Wireless Protocols in Device Communication in the Industrial Internet of Things: Systematic Review

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Abstract. The technological revolution proposed by the Internet of Things (IoT) allows interconnections between users, devices, and the internet. Regarding Industries, the interconnection between devices, industrial applications, and computer networks is called the Industrial Internet of Things (IIoT). Industrial environments present a particular scenario regarding the difficulties faced concerning wireless data exchange between devices. This article proposes an examination of the state of the art of wireless communication protocols used in industry 4.0 through the systematic literature review (SLR), where 10 papers were selected (from 179) to answer the research questions. As the main results of this review, we can mention the summary of the main characteristics of wireless communication protocols applied in the industry, an overview of the principal authors in this area (43 authors), and a summary of the main challenges. Among the main challenges are the optimization problem related to interference and noise in the different industrial environments, the impact on communication between wireless devices due to physical obstacles, and the natural restriction of resources concerning IoT and IIoT devices. Another challenge is the few protocols aimed at the industry that support IPV6. In this review, we identified a tendency to increase interest in this field of research as well as present open fields and opportunities, such as the development of lightweight protocols for devices with severe resource limitations, the need for solutions aimed at observability IIoT devices, and strategies aimed at minimizing the impacts of interference in wireless IIoT communications.

Keywords: Industrial Internet of Things (IIoT) · Industry 4.0 · Systematic literature review (SLR) · Wireless

1 Introduction

As Its name suggests, IIoT concerns the possible applications of IoT for the industrial area. This application of the IoT predicts the decentralization of indus-

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trial processes while requiring an interconnection of these systems [10]. Thus, to proposing to carry applications in IoT to Industrial context, must be necessary to consider the increase in complexity related to specific industrial processes considering the needs related to scalability, according to the industry's growth itself [10]. So, It's important to think about a real impact in terms of resources and capital.

Nevertheless, IIoT should not be restricted to traditional data collection or simple automation, but be a means for exponentiating processes by also using more accurate real-time data analysis for industry and business [10]. On therms of accurate, real-time analysis of production, will be working based on data collected at the moment and thus generate up-to-orientated production data. The benefits of this type of industry are also understood by the production of traceable objects, whose raw materials are localized, as well as its defects and causes of low quality [10].

In this sense, it is observed that not only a physical structure in the sense of machinery or human resources but the need to think at a network structure that enables the realization of the IoT industry model is created. Based on changes in industry requirements and in huge demand for bandwidth, speed, data consumption, data analysis, and use of this data, at the level of great industries and its production it is necessary to implement protocols and technologies that can cover the needs of the market, since the connection with wires, in this proportion, is unthinkable [8]. During the systematic review, some challenges were found in the area of IIoT, among them, is the lack of compatibility between protocols used in the industry environment with Internet Protocol version 6 (IPv6). In this sense, the article [13] brings a proposal to develop a new solution with hardware that does the translation from IPv6 to Industrial Wireless networks that cannot communicate through this protocol.

Using this solution, it's possible to improve the communication and monitoring of applications within the network and make it compatible with networks that use the IPv6 protocol. Another challenge faced it's about identifier security related issues in wireless protocols in natural restriction of resources concerning IoT and IIoT devices, [7] proposes a Lightweight & Secure Industrial IoT Communications via the MQ Telemetry Transport Protocol, where Message Queue Telemetry Transport (MQTT) is used as a lightweight protocol suitable for the industrial domain. Then are evaluated different security mechanisms used to protect the MQTT-enabled interactions on a real testbed of wireless sensor motes.

Also, we identified the most frequent challenge presented is related to interference and noise problems in the different industrial environments. In this sense, [1] shows some challenges and issues in a real implementation for smart production in the context of Wireless connectivity in Industrial sensor and control networks. They propose an implementation of a LoRaWAN, a low-cost solution for the industry with a wireless solution.

