5G-Enabled IIoT Framework Architecture Towards Sustainable Smart Manufacturing

https://doi.org/10.3991/ijoe.v18i04.27753

Fadwa Mahiri(✉), Aouatif Najoua, Souad Ben Souda
Signals, Distributed Systems, and Artificial Intelligence Laboratory,
Hassan II University of Casablanca, Casablanca, Morocco
fadwa.mahiri-etu@etu.univh2c.ma

Abstract—With the rapid growth of advanced technologies in the manufacturing sector, a revolution in manufacturing systems is underway and smart manufacturing and its sustainability is becoming the key components towards the fourth industrial revolution. In this context, the IIoT (industrial internet of things), represents a bridge between the digital and physical environment by providing an interactive relation between smart devices and machines also through data sharing. Therefore, it creates a working environment where decisions are made in real-time. The huge data amount generated through the manufacturing system, the high reliability, low latency, and high connectivity demands of IIoT-enabled intelligent manufacturing system requires an advanced wireless transmission technology that goes far beyond the 3rd and 4th generation mobile network. 5G is the most appropriate communication technology for this new IIoT enabled smart manufacturing system's requirements. Based on the requirements of sustainable smart manufacturing and the characteristics of the 5G wireless communication, this paper proposes a 5G-enabled IIoT framework architecture towards a sustainable smart manufacturing environment, that will allow the support of manufacturers and smart factories in the industrial 4.0 revolution. This is by improving while enhancing efficiency, process and product quality, and sustainability in the whole manufacturing system. Besides, the security threats and challenges of the 5G-IIoT enabled smart manufacturing are also analyzed.

Keywords—5G technology, industrial IoT, smart manufacturing, sustainability

1 Introduction

With the rise of advanced manufacturing technologies applications, such as big data, IoT (internet of things), edge and cloud computing, cyber-physical systems, and developed sensing technologies, the current manufacturing is experiencing drastic changes, and smart manufacturing is gaining a lot of manufacturer's attention, also the green trend of conserving the Earth's resources and protecting the environment is overwhelming as global awareness of environmental conservation grows [1]. Smart manufacturing goes beyond conventional manufacturing, it is innovative, networked, and service-oriented manufacturing. In this advanced production era, sustainability is also a more competitive approach in manufacturing. Elkington considers sustainability as the fragmented relationship between three sustainable dimensions: economic, social, and environmental [2].

Fig. 1. The triple bottom line [2]

For Zhang and Haapala [3], sustainable manufacturing is: "producing products in a way that minimizes environmental impacts and takes social responsibility for employees, the community and consumers throughout a product's lifecycle, while achieving economic benefits".

Moreover, a sustainable production lifecycle is comprised of four different interrelated phases:

First, the design of the product and production phase which consists of the early incorporation of sustainability in production processes and resources [4].

Second, the production planning phase which goes beyond minimization of inventory and meeting delivery time limit, to sustainable objectives like minimization of energy consumption, gas emissions, and safety [5].

In the third phase, the evaluation of local and global integrated systems from long- and short-time perspectives is made according to sustainable criteria [6].

The fourth phase is product recycling and remanufacturing in which the recovery is made according to sustainable indicators like the value of end-of-life. The products or part of products are collected, reconditioned reused, or recycled [7].

