Chapter

Digital Agriculture and Intelligent Farming Business Using Information and Communication Technology: A Survey

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Abstract

Adopting new information and communication technology (ICT) as a solution to achieve food security becomes more urgent than before, particularly with the demographical explosion. In this survey, we analyze the literature in the last decade to examine the existing fog/edge computing architectures adapted for the smart farming domain and identify the most relevant challenges resulting from the integration of IoT and fog/edge computing platforms. On the other hand, we describe the status of Blockchain usage in intelligent farming as well as the most challenges this promising topic is facing. The relevant recommendations and researches needed in Blockchain topic to enhance intelligent farming sustainability are also highlighted. It is found through the examination that the adoption of ICT in the various farming processes helps to increase productivity with low efforts and costs. Several challenges are faced when implementing such solutions, they are mainly related to the technological development, energy consumption, and the complexity of the environments where the solutions are implemented. Despite these constraints, it is certain that shortly several farming businesses will heavily invest to introduce more intelligence into their management methods. Furthermore, the use of sophisticated deep learning and Blockchain algorithms may contribute to the resolution of many recent farming issues.

Keywords: intelligent farming, food security, fog/edge computing, blockchain, digital twin, artificial intelligence

1. Introduction

Recently, the agricultural domain is facing numerous challenges related to the need to permanently increase productivity, climate change management, crop health monitoring, and irrigation water management, as well as fertilization optimization. To address these constraints, IoT technology is opening up new promising technological paths and pushing the future of agriculture to the next level. Indeed, many advantages are offered by IoT systems for intelligent farming, such as a panoply of sensor networks to optimize irrigation and agricultural inputs management, as well as improvement of the agricultural engine guidance and maintenance. Agricultural sensors implemented in the fields are estimated to reach 12 million by 2023, this revolution of smart devices will provide many remote facilities to manage seeds, irrigation, fertilizers, and early disease detection by collecting real-time data about the field and the environment. We mean by intelligent farming the integration of smartness in the farming processes, not only for the land management but also in the other chain links notably logistics and supply chain, transportation [1–4], as well as storage. The need for automation in the agricultural domain to overcome the constraints imposed by classical methods of farming became more essential than before. Furthermore, the availability of water in a sufficient quantity and quality has been recently become alarming because of the climate change phenomenon. Consequently, many technological, economical, and social policies have to be implemented according to many recent studies that focused on water management topics [5]. Thanks to the smart and low-cost dedicated sensors, irrigation tasks will be precise and the productivity will be rapidly increased, without ignoring the important contribution in hydrological resources preservation. Traceability of the food supply chain (FSC) is an important key factor to ensure the quality and safety of food transportation and identification in a regulatory manner, as well as protect perishable food against waste. Dairy farming is another farming process that has taken benefits from the integration of information and communication technology in the farming industry, it helps farmers to adopt more accurate practices in dairy management [6] to monitor the heat of oestrus to improve reproduction, as well as the animal health check and monitoring [7].

Highly intelligent farming or high intelligent farming are two concepts that refer to the use of high tech in farming processes to enhance the efficiency of daily work. In fact, using technological innovation in farming is not new, but the rise of some disciplines, such as IoT, fog computing, satellites, drones, smartphones, and Blockchain, are things that will push smart agriculture and precise farming industries to a high level in the coming years. We believe that implementing ICT in the farming world will enable farmers to better understand and interact with their farms by collecting data about changing variables and giving commands according to the situations. All of these technologies will give the ability to the farms to make a big transition from being simple physical environments to highly intelligent and abstract worlds.

Despite the existence of several studies and surveys that introduce the issue of integrating ICT in farming processes, we find that these surveys either focused only on one farming process or do not investigate deep enough this integration. Moreover, investigation of Blockchain technology, its benefits for the farming industry, and its required research to build sustainable development, need to be elaborated. To fill these literature gaps, we propose this survey as one of the most mature studies of its kind that presents a systematic and developed state-of-the-art for integrating ICT in the farming world.

The remainder of this work is further structured as follows: The research methodology is presented in Section 2. Then, the general review of IoT-based systems' requirements is discussed in Section 3. Next, Section 4 provides the components of an intelligent farming IoT model. After that, the open challenges resulting from IoT-fog computing integration are discussed in Section 5. The applications of Blockchain in intelligent farming and the discussion part are then presented in Section 6. The conclusion and summary are provided in Section 7.

2. Research methodology

This survey extensively studies the knowledge related to the intelligent farming domain. It inventories and summarizes the integration of ICT in the IF field. The potential of this survey regarding the other works is to evaluate the implementation of Blockchain in the IF topic.

2.1 Reference management

The references related to our research area are collected and filtered, 104 references have been retained based on the following four criteria: (1) High priority was given to recent studies, which means that most of the selected papers were published between 2017 and 2021, and some of them are in press. (2) The timeliness and novelty of the study in the intelligent farming field is another criterion that has been given more priority. (3) The significance to the field and the potential impact on the course of future work in the area of smart farming, were also criteria that have been taken into account while selecting the examined papers. (4) Since the potential of our survey is the evaluation of the applications and benefits of Blockchain technology for the farming industry, we have given more importance to the studies that have explored Blockchain technology within farming environments. A variety of questions that are addressed in this survey can be summarized as follows—(Q1) what type of ICT systems and frameworks are used in the implementation of IF solutions? The answer to this question gives a general study of relevant technologies and protocols adopted in IoT systems as well as fog/edge computing platforms. These technologies represent the basis of many implementations in many fields including intelligent farming, (Q2) is there an IoT model structure that can be adopted to build IF solutions? To answer this question, a five-layer model for intelligent farming is presented, (Q3) how Blockchain technology can be used in the IF domain, and what impact might this have on IF practices improvement? The answer to this question leads us to introduce the

Source	Hardware and protocols	Cloud computing	Fog computing	Blockchain
Ratnaparkhi et al. [8]	✓			
Tahsien et al. [9]	✓			
Hajjaji et al. [10]	✓	✓		
Farooq et al. [11]	✓	✓	✓	
Mekala et al. [12]	✓	✓		
Cisternas et al. [13]				
Lova Raju et al. [14]	✓	✓		
Shi et al. [15]	✓	✓	✓	
Muangprathub et al. [16]	✓	✓		
Bacco et al. [17]		✓	✓	
This survey	✓	✓	✓	✓

Table 1.
Comparison between this survey and other previous surveys.

most recent novelty of Blockchain usage in the IF domain, as well as the challenges and the needed researches to enrich this debate.

2.2 Comparison with other smart agriculture state-of-the-arts and reviews

Starting from the examined papers, we have identified several state-of-the-arts, surveys, and reviews, each type of those papers discussed the use of ICT in intelligent farming based on specific ICT disciplines. Some previous surveys focused on the hardware used to implement IF applications, and others covered the integration of IoT with fog/edge technologies to optimize some metrics. Some points are common between our work and others, such as the description of the hardware and protocols adopted in IF systems, and the implementations of IF applications in cloud/fog computing environments. In this work we studied the Blockchain discipline related to the farming domain, this point has not been obviously covered by the other surveys. **Table 1** summarizes the comparison between this survey and the other previous works.

3. A general review of IoT-based systems' requirements

In most cases, precision agriculture data are communicated wirelessly between sensors, or between IoT devices and the core using several kinds of communication protocols, these protocols define the rules and the different formats of the communicated data. The secret behind the success of IoT systems is the development of communication protocols [18, 19], such as RFID (Radio Frequency Identification), NFC (Near Field Communication), IEEE 802.11 Wi-Fi, IEEE 802.16 Wi-Max (Worldwide Interoperability for Microwave Access), IEEE 802.15.4 LR-WPAN (Low-Rate Wireless Personal Area Networks), 4G and 5G cellular networks, IEEE 802.15.1 Bluetooth, ZigBee, ANT/ANT+ networks, DASH7, Enocea…).

Unlike the fog computing paradigm, the traditional cloud computing approach is characterized by centralization, high latency, and more network failures. These characteristics among others make cloud computing unsuitable for IoT applications where time and mobility are crucial factors. In the IoT context, fog computing is a new computing approach that helps to distribute the load of processing and make it so close to the sensing layer. One of the solutions that were proposed to accelerate the processing and compensate for the resource limitation of IoT devices is computation offloading. This concept allows devices to fully/partially offload their computation tasks to resource-rich cloud infrastructures [20]. But this solution bypasses only the cloud computing limitations and does not propose a real solution to resolve them. A group of researchers [21] discussed the usefulness of another concept called computation onloading. This concept is based on bringing cloud services to the edge of the network to satisfy the requirements of IoT devices in terms of bandwidth and latency.

Many contributions are proposed to improve the shared characteristics between cloud and fog computing, notably the generated latency between requesting the task execution and receiving the response, the energy consumed during the task processing, the resource management strategy that defines the provided quality of service, the security issue directly linked to the privacy of generated data, the mobility support to ensure the best quality of service to the end devices, the interoperability between smart things, the scalability related to the exponential increase of the number of IoT devices, and finally the bandwidth needed to transmit data from the network of smart objects to the processing center.

The latency generated by the cloud is significantly important, this is an issue for new IoT mobile applications that need real-time responses to their requests. To enhance this characteristic through the fog/edge computing model, Yang et al. [22] developed an offline heuristic algorithm, SearchAdjust, to minimize the average latency for Multiuser Computation Partition Problem (MCPP). In the same context, Yousefpour et al. [23] developed and evaluated a policy to reduce the service delay for IoT devices based on offloading and sharing load approach. In another work, Molina et al. [24] proposed a strategy of uplink/downlink, and edge computational resources allocation in a multi-user scenario to achieve latency and energy efficiency in task processing. Ren et al. [25] investigated the collaboration between cloud computing and edge computing, where the tasks of mobile devices can be partially processed at the edge node and the cloud server. A joint communication and computation resource allocation problem is formulated to minimize the weighted-sum latency of all mobile devices.

Regarding the energy consumption issue, most of the processing tasks are carried out in the cloud computing data centers that increase the quantity of energy needed for query transmission and execution. This consumption is minimized in the fog/edge computing model because the majority of computing tasks are distributed over several end devices or offloaded to the edge mini data centers. In this context, Xiang et al. [26] proposed a policy to efficiently optimize energy in LTE (Evolution Long Term)/Wi-Fi link selection and transmission scheduling, as well as developed an approximate dynamic programming algorithm to reduce energy consumption in the MCC (Mobile Cloud Computing). Ge et al. [27] proposed a game-theoretic strategy to reduce the overall energy dissipation of both mobile devices and cloud servers considering the offloading technique in the MCC system. Chen et al. [28] adopted a game-theoretic approach to propose a multi-user offloading solution for mobile-edge cloud computing, their proposed solution aims to achieve energy efficiency in a multi-channel wireless interference environment.

