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Industrial Internet of Things: Specificities and Challenges

Georgios Z. Papadopoulos[1] | Fabrice Theoleyre*[2] | Xavi Vilajosana[3]

[1]IRISA, IMT Atlantique, Rennes, France
[2]ICube Lab, CNRS, Illkirch, France
[3]Computer Science, Telecommunications and Multimedia department, Universitat Oberta de Catalunya, Barcelona, Spain

Correspondence
*Fabrice Theoleyre, ICube Lab, CNRS, Pole API, Bd Sebastien Brant, 67412 Illkirch Cedex, France. Email: theoleyre@unistra.fr

Summary

1 | MOTIVATION

More than one decade ago emerged the Internet of Things (IoT) paradigm, which enabled new applications to be incorporated in our everyday life. We have now a large variety of radio technologies (e.g., IEEE Std 802.15.4-2015, Bluetooth, WiFi, LoRa, Z-Wave) to connect more and more smart objects. Wireless technologies have evolved to address best effort scenarios in which reliability is traded-off by bandwidth and data rate.

The specific requirements imposed by industrial applications are not comparable to mass-market needs driven by the demand of broadband and massive connectivity oriented to end user services and applications. Latency, reliability and energy consumption requirements did not consider the critical operation of industrial assets, which have been left aside and operated by wired buses for the last 30 years. This has shaped the way industries are today and limited solutions in which mobility or the lack of wires would have facilitated production processes. Yet, and understanding that industries equipment is built to last for more than 30 years, wireless could have been seen as a perfect tool to extend and instrument legacy equipment. However, the objectives of the standardization bodies and manufacturers aimed to address other more relevant areas, in which reliability was a secondary objective.

We face to a huge variety of potential applications in the industrial space, including System Automation, Wireless Control, Predictive maintenance and anomaly detection among others[1]. Considering the requirements in terms of reliability, bounded jitter and delay and efficiency, research and standardization are still required to overcome current technological barriers. We need to tackle the problems of adaptability and compatibility to legacy technologies, the standardization barriers and the lack of trust to digital technologies from the industrial sector[2]. Therefore the development of the Industrial IoT is tighten to the advances in ICT technologies in directions that diverge from those developed during the IoT and WSN hypes, opening new research and development opportunities this time, driven by already existing applications whose functionality needs to be broadly extended.

2 | KEY CHARACTERISTICS OF WIRELESS INDUSTRIAL NETWORKS

Wireless transmissions create specific challenges to tackle. Indeed, we need to redesign the algorithms and protocols that were invented to work properly in wired networks where, everything is finely controlled.

2.1 | Low Power Networks

The wide application ecosystem in the industry opens a large landscape for wireless networking research. Some critical applications may rely on battery-powered devices, e.g., human operators may employ smart remote controls, to control the production line in real-time. In a general manner, wearable devices are often energy constrained[3].

However, it has to be well understood that machinery is often mains powered and the limits are not imposed by energy availability but rather performance may be the key. Performance can be understood from different angles, including high bandwidth, low jitter/delay or reliability. Understanding this trade off is crucial in order to provide meaningful solutions[4]. It is important, therefore, to analyze the requirements and differentiate them to those that motivated the research in the early WSN and IoT fields.

2.2 | Lossy Networks

Wireless transmissions are known to be lossy by nature. A packet may not be decodable by the receiver due to e.g., external interference, a low signal strength. Acknowledgments and Automatic Repeat ReQuests (ARQ) may help to improve the reliability, but they also mechanically increase the number of transmissions, and increase also the latency. Unfortunately, asymmetrical links are common in indoor environments[5] and jeopardize these solutions: both directions for a specific radio link may exhibit very different Packet Error Rates.

Even worse, the link characteristics are very time-dependent[6]. More precisely, we may face to a very bursty behavior: a sequence of packets may be dropped consecutively, even for medium quality links[7]. Unfortunately, critical applications suffer particularly from this situation if the infrastructure cannot respect a maximum end-to-end latency.

2.3 | Shared Access

Traditional networks have shifted from a shared access to contention-free Medium Access Control: the physical bandwidth is fully dedicated to a pair of network devices. Wireless networks are based intrinsically on broadcast: any device close to the transmitter is prone to decode the packet if it maintained its radio chipset awake during the whole transmission. This shared access create two antagonistic effects:

collisions (negative): two transmitters must *share* the radio bandwidth. Even worse, collisions may be particularly challenging to tackle in complex topologies, where hidden terminals, and asymmetrical situations may arise;

diffusion: overhearing consists in maintaining several receivers awake to receive a packet. This positive effect may be exploited to improve the reliability while limiting the number of transmissions[8].