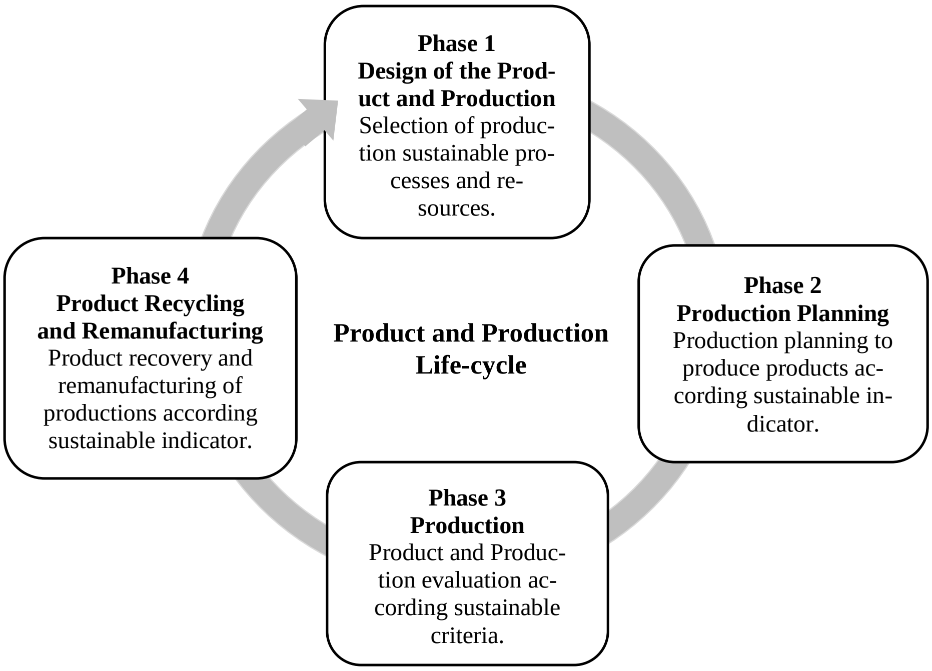

Fig. 2. Lifecycle of sustainable product and production [8]

Besides, sustainable smart manufacturing supports manufacturers to carry out development plans, reduce resource and energy consumption and pollution through the whole lifecycle. Sustainable smart manufacturing also seeks the conversion of data generated through the product lifecycle into manufacturing intelligence. In this context sustainable smart manufacturing systems experienced an explosive growth of connected devices and generated data, Therefore the IIoT (industrial internet of things) will have an important role in this modern manufacturing as the huge number of devices, sensors, actuators, and other machine types become interconnected to each other generating then an enormous heterogeneous amount of data. In these circumstances, IIoT architecture must be adapted to sustainable smart manufacturing applications and system connectivity requirements. Based on this, how can the different communication interfaces be connected and their generated data managed in the sustainable smart manufacturing system to reach sustainability, quality assurance, and performance optimization? and how to meet this system's connectivity requirements while ensuring its availability and security?

Based on the aforementioned concepts, we defined the following research question: how to connect the different devices included in the manufacturing system, while ensuring the availability and security of the network in a sustainable smart manufacturing environment?

In this paper, we propose a 5G-enabled framework of Industrial internet of things IIoT architecture for sustainable smart manufacturing environments. This five-layer novel framework architecture benefits from new technologies such as 5G. The proposed architecture makes more efficient analysis, simplifies, identifies, organizes, and standardizes the key elements of the future industrial IoT in sustainable smart manufacturing systems.

This paper is organized as follows: The second section expounds on the methodology followed in the development of the research work. The third section introduces the industrial internet of things and its key technologies. The fourth section relates the mobile wireless technologies evolution and the 5G technology. The fifth section deals with the IoT (internet of things) and its existing architectures. In the sixth section, we propose a new framework of 5G-enabled IIoT architecture for sustainable smart manufacturing systems. In the seventh section, we relate some security threats in 5G-enabled IIoT. Finally, in the eighth section, we conclude this paper.

2 Methodology

To respond to the research question and clearly define the aspects of the paper while selecting relevant articles, we carried out our research using a web of science and science direct databases and the keywords: “Industrial” AND “internet of things” AND “smart manufacturing” AND “5G”.

After reading the titles and abstracts only the relevant articles were retained in our readings and 29 articles remained as a baseline for the development of this research paper.

The starting point of our research was the review of the literature. As with any other research, the state of the art is an essential element to situate the main research question mentioned in the previous section, about the old work done on the same subject. Thus, our strategy begins with a review of work on the industrial internet of things, mobile wireless technologies, and 5G in the manufacturing sector. The Internet of Things (IoT) and its existing architectures were also reviewed to have an overview of the techniques and approaches developed to manage data in the IoT. The literature review then allowed us to position our research compared to others, as well as to validate the originality and contribution of present work.

Through a qualitative conducted secondary research methodology based on the mentioned literature review we constructed a framework of 5G-enabled IIoT (industrial internet of things) architecture for a sustainable smart manufacturing environment that supports the deployment of major sustainable smart manufacturing applications, satisfy their quality requirements and enable efficiency, and sustainability enhancement. We also discussed the advantages and security issues that should be taken into consideration when implementing the proposed framework.