In the classical cloud computing approach, the efficiency of resources management is less compared to the fog/edge computing approach, this is due to the existence of more sophisticated algorithms that proved their efficiency in resources allocation. In this window, Mostafa et al. [29] proposed an automated fog selection and allocation scheme of task requests by IoT devices. In another work, Jana et al. [30] proposed a QoS (Quality of Service)—aware resource management technique for the efficient management of resources. Souza et al. [31] developed a scheme that combines fog computing and cloud resource allocation. Aazam et al. [32] proposed a user characteristic-based resource management for fog, which performs efficient and fair management of resources for IoT deployments. Delegating data protection to the cloud layer without implementing mechanisms to protect data at the end device level is an inefficient strategy. The best way is to ensure end-to-end data protection, the fog/edge computing model is mainly concerned by this issue compared to the cloud computing approach that focuses on data protection at the cloud level. Das Manik [33] proposed a security protocol for IoT applications based on Elliptic Curve Cryptography (ECC). Hernández-Ramos et al. [34] proposed a new mechanism of lightweight authentication and authorization to be embedded in a smart object based on DCapBAC (Distributed Capability-Based Access Control). Zhang et al. [35] suggested using Ciphertext-policy attribute-based encryption (CP-ABE), which is a recognized cryptographic technique to ensure data confidentiality and provide firm access control.

The majority of IoT devices used in smart cities or smart environments are geographically distributed, mobility of IoT devices and applications should, therefore, be supported by the adopted computing approach. As a result, many works are proposed to enhance the mobility of end devices in the fog/edge model since this characteristic is less present in the traditional cloud computing model. For this purpose, Chaisiri et al. [36] proposed a mobility-aware offloading priority design, it aims to precisely anticipate users' mobility profiles and channels. In the same context, Prasad et al. [37] proposed an approach for mobility management along with traffic control to offer better users' QoE (Quality of Experience) with latency-tolerant tasks. Ning et al. [38] constructed a three-layer VFC (Vehicle Fog Computing) model to enable distributed traffic management and minimize the response time of citywide events collected and reported by vehicles.

Interoperability is another important difference between the fog/edge computing model and the cloud computing approach regarding provided smart services. The interoperability requires that all interfaces of cloud-based or fog/edge-based systems are wholly understood. Despite that cloud computing offers more interoperability for some distributed applications, it is difficult to cover smart things applications due to the big heterogeneity of manufacturers and systems. Contrary to cloud computing, fog/edge computing is more open to the end devices and tends to ameliorate the interoperability issue in an IoT system. Starting from this requirement, Jayaraman et al. [39] proposed an OpenIoT platform used for the digital agriculture use case (Phenonet), the OpenIoT enables semantic interoperability. Desai et al. [40] proposed a semantic web permit architecture to afford interoperability among smart things. Ullah et al. [41] proposed a semantic interoperability model for big-data in IoT (SIMB-IoT) to deliver semantic interoperability among heterogeneous IoT devices in the health care domain.

In the traditional cloud computing model, the number of smart supported devices and applications increases at a slow rate oppositely to what happens in fog/edge computing systems. Scalability is an essential feature that defines how resources provisioning is performed and what components can be scaled, notably the storage capacity, the number of fog/edge nodes, the connectivity solutions, and the internal hardware or software of fog/edge nodes. Tseng and Lin [42] designed a mechanism to dynamically scale in/out the serving instances of the middle nodes to make the whole IoT/ M2M (Machine to Machine) platform more scalable using an industrial IoT (IIoT) scenario. Vilalta et al. [43] proposed a new fog computing infrastructure named TelcoFog that can be installed at the edge of the mobile network of the telecom operator to provide several services, such as NFV (Network Function Virtualization) and MEC for IoT applications, the benefits of the proposed infrastructure are dynamic deployment, scalability, and low latency. Gupta et al. [44] proposed a highly distributed service-oriented middleware called SDFog (Software-Defined Fog) based on cloud and fog capabilities as well as SDN (Software-Defined Networking) and NFV to satisfy the required high level of scalability and QoS.

The bandwidth needed to transmit the data collected is closely tied to the generated latency, the biggest amount of data requires more bandwidth to be transmitted to the cloud data centers, which means more latency in the transmission process. Optimizing the bandwidth in a fog/edge environment directly minimizes the delay resulting from the transmission process because the processing resources are located close to the end devices. In this context, Ito et al. [45] proposed a bandwidth allocation scheme based on collectible information. Gia et al. [46] introduced the processing of ECG (electrocardiogram) features using fog nodes, their results disclosed that fog helps to achieve more efficiency in bandwidth and low latency in the data processing. Bhardwaj et al. [21] argued the utility of "onloading" cloud services to the edge of the network to address the bandwidth and latency challenges of IoT networks.

4. Components of an intelligent farming IoT model

Before deciding to integrate IoT infrastructure in a given smart farming business model, it is first mandatory to understand the components of the IoT model, because this is the best way to analyze business technology compromises, and better define the requirements of the farming process system. **Figure 1** illustrates the five layers comprising of the smart farming IoT model, each layer is explained in greater detail below.

4.1 Hardware sensor and actuator layer

This component is located in the bottom layer of the IoT model, it can also be called the data collection and actuation layer, it is considered as the link between the farm physical world and virtual data management and decision making. Functionally, this layer is responsible for sensing capabilities to gather data about the physical farming variables that we want to measure, as well as take actions to change the environment depending on the scenario of the made decision. In this layer, it is recommended to take into account the hardware characteristics, such as size, cost, useful lifetime, reliability, performances, as well as the scenario of use. Physical sensors existed for a long time before even the emergence of IoT devices, the only difference is that their uses have become more sophisticated and they have been used more ubiquitously. The intelligent farming sensors can be manufactured separately or embedded in a specific

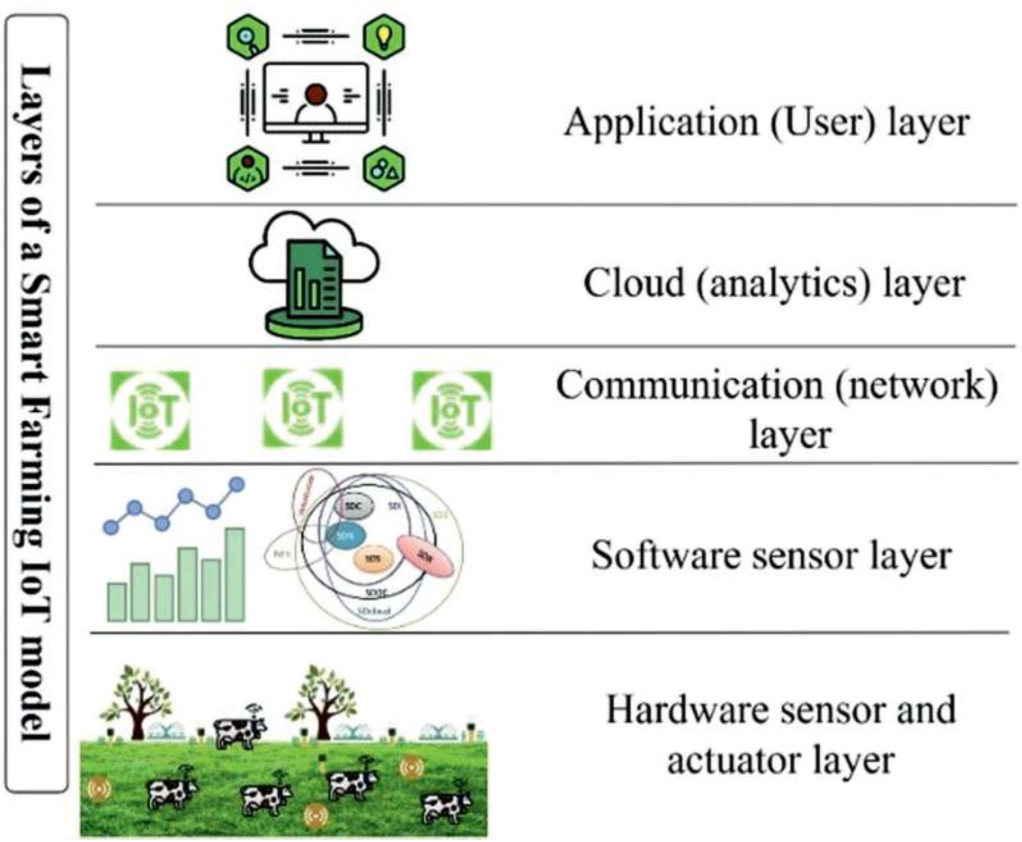

Figure 1.
The five layers of a smart farming IoT model.

one board and dedicated to a particular application. The common applications of sensors are to measure temperature, humidity, geographical position, light and sound sense, and much more.

The farming actuators are the translators of the decision to comprehensive and useful energy capable to change the environment from one condition to another, such as guiding an agricultural engine, changing the temperature, making a movement, or enabling/disabling a pump. Operationally speaking, actuators can take three forms—pneumatic using air pressure, electrical using electrical energy, and hydraulic based on the power of liquids.

4.2 Software sensor layer

This layer represents the point of connection between the physical world and the fog-cloud environment, it defines how an object can be smart by doing local analytics, take simple decisions, or control other devices. This layer enables the "software-defined hardware infrastructure (SDHI)" or "resource desegregation" [47] concept, which is one of the software-defined environment taxonomy. This concept is of great interest today because it considers physical hardware as a modular component offering more flexibility, agility, automation, and optimization in cloud resource allocation. It provides a new pool of resources-based vision and strategy to efficiently manage available hardware resources to serve multiple applications, this offers more programmability to the infrastructure. It exists in literature more similar concepts like virtualization technique [48, 49], Virtual Network Function (VNF) [50, 51], Software-defined cloud (SDCloud) [52, 53]. This layer is important and critical at the same time. Important because it can be used to minimize the hardware complexity, in other words, instead of being stuck in a fixed hardware architecture which is complex and expensive to build in most of the time, it is possible to design generic hardware like Field Programmable Gate Arrays (FPGA) and program it for various scenarios. And critical because it is the only gate through which the data flows from the physical world to cloud or fog environments, thus the definition of an OS (Operating System) that manages the hardware and the running applications is considered a critical task.