For instance, a control packet can be received (and decoded) by any neighbor, limiting also the radio bandwidth used by the transmitter. Similarly, high reliability may be achieved with anycast routing: several receivers are selected for a single transmission, to reduce the probability of packet losses[9].

Last but not least, this effect tends to be exacerbated by the fact that wireless networks often provide a low bandwidth, several orders of magnitude lower than for traditional wired networks.

3 | OPEN CHALLENGES AND OPPORTUNITIES

Creating added value in the industrial application landscape requires the development of tailored technologies that address the important challenges of the sector. In the following we review some of them:

3.1 | Interoperability with Industrial Standards and Architectures

Industrial standards and ICT standards are driven by non-connected committees causing the evolution of the fields to diverge while sometimes addressing the same sort of problems. A question now that ICT technologies and industrial application need to meet is how these worlds will interact and converge and what architectures will be developed so technologies that have been designed by the industry can now be integrated to digital systems and vice versa, of course, without having to duplicate the efforts. Research directions towards enabling digital plug and play technologies in industrial settings need to be investigated, also the development of measures to support the fast evolution of ICT technologies, a very counter-intuitive fact for industrialist which have protocols that are widely used for decades.

3.2 | Mobility Support

One of the key challenges when instrumenting industrial scenarios is the support to moving objects. Today, mechanical solutions are developed in order to connect wires to moving objects such as robotic arms. Yet those impose important mobility limitations and become real maintenance problems. Dealing with mobility is therefore a challenge to be addressed by wireless technologies fostering its applicability in the industrial space. Among other it seems important to address mobility while still ensuring deterministic properties in the wireless links. This, per se, may require a combination of different techniques, being reactive to topology changes or network configuration while still meeting the stringent performance requirements in terms of latency or bounded packet losses.

3.3 | Wireless for positioning

One of the most researched technologies in the last 15 years is indoors positioning. Industries are the potentially major adopters of such technologies as identifying the position of assets and workers is a critical information to improve work efficiency and safety. Wireless networks are key to fulfil the vision in which industrial objects are precisely located in the production lines, but yet, and due to the nature of industrial settings, it is still open to understand if the performance of such techniques is suitable for the scenarios. Approaches based on angle of arrival, time of flight and ultra-wide band pulses may now be challenged against industrial conditions.

3.4 | High performance wireless

Derived from the WSN and IoT requirements, wireless networks with potential application in the Industrial field have been developed with low power as a key constraint. This has imposed many restrictions to the performance of that technologies leaving aside properties that may be valuable in industrial fields. Automation and control applications for example rely in control loops with very significant timing constraints. Common control loops in industrial buses have periods of 1 to 10ms. Wireless networks with that capabilities need to trade of performance to resource utilization which has a direct mapping to energy consumption. Research directions to address these requirements are therefore relevant now that wireless may enable new ways of building machinery, with less mechanical restrictions but always conditioned to address reliably this high performance needs.

3.5 | Reproducibility

The behavior of a wireless infrastructure has to be *reproducible*, leading to the same results, when facing to the exactly same conditions[10]. Unfortunately, we do not have yet the keys to predict how exactly a wireless infrastructure will behave before a real deployment. In particular, how can we explore the network capacity limits? With battery-powered nodes, could we predict accurately their lifetime?

Consequently, we need to more accurately explore the reproducibility concept, and to construct benchmarks. To our mind, reproducibility requires, i) Exhaustive description of the setup so that we can reproduce the same situation; ii) Scenario Replay, where everything is scripts and automatized; iii) A raw dataset is provided by the benchmark; iv) A public repository should collect the whole dataset, so that any researcher or engineer can analyze the results, and verify that the solution fits well the requirements he/she identified.

3.6 | Tragedy of the Commons

We envision a wide adoption of the IoT technologies for a large set of innovant services. Typically, several networks may be deployed in a smart factory, possibly using different wireless technologies. In this context, each deployed network must carefully handle external interference, which is exhibits a local pattern[11]: a radio channel may perform very poorly for some radio links, while providing a very high reliability for other ones. Thus, blacklisting techniques try to identify the *good* radio channels to use only the most efficient ones[12]. However, less selfish approaches should also be investigate. Indeed, we should avoid the tragedy of the commons that very dense deployments will for sure occasion[13]. The different networks and technologies have to cooperate to share fairly and efficiently the bandwidth. It is not acceptable that e.g., Wi-Fi networks may preempt the medium compared with low power networks. Explicit resynchronization[14] among different networks helps to reduce the number of collisions. However, implicit, technology specific mechanisms have still to be proposed.

4 | THIS SPECIAL ISSUE

This Special Issue comes really timely for relevant research communities, and provides a valuable contribution to this emerging field. Via a thorough review process, five papers have ultimately been selected in this special issue. Since we selected the papers based on their scientific quality and the strength of their contributions, we cannot argue that they cover all the topics of the domain. However, we are delighted to present a consistent special issue, covering a large set of problems in the Industrial Internet of Things.

