Proceedings

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Welcome to the 43rd Annual Conference of IEEE Industrial Electronics Society - IECON 2017

IECON is the flagship annual conference of the IEEE Industrial Electronics Society (IES), focusing on industrial and manufacturing theory and applications of controls, communications, instrumentation, electronics, and computational intelligence. On behalf of the IEEE Industrial Electronics Society, we warmly welcome all of you to IECON 2017, from 29 October – 1 November 2017 at the China National Convention Center, Beijing, China.

We have organized sixteen technical track sessions to share recent advances in research, technology, applications, educational methods and industry interests related to:

- Control Theory and Applications
- Communications for Industrial and Factory Automation
- Cloud Computing, Big Data and Industrial Informatics
- Electrical Machines and Drives
- Fault Diagnosis / Fault Tolerant Control
- Power Systems
- Power Electronics
- Energy Storage Systems
- Transportation Electrification
- Renewable Energy
- Mechatronics and Robotics
- Signal Processing and Artificial Intelligence
- Micro / Nanotechnology
- Industrial Cyber Physical Systems
- Embedded Systems and Chips
- Industrial Electronics and Education

A further 85 special sessions focusing on developments in specific and emerging research topics and 14 tutorials covering a broad spectrum of IES technical interests have been organized.

We are also pleased to co-host IES Industry Forum 2017, IES Women in Engineering Forum 2017, IES Students and Young Professionals Forum 2017, and the 11th International Workshop on Service-Oriented Cyber-Physical Systems in Converging Networked Environments.

We are proud to announce an IES record of **2068 research article submissions** to IECON 2017, from which **1428 manuscripts were accepted** and will be presented at the conference, representing an acceptance rate of 69%.On average, each paper received 3.38 peer reviews with over 3000 reviewers participating in the process.

The overall review process was monitored and finalized by the Chairs and the respective committees.

We have organized four plenary sessions presented by the following high profile keynote speakers:

- Theory and Design of PID Controller for Nonlinear Uncertain Systems (Monday, 30 October)
  Professor Lei Guo (Chinese Academy of Sciences, China), Member of the Chinese Academy of Sciences, Foreign Member of the Royal Swedish Academy of Engineering Sciences, IEEE/IFAC Fellow
- Target Optimization and Path Optimization for Energy Structure Transition (Monday, 30 October)
  Professor Yusheng Xue (State Grid Electric Power Research Institute, China), Member the Chinese Academy of Engineering
- Cyber Physical Computing System Enabling Intelligent Robotics and AI: Vision to Realization towards Innovation

Economy (Tuesday, 31 October)
Professor Ren C. Luo (Fair Friend Group Corporation and National Taiwan University), Past President of IES, IEEE Fellow

- Power Electronics as the Core of Future Energy Scenario (Tuesday, 31 October)
  Professor Leopoldo Garcia Franquelo (Harbin Institute of Technology, China) Past President of IES, IEEE Fellow

The IES Industry Forum will feature nine industry speakers across three morning sessions on, Transportation Electrification and Mobility, Smart Cities/Smart Grids and UAV/Autonomous Systems.

IECON 2017 delegates are invited to network at a variety of social events, including the welcome reception (Monday evening, 30 October), Gala Dinner (Tuesday evening, 31 October), morning and afternoon teas/coffees and buffet lunches.

In addition to the on-site programs, we encourage you to enjoy a variety of outstanding local attractions in and around Beijing, China, enjoying its beauty, history and hospitality. Finally, we would like to thank all conference committee members, our reviewers and our volunteers who have graciously contributed their time and efforts to make your conference experience in Beijing, a memorable one. We sincerely appreciate our technical co-sponsors, Academy of Mathematics and Systems Science of Chinese Academy of Sciences, Beijing JiaoTong University of China Aerospace Science & Industry Corp., National Natural Science Foundation of China, China Society for Industrial and Applied Mathematics, Chinese Society of Command and Control, Chinese Association of Automation, Systems Engineering Society of China, Chinese Power Supply Society, Chinese Electrotechnical Society, Beihang University of China, Southeast University of China, Royal Melbourne Institute of Technology University (RMIT University) of Australia, and Taiwan Power Electronics Association (TaiPEA).

We hope you enjoy the IES conference experience in Beijing and the wonderful autumn atmosphere and cultural experience that are currently on offer in Beijing, China.

Yours sincerely,

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Xinghuo Yu, Jinhu Lu, Kamal Al-Haddad and Luis Gomes

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Past, Present and Future Trends in Industrial Electronics Standardization

V. K. L. Huang*, D. Bruckner†, C. J. Chen‡, P. Leitão§, G. Monte¶, T. I. Strasser‖, K. F. Tsang**

*Sage Technology Resources, CA, USA, email: v.huang@ieee.org
†B&R Industrial Automation GmbH, Open Automation Technologies, Eggelsberg, Austria, email: bruckner@ieee.org
‡Innovatech Solutions, Inc., NJ, USA, email: c.j.chen@ieee.org
§ Polytechnic Institute of Bragana, Campus Sta Apolónia, 5300-253 Bragança, Portugal, email: pleitao@ieee.org
¶Universidad Tecnologica Nacional, Regional del Neuquen, Plaza Huincul, Argentina, email: gustavo.monte@ieee.org
‖AIT Austrian Institute of Technology, Center for Energy, Vienna, Austria, email: thomas.i.strasser@ieee.org
**Department of Electronic Engineering, City University of Hong Kong, Hong Kong, email: ee330015@cityu.edu.hk