3 Internet of Things (IoT) for manufacturing

3.1 The IoT definition

The need to connect numerous physical objects to the internet advanced the adoption of IoT. The IoT was introduced by Kevin Ashton in 1999 while he was looking for a way to connect RFID (radio frequency identification) information to the internet to improve the business of P&G [9].

The IoT is defined as “the ability to connect, communicate with, and remotely manage an incalculable number of networked, automated devices, from the factory floor to the hospital operating room to the residential basement. It is a scenario in which storage, computing, and communication technologies are embedded in everyday objects. Processing, storage, and communication capabilities attached to an object turn into a service for which users pay peruse.” [9].

The elements that enable IoT to ensure their functionality are classified as follows in Figure 3:

Fig. 3. The IoT Elements [9]

There are diverse applications of the internet of things in different domains. The main applications of IoT are Personal and home, Enterprise, Utilities, and Mobile [9].

The industrial IoT (IIoT) is the IoT applied in several sectors that are related to industries such as manufacturing, logistics, and energy domains, it is considered as the next industrial revolution [10] given that industry is a critical component of a country's technological advancement, job creation, and economic stability, it is a key component of the value chain [11]. To ensure their competitivity manufacturers must develop their network with the IIoT as this new technology focuses on smart manufacturing: automation, smart production, production control, and quality control, IoT technologies are foremost in smart manufacturing specifically for the management of sustainable production, monitoring of energy consumption and industrial emissions. [12] [13]. IoT improved remanufacturing efficiency by at least 30% [14]by tracking lifecycle data using sensors [15].

3.2 Basic IoT architectures

The architecture of an IoT system is made up of several levels that communicate with each other to connect the tangible world of objects to the virtual world of networks and the cloud. Not all projects adopt a formally identical architecture [9].

However, there are several IoT architectures, the most prominent model is the basic IoT architecture known as:

The three layer architecture. composed from the Perception Layer, the Network Layer, and the Application Layer, where:

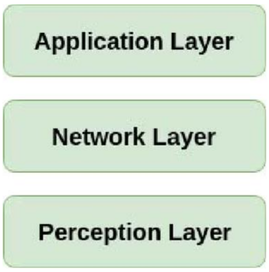

Fig. 4. Basic IoT architecture [16]

- **The Perception Layer:** is the layer of devices, objects, and sensors. This layer consists of identifying objects and collecting data and information. It incorporates different technologies such as RFID tags, GPS, and sensors networks.
- **The Network Layer:** Known as the transmission layer, is transmitting and processing data coming from the perception layer, it is also helping in the management of network and information services. It includes technologies like Bluetooth, WiFi, 3G, and Zigbee.
- **The Application Layer:** This layer aims to highlight the industrial and social needs of IoT to intellectualize the industry.

The five layer architecture. The five-layer architecture is a combination of TCP/IP and communication model with IoT requirements, it is composed of five layers as shown in Figure 5:

Fig. 5. 5-Layer architecture for IoT [9]

- **The object Layer:** which is a layer of Perception, Sensing, and devices that aim to collect and process in real-time the information coming from sensors, actuators, and other smart devices on the network. The sensors used in this layer are low power consumption with low data rate connectivity. Several technologies are used in this layer like RFID tags, 2D- Bar code, Infrared sensors, and Nanotechnology. The Big Data generated in this layer, after being digitized is transmitted to the object abstraction layer for more processing.

- **The Object Abstraction Layer:** This Layer is a transport/ Network layer, where the process of data management and cloud computing are operated, so it must support massive volumes of IoT-generated data. It also requires a reliable and strong performance, concerning private-public or hybrid networks. This layer uses technologies such as Bluetooth low energy which provides 10 times faster data transfer speed and 15 minutes latency lower in compared to classic Bluetooth. Another technology used in this layer is the Universal Mobile Telecommunications Service (UMTS) which is a packet-based transmission of Multimedia, text, and videos with up to 2 Mbps data rates.
- **The Service Management Layer:** Also called Middleware/Processing Layer where the Big Data coming from the object abstraction layer is stored, analyzed, and processed, and interaction of heterogeneous devices is allowed without taking into account the hardware platform. The main function of this layer is to make decisions and according to these decisions, provide service to the customer. Technologies like Ubiquitous computing and fog computing are used in this layer.
- **The Application Layer:** exploits functionalities of the lower layers and provide services of customer needs in every industry. It can also assure the integration between distributed systems and applications using service composition technologies and standard web service protocols.
- **Business Layer:** Creates business models and evaluates existing applications and services to keep going the whole IoT system. Based on data coming from the application layer business and profit, models are built to support the decision-making process and assure optimal investment.