The first paper *"Operations, Administration and Maintenance (OAM) features for Reliable and Available Wireless (RAW) Networks"* details the mechanisms to set-up to maintain a wireless industrial network fully efficient. Indeed, the wireless infrastructure must respect strictly some Service Level Objectives by using wireless transmissions, which are stochastic by nature. Thus, we need mechanisms to supervise, detect faults, and reconfigure the network to keep operating smoothly without any end-to-end failure. By exploiting the redundant nature of the wireless topology, it is expected to maintain high reliability and to respect upper bounded end-to-end latency.

The second paper *"Impact of Interference Aware Metrics on Iterative Multipath Routing for Industrial WSN"* focuses on the routing problem. Indeed, multipath routing seems required to provide high reliability: by exploiting multiple paths in parallel, the wireless infrastructure can be fault tolerant. However, we have to select the most efficient set of paths, i.e., the paths which minimize mutual interference. This paper tries to quantify the accuracy of the routing metrics to capture this independency metric.

6TiSCH is a very promising stack for industrial networks based on the popular IEEE802.15.4-TSCH standard. Two papers focus on this specific technology. The paper *"6TiSCH Minimal Scheduling Function: Performance Evaluation"* focuses on the scheduling problem. More precisely, the scheduling function is in charge of determining how many transmission opportunities should be reserved by each radio link. While this approach is fully distributed, the minimum amount of bandwidth has to be reserved to respect the SLO while minimizing both the energy consumption and the radio resource reserved for a given flow.

The paper *"Trace-Based Simulation for 6TiSCH"* tries to respond to the reproducibility problem. It is extremely time consuming to conduct experiments, challenging to interpret the results, and complicated to provide reproducible results. Thus, exploiting a dataset seems a promising way to mix the advantages of experiments and simulations, as a first step before real-world evaluations. This paper presents a very practical tool for the research community, to provide a benchmarking solution for simulations in wireless industrial networks that use the 6TiSCH stack.

Finally, the paper *"TSCH-over-LoRA: Long Range and Reliable IPv6 Multi-hop Networks for the Internet of Things"* explores how the TSCH concepts may be adapted to another wireless technology. LoRa enables long range communications, but is not deterministic: it is very challenging to provide both high reliability and a bounded latency. Thus, scheduling the transmissions on top of a LoRa radio chipset allows the network to control finely the latency and to avoid collisions. This paper represents a pioneering piece of work to explore how any wireless technology may be transformed to support real-time flows.

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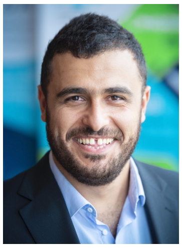
AUTHOR BIOGRAPHY



Georgios Z. Papadopoulos serves as an Associate Professor at the IMT Atlantique in Rennes, France. Previously, he was a Postdoctoral Researcher at the University of Bristol. He received his Ph.D. from University of Strasbourg, in 2015 with honors. He has been involved in the organization committee of many international events (e.g., IEEE ISCC'20, AdHoc-Now'18, IEEE CSCN'18). Moreover, he has been serving as Editor for Wireless Networks journal and Internet Technology Letters since 2018. He is author of more than 60 peer-reviewed publications in the area of computer communications, networks and security. He actively participates at the IETF standards organization with multiple drafts in the ROLL and RAW Working Groups. His research interests include Industrial IoT, 6TiSCH, LPWAN, Wireless Battery Management System, and Moving Target Defense.

Fabrice Theoleyre is a researcher at the CNRS. After having spent 2 years in the Grenoble Informatics Laboratory (France), he is part of the ICube lab (Strasbourg, France) since 2009. He received his Ph.D. in computer science from INSA, Lyon (France) in 2006. He was a visiting scholar at the University of Waterloo (Canada) in 2006, and a visiting researcher at INRIA Sophia Antipolis (France) in 2005 and at Inje University (Korea) in 2014. He's involved in about ten TPC per year, and has been area editor for Ad Hoc Networks since 2018. He has been associate editor for IEEE Communications Letters and guest editor for Computer Communications and Eurasip JWCN. His research interests encompass distributed algorithms, wireless networking, experimental evaluation, and industrial networks.

Xavi Vilajosana received his B.Sc./M.Sc. Degree in Computer Science Engineering in 2004 from the Universitat Politècnica de Catalunya and Ph.D. degree in Computer Science and Distributed Systems in 2009, from the Universitat Oberta de Catalunya (UOC). He is a Full Professor at the Computer Science, Multimedia and Telecommunications department and a Principal Investigator at the Wireless Networks Research Lab (WiNe), at the Universitat Oberta de Catalunya (UOC).

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