This paper presents a systematic literature review (SLR), aiming to understand state of the art and related trends as wireless communication protocols in the context of the Industrial Internet of Things (IIoT). Section 2 presents the

main aspects of the methodology, adopted for the present review, while Sect. 3 presents the results of the review method. The results are discussed in Sect. 3. Finally, Section 4 presents the conclusions, limitations, and future work.

2 Methodology

This study proposes a systematic literature review (SLR), for which the conduction was carried according to the process that Kitchenham [8] proposed. The SLR was conducted aiming to identify and analyze the state of the art of wireless protocols used in the communication of IIoT devices. The steps to carry out this research was as follow: defined the guiding questions, defined a search string, set criteria for inclusion and exclude studies according to a quality assessment (of what is sought), and, finally, put the steps into practice for the collection and selection of articles in the area in question. Then, the detailed explanation of the steps taken follows:

2.1 Research Questions

The following research questions guided this review:

- RQ1. What are the main characteristics of IIoT-based wireless communication protocols in the industry?
- RQ2. What are the challenges and opportunities related to IoT-based monitoring applications in the industry?
- RQ3. Who are the main authors of works in the area of wireless communication protocols in IIoT?

The main characteristics investigated in RQ1 were to identify the protocols used in the link and application layers and the communication architectures used specifically in wireless communication. RQ2 allowed the analysis of the relevance of the considered works and, in this sense, understanding of the demands that are still needing investigation in the area. On the other hand, RQ3 allowed the development of a more accurate study about the context to the analysis of the articles was not superficial and without foundation.

2.2 Search Process

The database used for the selection of studies was Scopus (Elsevier), once it indexes the main databases in the computing area.

To define the search string the terms collected through the exploratory stage of the search were used. The main objective was to obtain the largest number of papers related to the application of wireless communications in the industry. Thus, the search string used was ((“protocol” OR “protocols”) AND (“iiot” OR “industrial internet of things”) AND “wireless”).

2.3 Inclusion and Exclusion Criteria

This investigation included researches published from 2017 to 2021, fully available in the searched databases, peer-reviewed, and whose abstract has presented all the following items: context, objective, method, and results. The research excluded papers published as short articles, studies with unclear research questions, process, and also unclear data extraction process. In addition to that, it also excluded duplicate studies, studies in languages other than English, papers not accessible from free of charge, and those studies that did not identify the protocols used in wireless communication.

2.4 Quality Assessment

The studies were analyzed according to the quality assessment criteria defined according to Dyba [4] guidelines. The quality assessment criteria were described below.

- QA1. Is there a clear statement of the aims of the research?
- QA2. Is there an adequate description of the context in which the research was carried out?
- QA3. Is the study of value for research or practice?
- QA4. Is there a clear statement of findings?

Each study was evaluated from the perspective of the 4 assessment questions cited receiving the following score: 0 if the study does not meet the criteria, 0.5 if the article partially satisfies the criteria, and 1 if the study completely meets the criteria.

2.5 Data Collection

The principal data extracted from the studies were: title, authors, objectives, application protocols, wireless protocols applied, hardware platform, network topology, challenges, opportunities, and additional comments.

3 Results

This section presents the main results of the review, a summary of the studies used to answer the research questions, and the results of the quality assessment of the studies.

3.1 Search Results

Since the search string was applied in the Scopus database, 179 papers (stage 1) resulted. We read titles (stage 2), of which we adhered to 57 titles. In stage 3, we read abstracts, in which 10 studies returned. Finally, the 10 studies returned in stage 4 were read in full to answer the research questions.

Figure 1 demonstrates the selection process. The results of the data extraction of the 10 studies are presented in https://cutt.ly/MlpZdkn. Table 1 shows the studies considered useful to answer the research questions (Stage 4).