***Abstract*—The Standards Group of the IEEE Industrial Electronics Society (IES) has been active in standards for industrial electronics in recent years, focusing on sensors and sensors networks, real-time industrial communications and industrial agents in the automation fields. It has also participated and collaborated with other IEEE societies such as the Instrumentation and Measurement Society (IMS) in the IEEE 1451 sensor networks standards family, and with government entities such as the US National Institute of Standards and Technology (NIST). This paper gives a brief synopsis of IES standards activities and the trends it sees in industrial electronics standardization in the coming emerging technologies such as Internet of Things (IoT)/Industrial IoT (IIoT), 5G communications, industrial wireless and possibly transportation electrification. All these technologies are expected to be disruptive to the industry in the coming years and standards must be generated to be effective and beneficial to industry and society. The IES Standards Group anticipates more contributions to the IEEE 1451 standards family, industrial agents, industrial wireless applications with NIST, and possibly with standards activities within Industry 4.0 in the coming years.**

I. Introduction

The IEEE Industrial Electronics Society (IES) has been active in industrial standards activities in recent years, and the trends of emerging technologies leads to the need of more standardized activities to benefit industry and society. The focus of the activities is currently on sensors and sensors networks, real-time industrial communications and industrial agents in the automation fields but will be enlarged in the future to Internet of Things (IoT)/Industrial IoT (IIoT), 5G communications, industrial wireless and possibly transportation electrification.

This paper captures a snapshot of the activities by IES, organized in the following sections on Present and the Future. The last two sections conclude with the present activities undertaken by the IES Standards Group and suggested future standardization directions. This will cover IES Fields of Interest (FoI) and potential opportunities for standards activities in industrial electronics.

A survey of IES publications on standardization activities done in 2010 showed the following fields of interest citing standards [1], [2], and shows power and power electronics, communications and informatics, and industrial automation as dominating the standards landscape, see Table I. Since then, the IES has moved forward with standards activities covering areas in industrial sensors and smart transducers, industrial agents, industrial communications and automation.

TABLE I
SURVEY OF IES STANDARDIZATION PUBLICATIONS [1].

Focus Area	Count
Power and power electronics	44
Industrial automation	19
Controls, sensors and actuators	2
Robotics	0
Communications/informatics	27
Transportation	5
Other	10

While the focus of IES standardization activities are on IEEE standards governed by IEEE-SA, a short note on other prominent standards bodies mentioned in this paper are in order. IEEE-SA (Standards Association) is a leading consensus building organization developing and advancing global technologies through IEEE, facilitating standards development and standards related collaboration with thought leaders in excess of 160 countries[1]. Other leading standards bodies are the ISO, IEC and ITU. The International Organization of Standardization (ISO) is a global network of world's leading standardization bodies (with members from 163 countries) developing international standards[2]. The International Electrotechnical Commission (IEC) is the world's leading organization that prepares and publishes international standards for all electrical, electronic and related technologies[3]. The International Telecommunications Union (ITU) is a United Nations specialized agency for information and communications technologies (ICT). ITU allocate global radio spectrum and satel-

[1] http://standards.ieee.org/about/ieeesa.html
[2] https://www.iso.org/what-we-do.html
[3] http://www.iec.ch/about/?ref=menu

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lite orbits, develop technical standards ensuring networks and technologies seamlessly interconnect, and strive to improve ICT access to underserved communities worldwide[4]. These three global standards organizations (IEC, ISO, ITU), when appropriate, cooperate with each other ensuring standards fit together seamlessly and complement each other. Lastly, the American National Standards Institute (ANSI) mission is to promote and facilitate voluntary consensus U.S. standards and conformity assessment systems, strengthening the U.S. marketplace position in the global economy[5]. ANSI is the official U.S. representative to the ISO and IEC international standards bodies.

II. Present

IES is presently actively engaged in IEEE standards activities in the areas of Industrial Sensors and Systems, Industrial Communications, and Industrial Agents. Additionally, standards-related efforts in projects dealing with smart grids are undertaken with the possibility of standards development.

A. Industrial Sensors and Systems

The world is moving toward a fully interconnected state, and includes also industrial environments. Even though consumer and industrial networks have different objectives and requirements like determinism, security and safety issues, they share many concepts and the division line is diffuse. These complex networks base their operation on four fundamental pillars (sense, connect, process, share) as outlined in Fig. 1.

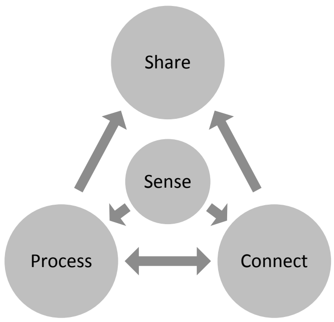

Fig. 1. Four elements that define a network; depending on the order of execution and the physical location, totally different networks are generated.