3.3 IoT enabled smart manufacturing

In the manufacturing field, the key survival of companies is optimization, these companies are now assessing the opportunity to leverage IoT technology in their manufacturing systems to become more efficient and remain competitive. SC management is also more efficient thanks to the Internet of Things[17].

To become IoT-enabled a smart manufacturing system needs to be composed of three building blocks as mentioned below [18].

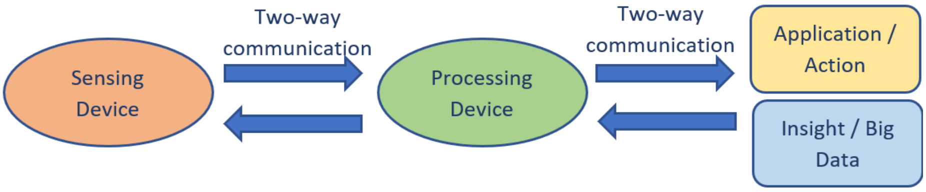

Fig. 6. Building blocks of IoT-enabled smart manufacturing system [18]

In the sensing device block, many devices can be used like RFID (radio frequency identification) or any other sensor to sense an object, person, or temperature measure. Data gathered from sensors is processed in real-time by a microprocessor or microcontroller in the second building block. In the third block, the wireless two-way communication nodes help in transferring communication between the two other blocks to execute tasks.

The IoT-enabled manufacturing is exploited in various segments of manufacturing like factory visibility: In fact, IoT-equipped factory has real-time access to the information which leads to efficient collaboration [19] for example maintenance function where the managers are informed in real-time about machine status and production in advance, this can reduce downtime for action and decision making. Also, the quality can be significantly improved when knowing the problem earlier production can be shut downed in advance, this will eliminate product wastage.

Additionally, IoT-enabled manufacturing helps improve automation while using IoT and IP networks to connect and ensure data sharing in the whole system. Automation and flexibility are considerably improved, delivering real-time control to enhance optimization, empowering horizontal association between devices, and offering protected inclusion of services[18].

Another important issue in enabled IoT smart manufacturing is energy management, the system can benefit from data gathered and shared in the IoT equipped system to generate modeling and management tools of energy optimization.

4 Mobile wireless technologies evolution and 5G for manufacturing

With the massive growth of IoT applications, the need to connect billions of devices is increasingly rising which demands new network requirements like high throughput, low latency, high capacity and reliability, quality of service (QoS), and quality of experience (QoE). To meet these requirements, 5G can make significant value addition to the next IoT generation.

4.1 Mobile wireless technologies evolution

Since the 1970s, radio technologies knew an accelerated evolution and revolution, the first generation (1G), second-generation (2G), to third-generation (3G), to fourth-generation (4G), and then to fifth-generation (5G).

First-generation (1G). Came with the development of telecommunication technologies in 1980 based on analog cellular systems, it has various applications like cordless telephone, Total Access Communication System (TACS), Advanced Mobile Phone System (AMPS) as the most outstanding systems of 1G [20].

Second generation (2G). Appeared in the 1990s based on digital transmission in reverse of analog transmission of the first generation. this digital transmission had a positive impact on the lower battery consumption. Moreover, 2G networks had better data services and efficiency spectrum. Otherwise, in the 2G era, the SMS text messages and MMS picture messages were introduced thanks to technologies like Digital AMPS, Code Division Multiple Access (CDMA), and Personal Digital Communication (PDC)[20].

Third generation (3G). Happened in 2000 with high-speed IP networking compare with 2G, 3G is four times quicker with around 125 Kbps- 2Mbps speed range. This made a destructive effect on the other networks and their related industry. Instead of using circuit switching, packet switching was used for data transmission. In the 3G era technologies like High-Speed Packet Access (HSPA) and Universal Mobile Telecommunication System (UMTS), enabled us to have Video calls and mobile TV technologies[20].

Fourth generation (4G). In 2010, knew an increased growth of mobile broadband, higher bandwidth services than the 3G one, and a speed data transfer up to 1001 Mbits/s downloads. Offering wireless modem between portable computers and smartphones, IP telephony, video conferencing, and cloud computing. 4G used technologies such as Long-Term Evolution or LTE, LTE Advanced, LTE Advanced Pro, and Worldwide Interoperability for Microwave Access (WiMAX) [20].

