

4th International Conference on Industry 4.0 and Smart Manufacturing

5G in Logistics 4.0: potential applications and challenges

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Abstract

The transition of logistics processes towards Logistics 4.0 (or Smart Logistics) – the specific application of Industry 4.0 in the logistics systems – contributes to the increasing need to establish reliable and efficient communication networks, to manage considerable amounts of data exchange between equipment, products, vehicles and workers. The combination of the Internet of Things (IoT), big data, cloud computing, and artificial intelligence, allows improvements and optimisation in many logistics processes, but claims for advanced stable real-time communication. The fifth generation of Mobile Communication Networks, the so-called 5G, has the potential to meet these requirements and substantially support the development of Smart Logistics. Through a systematic literature review, this paper aims to identify the main logistics areas and activities in which 5G can be implemented, pointing out the expected benefits and the related technologies that can boost its large-scale adoption. The literature review also allows identifying the main challenges that currently prevent the 5G adoption in logistics processes, suggesting future research directions.

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Peer-review under responsibility of the scientific committee of the 4th International Conference on Industry 4.0 and Smart Manufacturing

Keywords: 5G; Logistics 4.0; 5G networks; Wireless communication network; Smart logistics.

1. Introduction

Manufacturing and logistics systems are evolving rapidly, thanks to the introduction of digital and automation technologies that are revolutionising the way in which we manage assets, materials and the workforce. The paradigm of Industry 4.0 paved the way for the concepts of Logistics 4.0 and Smart Logistics that are now commonly and interchangeably used to identify the specific application of Industry 4.0 in the logistics systems in order to provide the sustainable satisfaction of individualised customer demands without increasing costs [1]. Indeed, the introduction of

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digital technologies for managing material and information flows has recently promoted the development of more efficient logistics systems and supply chains at large.

Since the backbone of Industry 4.0 is the availability of a huge variety of data from multiple sources, data collection and management cover a major role also in the Logistics 4.0 field, claiming for increasing technical and analytical efforts to improve data flows management and exploitation. In particular, the introduction of the Internet of Things (IoT) in logistics management concurs with the implementation of highly transparent processes characterized by integrity control and dynamic reconfiguration of the networks based on real-time communication and collaboration [2]. The combination of IoT and other technologies, such as big data, cloud computing, and artificial intelligence, allows considerable improvements and optimization in many logistics processes, e.g., freight transportation, warehousing, and delivery [3].

Recently, in parallel with the advances in manufacturing and logistics systems, also Wireless Communication Networks (WCN) went through an evolution, with the formalization of emerging technologies for boosting the data exchange in multiple sectors, ranging from the entertainment, the public safety, the smart cities and finally in the industrial field. The last WCN communication generation, the 5G network, has been released starting from 2019, covering the main limitations of the previous standard, the 4G, offering disruptive possibilities in the data exchange thanks to the enhanced Mobile Broadband (eMBB), the massive Machine Type Communication (mMTC), and the Ultra-Reliable Low Latency Communication (URLLC) [4].

Although some 5G applications are already well-established in the consumer market, such as cloud gaming and entertainment video streaming, they do not occur in the industry, particularly in the logistics systems. First applications have been envisioned and tested in a few academic laboratories and industrial companies, but we are still far from worldwide adoption of the 5G networks. Next to the potential of optimizing manufacturing and logistics processes, currently, some challenges remain open and prevent companies from investing in 5G [5]. Further investigation at academic and managerial levels is required to allow a better acceptance and adoption of the technology in the industrial context. Indeed, few contributions systematically assessing the potential application of 5G in manufacturing context, such as [5], can be found. Nevertheless, specific in-depth analysis and systematic reviews of the literature about the relationships between 5G and industrial logistics application are still missing.

To cover this gap, the main objectives of this work can be summarized in the following research questions:

RQ1. Which are the potential applications of 5G networks in industrial logistics?

RQ2. Which are the challenges and barriers that currently prevent companies from adopting 5G in logistics processes?

For answering these questions, this paper aims to explore the potential application of 5G network in industrial logistics based on a systematic literature review (SLR). Through the bibliometric and content analysis of the extant literature, this research aims to identify the main logistics area in which 5G could be successfully applied, shedding light on the expected benefits and the related technologies useful to promote more integrated Logistics 4.0 scenarios. At the same time, this study aims to collect and classify the main barriers and challenges that currently prevent the wide adoption of 5G to propose future research and development directions for academia and practitioners.