4.3 Communication (network) layer

In some contexts, this layer is called connectivity, it defines the manner of how data are sent and received between the cloud and the smart devices. The connectivity function has resulted from the combination of two essential elements—protocols and physical hardware used to transmit the signals. In the beginning, RFID is used by the objects to communicate with each other [54] without human intervention. With the emergence of 5G cellular network, a great opportunity is offered to accelerate the IoT systems' development, particularly with the emergence of the MTC (Machine Type Communication) concept, which is also called machine to machine communication, it refers to automated data communications among devices. According to the 3GPP (3rd Generation Partnership Project), it exists two modes of communications in MTC applications—the first mode can occur between an MTC device and a server, and the second can happen between a network of MTC devices [55]. Choosing the communication mode and protocol is a critical task for IoT project owners. This modeling step defines not only the communication with the cloud but also determines how IoT objects communicate with each other. Many communication technologies can be used, for instance, Bluetooth, ZigBee, Wi-Fi, and optical wireless communication for small coverage areas [56, 57]. Sigfox [58] and LoRa, LoRaWan (Long Range Wide Area Network) [59] have been conceived for a wide coverage area. Moreover, 5G is adopted to enhance all traditional mobile communication performances, and respond to multiple connectivity requirements of IoT applications, such as introducing low latency and reliability.

The heterogeneity in communication protocols as well as the complexity of manufacturers' models lead us to think about solutions to ensure the interoperability between IoT platforms and services. Consequently, the IoT middleware concept is immerged and many solutions have been proposed. The propositions can be classified into three big families [60]: Actor-based IoT middleware, cloud-based IoT middleware, and service-based IoT middleware. The first proposition of the actor-based middleware project offers an easy deployment in the distributed environments since it uses actor or agent concept, this middleware plays the role of a bridge between IoT devices and cloud services, it first works presciently to correctly receive data from each IoT device. It next sends the collected data to the cloud using HTTP (Hypertext Transfer Protocol) over TCP/IP protocol. The second family enables the terminology of the cloud of things (CoT) that was introduced by Yuriyama et al. [61], it is an enabler that lets us exploit and manage wireless sensors homogeneously without worrying about the manufacturer's physical complexities. CoT uses cloud capabilities in terms of elasticity of resource provisioning as well as automation, scalability, and cost-effectiveness. Considering this family of IoT middleware, the access of IoT devices to the cloud resources is ensured by the Application Programming Interface (API) of the cloud service provider or through the product vendor's application, as shown in **Figure 2(a)**.

The last family of IoT middlewares refers generally to the open-source platform named OpenIoT project, the objective behind proposing the SaaS (Sensing as-a-Service) solution is to find an adequate way to extract data from virtual cloud sensors without worrying about the physical architecture of the sensor that was behind the collected data. The architecture of the service-based IoT middleware is given in **Figure 2(b)**.

The most common criteria that is recommended to put in mind while choosing the adequate IoT middleware are stability regarding the application, the deployment mode (open source or commercial), the payment model (by the number of device/messages or using pay as you use mode), the level of security needed (depends on the criticality of the application and the managed data), the hardware compatibility

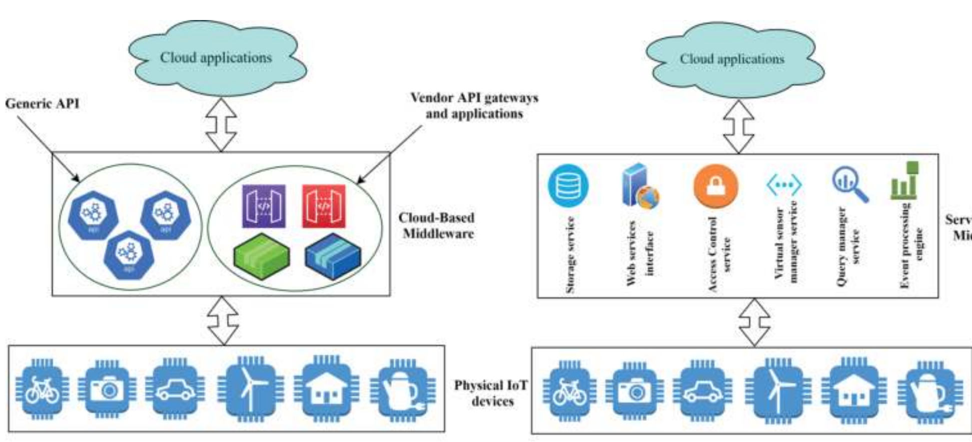

Figure 2.
Cloud-based and service-based IoT middleware.

(some commercial IoT Middlewares support the integration of some kind of hardware devices like Arduino and Raspberry), the protocol that the application requires (since it exists multiple types of communication protocols, some of them are open and others are proprietary), and either the middleware platform supports the required analytics or not (it depends on the nature of data that the application need which can be in real-time or historic).

4.4 Cloud (analytics) layer

IoT applications produce periodically what we call big data and send them to the backbone to be managed. The challenge for an IoT project manager is to consider many critical factors to conceive the right cloud architecture. This layer should take into account the essential 5 V of big data from the beginning, the 5 V as mentioned in Ref. [62] includes volume, variety, velocity, veracity, and value. The designed cloud architectures for IoT applications take many models depending on the project manager's perspective.

The model can be SaaS (Software as a Service), the customer in this case, does not have any knowledge about the platform architecture, the client only has a web interface or an API to interact with the provider platform, this model, in general, requires additional fees and the client still stuck in "Vendor lock-in," this means that more complexity and costs will be charged by the client if for any reason, decides to switch to another service provider.

The second model is PaaS (Platform as a Service), the client in this case has multiple choices of software bricks that can be used on-demand to build IoT applications without worrying about server management. This model provides many bricks for IoT solutions such as device management, storage, connectivity with other IoT fleets, collection, and transmission, as well as some machine learning options for decision-making support. The advantage of this model is the great ability offered by the vendor to the client to customize the IoT applications based on the offered software catalogs. But unfortunately, this can have some additional hidden costs.

The third kind of model is licensed or on-premise. Here, the vendor only makes support available to the client. The client buys software packages and the license, then installs them in his own managed infrastructure. All the maintenance tasks are under the client's responsibility. The open-source solutions are identical to the licensed model, the only difference is that the software packages are freely available, the solution maintenance is ensured by a community of volunteer developers. In some cases, the maintenance is performed by an enterprise and proposes the solution as a free package, while providing a paid version with other options. The tailor-made feature is another option adopted by many customers, it consists of engaging an external integrator to entirely conceive the IoT solution. In this case, the source code is owned by the application owner, he can use it subsequently to achieve the project evolutivity.

4.5 Application (user) layer

This layer is the most closer to the customer, it is generally used to ensure user-machine interaction, it defines how data is presented to the end-user depending on the user's requirements. In most cases, this layer is a web-based application. Some users require desktop, mobile, or wearable applications. Practically, the application layer is hosted somewhere in the provider's cloud to ensure the AAA

(Anytime, Anywhere, Application) capability. The most important thing that the IoT solution designer should understand is what the final users attend from the solution, and how this job can be done.

5. Open challenges of IoT-Fog integration in the IF context

5.1 Real-time processing

Fog computing provides required resources at the edge of the network to deliver real-time services for demanding applications (e.g, video streaming, gaming, video analytics, and robot-fog interactions [63]). When it comes to IoT data processing on a large scale, we can distinguish between three processing concepts [64], as illustrated in **Figure 3**.

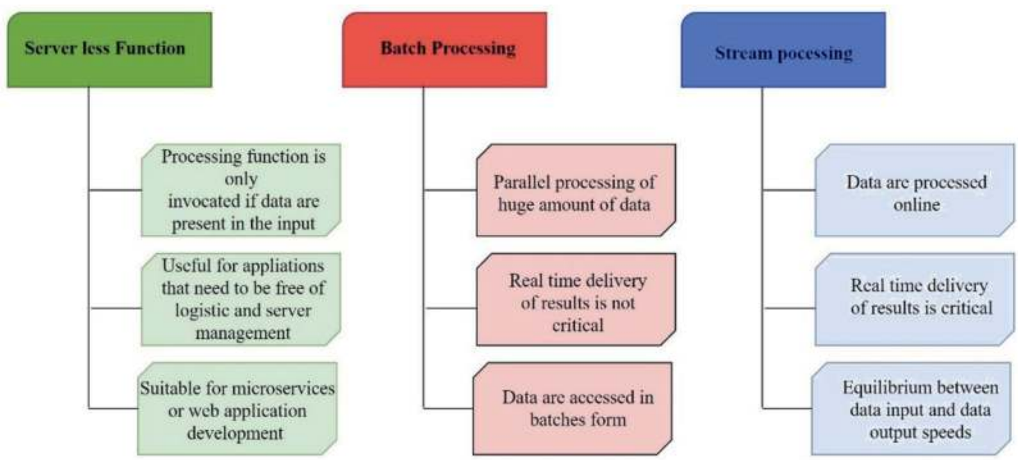

Figure 3.
Available modes of processing for IoT applications.

The serverless function also called Function as a service (FaaS), refers to the simplest processing model where data are present in the input of a black box, the results of processing are then gathered in the output without any session stat. The second processing concept is called batch processing, here, data are processed in small parts and often simultaneously, this type of processing is considered in situations when a large amount of data need to be processed, input data are accessed in batches form, or data need complex processing. The last processing mode is called stream processing, it refers to on-the-fly processing where data are processed online and the results are delivered instantly, this mode of processing is appropriate in case of real-time results are needed. Since IoT applications are diversified and data are generated and sent continuously to fog computing nodes, each processing mode can be adopted for a specific scenario.

5.2 Resource scheduling and management

It was expected that a huge number of IoT devices will be online shortly, meaning that the amount of generated data will be also colossal. Resource management policy is a determining factor in evaluating the quality of service delivered to IoT devices and applications. This policy depends on many factors such as the nature of the application requiring the resource. If the application allows delay of processing, all its requests are forwarded to the cloud resources to be executed there. But if the application is time-sensitive, all its requests are served by fog computing nodes.

5.3 IoT geo-distribution and mobility

Geo-distribution is one of the primary characteristics of smart devices. An object is most of the time moving from one geographical area to another, this mobility generates delay and packet loss [57]. Fog computing has to provide necessary mechanisms and resources to facilitate fog users' access at anytime, anywhere, and without any delay or loss, given that devices are highly distributed, handover is a critical mechanism among others that should be taken into account while conceiving and implementing fog computing architecture.

5.4 Latency minimizing

Most IoT devices have resource limitations in terms of communication, storage, and computation. As a direct result, the connected object needs a powerful infrastructure that can provide these requirements within a milliseconds scale. Cloud computing is known for its big latency, which makes it unsuitable for time-sensitive applications. On the other hand, the fog computing challenge is to provide necessary resources at the edge of the network to process data and serve IoT devices' requests within milliseconds to a few seconds scale. Fog computing serves also the central cloud by sending reports for data visualization purposes [65].