Fifth generation (5G). The next wireless upgrade technology is 5G that goes beyond the 4G it is faster and more efficient in spectrum use. [20]. According to the report of International Data Corporation (IDC), 5G will lead 70% of companies to spend $1.2 billion on connectivity management solutions [21]. It is expected that 5G will change radically mobility, it will have new mobile communication technologies such as Autonomous vehicles, Google Home, and smartphones[20].

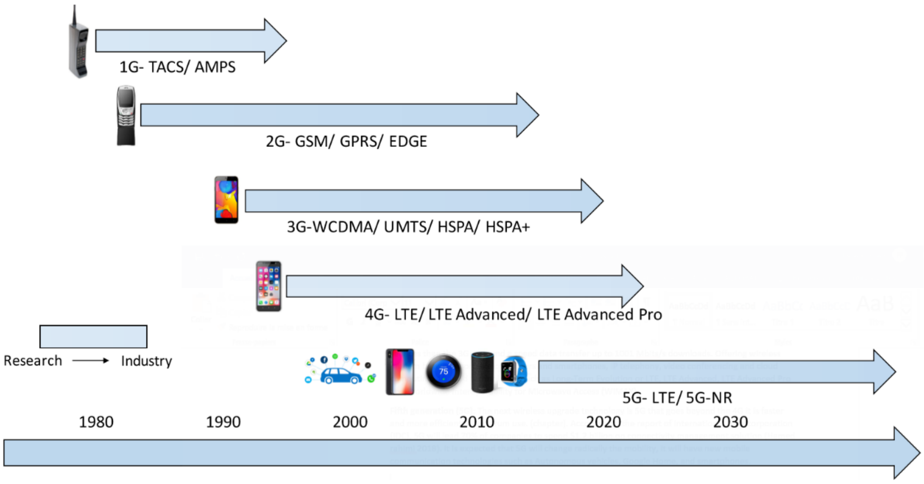

Fig. 7. The evolution from 1G to 5G [20]

The 5G became a leading way to improve IoT applications by connecting billions of intelligent devices this can be only achieved by the development of M2M (Machine to machine) communication while reducing battery consumption, cost, latency, and ensuring the system's security and privacy[20].

The 5G will also have a higher frequency between 3 and 300 GHz, a high data rate with more than 1 Gbps, dynamic information access and M2M enabled IoT networks with embedded AI (Artificial Intelligence).

4.2 Key 5G characteristics for smart manufacturing

One of the major differences between 5G and previous generations of networks is the 5G's intensive concentration on machine-type communication (MTC) and the internet of things (IoT). The capabilities of 5G extend far beyond mobile broadband with ever-increasing data rates [22].

The fifth generation of mobile communications (5G), in addition to expanded broadband capabilities, provides advanced wireless connectivity for vertical industries such as manufacturing. The 5G supports, the following three essential types of communication:

- **Enhanced mobile broadband (eMBB):** That offers wide enhanced coverage and extremely high data rates that go well beyond those of 4G [22].
- **Massive-type communication (MTC):** That provides ubiquitous connectivity with low software and hardware device requirements while supporting battery-saving low energy operation [22].
- **Ultra-reliable low-latency communication (URLLC):** That smooths the application's execution with highly critical and very demanding requirements in terms of end-to-end low latency, reliability, and availability. A concrete example of these applications in manufacturing is industrial automation and control that requires high-performance connectivity [22].

In a big-data-driven smart manufacturing environment, 5G becomes an essential networking technology it will give the system the possibility to connect more devices to heterogeneous manufacturing resources reliably, securely, and uninterrupted [23] carrying out a large-scale communication, thanks to its higher speed, low latency, and high-capacity connection devices as well as massive IoT connectivity [24]. This will consequently improve real-time operation control and decision-making capabilities, flexibility, versatility, usability, and efficiency in the sustainable smart manufacturing system of future sustainable smart factories[25].

5 Proposed 5G-enabled IIoT architecture framework for sustainable smart manufacturing environment

As mentioned in the previous section, the 5G wireless communication network provides a wealthy possibility for implementing and developing industrial IoT. With the promotion of smart manufacturing, the construction of smart factories has put forward higher demands for data transmission rate, transmission latency, coverage, reliability, large-scale connections, and security.