The paper is structured as follows. Section 2 will provide background about the 5G technology, describing the main technical features that can improve logistics activities. Section 3 explains the methodology used to perform the systematic literature review, detailing all the steps of the research workflow. Section 4 presents the results of the SLR, providing a discussion of the main contents of the analyzed papers in terms of logistics applications and industrial cases. Finally, Section 6 will discuss the expected benefits of 5G and the challenges to its implementation. Section 7 concludes the paper with final remarks, limitations and further research paths.

2. Background and motivation

In the last years, the advances in the development of Information and Communication Technologies and tools for industry promoted the transition from traditional manufacturing and logistics systems to Industry 4.0 and Logistics 4.0. Such scenarios require the interconnection of equipment, materials, vehicles, tools, and workers, and generally have strong requirements for large-scale connection and real-time communication [5]. In particular, Logistics 4.0 relies on digital technologies such as the Internet of Things, Cyber-physical systems, Big data-based systems and Cloud-based systems to efficiently fulfil the demanding customers' requirements in terms of delivery dates and lead

times [6]. Logistics 4.0 applications mainly concern the implementation of autonomous systems and robots for material handling, the adoption of identification and traceability solutions, and the implementation of decision-support tools to enhance logistics management at large [7]. For these purposes, highly reliable communication networks must be established inside and outside the factories, supporting inbound and outbound logistics 4.0 activities.

Currently, industrial networks are based on the integration of complex heterogeneous systems. About 90% of industrial communication is based on wired technologies, such as EtherNet, PROFINET, and ModbusTCP protocols, while wireless communication such as the one offered by Wi-fi are becoming increasingly attractive only in recent years supporting the requirements of reconfigurability and modularity in modern factories [8]. The 5G constitutes the latest generation of mobile communication technology developed to upgrade the reliability and speed of data exchange and represents a significant leap forward in the world of telecommunications in industrial systems. The main features of this new technology can be summarized as follows [4, 9, 10]:

- The data speed turns out to be much higher compared to 4G. The maximum theoretical speed will be 10 Gbps (Gigabits per second), thus allowing a huge quantity of data to be transferred and handled simultaneously.
- Ultra-Reliable Low-Latency Communication will allow ultra-responsive connections. Latencies of less than 1 millisecond will be reached and ultra-high reliability (up to 99.999%) and network availability are guaranteed.
- Power consumption is lower compared to previous technologies. "Stand-by" (sleep) modes can be used to save up to 50% energy, compared to the maximum 20% savings of 4G technology.
- Connection density, i.e., the number of devices connected simultaneously and the data flow that can be handled, is around one million connections per square kilometre.
- 5G frequencies will exploit new enlarged spectrum bands, i.e., possible frequency bands ranging from 30 GHz to 300 GHz.

Considering the abovementioned characteristics, 5G has the potential to support smart logistics processes concerning the possibility to increase the intelligence in managing and coordinating material flows, enhancing the visibility and transparency for improving logistics and supply chain control, and finally concurring to the creation of resilient and reconfigurable networks for supply management. Nevertheless, 5G in Logistics 4.0 is still under-researched, and few industrial applications exist, thus requiring further investigation.

3. Methodology

A systematic literature review (SLR) has been chosen as a method for this work because of the innovative nature of its goal, which is to understand the role of 5G networks in logistics by evaluating the main benefits and barriers. A literature review can be viewed as "systematic" if it "is based on clearly formulated questions, identifies relevant studies, appraises their quality, and summarizes the evidence by use of the explicit methodology" [11]. Moreover, an SLR provides a replicable research protocol with a detailed description of the performed steps within the SLR, which enables an in-depth evaluation of the conducted study. This research has been made according with the guidelines proposed by [11] and in particular, a three-step protocol has been followed to guarantee a correct procedure for performing automated research, ensuring its replicability [12]. This section thoroughly defines the inclusion/exclusion criteria (Section 2.1), paper-selection criteria based on titles and abstracts (Section 2.2) and the final selections based on reading the full texts and the snowballing approach (Section 2.3).