For each concept, answers are needed for three questions: What? How? and Where? For example, how to share? where to process? or what to transmit? The answers to these questions define the complete system, its topology, structure and the information treatment. For example, Where to process? create new paradigms such as: cloud, fog, and edge computing.

Communication channels in industry are mostly wired. Recently, wireless communication is gaining popularity especially for monitoring purposes. The high reliability of spread spectrum systems coupled with redundancy and high interference resistance, create the right conditions for these systems to be inserted more and more into industry. The advantages of wireless systems are: self-organization, rapid deployment, flexibility, and inherent intelligent-processing capability, [3].

A smart sensor in the past was a transducer that had digital connection capability. Today it is a sensor that is aware of what it measures, validates its own measurement and performs signal processing to extract knowledge and share it with other devices in the system. It is important to note that there is an exchange between data flow and signal processing.

The rate of adoption of recent technologies in the industry is much lower than in consumer environments, as there are different objectives and involves security and reliability issues. This is the reason why we have IOT and IIOT. Although the essence of these networks is similar, the standards that will emerge in each of them will be completely different.

The IEEE 1451 family is aware of this technological convergence and is deploying a huge activity in connectivity, wired and wireless, in the form of knowledge sharing and sensory signal processing capabilities.

B. Industrial Communications

Industrial communication as of today is organized mainly according to the automation pyramid (see Fig. 2). On top, in the computer level, standard IT protocols (Internet Protocol Suite[6]) are used. For machine to machine and process communication, OPC UA (IEC 62541) plays a quickly increasing role next to the traditional M2M Ethernet-based fieldbusses (PROFINET, EtherNet/IP, CC-Link IE). Inside the machine, protocols with hard real-time capabilities (also known as real-time Ethernet) dominate the field[7]. According to their market shares, among the most important ones are EtherCAT, PROFINET/IRT, POWERLINK, and Sercos III. Although those technologies share common requirements, their implementations differ a lot. Hence, a comparison of those technologies is a complicated issue and depends heavily on the desired application (process control, motion, IO, centralized vs. decentralized control, etc.). An endeavor to compare some real-time Ethernets in various categorized has been undertaken by the Ethernet Powerlink Standardization Group (EPSG)[8].

All above mentioned industrial Ethernet technologies are standardized in the IEC. Their performance indicators can be found in IEC 61784-2 (Industrial communication networks – Profiles – Part 2: Additional fieldbus profiles for real-time networks based on ISO/IEC 8802-3). Their protocol specifications can be found in IEC 61158 (Industrial communication networks – Fieldbus specifications). Lately, activities in the IEEE have been started in order to standardize a protocol for hard real-time communication for the millisecond and sub-millisecond communication cycle range, where Ethernet

[4]http://www.itu.int/en/about/Pages/default.aspx

[5]https://www.ansi.org/about_ansi/overview/overview?menuid=1

[6]https://en.wikipedia.org/wiki/internet_protocol_suite

[7]Globally, the market shares of industrial Ethernet and traditional field busses in industrial communication are already comparable (source: https://www.anybus.com/images/librariesprovider6/default-album/company-images/network-shares-according-to-hms-2017.jpg), while in new developments mostly Ethernet-based ones are applied, which makes the share ramp up. Devices with traditional fieldbus interfaces are more and more substituted and shipped only for legacy products and plants.

[8]http://www.ethernet-powerlink.org/en/downloads/industrial-ethernet-facts/

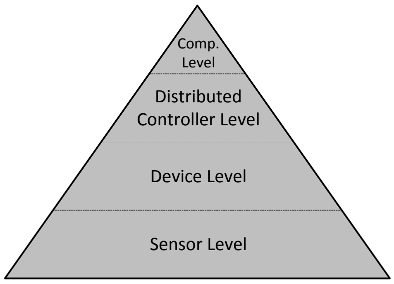

Fig. 2. Automation pyramid – different levels of communication needs.

POWERLINK has been selected by the Working Group of the IEEE P61158 project, hosted by IES. IEEE 61158 has already been balloted and has been approved by IEEE-SA in June 2017.

Industrial wireless communication provides ubiquitous access to industrial network resources and applications. Wireless communications has drawn attention for high mobility, real-time, high scalability and low cost performances. Several typical widely used wireless communication standards and protocols are introduced.

WiFi is a popular wireless technology based on the IEEE 802.11. Standards of WiFi are expanding from IEEE 802.11(a,b,g,n,y) to recently announced new standards IEEE 802.11(ac,ad,af). It performs similar to the Ethernet network but no cabling or wiring is needed. WiFi normally operates in the 2.4GHz or 5 GHz frequency band which is license free worldwide. WiFi offers a high bit rate and high flexibility. The maximum data rate can be up to 150Mb/s, which means WiFi has the potential to be applied in the industrial network with high throughput demand. Despite WiFi provides high data rate transmission, WiFi consumes high power to facilitate the high data rate transmission. The installation of WiFi is also expensive. Therefore, if power saving is not the prime requirement, WiFi may serve as a potential solution for real-time industrial communications.