In the view of all aforementioned elements a 5G-enabled IoT architecture framework is proposed in this section, including five layers as shown in Figure 8:

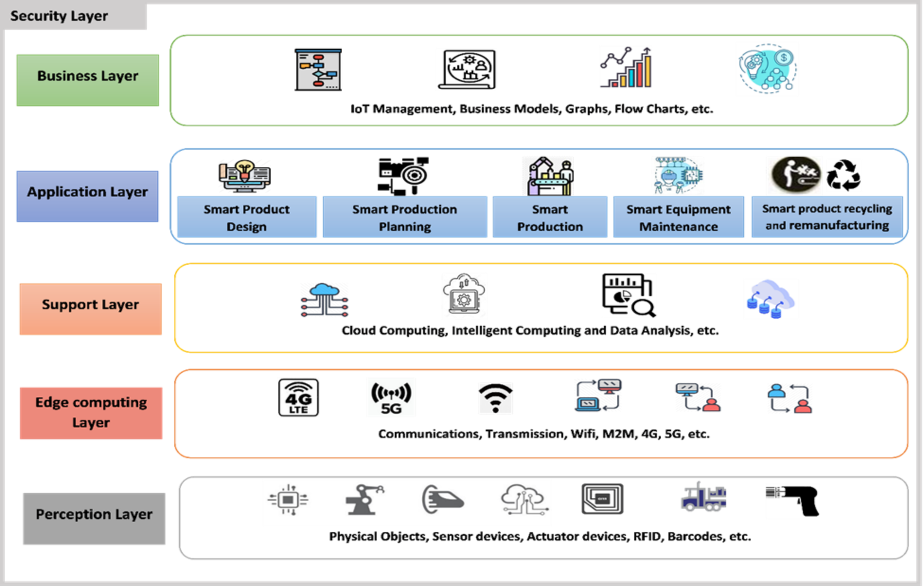

Fig. 8. Proposed architecture framework of 5G-enabled IIoT in sustainable smart manufacturing

Perception layer. This layer aims to collect data from different devices, from one hand the hardware part such as sensors, actuators, controllers, barcodes, and RFID. On the other hand, IoT objects or devices like industrial equipment, smartphones, tablets, computers, and intelligent machines [20].

Edge computing layer. In this layer the communication protocol and network are defined thanks to edge computing, using networks to transmit the collected data from the perception layer to the edge or cloud, the networks used for this purpose are WiFi, 4G, and also 5G that can enhance the device-to-device or machine to machine (M2M) communication. 5G is considered a strong technology solution for MTC devices connectivity as it supports data high rate, provides low latency and ensures robust connection [20].

Moreover, to make decisions at the edge level, the data is processed by nodes or their leaders. In this context, with the high number of connected devices, 5G will allow multi-access edge computing to be more powerful and will significantly contribute to the edge layer [21].

Support layer. It represents the support platform for other layers, it includes from one hand cloud computing where the data gathered from the edge is processed or reprocessed. The 5G implementation will allow devices to perform these operations, that is, distributed in parallel among the devices to enhance efficiency, sustainability, and scalability, and speed in the IoT system [21].

On the other hand, this layer also includes data analytics to produce manipulable information from data.

The increase of data amount, the integration of 5G technology, and the new big data algorithms will improve and highlight the role of the support layer in IIoT (industrial internet of things) of the future [21].

Application layer. This layer provides several applications and services based on the data processing transmitted from upcoming layers. In this layer, devices make decisions based on resulting artificial intelligence learning. The 5G-enabled IoT applications in a sustainable smart manufacturing environment are:

- **Smart Product Design:** where the market and marketing data and user behavior gathered from the internet is analyzed and exploited to meet the customers' needs and market trends [26].
- **Smart production planning:** In this phase, different data are analyzed such as material quantity data, distribution plan, and delivery time to develop production plans using intelligent optimization algorithms[26].
- **Smart production:** The analysis of data obtained in previous layers helps in predicting an appropriate range of involved manufacturing factors to enhance better uniformity, energy efficiency, and sustainability[26].
- **Smart equipment maintenance:** In this application phase product quality and fault detection data received from previous layers are combined and analyzed. The failure and products in use lifetime can be predicted during manufacturing planning enabling then energy consumption and amount of used material reduction[26].
- **Smart product recycling and remanufacturing:** The historical degradation of products status data and RFID (Radio-frequency identification) tags provide inspectors with identification codes to help them in taking decisions of defective part classification and recovery costs and benefits estimation[26].