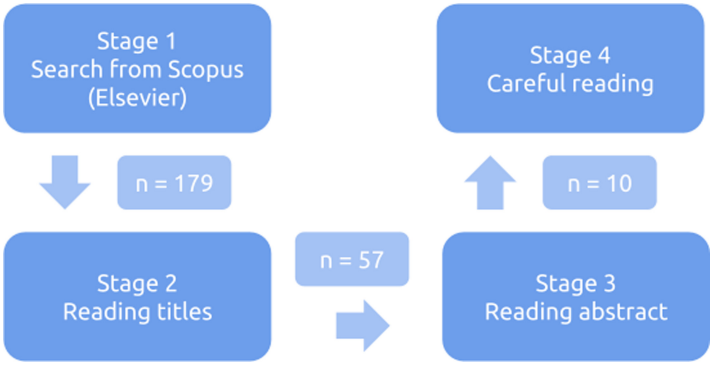

Fig. 1. Stages of the selection process.

Table 1. 10 studies object of step 4 - Careful reading.

Id	Author	Year	Venue
T1	Van Leemput D., et al.	2021	Journal
T2	Seo H., et al.	2021	Journal
T3	Hermeto R.T., et al.	2019	Journal
T4	Lino M. T. et al.	2020	Journal
T5	Ahmed A., et al.	2020	Conference Paper
T6	Karaagac A, L. et al.	2020	Journal
T7	Suresh Babu B, X. et al.	2020	Journal
T8	Wei M., et al.	2020	Conference Paper
T9	Wu H.-T., et al.	2019	Conference Paper
T10	Katsikeas S., et al.	2017	Conference Paper

3.2 Overview of Studies

Considering the origin of the selected studies, 60% of them were from journals and 40% from conferences.

Figure 2 shows that there is a tendency to increase interest in publications.

Figure 3 presents the main technology stack wireless communication standards identified in the included papers. The technology view was organized into three layers based on TCP/IP model: i) Application layer, ii) Communication layer, iii) Device layer.

Discussion

In this section, answers to research questions and review limitations will be discussed.

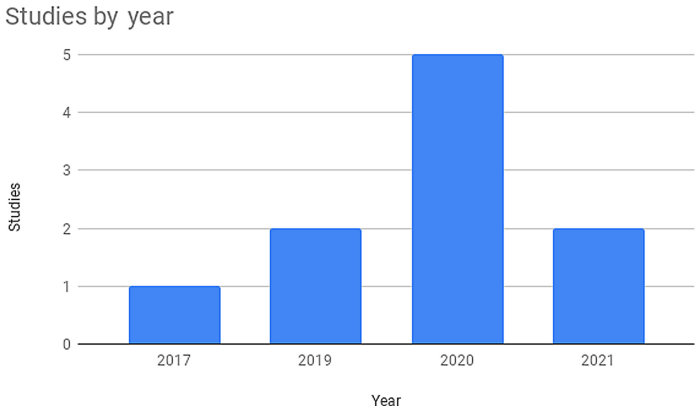

Fig. 2. Stages of the selection process.

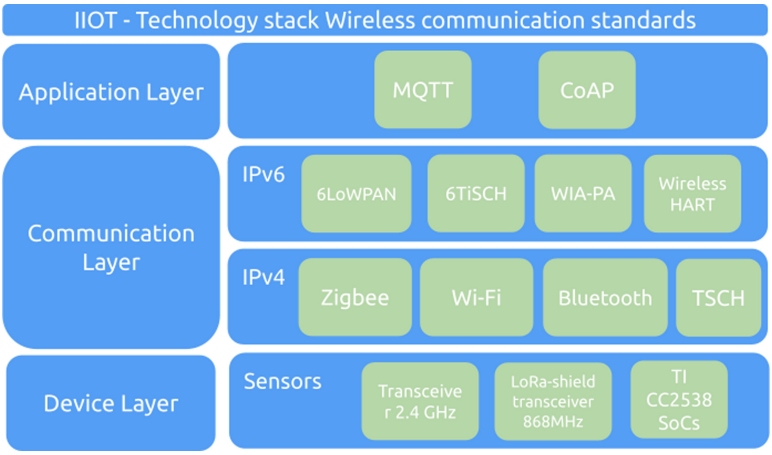

Fig. 3. Technology stack wireless communication standards.