Bluetooth is a short-range ratio link for the transmission of data and communication signals between mobile devices. Bluetooth low energy (Bluetooth LE, BLE, marketed as Bluetooth Smart) is a wireless personal area network technology designed and marketed by the Bluetooth Special Interest Group aimed at novel applications in the healthcare, fitness, beacons, security, and home entertainment industries. The maximum distance is about 100m at a maximum data rate of 3 Mb/s and it operates at 2.4GHz ISM band. Though BLE has a lower consumption, it is limited by the network size in general. Therefore, BLE may be considered in small scale wireless communication industrial applications to provide low power, high mobility services.

ZigBee is governed by IEEE 802.15.4 with the goal to provide low power consumption, low cost, and high scalability performance. ZigBee shares some similarities with Bluetooth such as short-range transmission and low production cost. ZigBee is more energy conservable than Bluetooth and is a better candidate for smaller packets over a large network. Typically driven by mesh network, ZigBee can form a large scale wireless network and provide seamless interoperability and communication among Internet of Things devices.

C. Industrial Agents

Multi-Agent Systems (MAS) [4], [5] is a paradigm derived from the distributed artificial intelligence field that promote distribution, decentralization, intelligence, autonomy and adaptation, contributing to achieve flexibility, robustness, responsiveness and reconfigurability [5]. A MAS system can be defined as a ecosystem of autonomous and cooperative computational entities, known as agents, which may have a counterpart representation, e.g., physical devices or logical objects. In these systems, the overall behavior emerges from the interaction among the distributed agents, each one possessing its own knowledge and skills.

Industrial agent-based solutions, aligned with the Cyber-Physical Systems (CPS) concept where the agents introduce distributed intelligence in the cyber counterpart [6], expand the potential application domains of MAS and at the same time adds the required flexibility, robustness and responsiveness to industrial automation systems.

Standardization is a critical issue for the industrial adoption of CPS solutions, and particularly industrial agents, since the compliance with industrial standards strongly affect the deployment of these industrial applications. The Foundation for Intelligent Physical Agents (FIPA) has produced specifications for the development of heterogeneous agent-oriented software solutions, being currently the only standard for the development of MAS systems. FIPA specifications are grouped in the following five categories [7], [8]:

- *Applications:* defines the application areas where FIPA agents can be deployed, representing ontology and service descriptions specifications for a particular domain.
- *Abstract architecture:* defines the required abstract entities to build agent services and an agent environment.
- *Agent communication:* defines the Agent Communication Language (ACL) and the interaction protocols for the conversation among agents.
- *Agent management:* handles the control and management of agents within and across agent platforms, and specify a reference model that defines the basic structure of a FIPA-compliant MAS.
- *Agent message transport:* handles the transport and representation of messages across different network protocols.

The accomplishment of industrial environments imposes specific requirements that are not covered by FIPA specifications. As an example, the interconnection of intelligent software agents with hardware devices performing (real-time) control is mandatory in CPS, but at the moment, it is not sufficiently addressed in FIPA specifications. In this area, the ISO 9506 standard, known as MMS (Manufacturing Message Specification), established the first guidelines in this field by defining the application layer of the ancient MAP (Manufacturing Automation Protocol), and consequently providing a platform capable to interconnect various industrial computerized devices supplied by different suppliers [9]. In this way, a prominent opportunity arises concerning the establishment of standards for interfacing industrial agents with physical hardware devices, which is being addressed by the IEEE P2660.1 working group that is developing recommended practices for integrating software agents with low level automation functions, simplifying the interoperability in CPS systems.

D. Intelligent Power and Energy Systems – Smart Grids

The large scale integration of renewables, energy storage systems, and electric vehicles into future smart grids requires more sophisticated and advanced automation technologies. For the implementation of those concepts and approaches proper Information and Communication Technology (ICT) is needed. The most important ICT-related standards supporting interoperability and scalability needs in future intelligent power grids with an enormous amount of interconnected and networked components exchanging power and information in a bidirectional manner are outlined below [10].

International standards are important in order to develop interoperable solutions for smart grid solutions. It is highly recommended to keep the development of new concepts, components, and devices – connected to the power system – aligned with standards describing how the corresponding design and implementation have to be carried out. Among other issues this includes also the information exchange between those components. On international level various standardization organizations and bodies addressing this fact. A comprehensive overview of ongoing activities, projects, and standardization roadmaps related to intelligent power systems and smart grids is provided e.g. by Gungor et al. [10].

The International Electrotechnical Commission (IEC) plays a very important role on international level providing common rules and standards for the planning and operation of intelligent power systems and active distribution grids. Fig. 3 provide a brief overview of the most important IEC smart grid standards (i.e., IEC TR 62357 – Seamless Integration Architecture (SIA), IEC 61970/61968 – Common Information Model (CIM), IEC 61850 – Substation Automation, IEC 62056 – data exchange for meter reading) [11].

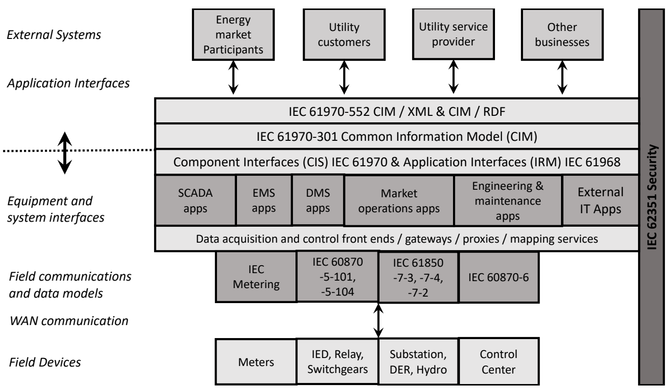

Fig. 3. Overview of IEC TR 62357 – Seamless Integration Architecture [12].