Business layer. This layer manages the whole IoT system, requiring the design of better business models like IIoT data privacy, trust models, and real-time instrumentation return of investment (ROI) [27].

Security layer. This layer covers all the previous layers, and intersect with each of them.

- First, security in the perception layer lies in the protection of sensor data, Key agreements, and the management of data strategies.
- In the second layer "edge computing layer" it is important to ensure a secure edge computing, identity authentication, and encryption mechanism.
- The third layer or support layer must secure cloud computing, enable better encryption algorithms and protocols, and enhance protection using an anti-virus.
- In the application layer, privacy and information should be protected and worldwide policies and standards must be respected[20].
- Finally, in the business layer, attention is addressed to the protection of privacy and information[20].

6 Discussion

The 5G-enabled IIoT proposed architecture framework provides several advantages to sustainable smart manufacturing in terms of technicity, product quality, and sustainability as summarized in Table 1:

Table 1. Framework advantages to sustainable smart manufacturing

	Advantages	**Description**
Technicity	Large-scale smart interconnection of heterogeneous equipment	The system supports fast transmission without a need for base stations and can interconnect a large scale of heterogenous equipment on a shop floor [28]
	High reliability and low latency industrial automation and control	The 5G characteristics like high reliability, low latency, high transmission rate, allow real-time man-machine and machine-machine collaboration providing then real-time production status [28]
	Edge computing has driven IIoT	Thanks to SDN in 5G networks transmission, the data flow can be controlled between servers and communication terminals. To reduce occupancy rate, and network latency, part of the data is processed at the edge level [28]
	3D/Multimedia assisted interaction	5G facilitates the enhancement of virtual-reality augmented based smart manufacturing and product design
Product quality	Performance improvement and customer experience access gain	Thanks to remote software connected to integrated sensors that send fault system instructions to customers to fix a particular problem. This allows the company to comprehend their overall experience and gives the management team a lot more help and direction.
	Minimization of warranty and non-quality costs	The early detection and prevention of faults identified by connected devices in the system avoid the company from distributing defective products and paying the non-quality cost, increasing then the customer satisfaction
	Rework and scrap elimination	In the 5G-IoT enabled manufacturing process thanks to machine-to-machine communication, any deviation can be detected and located, and then the system is tuned, bringing the final product within the stipulation [14]
	Service contract renovation	The appropriate service time can be determined by sensors, which optimize product servicing time and minimize customer service expenses
Sustainability	Machine and tool lifetime prolongation	By tracking and monitoring performance, a product’s lifetime can be significantly increased. Additionally, product’s efficiency can be enhanced by determining the product’s maintenance requirements
	Energy and water preservation	The multi-beam forming directional transmission technology of 5G allows a low energy consumption transmission network. In addition to that in a 5G-enabled IoT smart manufacturing system, the usage of energy and resources like water in every unit can be tackled by facilitating then energy management and ensuring its effective resource utilization[14]
	Product miles reduction	By tracking products using sensors like RFID, the optimal route of product’s distribution can be detected and thus customers are delivered at the right time [14]

So, the 5G enabled-IIoT presents several advantages to the smart manufacturing systems that seek to remain sustainable. However, some issues should be taken into consideration when implementing the proposed framework like security issues. In our framework, the security intersects with each layer of the 5G-enabled IIoT, which means that in presence of one security flaw the whole manufacturing system can be affected.