5.5 Security and integrity enhancement

Recently, IoT-generated data may represent the secret of an individual or an industry, indeed, they need to be protected in the transit phase and in-rest. The fog computing paradigm must ensure confidentiality-integrity and availability of data through efficient cryptographic algorithms. The security mechanisms offered by fog have to be light and less resource-consuming to be more adapted to the limited properties of end devices. In another hand, collected data are analyzed and treated locally in fog data centers instead of sending them through the internet to the cloud datacenter, this point helps a lot in data security reinforcement.

5.6 High availability

The exponential rise of IoT-generated data demands a reliable platform that can manage this huge amount of data. The temporary loss of connection is not an issue in the case of cloud computing scenarios. Whereas, a short loss of connection can lead to disastrous consequences for an autonomous vehicle system or an application impacting citizens' safety.

5.7 Networking, and storage enhancement

This is another big challenge for fog computing, especially after the emergence of software-defined environments such as SDN (Software-Defined Networking), SDHI (Software-Defined Hardware Infrastructures), VNF (Virtual Network Function), virtualization, SDC (Software-Defined Computing), SDI (Software-Defined Infrastructures), SDS (Software-Defined Storage), and others. Implementation of such techniques in fog networking requires a radical change in fog computing infrastructure design. It is not simple as it looks, but once it is done, all the other benefits especially latency minimization are achieved.

5.8 Energy consumption

By definition, the IoT objects collect and transmit data using wireless connections; fog computing also supports wireless D2D (Device to Device) connectivity, whereby the networks of devices can decrease significantly their energy consumption since a big amount of requests are executed in fog nodes. From another perspective, fog computing contributes to decrease cloud computing energy consumption because most of the IoT requests are onloaded to the border of the network.

5.9 Scalability

This feature is widely required in fog computing infrastructure. The fog data centers need to support the load balancing, agility, and elasticity of runtime, these variables contribute to efficiently control the variation in fog computing workload. This challenge is strongly linked to geo-distribution, since it has been often required for the fog data center to be efficiently geo-distributed, in that way each fog datacenter serves IoT devices existing in its coverage area. The need for scalability is triggered by the instant and high demand for the workload that can be created by IoT devices.

5.10 Complexity

It is obvious that IoT devices are limited in resources point of view, so onloading tasks to the fog layers reduce the computational complexity of IoT devices [66]. From another perspective, the fog/edge computing approach reduces network architecture complexity, as well as decreases the number of points of failures in IoT systems. Integrating ML capability in the fog layer minimizes the complexity of the decision-making process.

5.11 Heterogeneity

IoT architecture is becoming more heterogeneous day after day. A relevant definition of fog computing given by Yi et al. [67] mentioned that "*Fog Computing is a geographically distributed computing architecture with a resource pool which consists of one or more ubiquitously connected heterogeneous devices (including edge devices) …*," this definition confirms that fog computing is supposed to manage data and devices coming from varied manufacturers. These devices have different physical characteristics and require a variety of deployment methods.

6. Blockchain technology for digital farming

We mean by Blockchain a digital and distributed ledger that protects the history of any digital asset from any alteration or unauthorized modification, this protection results from the use of hashing, cryptographic techniques, public-private key functions, distributed databases, and processing, as well as consensus algorithms. Blockchain is historically conceived in the creation of Bitcoin [68] by "*Satoshi Nakamoto*" in 2008 as a novel cryptocurrency purely digitalized. Although this technology is still in its early stage, it recently creates a technological revolution, thanks to its brought advantages, such as guaranteeing transparency, auditability, anonymity, decentralization [69], and independency, as well as reducing the risk of frauds in transactions between machines in a P2P (Peer to Peer) network. In the food and farming context, the combination between Blockchain and IoT is a promising contribution that immerged to improve the traditional methods of farming management. Blockchain technology can provide farmers with new solutions to smartly manage and monitor soil, engines, warehouses, livestock, logistics, and supply chain. It was expected in Ref. [70] that the utilization of this technology in the supply chain market will reach $ 429.7 million by 2023. The need to build trust between the food producers and the consumers in the agri-food sector is a big concern that can call Blockchain technology to provide transparency, efficiency, and sustainability in the agri-food chain. Moreover, the more quantity and diversity of food is produced, the more compliances and audits are required, the information resulting from the audits is still managed with traditional paper or stored in a centralized database, this approach of management is susceptible to suffer from many issues such as error, lack of integrity, and data consistency, as well as fraud and corruption in the case of paper-based information [71].

The following sub-sections discuss the possible solutions on how Blockchain technology can be used in digital farming and smart agriculture. Each section discusses some of the most relevant platforms adopted in Blockchain use cases upon which IoT-based intelligent farming applications are based. After consulting this sub-section, the reader will discover an obvious complementarity between the use cases, it is up to the implementer of the Blockchain-based application to decide either to combine many use cases in one system or to focus on one use case in its contribution. **Figure 4** illustrates the possible seven use cases of Blockchain in IF.

6.1 IoT security optimization

It is difficult for the traditional vision of networks to provide the requirements of IoT-based IF systems notably latency, bandwidth, security, and reliability. A Blockchain-based security architecture proposed to monitor the integrity of IoT collected data by checking and preventing unhallowed alteration that can be caused by DDoS (Distributed Denial of Service) attacks on delivered data [72]. The Blockchain-based solutions for improvement of IoT security in green agriculture cover many areas [73] such as public key infrastructure support [74], machine learning-based systems [75], access control improvement [76, 77], reputation and trust use case [78, 79], amelioration of authentication and identification of IoT objects thanks to the bubble of trust system [80]. The bubble of trust is analogically a private VLAN (Virtual Local Area Network) of sensors, communication between sensors in the same bubble is fully private and secured because it must be validated by the Blockchain network, furthermore, no communication out of this bubble is authorized. **Figure 5** shows a proposed scenario on how can Blockchain be applied to secure transactions in an IoT system. When the positioning system collects the location of the smart tractor, a transaction is occurred and is inserted in a new block, the generated block is sent to the other miners for checking the solution used in the mining process. Once the

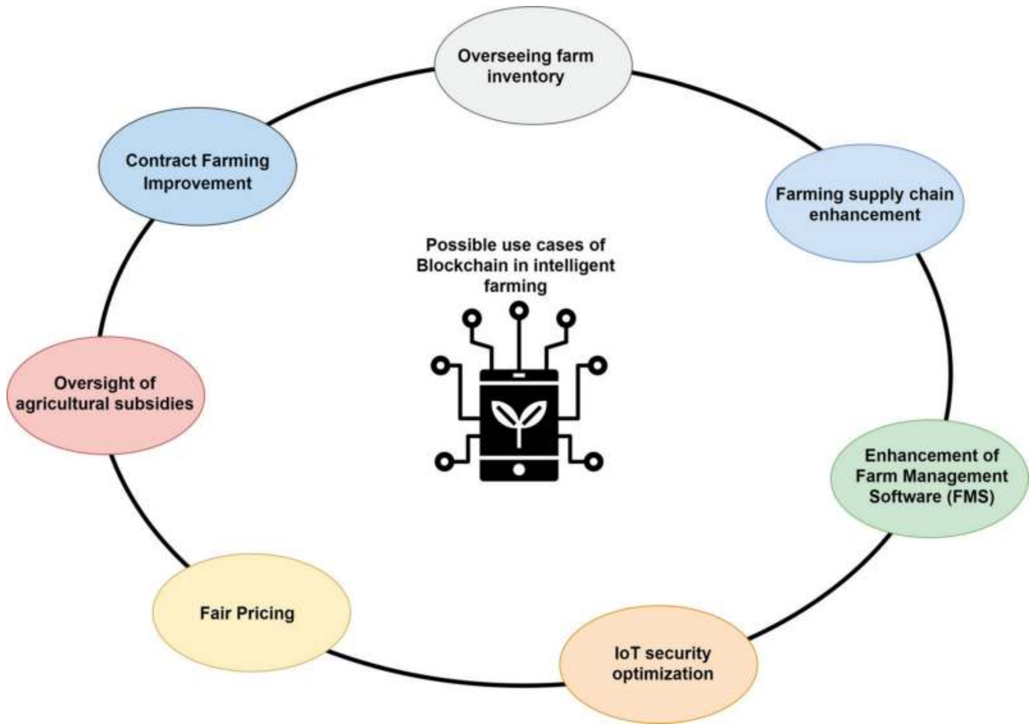

Figure 4.
The possible use cases of Blockchain in intelligent farming.

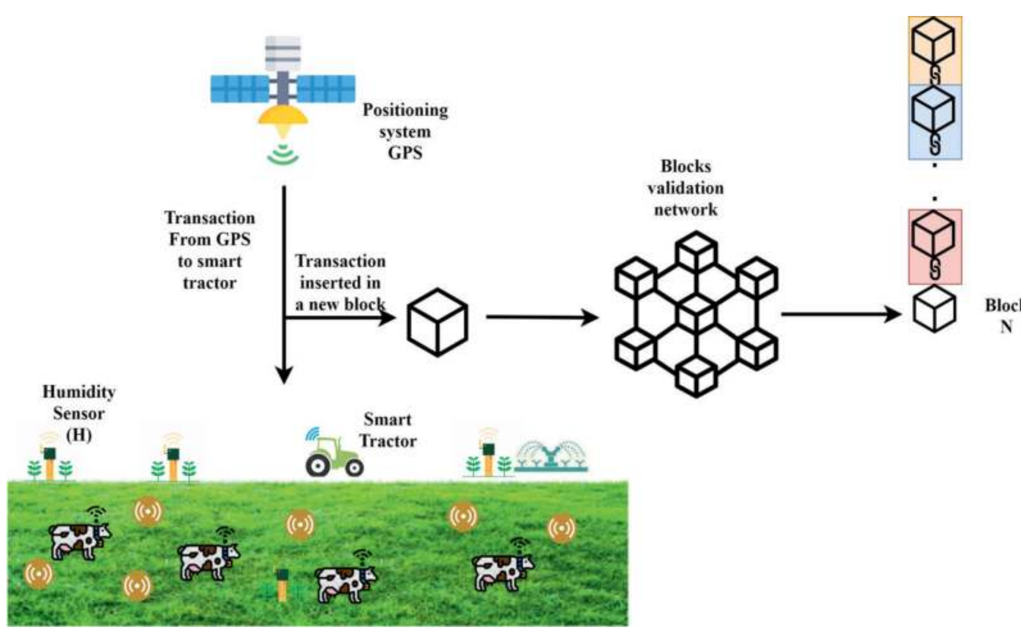

Figure 5.
A proposed scenario of a Blockchain-based IoT security optimization application.

mining solution is validated, the block is addressed to the Blockchain nodes for validation, and stored in the Blockchain once it is verified. This process is fully decentralized and uses cryptography techniques and hashing.