3.1. Inclusion/exclusion criteria

First, a list of keywords and inclusion criteria was created. The research focused on papers published in refereed journals in logistics, operations, management and economics. We decided to start the period of the analysis in 2019, since the Release 15, namely the first full set of 5G standards, has been delivered at the end of 2018 [13]. Conference proceedings and grey literature (i.e., technical reports and works in progress) were included in the corpus of collected papers considering the topic's novelty. Therefore, the review was limited to peer-reviewed publications to maintain homogeneity among the papers in the corpus [11], gain consistency across themes and sources and ensure the selected papers' quality [14]. The search was conducted based on the list of keywords and inclusion criteria summarized in Table 1. The SCOPUS database was used in the analysis because most academics recognize it as one of the most

complete bibliometric databases of scientific and technical peer-reviewed literature [15]. The query was launched, resulting in the extraction of an initial corpus of 187 papers.

3.2. Paper selection based on titles and abstracts

Each of the three researchers involved in this study reviewed the title and abstract of each paper in the selection. Following discussions, the authors removed papers from the corpus that lay outside the research scope. In particular, excluded papers focused too much on peculiar fields such as agriculture, ports, airports, and healthcare. Also, the papers mainly focused on production and manufacturing that only refers to logistics in an approximate way, without analyzing logistics processes, tasks and applications have been excluded. After title and abstract reading, only 24 papers remain in the analyzed corpus.

Table 1. Systematic literature review inclusion criteria

Inclusion Criteria	Description
<i>Keywords</i>	5G* AND logistic* AND NOT Logistic* regression*
<i>Language</i>	English
<i>Document types</i>	Articles, Conference and Grey Literature
<i>Source types</i>	Peer-Reviewed Journals, Conference and Grey Literature
<i>Subject areas</i>	Business, Management, Accounting; Engineering; Computer Science; Decision Sciences
<i>Time interval</i>	2019 – 2022 (*partial)

3.3. Paper selection based on reading full texts and the snowballing approach

The final step of the protocol entailed refining the list of selected papers. The authors read the full versions of the candidate papers and then excluded 2 papers that lay outside the scope of the research. At this point, a corpus of 22 papers had been analyzed. After that, a forward and backward snowballing process was conducted, yielding a final corpus of 25 papers. Backward snowballing exploits the reference list to identify potential new papers to be included.



Fig. 1. SLR results according to the selection protocol that the authors performed

The authors read titles, abstracts and full papers if necessary and then decided whether to include them in the final corpus. Forward snowballing identifies new papers starting from analyzing papers that cited the ones contained in the first corpus. The approach to going through the papers is similar to the backward method [16]. The two procedures were iterated until no new papers were found (Fig. 1).

4. Results

4.1. Bibliometric analysis

The final corpus comprises 25 papers, 15 published in Journals and 10 published as Conference Proceedings. The presence of such a large number of conference papers makes us realize that the subject matter is not yet well established.

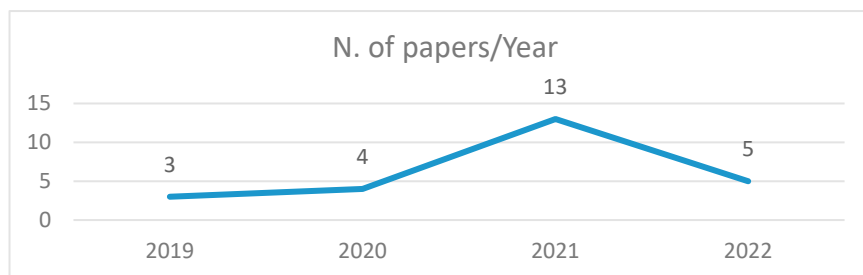


Fig. 2. Number of papers in the corpus per year (* = partial year)

In addition, most of the journals and conferences considered are related to technological innovations in the industrial and manufacturing environment, and not directly related to logistics applications.

However, as it is possible to observe from Fig. 2, there has been an increasing interest in the 5G application in the logistics field in recent years.

From the perspective of the geographic distribution of papers, based on the nation of the affiliation of the first author of each paper, we see a clear dominance of China that, thanks in part to a large number of domestic communications and ICT companies and the push of government investment in this direction, has begun to develop different types of applications for 5G technology. It can be seen from Fig. 3 that significant interest in 5G applications in logistics has also developed in India and Spain. Again, the motivation lies in the decision by some of India's leading companies to invest in 5G and the Spanish government's decision to give incentives to domestic companies that make modernization investments in this technology. Other countries (i.e., Germany, Taiwan, Belgium, Greece, Australia, South Korea, Chile, Canada and Germany) figure in the paper list with only one paper.