Comparable suggestions in the field of smart grid standardization have also been reported by other institutions like the "NIST Framework and Roadmap for Smart Grids Interoperability Standards" [13], the "DKE German standardization roadmap for Smart Grids" [14], as well as the "IEEE Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), End-Use Applications, and Loads" [15].

The German DKE smart grids roadmap [14] suggests for the the development and implementation of control logic the IEC TC 65 standards IEC 61131 for Programmable Logic Controllers (PLC) and IEC 61499 for distributed intelligent automation systems. Both approaches provide interesting and promising concepts and definitions [14]. Furthermore, the IEC TC 65 automation-oriented approach OPC Unified Architecture (OPC UA), defined in IEC 62541, gets nowadays a lot of interest from the smart grid community [16] for the platform-independent data exchange between distributed devices. OPC UA can be assumed as potential, standardized underlying communication layer for future networked smart grid applications [17].

All the above mentioned standardization activities focus mainly on the planning and operation of smart grid systems. Standards supporting the design, implementation, validation, roll-out of new technology are partly missing. There is still opportunities for future standardization activities

III. Future

Many emerging technologies in the near future are becoming disruptive to some of today's industrial automation, power generation and automotive industries, as well as service and consumer industries. Such technologies in telecommunications and IoT/IIoT have caused industries to look at new ways of doing business and deployment of products, services, and resources. In the early development and adoptive years, technologies are deployed without standards, therefore creating niche areas of use and small volume sales until the technology catches on, and become defacto standards or standards are being set. Standards are recognized as essential for business and product development for large scale manufacturing, consumer acceptance and product reliability. IES is continuing to be engaged in the forefront of emerging technologies such as IIoT, industrial wireless and industrial sensor networks.

A. Industrial Internet of Things

The automation market is facing a time of change with disruptive character driven by the possibilities of the Internet, sometime referred to as the fourth industrial revolution. The changes have been even accelerated by governmental initiatives like the German "Industrie 4.0" or similar initiatives around the globe. They foster the previously separated fields and markets of IT (Information Technology) and OT (Operations Technology) work together. This allows manufacturers to stay competitive and unveil numerous benefits to their customers. A main target of initiatives such as "Industrie 4.0" is to secure the economic growth of the the developed economies by keeping production sites and enabling them to cope with the changing customer demands.

A technical backbone of bridging IT and OT is the combination of OPC UA and TSN. OPC UA is used for providing a modern way of describing assets like process and control information in the form of the OPC UA Information Model. It also defines access to that model in terms of browsing and asynchronous and real-time subscriptions, the latter in the newly published form of Part 14 – a Publisher/Subscriber model. Another noteworthy feature of OPC UA is its built-in security model. TSN on the other hand refers to a Task Group of the IEEE 802.1 standardization Working Group[9]. It adds useful features for industrial applications to standard Ethernet like time synchronization (IEEE 802.1AS) and timing guarantees for message transfer (IEEE 802.1Qbv), which have previously been unique to proprietary hard real-time protocols. Those real-time features combined with the OPC UA Information Model provide a holistic communication infrastructure for industrial communication from sensors to the cloud.

The IoT – the interconnection of intelligent devices and management platforms, with little to no human intervention, facilitates a smart, connected world. The unprecedented growth in IoT communications is predicted to accumulate to over 20 billion connected IoT devices, by the year 2020 [18]. Applications for the IIoT, which is a natural evolution of the IoT (see Table II), emphasizes the autonomous nature of machines with no human intervention. This revolution is facilitated by the collection, aggregation, and analysis of sensor and device data to maximize the efficiency of machines and the throughput of operations and processes. IIoT applications span motion control, machine-to-machine interactions, predictive maintenance, smart-grid energy management, big data analytics, smart cities, and interconnected medical systems.

TABLE II
COMPARISON BETWEEN IOT AND IIOT (ADOPTED FROM [18]).

Category	IoT	IIoT
Exchange of data	For Consumer usage, Business to consumers	For industrial purpose, Business to business
Main Purpose	To improve consumer convenience	To extend existing manufacturing
Market	Consumer Level	Enterprise
Human Interaction	Reactive	Autonomous
Connectivity	Consumer grade	Secure

With increased pervasiveness of wireless access, cellular connectivity is becoming even more valuable as an important access methodology for IIoT. Cellular technologies are already being used for wireless IIoT access in several applications, as described in Table III, and are expected to be further utilized for future use cases requiring ubiquitous mobility, resilient networks, robust security, economic scale, and communications independent of third-party access such as digital subscriber lines and fixed lines.

However, such systems face the challenge of facilitating the interconnected web of IIoT devices in a manner that

TABLE III
WIRELESS IIOT ACCESS CATEGORIES (ADOPTED FROM [18]).