3.3 RQ1. What are the Main Characteristics of IIoT-Based Wireless Comunication Protocols in the Industry?

According to Damasevicius [3], IoT applications have brought great advances in several segments, including in the industrial area. These IoT devices, in general, are adopted as a means of data transmission by the use of some wireless communication protocols. In Table 2, we can see the protocols that are currently used by IoT applications according to Damasevicius [3].

Table 2. Communication protocols used in IoT applications.

1	Wireless Fidelity (WiFi)
2	Near Field Communication (NFC)
3	ZigBee
4	Z-Wave
5	Bluetooth
6	Radio Frequency Identification (RFID)

Next, we can observe the application and communication protocols that are most used in IIoT-based applications

Application Protocols. Regarding the application protocols used, Whei [13] uses CoAP (Constrained Application Protocol) to demonstrate an IEEE 802.15.4-2015 TSCH industrial IoT implementation. Wu [14] uses Highlights the Message Queue Telemetry Transport (MQTT) to evaluate different security mechanisms while Ahmed [1] proposes the implementation of a LoRaWAN through a low-cost solution for the industry.

Wireless and Communication Protocols. About the wireless communication protocols used in the studies, 70% of the articles use variations of the Zigbee IEEE 802.15.4 protocol with time Slotted Channel Hopping(TSCH). In [5] Hermeto uses Zigbee IEEE 802.15.4 with 6TiSCH. Table 3 shows the frequency of occurrence of wireless protocols in the studies indicated.

Proposed Algorithms and Protocols. Among the 10 articles analyzed, 8 of them had new implementations of solutions. These solutions are divided between applications with hardware and communication protocols. For the applications, two of the studies worked on development: in the first one, proposed by Ahmed [1], we have a factory monitoring using Arduinos with sensors connected to it, wherein its infrastructure communicates through LoRa-Shields sending its data to a Raspberry Pi, which acts as a gateway to send data to the application server. In the second application, proposed by Wei [13], the hardware developed allows wireless IIoT networks to communicate with the application servers through the Internet Protocol version 6 (IPv6). For the new protocols developed, we have the following solution: Van Leemput [12] brings the creation of TSCH MAC, which modifies an existing protocol TSCH, implementing a new Multi-PHY transmission. Seo [11] proposes a new distributed consensus protocol that is more tolerant of transmission failures. For Lino [9] we have a new communication model (DyRET algorithm), using the Load-SDA algorithm and CSMA-CA protocol. Karaagac [6] brings an implementation proposal based on In-Band Network Telemetry and applicable, mainly, to the 6TiSCH protocol, but it can also be used in 802.15.4e-like TSCH-based. Finally, Babu [2] proposes

Table 3. Frequency of occurrence of wireless protocols.

Protocol	Studies	Frequency
802.15.4	T1, T3, T4, T6, T7, T9, T10	7
LoRaWAN	T5, 10	2
WirelessHART	T8	1
WIA-PA	T8	1
Bluetooth	T2	1

a new algorithm "REES Model" associated with the TSCH protocol, which can provide high traffic applications without affecting the power consumption of devices on a MANET network, with the ability to activate or deactivate additional slots dynamically, without the need to rearrange new schedules according to the protocol.

Hardware Platforms. Seo H. [11] uses a platform with Bluetooth-based communication. Ahmed [1] uses a hardware platform based on Arduino-Uno and LoRa-shield transceiver. Karaagac [6] proposes a solution based on In-Band Network Telemetry and applicable to the 6TiSCH protocol using the Zolertia Remote platform through ZigBee.

Communication Topologies. The main communication topologies identified in this review were 1) Wireless communication between sensors and a central node [1,2,4,6] e [13] and Peer-to-peer [5] e [6].

3.4 RQ2. What are the Challenges and Opportunities Related to IoT-Based Monitoring Applications in the Industry?

In general, there was a great need for studies and implementations in the area, given the diverse nature of the difficulties encountered. They extend from the communication of industry bodies with *business*, focusing on monitoring; the improvement of collected data, and ways of using that data, in addition to improvements on the internet within the industry itself. Such diversity shows that the problems are multiple and dispersed.

