateways are highly recommended for increased reliability [9,15,25,67].

***Data and Network Security***: Passive attacks on wireless sensor networks (WSNs) are able to retrieve data from the network, but do not influence over its behaviour. On the other hand, active attacks directly hinder the provisioning of services [9, 84]. These security attacks directly affect the energy consumption and due to the large amount of energy consumed at the MAC layer, it is particularly vulnerable to many different security attacks. More research on behavioural modelling of security attacks is needed [9]. Currently, the wired fieldbuses connecting SCADA and automation system to wireless devices lack security extensions. This loophole is potentially a severe challenge since scalable and modular solutions cannot be provided when integrating new wired/wireless devices into existing automation systems [10].

***Standardization Issues***: WirelessHART and ISA 100.11a are competitors in a quest of becoming the de facto global standard for wireless instrumentation for factory and process automation [85]. The key questions are *(1) are the two standards compatible? (2) Can they coexist in a single automation network?* Clearly there are concerns about coexistence and interference leading to reliability and latency problems and about multiple protocols sharing the same bandwidth. Users of the wireless technologies are ideally looking forward to a single global standard to address these issues [86,87]. However, such a standard is very much unlikely to be adopted in the immediate future. The team which was tasked to work on the ISA100.12 as the convergence of WirelessHART and ISA100.11a has not been able to make any progress on this issue [88].

***Application specific challenges in Control systems*:** The application of wireless instrumentation in process control may be limited because it will require modification to PID algorithms, appropriate risk analysis and good, fail-safe design practices [12,102,89]. Failure of a control loop may cause unscheduled plant shutdown or even severe accidents in process-controlled plants [17]. There it may be prudent to state that at present, applications of wireless instrumentation technologies in process control are mainly for monitoring purposes. Nevertheless, some technology companies like Yokogawa has already released some wireless instruments based on the ISA100.11a process control applications that require real-time responsiveness and robustness, which correspond to Classes 1 and 2 in Table 1.

### *B. Some Future Research Directions*

Generally, the adoption of wireless instrumentation will bring massive savings in terms of costs, field installation time, and overall weight of devices. Wireless instrumentation products on the market include integrated gateways, adapters, temperature transmitters, pressure transmitters and vibration transmitters. ABB [53], Emerson [60], Endress & Hauser [90], Pepperl & Fuchs [91], Phoenix Contact [92] and Siemens [93] are the leading companies in the provision of WirelessHART products. On the other hand, ISA100.11a products companies are CISCO [94], Honeywell [95], and Yokogawa [96].Wireless instrumentation brings forth enhancements to existing automation networks by allowing for extended monitoring and compliance with health and safety regulations.

***WSNs/ Wireless instrumentation and Cloud Computing*:** Industrial Instrumentation technologies of the future are envisaged to be adaptable and agile, cloud computing can be considered as a promising solution in this regard. Cloud computing is becoming a promising technology to provide a flexible stack of massive computing, storage, and software services in a scalable and virtualized manner at low cost. Sensor-Cloud infrastructure is becoming popular and can provide an open, flexible, and reconfigurable platform for several monitoring and controlling applications [97]. Research into the opportunities of implementing the Cloud Computing paradigm into wire-less instrumentation for process automation should be enhanced so that WSN-based technologies will be able to handle more complex situations of real world applications in the process industries.

***Advanced security and Anti-jamming techniques***: WSNs rely on the use of the open transmission media. This exposes industrial WSNs and wireless instrumentation infrastructure from radio jamming attacks which may result in corrupted transmission packets and low network throughput. The defence techniques proposed in literature, such as channel surfing, error correction codes and transmission power adjustment are, generally suitable for only a limited range of networks and specific jamming conditions [98]. The great challenge is that the sensor network undergoes varying jamming conditions over time. Research into adaptive approaches to anti-jamming for industrial wireless sensor networks is greatly called for so as to secure the wires instrumentation systems that will drive the future of industrial automation.

***Dynamic Routing Protocols***: While several WSN layer protocols have been proposed to utilize sensor's energy to prolong the life time of deployed WSNs, there has been little research on the routing protocols that implement network dynamics that use multi-sinking [99]. The research issues may need to centre on the implementation of the dynamic protocols without compromising security and quality of service requirements.

***Energy harvesting in wireless sensors***: While the majority of WSNs are battery powered, limitation of battery power is that it needs frequent replacement/recharging, which is costly and cumbersome for a large quantity of wireless devices deployed over a wide area. Energy harvesting is the possible solution that addresses this challenge to create truly autonomous wireless devices and hence improve energy efficiency in networked wireless automation systems. Ambient energy is available in abundance in the process industry for example: heat difference between a steam pipe and ambient surroundings, mechanical vibration from electric motors and RF noise. This ambient energy can be harvested and converted into usable electrical energy, which is then used to power the wireless device. Thus energy harvesting will bring energy efficiency to industrial instrumentation since it eliminates the need to charge or replace flat batteries. In fact, the need to exchange batteries may very well off set the savings of having wireless sensors in the first place! [100]. Perpetuum Ltd has already announced availability of a vibration energy harvester power module option for the Emerson Rosemount 3051S Smart Wireless transmitters [101]. Future research deliberately targeting energy harvesting and ultra-low power electronic circuitry would ultimately enable wide scale deployment of truly autonomous wireless instrumentation technologies.

## IV. CONCLUSIONS

Wireless instrumentation provides opportunities for greater insight into machine behaviour, less unplanned down time, improved data analysis, and a safer working environment, which all translates into dramatic improvements in plant maintenance at reduced costs, and increased competitive productivity. There has been successful application of wireless devices based on WirelessHART and ISA100.11a for process measurement, machine monitoring and supervisory control. To improve the adoption of WSN-based technologies in the automation industry, future research and development need to focus on improving the reliability, security and energy efficiency of wireless instrumentation technologies.

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