Access	Connection forecast (2020)	Sample Applications	Sample Technologies
High-power wireless	+2 billion	Driverless cars, etc.	LTA-A Pro, 802.11 ac/ax
Low-cost wireless	+5 billion	Smart home, etc.	LTE, HSPA, BT, 802.11 n
LPWA	+11 billion	Sensors, etc.	NB-IoT, Sigfoxm EC-GSM, LoRaWAN

is secured, flexible, affordable, energy efficient, and easy to provision, manage, and scale while delivering robustness and acceptable performance [19]. The challenge can be met through promising new solutions to be used as building blocks to meet IIoT challenges. Hence, Low-Power Wireless Access (LPWA) cellular connectivity attracts a tremendous amount of interest as it caters to the needs of a wide range of wireless IIoT applications. Unlike wireless categories detailed in Table III, LPWA connectivity solutions are developed based on a simple, challenging, set of correlated *requirements:efficient* signaling and channel access protocols to support massive connection densities, extreme energy efficiency to extend a battery-powered device operation to ten years, ultra-low cost to enable large scale adoption in an economically feasible manner, and extended coverage to enable versatile device deployment with high reliability. LoRa, also refers to Low Power Wide Area Network (LPWAN), is a long-range communication technology and its low power consumption design renders devices batteries to survive 10 years. With an excellent performance on sensitivity, LoRa has a wide coverage (i.e., $>$1km coverage) regardless of indoor/outdoor environment. Besides, large amount of nodes can be supported by one LoRa network.In order to reduce the power consumption, the data rate of LoRa is low. Therefore, LoRa might be a candidate solution for long range and low cost applications with low data rate requirement (e.g. industrial control, agricultural monitoring, logistics, etc.).

B. Industrial Wireless

1) Overview: The use of wireless technologies in industrial applications was limited for a long time due to highly fluctuating quality of wireless transmission channels. Specifically transmitted electromagnetic waves experience reflection, scattering, and diffraction causing multipath scattering at the receivers resulting in packet errors and losses contributing to higher transmission delays, especially when it is used in harsh industrial environments, mobile and rotating scenarios. The end user doubts have been reduced significantly over the decade with the development of diverse wireless standards and well-suited protocols. With the development of KNX RF in 2006 and ZigBee in 2007, the first standard for building automation was introduced. With the scope of the HART 7 specifications in 2008, the first standard, WirelessHART, for the process automation was released in late 2007 [20].

However, some industrial applications of wireless technologies impose stringent requirements including: *(a)* Low

[9]http://www.ieee802.org/1/pages/tsn.html

latency times due to extreme short symbol durations; *(b)* Robust against the effects caused by multipath scattering; *(c)* Reflection and scattering are frequency selective; *(d)* Using a high bandwidth reduces the probability of deep fading; *(e)* Energy efficiency due to the low spectral density power, and *(f)* Data rates of up to several Gbps. As a result, wireless solutions before the availability of 5G may not be suitable for critical industrial applications.

5G integrates new radio concepts making it possible to provide 1,000 times higher mobile data volume per area; 10 to 100 times higher number of connected devices, 10 to 100 times higher user data rates, 10 times longer battery life for low power massive machine communication and 5 times reduction in end-to-end latency [20]. The global research on 5G networks has identified the need to rework the radio access network architecture to support novel services and usage scenarios [21].

3GPP's standardization of 5G radio access technology is targeted for commercial availability in 2020. The 5G will provide a wide range of carrier frequencies and deployment options, diverse use cases with very different user requirements, small size base stations, self-backhaul, massive MIMO, and large channel bandwidths.

2) 5G Requirements and Use Cases for Industrial Applications: 5G will use an open system architecture that evolves from existing wireless technologies and is complemented by new radio concepts including Massive MIMO, mmWaves, Ultra Dense Networks, Moving Networks, Device-to-Device Communication, Ultra Reliable and Massive Machine Communications. It allows 5G to achieve the enhanced capabilities including: *(a)* near-zero latency, *(b)* near-instantaneous communication, *(c)* greater efficiency, *(d)* agile networks, and *(e)* seamless connectivity [22]. The following 5G use cases represent various key industrial sectors:

- *Automotive:* Increase in autonomous driving, improved traffic safety, and increased productivity
- *High-Tech Manufacturing:* Allow devices in an assembly line communicating with control units with a sufficiently high level of reliability and sufficiently low latency and controls remote robotics.
- *Intelligent Transportation Systems:* Provide efficient traffic management, dynamic traffic rerouting, and traffic light control.
- *Emergency Communications:* Provide a reliable network that can help with the search and rescue of humans, and the identification and rectification of catastrophic problems involving machinery.
- *Healthcare:* Remote medical examination and surgery enables very low latency for telehaptic control.
- *Financial Services:* Provide secure cloud-based services.
- *Media and gaming:* Supports 4K streaming to mobile devices that allow an individual users desire to be able to enjoy media anytime and anywhere.
- *Teleprotection in a smart grid network:* Provide the ability to react to rapid changes in the supply or usage of resources to avoid transient system failures.

Note that 5G may not be able to satisfy all stringent automation demands for real time and replace dedicated industrial automation networks for IIoT and ICPS [23]

3) 5G Standardization Status: ITU-R has requested organizations to standardize a new interface based on their recommendations for performance and capabilities for 5G. This includes complete technical performance specifications, evaluation methods and criteria, a format of submission, and send the liaison statements for IMT-2020 application to standardization organizations by 2017. After the mid-2019 submission deadline, ITU-R will complete the final evaluation and authorization of IMT-2020 by 2020 [24].