As for the difficulties from which the works arose, there are more general challenges such as the optimization of problematic factors in the different environments. 30% of the studies were concerned with this issue, while 20% of which focused on factories, or, still, on development network structure based on IPV6. Emphasizing that every research is in the scope of improving the forms of the wireless connection in IIoT.

Article [6] when dealing with the challenges that the non-IP industrial wireless network faces when trying to access IPV6, presents one of the challenges that are quite different from the others. In it, the author cites the problem that

few protocols aimed at the industry support IPV6, although there are efforts to overcome this barrier. In this sense, the main challenges for this purpose are listed, namely: the difficulty of carrying out both the development and the implementation of systems for wireless networks for IPV6 at the industrial level, due to the scarcity of wireless networks with IPv6 IoT; the difficulty of obtaining gateways for industrial wireless networks and the impossibility of IPv6 access "in the northbound"; and, yet, the possible inconsistency of deterministic data on the IPv6 internet. Although the future proposals are clear in this case, two different results were obtained for the challenge in question.

Articles [5] and [6] will focus on difficulties within the scope of monitoring what happens in the industry, with IIoT techniques both for disaster prevention and for better monitoring of production - respectively. Thus, while article I3 is part of the search for greater resource savings, [6] is part of articles [1,9,12, 14] when seeking to improve performance. Article [5] proposes for future work an improvement in the mechanism on which it is based, suggesting that the network be stabilized by merging or integrating data. On the other hand, [6] offers a less punctual proposal when suggesting the development of network management systems in search of a more flexible and reconfigurable industrial wireless solution.

The research presented in [5] aims to monitor IoT devices, taking into account the focus in terms of security. Article [7], on the other hand, is focused on applying the security of the network itself and not physical spaces. This same article points out the limitation of resources in embedded devices, which justifies the difficulty of finding alternatives for secure wireless protocols. Furthermore, it also cites interoperability, due to the unified character of the IoT, as one of the main challenges.

Table 4 summarizes the main challenges of the subject found in this review, as well as some of the solutions presented:

3.5 RQ3. Who are the Main Authors of Works in the Area of Wireless Communication Protocols in IIoT?

In this review, 43 authors working in the area of wireless protocols for IIoT were identified. Of these, 3 authors (Poorter E; Hoebeke J; and Li C.) appear more frequently (2 papers each). Of the articles included, the article [7] Katsikeas S. was the one with the highest number of citations (34) (Fig. 4).

The distribution of articles published by the institution was: Université de Strasbourg (4), CNRS Center National de la Recherche Scientifique (2), INRIA Institut National de Recherche en Informatique et en Automatique (2), Universiteit Gent (2), Center for Wireless Communications Finland (1), National Taipei University of Technology (1), Oulun Yliopisto (1), Seoul National University (1), Infineon Technologies AG, Austria (1), Deakin University (1), Foundation for Research and Technology-Hellas (1), Technical University of Munich (1), Technical University of Crete (1), Institut de Recherche en Informatique et Systèmes Aléatoires (1), Korea Advanced Institute of Science & Technology (1),

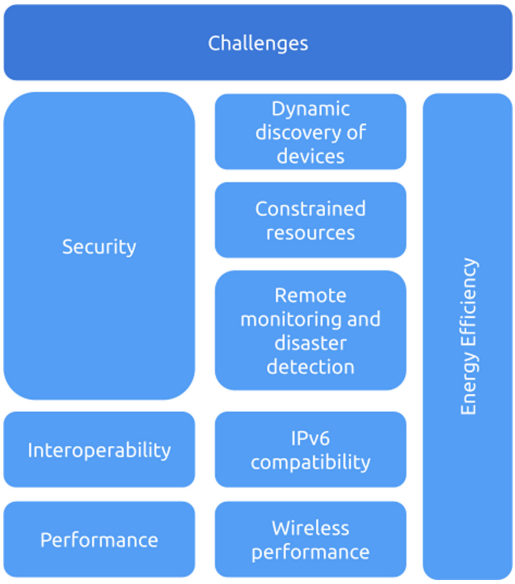

Fig. 4. Main challenges.