6.2 Fair pricing

Farmers are the weak link in the agri-food production chain, the price they got for their products does not reflect their real provided efforts due to the existence of multiple middle layers of buyers. This issue happens because they lack marketing opportunities, thus their products are not properly marketed, so they do not get the deserved price from the buyers. Thanks to Blockchain technology, farmers can reach more buyers and marketplaces than expected and can fairly discuss the right price of their goods. A decentralized farming approach named KHET is proposed by Paul et al. [81] to slightly reduce this issue, KHET platform enables farmers, companies, and buyers to communicate with each other, and make commitments based on the smart contract without any intermediary. With such a platform, farmers can finance their farming projects without requesting a loan from the bank. **Figure 6** illustrates a proposed model of how can farmers make deals fairly with retailers using Blockchain technology. The farmer and the retailers must be registered in the public Blockchain system, each one is identified with a unique identifier, which is its digital wallet address. The deals are made on a dedicated agricultural platform which is channeled with the Blockchain system using a dedicated API, the role of the API is to retrieve and verify farmers' and retailers' addresses. The farmers are now able to check and discuss the prices of their

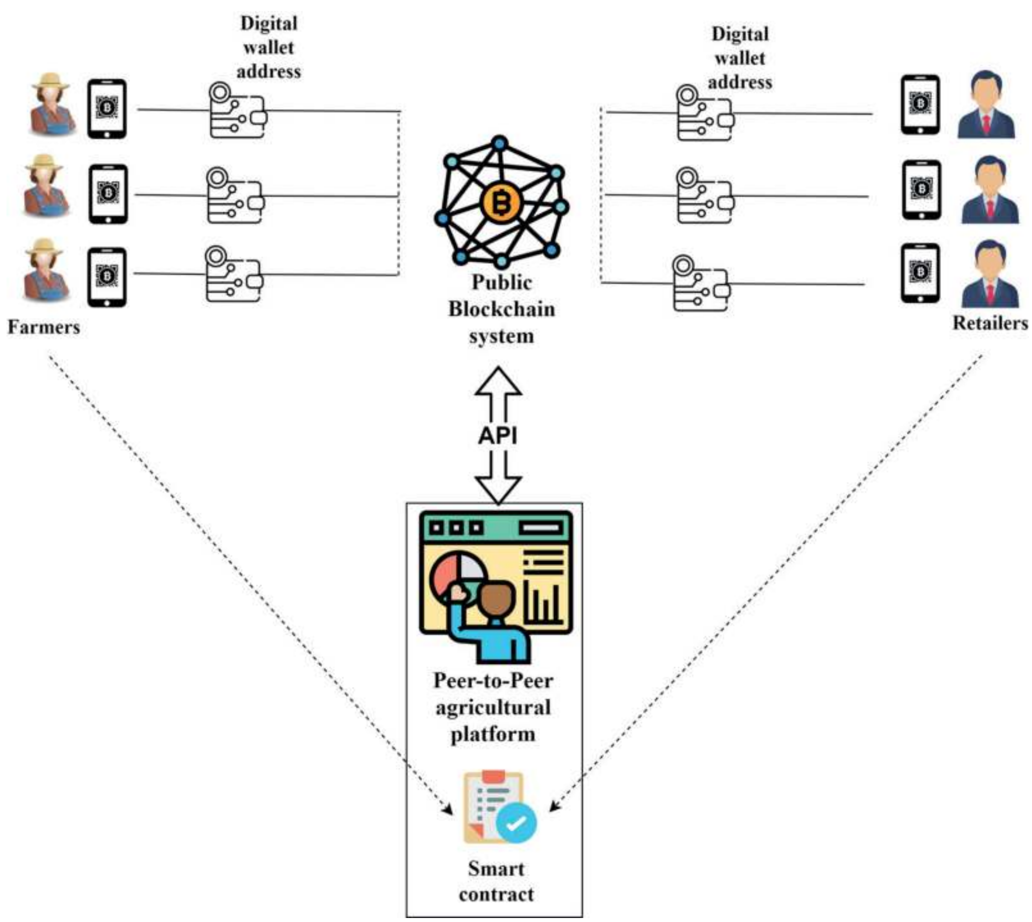

Figure 6.
A proposed model of agricultural fair pricing application based on Blockchain technology.

products freely and fairly with all interested stakeholders and without a middle-man. If the farmer and the retailer accept the conditions, the smart contract is established and the amount of money can also be transferred from the retailer's digital wallet to the farmer's digital wallet using the digital money platform.

6.3 Oversight of agricultural subsidies

To help farmers in their multiple investments and increase productivity, a new governmental subsidies distribution system should be adopted. The classical methods of distributing aids to farmers lack transparency due to information centralization and lack of coordination between agricultural stakeholders. With Blockchain, a decentralized ledger can be built to ensure agricultural information sharing in a secured manner. The digital ledger can be made publically available, thus farmers

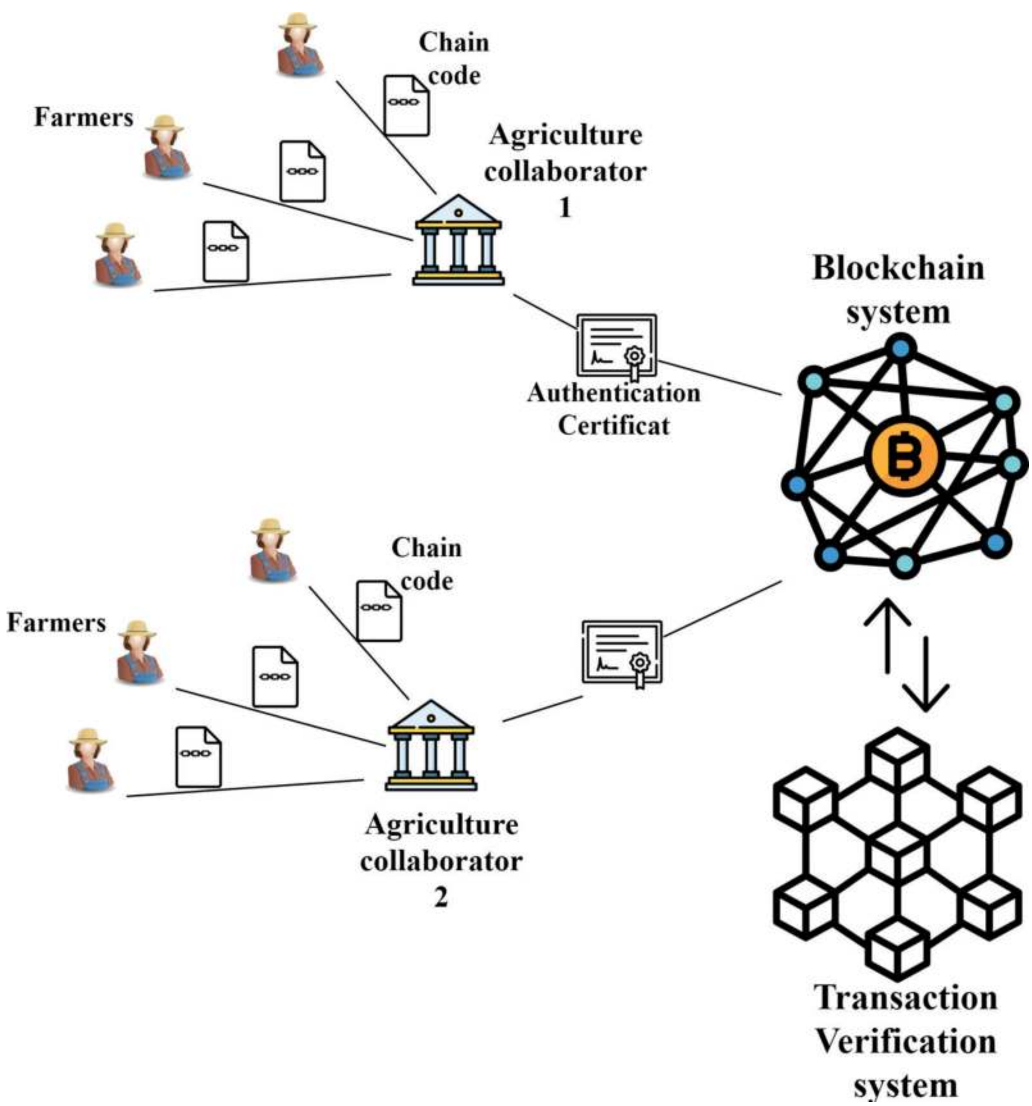

Figure 7.
A proposed scenario of single farmer identity management using Blockchain in a multi-collaborators environment.

can see if subsidies go it should be, as well as how much each farmer receives as aid. In this context, Abraham and Santosh Kumar [82] proposed a Blockchain-based system to ensure transparency and reliability of the information in the subsidies system. The scenario proposed in **Figure 7** provides a solution to deal with the problem of farmers' identity management in a multi-collaborators environment, each farmer is identified by a chain code which is a smart contract installed on the peers of the private system of the AD (Agricultural Department), each AD uses a certificate to authenticate the transaction in the public Blockchain system and keep a private validated ledger. When the farmer sends a transaction, it is accepted or refused depending on the rules and the policy described in the chain code. Agricultural departments are interfaced with the Blockchain system to share the information securely with each other using the unique identity of the farmer. When a transaction occurs between one or more AD, it must be validated by the transaction verification system, which is composed of the other agricultural collaborators. According to this scenario, farmers' information is transparent and reliable for all the agricultural collaborators, Thus, subsidies go to the one who deserves them.

6.4 Contract farming improvement

Smart contract occurs when it is self-managed without middle parties which increases automation and decentralization of the tamper-proof of data, Ethereum Blockchain [83] and Hyperledger Fabric represent an example of platforms that support this kind of technology. They allow developers to implement their Blockchain layer and applications, such as smart contracts, in a decentralized way. The Blockchain-based IF use case enables the final consumers and the partners to have full knowledge about the agricultural product that they want to buy or to retail. The integration of the smart contract with IoT by Umamaheswari et al. [84] helps to build trust between farmers and consumers by providing information about the origin and the environment in which the product is grown and stored, as well as the ability to track the transaction path. Moreover, the implementation of smart contract in the agricultural process improves the CIA (Confidentiality, Integrity, Availability) of data storing method and enable the public to get a trustable license based on the comparison between the products' stored information in the data private chain and those publically available [85]. Data sharing in the IF environment is one of the major challenges of the distributed and scalable IoT systems, this issue is managed by Ur Rahman et al. [86] through a data-sharing smart contract system with access control capability. The smart contract application is present in models proposed in **Figures 6-10**.