Fig. 3. Number of papers in the corpus per Country

4.2. Topics

The first significant distinction found within the papers in the corpus concerns the areas of application of 5G in logistics. It can be observed that 9 papers refer to internal logistics and 16 papers refer to external logistics. The term internal logistics (or inbound logistics) refers to all handling and storage activities of raw materials, work in progress, and finished goods that take place within the factory boundaries (i.e., picking, handling, packing, warehousing) while the term external logistics (or outbound logistics) refers to all transportation and supply chain management activities that take place outside the factory (i.e., supplier management, shipment management, vehicle and order tracking) [17]. Within internal logistics, two areas of investigation can be further distinguished: material handling and warehousing (Fig. 4a). Regarding warehousing, only two papers in the corpus deal with the topic, and both refer to the possible use of drones to perform warehouse inventory activities: 5G networks, in facts, allow drones to travel longer distances

without losing the signal [18, 19]. On the other hand, as far as material handling is concerned, excluding two literature reviews that refer to the uses of 5G in internal logistics (and specifically on material handling) [5, 20], the two main topics discussed are autonomous guided vehicles [21–24] and "vehicles-to-everything" [25], which is a concept similar to the internet of things but related to the connection of vehicles (both traditionally and autonomously driven) to other elements (e.g., machinery, racking, portals) in the factory.

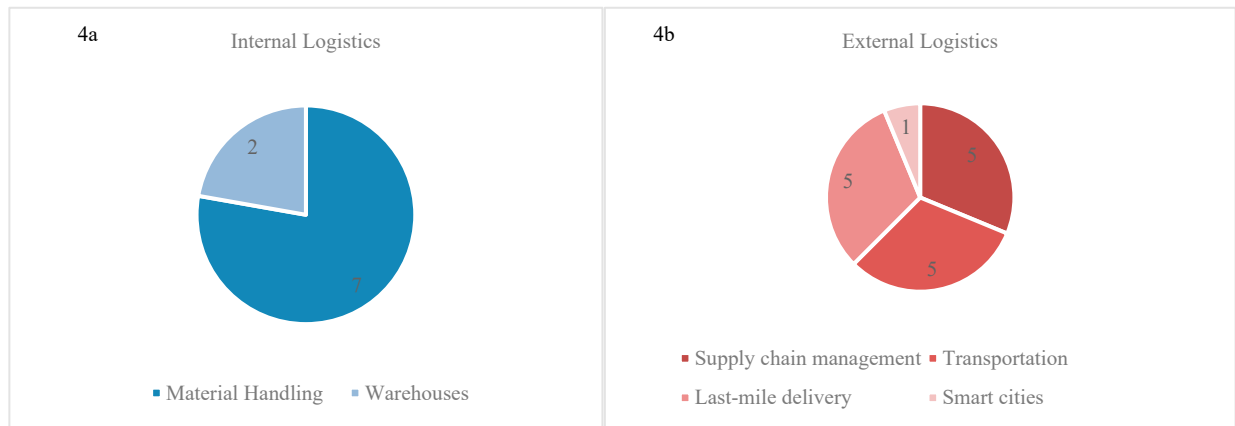


Fig. 4. Papers related to Internal (4a) and External Logistics (4b)

For external logistics, on the other hand, the topics covered are supply chains, transportation, last-mile delivery and smart cities (Fig. 4b). Although the keywords used were related to logistics and not supply chains, several articles deal with supply chains and transportation. This is because these articles mainly deal with 5G implementations that can be used in both external and internal logistics, and mainly refer to product and vehicle traceability.

Among the articles that explicitly refer to the supply chain, one is a literature review [10], and one deals with the topic of traceability along the supply chain in order to optimise the coordination between transporters and customers when receiving goods (e.g. transportation management systems, appointments for loading/unloading actions) [20] and three articles refer to applications of 5G in the fresh and cold chain to ensure the monitoring of product temperatures at all different stages of the supply chain [26–28].

The articles dealing with transportation are all related to the traceability of both parcels and vehicles, in particular concerning various critical issues concerning mainly cyber security [29, 30] and the need to integrate different technologies, databases and formats [31, 32] even among different countries [33].