Security is a major issue in 5G-IIoT because the cost of its threats is very expensive, it affects customer confidence, personal safety, and social trust. Some security threats in the 5G enabled IIoT (Industrial Internet of Things) are highlighted below:

- **Hardware security:** The first security threat is hardware security where cloning tags happens in sensors, attacks can also reach confidential information like passwords in wireless sensors like RFID. Moreover, attackers can attack a user-accessible IoT device and give fake information[20].
- **Software security:** The attackers can get enterprise and personal data by hacking operating systems like IOS and Android on smart mobile devices[20].
- **Cloud computing:** The denial of service (DoS) is the most common security threat in the cloud, when attackers detect the weakness, they damaged the system of cloud computing [20].
- **Network security:** Denial of service (DoS) is a common attack on networks, while Distributed denial-of-service (DDoS) is an edge computing attack. The attacker fakes the ID and communicates normally to gather IoT users' information[20].
- **Data leakage:** The design of business models obliges designers to implement some APIs, if these APIs are not protected enough, the data can be exposed to data leakage, which can affect the private information which has a serious outcome on cost[20].
- **Heterogenous network:** The several data types shared in the heterogeneous network can cause threats in the security of systems such as Dos attacks and malicious code injections. In fact, in case of a security lack in authentication and key agreement, the service can be easily attacked and shut down[20].

Otherwise, various other security threats can face manufacturing systems. These threats can happen maliciously or accidentally, but what is sure is that they are critical and incidents, and, in most cases, manufacturing has no mechanisms to prevent, detect and recover from these security attacks.

However, to face the security threats in the 5G-IIoT enabled sustainable smart manufacturing systems some security solutions might be taken into consideration the most relevant ones are:

The regulations, standards that guide network security, as an example the standard ISO/IEC 29180:2012 used to manage security in sensor networks domain provides a security framework for telecommunications and information exchange between systems for ubiquitous sensor networks [29].

Intrusion detection systems for production or process systems is another relevant security solution proposition, by observing the dynamic behavior and seeking to determine its abnormality to counter the attacks that are continuously evolving[29].

Additionally, one of the main challenges of building secure systems in the entire smart manufacturing is the shortage of skilled security personnel. With the move towards 5G-enabled IIoT manufacturing, the security issue will become more critical in the manufacturing systems, requiring then the implication of the entire manufacturing hierarchy from the engineers and security managers to factory level or users. However, despite the increase of awareness training, the majority of incidents happened because of personnel misuse in the system. So, with the increase of attacks, more attention should be addressed to the human factor in the management of security, especially on the factory floors[29].

Finally, in the 5G-enabled IIoT, security is a critical issue, and in manufacturing systems security threats are critical and incidents, malicious or accidental these security threats take place at least occasionally. So, it would be indispensable to have efficient post-incident management in the 5G-IIoT enabled sustainable smart manufacturing, to respond safely to incidents, bring the system to a safe state, and resume operations as quickly.

7 Conclusion

This paper proposes a 5G enabled IIoT architecture framework for sustainable smart manufacturing systems. The presented 5G-IIoT architecture framework is composed of six layers, the perception layer in which data is collected from different and heterogeneous devices, the data collected is then transmitted through the edge computing layer that communicates data thanks to strong technologies like 5G as it supports data high rate, provides low latency and ensure robust connection. The data gathered from the edge is processed or reprocessed in the support layer, and based on its resulting artificial intelligence learning, devices can make decisions in the application layer. After comes the business Layer that manages the hole IIoT system and the security layer that covers all the previous layers, and intersect with each of them.

As mentioned before the 5G-enabled IIoT proposed architecture framework, on one hand, presents a real improvement opportunity to smart manufacturing systems in terms of technicity, product quality, and sustainability. But on the other hand, there are still some challenges that can face these manufacturing systems when implementing this technology, the most relevant one is security. As the security in our proposed framework intersects with each of its layers, one security incident can affect the security of the whole manufacturing system. So, security solutions should be appropriate to each layer of the manufacturing system. Building strong security strategies such as intrusion detection systems, post-incident management, and security skills training are foremost in the 5G enabled IIoT sustainable smart manufacturing systems.

As security will become a critical concern in this new type of manufacturing system. The implication of the entire manufacturing hierarchy from the engineers and security managers to factory floors or users is a prerequisite. In this context, there is a direct need to pursue in future research work, the investigation of the role of the human factor in the security of manufacturing systems.

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9 Authors

Fadwa Mahiri ENSET Mohammadia, SSDIA Laboratory, HASSAN II University, Casablanca, Morocco.

Aouatif Najoua ENSET Mohammadia, SSDIA Laboratory, HASSAN II University, Casablanca, Morocco.

Souad Ben Souda ENSET Mohammadia, SSDIA Laboratory, HASSAN II University, Casablanca, Morocco.

Article submitted 2021-10-22. Resubmitted 2022-01-20. Final acceptance 2022-01-22. Final version published as submitted by the authors.