IV. Standardization Activities

Standards activities by IES are briefly listed here, with standards work in collaboration with other IEEE societies, either as a main sponsor, or a co-sponsor. It is noted that many standards span several Fields of Interest (FoI) of other societies, thus co-sponsorship allows a wider range of expertise in the participation in the development.

A. Standards developed/being developed by IES

Standards activities presently undertaken by IES are:

- *IEEE 21451-001-2017 standard – Recommended Practice for Signal Treatment Applied to Smart Transducers:* This standard was recently approved by the IEEE-SA as an IEEE standard. It now joins the IEEE 1451/21451 sensor networks family of standards. IES is the main sponsor of this standard, and it was co-sponsored by IMS.
- *IEEE P61158-2017 standard – Standard for Industrial Hard Real-time Communication:* This standard was recently approved by IEEE-SA as an IEEE standard. IES is the main and only sponsor of this standard.
- *IEEE P2660.1 draft standard – Recommended Practices on Industrial Agents:* Integration of software agents and low level automation functions. This standard is under active development, and is co-sponsored by the Systems, Man and Cybernetics Society (SMC). The IES Industrial Agents Technical Committee (TC) plays a leading role in the standard's active development.
- *IEEE P1451-99 draft standard – Standard for Harmonization of Internet of Things (IoT) Devices and Systems:* This standard is under active development. IES is the co-sponsor of this standard, with IMS as the main sponsor.
- *IEEE P1451-002 draft standard – Recommended Practice for Low Power Smart Transducers Applications:* This draft standard has been approved by IEEE-SA for active standards development. IES is the main sponsor and IMS is the co-sponsor.
- *IEEE P1451-1-5 draft standard – Standard for a Smart Transducer Interface for Sensors, Actuators and Devices – Simple Networked Management Protocol (SMNP) for Networked Devices Communication:* This draft standard has been approved by IEEE-SA for active development. IMS is the main sponsor and IES is the co-sponsor.

- *IEEE P2004 draft standard – Hardware-in-the-Loop (HIL) Simulation Based Testing of Electric Power Apparatus and Controls:* This standard has been approved by the IEEE-SA for standards development and is sponsored by IES sister society, Power Electronics Society (PELS). It is co-sponsored by the Industrial Applications Society (IAS) and IES. Standards activities are underway.
- *IEEE SCC21 – oversees the development of standards in the areas of fuel cells, photovoltaics, dispersed generation and energy storage:* This is a Standards Coordinating Committee effort where no one society can cover the full range of the activities and the working group membership consists of multiple IEEE societies contributing to the effort. IES is one of several societies involved.
- *IEEE SCC42 Transportation – coordinates IEEE standardization activities for technologies related to transportation, especially in the area of connected vehicles, autonomous/automated vehicles, inter- and intra-vehicle communications, and other types of transportation electrification:* IES is one of 10 – 13 societies involved in these emerging technologies that started with transportation electrification and now will span autonomous vehicles and connected vehicles, a fast growing field expected to disrupt the automotive industry.

B. Family of IEEE 21451/1451 Standards and IIoT

The IEEE 1451, a family of Smart Transducer Interface Standards, describes a set of open, common, network-independent communication interfaces for connecting transducers (sensors or actuators) to microcontrollers, instrumentation systems, and networks. The key feature of these standards was the definition of a TEDS (Transducer electronic Data Sheet), an innovative concept to allow identifying transducers themselves over a communication channel [25]. It started in 1993 and in those days the challenge was to make transducers plug and play devices. Since then, this family of standard has deployed a huge activity and now it is facing new challenges, see Fig. 4. From the point of view of IoT, the great challenge is to provide a unified language that allows devices of different nature to share their information. IIoT also adds considerations of reliability, safety and efficiency. An important project, currently active, is P1451-99 "Standard for Harmonization of Internet of Things (IoT) Devices and Systems". The purpose of this standard is to define a metadata bridge to facilitate IoT protocol transport for sensors, actuators, and devices. The standard addresses issues of security, scalability, and interoperability. It proposes to use XMPP (eXtensible Messaging and Presence Protocol) as a unified link to share information.

C. Industrial Wireless and NIST

In mid-2017, the Intelligent Systems Division of the US National Institute of Standards and Technology (NIST) formed a technical working group to develop best practices guidelines for selecting and deploying industrial wireless solutions within industrial environments like process plants and discrete manufacturing factories. These guidelines will consider the