Five papers refer to last-mile logistics, and even though they deal with topics that also appear in other areas, it was decided to create a separate category since these papers have their own focus on last-mile logistics. In particular, two papers deal with the use of drones for urban [34] and rural deliveries [35] and how 5G can improve the performance of this type of solution. The other three articles, on the other hand, deal with the optimization of parcel and vehicle traceability [36] and with transportation management systems software [37] that, integrated with sensors on parcels and vehicles, open up the possibility of implementing new urban logistics solutions such as delivery ridesharing [38]. Finally, an article discusses how a smart city equipped with the infrastructure to ensure an adequate energy supply and full 5G network coverage can enable the implementation of various services related to transport, logistics, and real-time tracking of vehicles and products, such as deliveries in urban areas with autonomous robots [39].

4.3. Technologies

The analyzed literature shows strong links between the 5G and other main enabling technologies of Logistics 4.0 exists. Among these, two main sets of technologies have been identified, i.e., technologies related to information flows and technologies related to material flows (Table 2).

The first category contains a wide variety of technologies, covering all the stages of the data value chain, i.e. data generation, acquisition, transportation, pre-processing, storage, and analytics [40]. Smart sensors and RFID are

employed in internal and external logistics to collect the most relevant parameters, such as temperature or humidity, that must be monitored to ensure the quality of goods during the storage and transportation phases [27, 28]. IoT is cited in almost all the papers as one of the pillars of Logistics 4.0 that can benefit the most from the 5G technology that enables massive, reliable and real-time data transmission from multiple devices, as required by the IoT manufacturing networks [5].

Table 2. Logistics 4.0 technologies related to 5G

Technologies related to information flows	Technologies related to material flows
IoT	Unmanned Aerial Vehicles (UAV)
Big data	Automated Guided Vehicles (AGV)
Smart sensors	Intelligent robotics
Microprocessors	
RFID	
Edge/ Cloud Computing	
Blockchain	
Artificial Intelligence	
Augmented Reality	
Simulation	

Embedded Microprocessors and Edge Computing are cited as promising technologies to perform efficient data-preprocessing combined to 5G: the first through the filtering of relevant information for the specific application and the latter through a decentralized computational model in which data, particularly critical from the most latency-sensitive applications, are analyzed directly where they are detected [33, 37]. Logistics companies use cloud systems as a platform for storing information [29] and, as highlighted by [5, 18, 26], Blockchain constitutes one of the most advanced and reliable technology to ensure the data security in distributed, open environments, in accordance to the requirements of 5G networks architectures. Finally, technologies for data analytics such as Machine Learning, Artificial Intelligence, Simulation, and Augmented Reality have been cited in research studies that exploit the 5G network to feed intelligent optimisation systems, able to leverage real-time data from equipment (e.g., drones and AGVs) to provide a timely decision about transportation routes, last-mile delivery, supply chain networks, malfunctioning recovery [21, 26, 34, 36, 37, 41].

The second category contains a limited number of technologies whose role is the automated handling and transportation of materials inside and outside the factory boundaries. Unmanned Aerial Vehicles, also referred to as drones, are expected to have a twofold relation with 5G. According to [18], 5G allows greater control of UAV trajectories, supports dense UAV connectivity, and orchestrates massive sea-air-ground communication networks. At the same time, drones can play an important role as nodes to receive data from the ground user equipment and transmit them to another base station of the 5G networks, thus adapting the flight path according to the data traffic load and assisting cellular networks [34]. Concerning AGVs, 5G can positively contribute to enhancing the remote control of vehicles and the vehicle-to-vehicle (V2V) communication, improving the current systems for collision avoidance in warehouses and putting forward new applications such as video surveillance [22, 31]. Finally, in the review paper by Cheng et al. [5], the integration of 5G with intelligent robot technologies is envisioned and applied to the shop floor logistics.

5. Discussion

The literature review results allow simultaneously identifying the main benefits and challenges in adopting 5G networks in Logistics 4.0. Fig. 5 depicts the main logistics applications that have been discussed, highlighting how they leverage on the three main features of 5G networks (i.e. enhanced broadband, massive connectivity, and low latency). The main expected benefits of adopting 5G in logistics concern the possibility to perform better monitoring and control of materials, logistics vehicles, personnel, and routes, in order to improve several aspects, including the real-time control of the warehouses' utilisation rate, the in-warehouse route optimisation, the SC supervision and tracking, the prediction of malfunctioning in AGVs. Considering the quality of service towards customers, 5G can enhance the efficiency in logistics delivery times and contribute to accurate monitoring of goods quality (particularly in food and cold chains) during all the logistics phases. All these benefits can be translated, in the mid-long term, into reduced labour costs due to the automation of handling, reduced transportation costs or, more generally, into better

resource utilisation (also due to the low power consumption) with consequent containment of the carbon emissions, towards more sustainable logistics management.