6.5 Overseeing farm inventory

Farmers work hard and wait for the post-harvest stage, it is difficult for a farmer to imagine any damage in quantity or quality of his produce. Massive quantities of agricultural products are wasted before it reaches the retailer. This big wastage can be avoided by monitoring some environmental parameters in the storage area. Humidity, temperature, and CO_2 concentration are some variables that can be tracked using IoT and sensors. Public ledgers using Blockchain allow to share information about the product storage operation between all the chain stakeholders, so big visibility about the product's history is provided to all interested collaborators. Moreover, combining IoT and sensors to gather information about the inventory, and public ledgers to implement strategies to monitor this information can be a perfect way

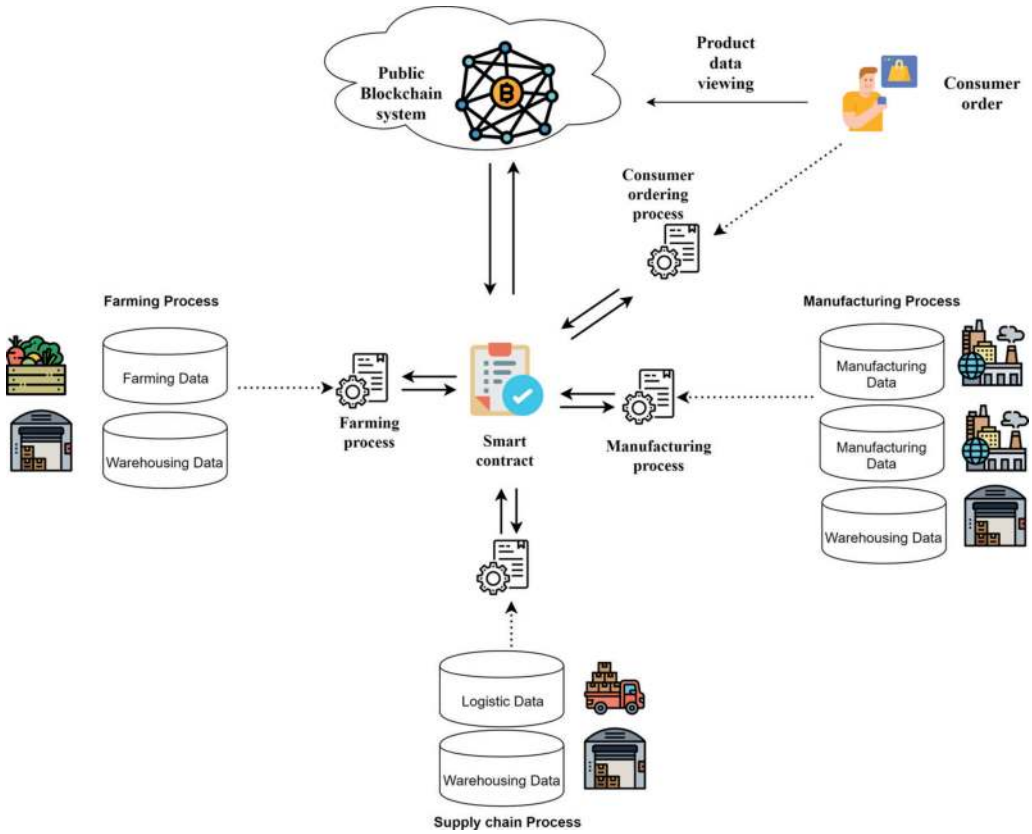

Figure 8.
A proposed scenario of overseeing farm inventory using Blockchain.

to manage inventories and logistics flows. Vendor-managed inventories (VMI) is a popular Blockchain-based collaborative inventory management policy, VMI might be founded on the smart contract between manufacturers, vendors, and buyers [87], consequently, each one of those collaborators can build its supply chain strategy and inventory policy management [88]. The proposed architecture in **Figure 8** illustrates a Blockchain-based system for product inventory management. Farming, manufacturing, and supply chain processes are authenticated using smart contracts and share the products' data in the Blockchain system publically available for consumers. All the transactions occurring between the consumer and the other stakeholders are managed and protected by the smart contract, the verified transaction are stored securely in the Blockchain. The consumer can check the information related to the products before ordering them, or track their safety on the farm, in the factory, or during the delivery process.

6.6 Farming supply chain enhancement

Demonstrating the quality of a product in a producer-consumer relationship is the critical weakness of community-supported agriculture [89]. Without transparency and mechanisms of tracking and monitoring in the production process, consumers are unsure about the safety of the goods they buy and receive. The traceability frameworks based on Blockchain technology in the supply chain is an important key feature not only to ensure the security of the on-chain or off-chain encrypted

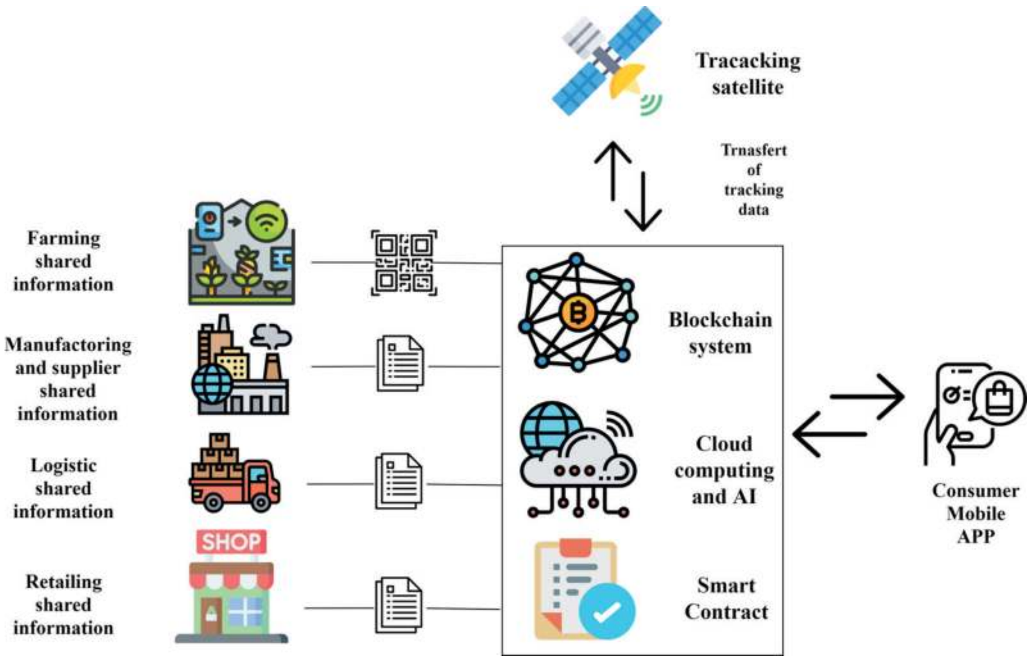

Figure 9.
A proposed model of supply chain enhancement using Blockchain technology.

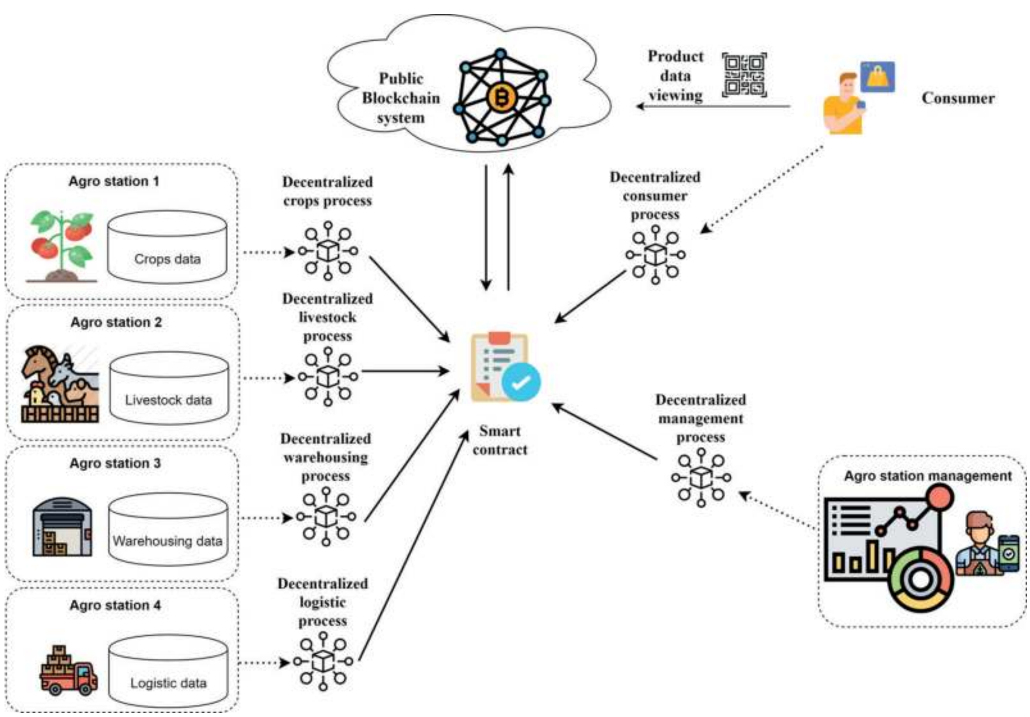

Figure 10.
A proposed Blockchain-based FMS scenario.

and stored data, but also to overcome the big latency that can be generated when querying databases [90] either by the public community or by the relevant partners. Combining IoT, RFID, and QR (Quick Response) code with Blockchain helps to build powerful supply chain systems to track agricultural food from farmer to retailer and make product information accessible to all users [91]. **Figure 9** shows a proposed model for a supply chain enhancement use case. The food information is shared in all the supply chain phases. IoT and sensors collect data related to the environment where the crop is grown, the manufacturing conditions, the shipment and logistic flow, and the retailing environment. The consumer through his mobile application generates a transaction (new command of a product) and checks the product's shared details. On the other hand, the supplier can make his offer, the smart contract is for protecting the valid transaction between consumer and supplier, as well as storing the new transactions in the Blockchain system.

6.7 Enhancement of farm management software

Modern farming requires the modernization of all its processes including FMS (Farming Management Software), traditional FMS are based on a classical client-server based-approach, this method does not satisfy the growing demand on inputs-outputs as well as enough security level for data protection. With Blockchain technology, more sophisticated and secured systems for supply chain management, smart greenhouse, and livestock are provided, so that farmers and analysts who care about data integrity and uncertainty will not worry anymore about intentional or accidental alterations that can be caused by one of the information flow manipulators. It is expected that the FMS market growth will reach $4.22 Billion by 2025 [92], thanks to the widespread of Blockchain solutions and the wide usage of IoT, sensors, as well as artificial intelligence in the farm management workflow. The model proposed in **Figure 10** explains an FMS use case. A secured and decentralized management of the farm's processes is achieved, the principal role of the smart contract is to authenticate all the decentralized processes and ensure the integrity of the transactions that can be occurred between them. The data gathered in each decentralized process are shared with the public consumers through the public Blockchain system, the consumer can check the origin, the expiry date, and other information related to the warehousing with a simple scan of the QR code of the product. If the consumer is satisfied, he/she can supply orders to the farmers, and the smart contract is established. The farm distributed processes and the consumers' orders are managed using the FMS decentralized consol.