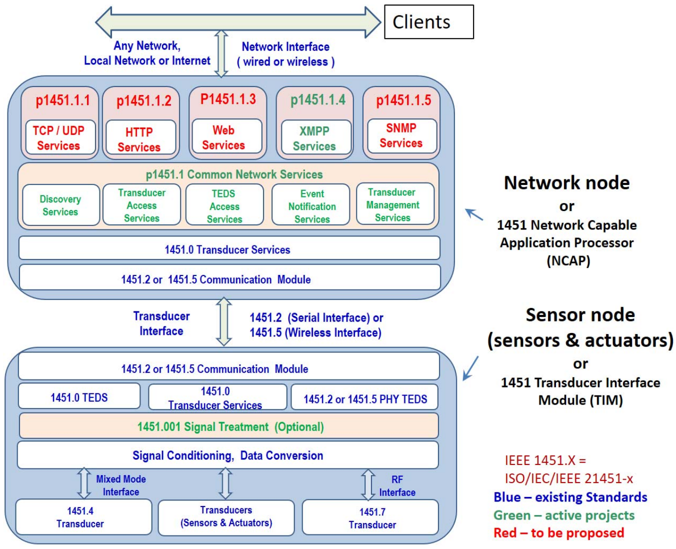

Fig. 4. Relationship diagram for IEEE 1451 standards family.

entire wireless ecosystem within factories, emphasizing on wireless systems operating on the factory floor. This will include factory and plant instrumentation, control systems and back-haul networks. They are aimed at addressing the current industry needs to have independent guidelines based on user requirements and will be technology and vendor agnostic. They are targeted to the factory floor for materials tracking, observation and process control, improvement of personnel safety and improvement of plant and factory operations. Classes of control systems will include both feedback and supervisory forms of control. The Technical Working Group (TWG) was formed as a result of an industrial wireless systems workshop held by NIST together with IES and IMS [26].

The development of the guidelines will be in collaboration among NIST, IES, IMS, ISA and members of industry[10], with follow-on workshops and meetings held throughout 2017 through 2018.

D. Standards Activities Mapping into IES Fields of Interest

IES Fields of Interest (FoI) as represented by its 23 Technical Committees (TCs) can be loosely grouped into four technical industrial clusters: Energy, Sensors and Control, Information and Communications, and a Cross-Disciplinary group, see Fig. 5. The standards activities presently undertaken by IES can be mapped into these clusters as shown in Fig. 6, with a few standards spanning multiple clusters. This should give a clear, visual representation of IES standards work within its FoI in industrial electronics.

V. Conclusions

IES have steadily built its capability in standards development in the last few years, specifically in its fields of interest in smart sensors and actuators, sensors networks, industrial communications and industrial agents. Building on

[10]https://www.nist.gov/el/intelligent-systems-division-73500/industrial-wireless-guidelines-technical-working-group

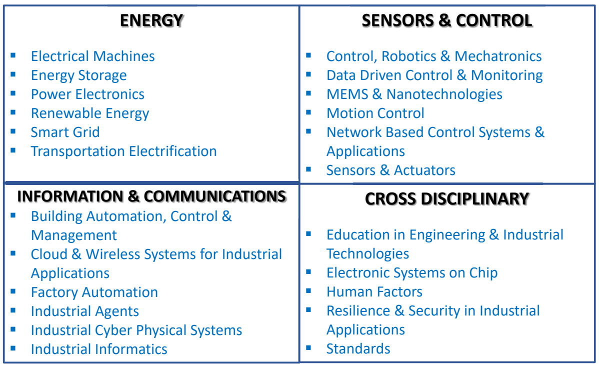

Fig. 5. IES Fields of Interest Clusters.

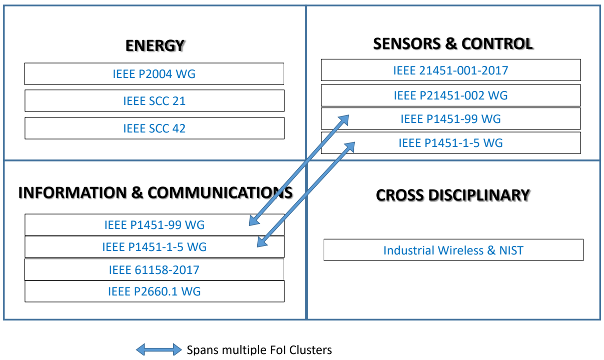

Fig. 6. IES Standards Activities – Present.

existing standards efforts in smart grid technologies can lead to new standards, especially working with IES sister societies. Industrial wireless, industrial communications, IoT/IIoT with sensors continue to command IES's standardization focus.

A potential standards area for IES to be in is autonomous and connected vehicles, where the auto industry are bombarded with new and disruptive technologies from communications, sensors and IIoT. This also could include standardization of transportation electrification and battery technologies for electric vehicles and energy storage, spanning a wide range of IES Fields of Interest as depicted in Fig. 7.

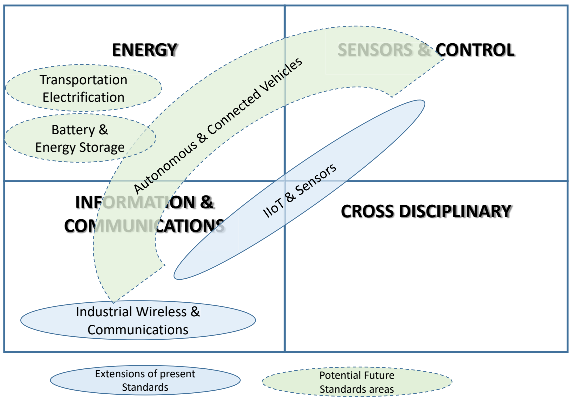

Fig. 7. IES Standards Activities – Future.

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