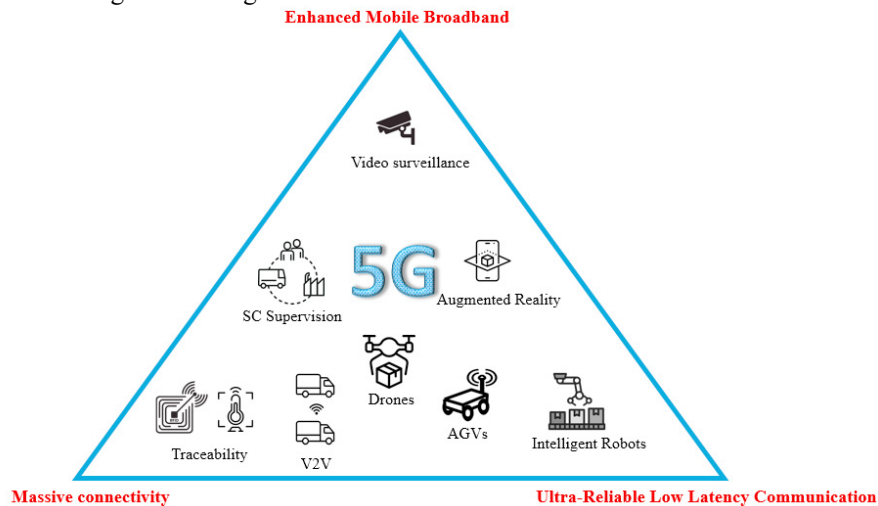


Fig. 5. Logistics application enhanced by 5G

However, it is not yet possible to fully enjoy all the benefits of this type of technology, as there are still many critical issues that were also highlighted by the papers analysed in the corpus reviewed.

In particular, the main challenges fall into the following three categories: integration with other technologies, cost, and issues related to privacy and security.

The critical issue currently holding back the expansion of 5G in enterprises is the problem of standards integration. In particular, [3] and [9] explore the difficulties due to the integration of 5G and other technologies such as AGVs, RFID sensors, Blockchain, and, generally, other ICT-related technologies. At the same time, [8] points out that the problem of standards integration is particularly critical in the case of adopting 5G in-vehicle in the case of crossing borders between different nations.

Solving the integration problems leads companies to make additional investments in ancillary technologies and training of their employees to increase skills in this area with a further increase in costs to bring the 5G network up to speed [17]. This cost is in addition to the already high costs involved in establishing a stable network infrastructure [14, 24] that requires a large number of 5G base stations and repeaters [10] that must be positioned so that they do not interfere with other elements located in the same environment and can provide complete coverage [11], especially in the case of a 5G network supporting unmanned vehicles such as drones [19] or AGVs [25].

Finally, it is necessary to highlight how 5G networks, by offering better accuracy in tracking and positioning of traditional or unmanned vehicles [2], also give rise to some issues related to the privacy of drivers [20] and the need to ensure the security of parcel and vehicle georeferencing data [22] through increasingly efficient cyber security measures [1] and Blockchain protocols [7, 25].

6. Conclusions

This paper explores the potential application of 5G network in industrial logistics based on a systematic literature review (SLR). The literature review outlines that several applications can be envisioned both in internal and external logistics, offering multiple opportunities to enhance the material and information flows toward more efficient, intelligent and sustainable logistics and supply chain management systems. However, few industrial applications of the 5G technology in logistics currently exist. This can be due to the fact that the integration of the 5G with other technologies is still complex and requires additional costs in workforce training in addition to the already high costs required to build a stable network infrastructure that provides full signal coverage. This research paper is an initial exploratory work on the possible applications of 5G networks in logistics and supply chains. It suffers from some limitations due to the small number of papers analysed, which are mostly theoretical. In the future, as the use of 5G

technology becomes more widespread, it will be possible to repeat the literature analysis on a more significant number of papers and begin to develop a larger number of both laboratory and industrial application cases to understand the fullest the possibilities of exploitation of the benefits of this type of technology in logistics.

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