7. Research and development in digital farming

An overview of the published literature on the actual status of ICT usage in digital farming, particularly IoT-fog/edge/cloud computing, and Blockchain technologies reveals that most growers are interested in understanding the optimum conditions in open-field and closed-field crop production that results in reducing inputs, and at the same time maximized crop yield and quality. Our previous studies and survey show that some of the trending research topics in this context include (1) development of digital twin models that receives live data from various wireless sensors for improving efficiency of crop production systems [93], (2) adaptation of multi-robot platforms for wireless and IoT data collection [94], (3) health assessment, stress identification, and early disease detection using UAV remote sensing [95], (4) development of soil-test kits that can be mounted on mobile-robots for spontaneous determination of macronutrients in soil [96], (5) yield prediction and yield estimation using model-based and AI algorithms [97–99], (6) evaluation of crop growth environment prior to the actual cultivation for preventing yield loss (i.e., predictive models that can be leveraged as a part of digital twin) [100], (7) development of virtual orchard models using photogrammetry [101], (8) smart irrigation with solar powered IoT controlled actuators [102], (9) reducing time losses of machinery and increasing their field efficiency by using fleet management software [103], and (10) robotic weeding and harvesting [104, 105]. The success of such systems in our point of view is intimately linked to some important factors like the accuracy and complexity of ML/DL algorithms used to make IF decisions, as well as the availability of enough datasets to train and validate the ML/DL algorithms. From a Blockchain point of view, the horizontal and vertical scalability of IoT systems introduces more complexity in data sharing models within IF systems. The success of Bitcoin, as a result of Blockchain, is proven but the mutual collaboration between Blockchain contributors requires more maturity. Moreover, more efforts and works have to be provided to sensitize the public, the community of regulators, and the contributors about the need to invest in Blockchain development, without forgetting to address the scalability challenge (technologically speaking, it has a direct impact on the number of transactions). Furthermore, farmers in IF ecosystems need to make payments and receive subsidies from the government using cryptocurrency, transactions in this situation are susceptible to be targeted with selfish mining [106]. Blockchain is an open system, any miner can join the chain, and selfish miners can outperform honest miners and then can threaten the security of the transaction. It is a fact that Blockchain frameworks and updates for coding are publicly available, but they often lack the needed level of validation and verification against bugs, security breaches, and errors [107], so new researches and efforts are required in this direction.

Another important needed research is how to achieve interoperability between the Blockchain projects namely cross-chain, or between Blockchain and the exiting data models. The required interoperability in Blockchain enables users to take the full benefits of distributed Blockchain in terms of sharing information smoothly. As the main purpose of Blockchain is to fight against the centralization aspect, a big concern should be given to show how to build a strategy to share agricultural data (known crops diseases and solutions, best practices to increase yield) between farmers' decentralized ecosystems. The environmental impact of these technologies is always ignored or never addressed. Since sensors and electromagnetic fields generated by gateways are directly interacting with animals, soil, and vegetation, a serious study should be made to evaluate the degree of impact that the waste material of such technologies can have on the environment.

7.1 Machine learning for IoT-based digital farming

The efficiency and effectiveness of agriculture are driven by machine learning and deep learning techniques, these two mechanisms enable machines to learn and analyze data without even being programmed. ML/DL has emerged simultaneously with the Big data discipline to detect relationships, analyze patterns, and make predictions in farming activities. An example of applying a supervised machine learning algorithm with multiple distance detection sensors for autonomous navigation of a field agent robot is proposed by the SunBot project and shown in **Figure 11**. This robot is used for health assessment inside berry orchards and to collect data for supporting digital agriculture. Since traditional approaches and methods for farming management do not allow to increase productivity, farms nowadays need to be partially or

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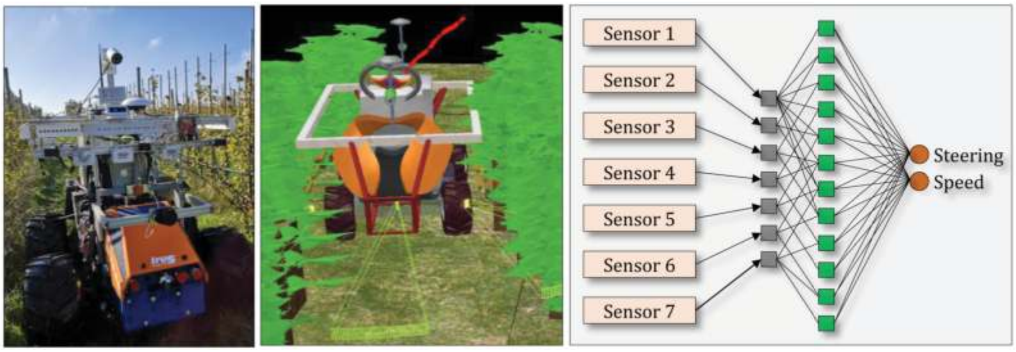

Figure 11.
Application of machine learning as a knowledge-based control approach for assisted navigation of a four-wheel steering field robot agent. Source: SunBot.de.

fully automated using IoT systems to collect data, and ML/DL to make data inspections and drive the decision-making tasks. ML/DL technology helps farmers and scientists to select the appropriate species that respond to specific requirements in terms of diseases resistance, adaptation for specific aquatic or soil conditions, this classification task was quite tedious for farmers or scientists, but with ML/DL, a huge quantity of unorganized data is gathered and analyzed automatically to finally choose which genome is suitable for breeding. In some cases, such as plant health monitoring, it is needed to compare plants according to their colors, leaf morphology, and shapes, in that case, ML/DL can be the solution to perform the fast and accurate classification. In this context, Thaiyalnayaki et al. [108] used SVM to classify soybean diseases, and [109] performed plant leaf diseases classification based on visible symptoms.

Soil management is another farming process that has benefited from ML/DL and IoT technologies, the buried sensors collect real-time data about the underground ecosystems such as temperature and moisture, and transfer them to ML/DL algorithms to estimate the quantity of water needed for irrigation, or evaluate the quantity of nutrients required for optimal growth of crops. Superficial sensors play a major role in measuring temperature, humidity, pressure, evaporation, and evapotranspiration, these climatological and hydrological parameters among others can be used by ML/DL algorithms to estimate exactly how much water is needed to irrigate a given surface area without any wastage. To avoid wastage related to weather forecast uncertainty, Chen et al. [110] used a short-term weather forecasts method to propose an optimal irrigation strategy. Another important role of ML/DL in intelligent farming is the accurate yield prediction in quantity and quality, this prediction can be useful in crop monitoring tasks and market price forecasting. From this vision, many popular ML/DL algorithms are compared in Ref. [111] in terms of three crops yield prediction, they reported good prediction skills of the SVM ML algorithm compared to the other tested ML/DL methods. Traditional methods to control crops diseases widely spread pesticides in all the field, this treatment method leads to wastage and does not ensure the required level of efficiency, as well as harming of environment. Modern farms use computer vision techniques to accurately detect where to apply pesticides, when to apply, how much is needed, and use drones to apply pesticides with high precision. Consequently, more financial benefits are won by the farmer with no environmental side effects. Weeds density detection and treatment are examples of computer vision use case that was applied by [112] to control the area of treatment.

Like crops management monitoring, there is livestock management monitoring, the use of IoT and ML/DL in this farming activity enables farmers to predict the productivity of meets and eggs based on actual or past data. For example, a drone can make a scan of the field and count the number and the position of the cattle. A computer vision system with smart cameras can monitor the mental condition of cows to detect their preferred time of milking or the quantity of feeds they want, as well as the amount of nutrients in their milk using sensors. The visible symptoms detected through computer vision techniques are used to measure animal welfare by monitoring the health conditions of animals, and predicting if a member of the cattle is sick or wants to eat or to drink.

7.2 Wireless communication for seamless connectivity in digital farming

Connectivity, as we said earlier, is an important component in IoT smart systems, this component is a challenging issue in rural environments where cellular network coverage may be absent, or only 2G networks are available, in this kind of cellular network, a limited number of devices can be supported that leads to a lack or reduced performance in data transfer. Nowadays, 3G/4G cellular networks are enough to build usual and smart farming applications. However, to unlock the potentials of IoT systems, two promising connectivity solutions, according to McKinsey Global Institute [113], are expected to be developed, these technologies are being referred to as "advanced" and "frontier." An example includes IoT-based collision avoidance sensors for autonomous electrical mowers that are capable of transmitting their distance measurement via WiFi and LoRa. While the main communication between different

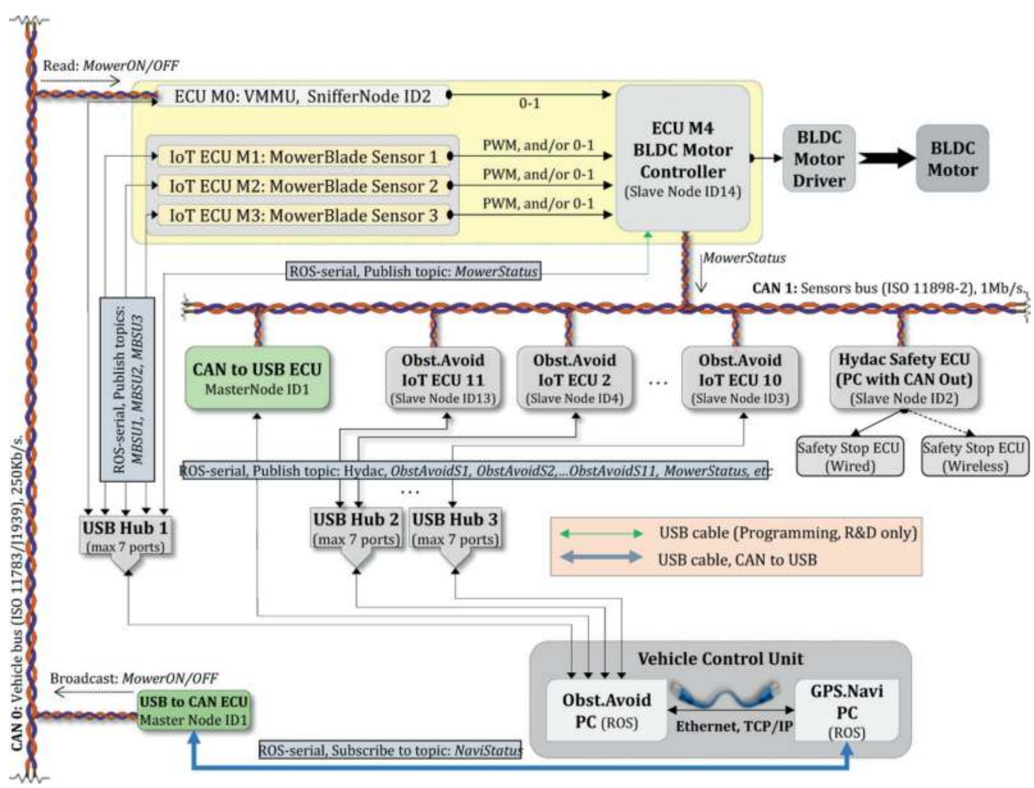

Figure 12.
Perception system with IoT-based LPWAN sensors for collision avoidance of a robotic mower. Source: SunBot.de.

electrical control units (ECU) for such system still relies on CANBUS and the detected distances can be logged on an onboard SD card (**Figure 12**), but the use of IoT-based ECUs that are independent of GPS and WiFi, provide the operator with LoRa messages for real-time monitoring of the mower status. This approach also makes possible simple switch control of the device in remote areas where WiFi and mobile coverage is not available. The architecture of this system is shown in **Figure 12**.