Table 4. Challenges summary

Challenges summary	
Challenges	Solutions
IIoT wireless communication systems vulnerable to interference due to heterogeneous environments	Implementation of a low-cost solution for the industry with a wireless solution and evaluating the stability of the performance of different protocols
IoT devices that are resource-constrained and do not support security implementations, such as using commonly used protocols	Implementation of lightweight variants of security protocols
Efficient and remote monitoring in industrial wireless sensor networks, including at the time of critical events	Design of a flexible, intelligent and efficient architecture for IIoT monitoring. Telemetry solution with powerful bandwidth, minimized use of resources and communication overhead
Interoperability and optimization of communication link between devices	Implement new protocols, automatically adaptable link layer between channels
IPv6 compatibility	Develop a protocol for IIoT networks that supports IPv6
Implementation of dynamic discovery of devices with limited resources	Large-scale dynamic reconfiguration for ZigBee-based wireless sensor cluster tree networks

IMT Atlantique (1), International Hellenic University (1). The institution that published the most was the Université de Strasbourg, appearing 4 times.

Figure 5 represents the distribution of articles between countries.

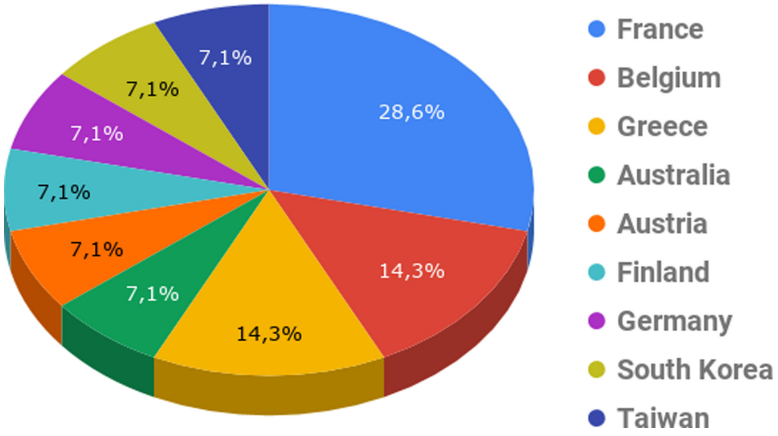

Fig. 5. Distribution of publications by country of origin.

3.6 Limitations of This Review

The main related limitations of this review include bias during the study selection and data extraction steps. As a way to remove the bias from these processes, we strictly followed the protocol described in Sect. 2 and did the review with 5 reviewers. Another limitation of this research was the inclusion of studies in English only since publications made only in other languages may have been omitted. As a final limitation of this review, we can mention the time of conducting the review, in which some new publications may have been made and not included.

4 Conclusions and Future Work

This research presented a systematic review of the literature carried out to identify the main applications of wireless communication protocols in the context of the industrial internet of things as well as the main challenges and gaps. For this, the steps described in Sect. 2 were strictly followed, in which 179 studies were returned from the search string. After the selection processes, data were extracted from the careful reading of 10 complete searches between articles in journals and conferences. Based on the extracted data, we were able to answer the research questions summarizing the main characteristics of wireless communications and protocols used in IIoT, as well as the main challenges in this

field and which the main authors are researching in this area. In this review, 43 authors working in the area of wireless protocols for IIoT were identified. About the wireless communication protocols used in the papers, 70% of the articles use variations of the Zigbee IEEE 802.15.4. From the distribution of studies per year, it was possible to infer that there is a continuous trend of increasing interest in research in this area. As main contributions, we can mention the compilation of the main challenges and the development of a technology view that summarizes the main standards and protocols used. In future work, we will present the development of a solution that addresses the mentioned challenge of dynamic discovery of IIoT devices safely and efficiently in terms of energy consumption.

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