The advanced connectivity represents the next generation of already existing infrastructures, we mention here the upgrade that is occurring by providers of 4G technology toward 5G, this upgrade offers more improvement in speed, bandwidth, and latency, and the number of supported devices will be increased as well. For now, the evolution of wired connectivity, such as optical fibers, can offer the best performances in terms of latency, bandwidth, and speed especially in the core of the network, or in environments where mobility is not a crucial factor. Not Far from wireless networks, the Wi-Fi Alliance has certified the new standard 802.11ax known as Wi-Fi 6/6Extended, this new connectivity solution offers for devices a wide range of frequency and improved gain of speed that was estimated to achieve 40%, the theoretical speed of the network was estimated to reach 10 Gb/s, the Wi-Fi 6E offers 11 Gb/s as a theoretical speed with larger spectrum channels. These advantages enable IF devices to be connected seamlessly and smoothly, and the number of supported devices will be improved as well. The revolution in connectivity solutions has also been made by short-range technologies (Bluetooth, Wi-Fi, RFID) and low power wide area networks (LPWAN, LoRa, LoRaWan, NB-IoT), these technologies are usually used for tagging, tracking, or identification. These technologies have become more sophisticated and adapted for seamless connectivity in intelligent farming. The frontier connectivity is mostly designed for high mobility systems that need high speed, reliability, security, and minimal latency. Low earth orbit (LEO) and 5G networks are two options that will be developed to satisfy all IoT requirements. LEO constellations provide seamless connectivity services for IoT-based IF systems installed in distributed rural areas, or in zones where the terrestrial network is not available, so satellite coverage is needed. The other option of frontier connectivity is the 5G cellular networks, which promises to combine all the advantages of wired fiber in the air to be more adapted to IoT systems and wireless sensor networks.

7.3 Connectivity challenges of wireless sensing under field conditions

In remote areas, it is more adapted to use wireless devices as they allow to cover wider areas, but the energy consumed by these devices and their limited source of energy creates a big challenge that needs to be addressed. **Figure 13** shows multiple solar-powered LoRa sensors that have been deployed in different berry orchards in the state of Brandenburg in Germany for IoT monitoring of agricultural parameters (i.e., air and soil temperature, relative humidity, soil moisture, leaf wetness, light condition, and dew-point temperature). The wider area the IF system covers, the more power is consumed, some solutions are proposed to solve this issue, such as photovoltaic panels and the choice of low power consumption sensors. For instance, if BLE or low power consumption devices are used, the coverage area will be reduced because energy consumption will also be reduced, but if a wider communication range is needed, Wi-Fi connectivity can be adopted but energy consumption will be high. Technologies like LPWAN, LoRa, and LoRaWan adopt more efficient energetic strategies and a high communication range. Another connectivity limitation is the wireless signal quality. In remote areas where geographical issues are encountered, the

Figure 13.
Implementation of multiple solar-powered LoRa sensors in different berry orchards for IoT monitoring of field parameters. Source: SunBot.de.

wireless signal may have an attenuation problem because of multiple environmental obstacles or electromagnetic noises that can be introduced. The propagation of wireless signals can also be an issue that can be mitigated by installing signal repeaters or designing more efficient topologies such as mesh. The IoT and WSN systems management is another solution to reduce the connectivity limitations of intelligent farming systems, some of the management best practices are: (1) Designing an optimal size of the sensor network, here the number of sensors and the number of intermediary nodes to reach the gateway are to be considered because this factor impacts the communication range and the latency of data transmission. (2) The calibration of all WSN nodes whether sensors or gateways, this maintenance action improves the lifetime of the battery, especially in devices that operate in a wide range [114]. (3) Using optimized transmission protocols, many protocols are identified in the literature as efficient solutions to optimize transmission tasks, either to save the energy of the battery, to optimize the routing strategy, or to increase the coverage area.

7.4 Challenges with IoT monitoring in remote areas

Other issues that are encountered when designing an IoT-based intelligent farming system are related to interoperability [115], technological development, data heterogeneity management, scalability and flexibility of the system, fault tolerance, complexity of the system and the harsh environment, energetic issue, and the need for professionals to implement and manage the system. The interoperability issue takes four different formats, it can be technical, organizational, semantic, or synthetical, all of these four components are interdependent, but the most common issue is the technical one, this is occurred due to the hardware and software differences between manufacturers, these differences imply heterogeneity in protocols and connectivity standards, so when implementing the IF system, the farmer finds himself in front of many incompatible technical choices that he should manage particularly if there is an already existing system that it has to be taken into account. The integration issue can go beyond hardware compatibility to software conflicts that can create a new challenge of integrating new IoT points with the existing management software or vice-versa. The velocity of technological development is another issue of IoT implementation in IF, the hardware and the software related to IoT systems are evolving rapidly, which leads to the continuous emergence of new efficient frameworks, the upgrade process can be expensive in terms of infrastructure or maintenance. The scalability and flexibility of the IF system measure the level of opening, centralization, ease of integration with other existing systems and platforms, and ability to scale the system in terms of the number of nodes and storage, this issue represents an example of organizational interoperability. We rarely find all the implemented components of the IoT system from the same manufacturer, this technological heterogeneity and the lack of a global standard that unifies the format of data managed by each technology is challenging for the farmer. Some efforts in this context have been made by the Agricultural Industry Electronics Foundation (AEF) to propose the ISOBUS database (actual version is ISO 11783-1:2017) as an attempt to fill the heterogeneity in data format for agricultural machinery, this issue represents an example of semantic interoperability. The fault-tolerance measures the robustness of the designed IF system. When implementing the IoT-based IF system, the farmer is invited to manage all the hardware faults and system errors that can be occurred, the fewer harmful events the system generates, the more reliability the system has. However, farmers need to have particular skills for better management of these damaging events. As we discussed before, the power strategy in IF systems represents a big issue that makes energetic barriers in front of IoT systems implementation and needs to be taken into account. Because the farming system is composed of multiple heterogeneous hardware and software components, the management and the integration tasks could be more or less difficult depending on the level of complexity generated by the adopted topology, the interoperability between the elements of the system, and the opening degree of the adopted technology. In fact, the complexity is not an issue for the farmer only, but the manufacturers also should consider it while designing their products. The reliability and efficiency of the IF system are greatly impacted by the environment where it is deployed, geographical and climatological characteristics such as high temperature, wind speed, heavy rain, and dusty environments can destroy the sensors or can make them totally out of service [116]. Thus, choosing the hardware that resists environmental damages is considered a big responsibility that should be

Figure 14.
Redundant LoRa sensors with modular accessories and multiple transmitters and gateways to overcome uncertainties and connectivity issues in actual field conditions. Source: SunBot.de.

considered when implementing the IoT-based IF system. **Figure 14** shows a modular IoT solution with multiple LoRa sensors and gateways that have been custom-built for the SunBot project to withstand harsh field conditions and overcome the issues with WiFi instability. Each sensor is benefitting from multiple transmitters to reduce the probability of signal loss, and multiple gateways to ensure data uploads to the private cloud.

8. Conclusion

The interactions between the human and virtual world are increasingly developing day after day, thanks to the widespread connectivity solutions and the ubiquity of connected objects that rapidly become smart. ML/DL also is one of the promising topics that gain recently the big attention of the research community since it capitalizes the efforts made in IoT data management fields and the evolution of Fog/cloud computing paradigms. In this survey, we discussed the IoT-based systems' requirements and shed light on the components of an intelligent farming IoT model as well as the open challenges resulting from the integration of IoT systems and fog computing technology. We talked later about Blockchain technology, its applications to improve the intelligence and the security of the farming field. From another hand, we discussed the needed researches to apply Blockchain more accurately in the farming domain. This paper is closed with a discussion about the main limitations that the implementation of IoT in intelligent farming is facing. In summary, the significant results of this survey can be summarized in the three following points—(1) this survey investigates the implementation of ICT in farming environments to solve many current serious issues related to management methods. IoT-based applications combined with machine learning are complete solutions to efficiently improve crop yields without wasting too much resources. The second result concerns Blockchain technology that can be integrated with IoT-based farming systems to provide efficient security solutions and build trust between farmers each other, or between farmers and consumers. Furthermore, we enable the reader to discover the seven significant applications of Blockchain in the intelligent farming field to improve security in IoT systems, fair pricing, agricultural subsidies oversight, the smart contract to securely manage the relationships between all the farming stakeholders, farm inventory overseeing, amelioration of supply chain and farm management software. This study also summarizes the open challenges resulting from the integration of IoT with fog/edge mining that creates many research problematics as well as makes the implementation of such solutions in the farming world very challenging tasks. (2) Many previous papers addressed the issue of implementing ICT in farming processes, but this work particularly elaborated the transition from cloud computing to fog/edge computing to serve IoT applications and added the integration of Blockchain in the farming field, its benefits, challenges, and applications. Finally, some recommended researches are needed to concretize the implementation of the proposed Blockchain models and propose another model for each farming activity. From another hand, the development of Blockchain technology requires serious investment efforts to provide a complete legal arsenal for better and safe implementation. (3) Although Blockchain technology is designed to build trust, its implementation in the intelligent farming workflow is still confronting many barriers related to the lack of trust [117] notably regulatory uncertainty (with 48%), lack of trust among users (45%), separate Blockchain systems not working together (41%), inability to scale (21%), intellectual property concerns (30%), and audit-compliance concerns (20%).

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