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Review

Survey of Intelligent Agricultural IoT Based on 5G

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Abstract: In the future, agriculture will face the need for increasing production, sustainability, wisdom, and efficiency, which will bring significant challenges to the development of modern agriculture. With the gradual popularization of 5G, advanced information technologies such as the Internet of Things and artificial intelligence promoted the evolution of modern agriculture to intelligent agriculture. The 5G-based Internet of Things will play an essential role in the development of smart agriculture. This paper investigates the research progress of 5G Internet of Things in smart agriculture. It sorts out the development status of 5G smart agriculture Internet of Things in recent years. Following that, the concept of 5G smart agriculture Internet of Things is put forward. It expounds on the connotation, architecture, and enabling key technologies. According to the key application scenarios of smart agriculture, practical cases are presented, the development trend and application value of 5G smart agriculture Internet of Things are shown, and the future development direction is put forward. Firstly, the concept of smart agriculture is distinguished, and the category scenarios of smart agriculture are summarized. Following that, the current review research on 5G-IoT is analyzed. This paper focuses on the analysis and summary of the changes brought by 5G to various key scenarios in smart agriculture. This paper analyzes the related key technologies and challenges, puts forward some key scientific problems, and summarizes the research ideas. Finally, the development trend and application value of 5G smart agriculture Internet of Things are shown. The future development direction is also proposed.

Keywords: 5G; smart agriculture; IoT; monitoring; deep learning; cloud-edge

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1. Introduction

The future of agriculture is facing serious challenges as people demand higher quality food. As shown in Figure 1, by 2050, the gap is expected to be huge, and this will pose a great challenge to resources and the environment. Academician Zhao Chunjiang claimed that the intelligent revolution of agriculture in the form of smart agriculture has arrived in the first issue of "Smart Agriculture". Smart agriculture is an advanced stage of the development of agricultural information from digitalization to networking and then to intelligence, which is a milestone for the development of agriculture, and agriculture is entering stage 4.0 [1].

With the commercialization and popularization of smart 5G technology, its characteristics of high speed, super-large connection, and ultra-low delay will have a profound impact on agricultural IoT. Combined with the rapid development of artificial intelligence, edge computing, cloud services, and other fields will achieve an epoch-making revolution in agricultural production mode. Smart Agriculture and 5G-IoT smart agriculture are respectively introduced below.

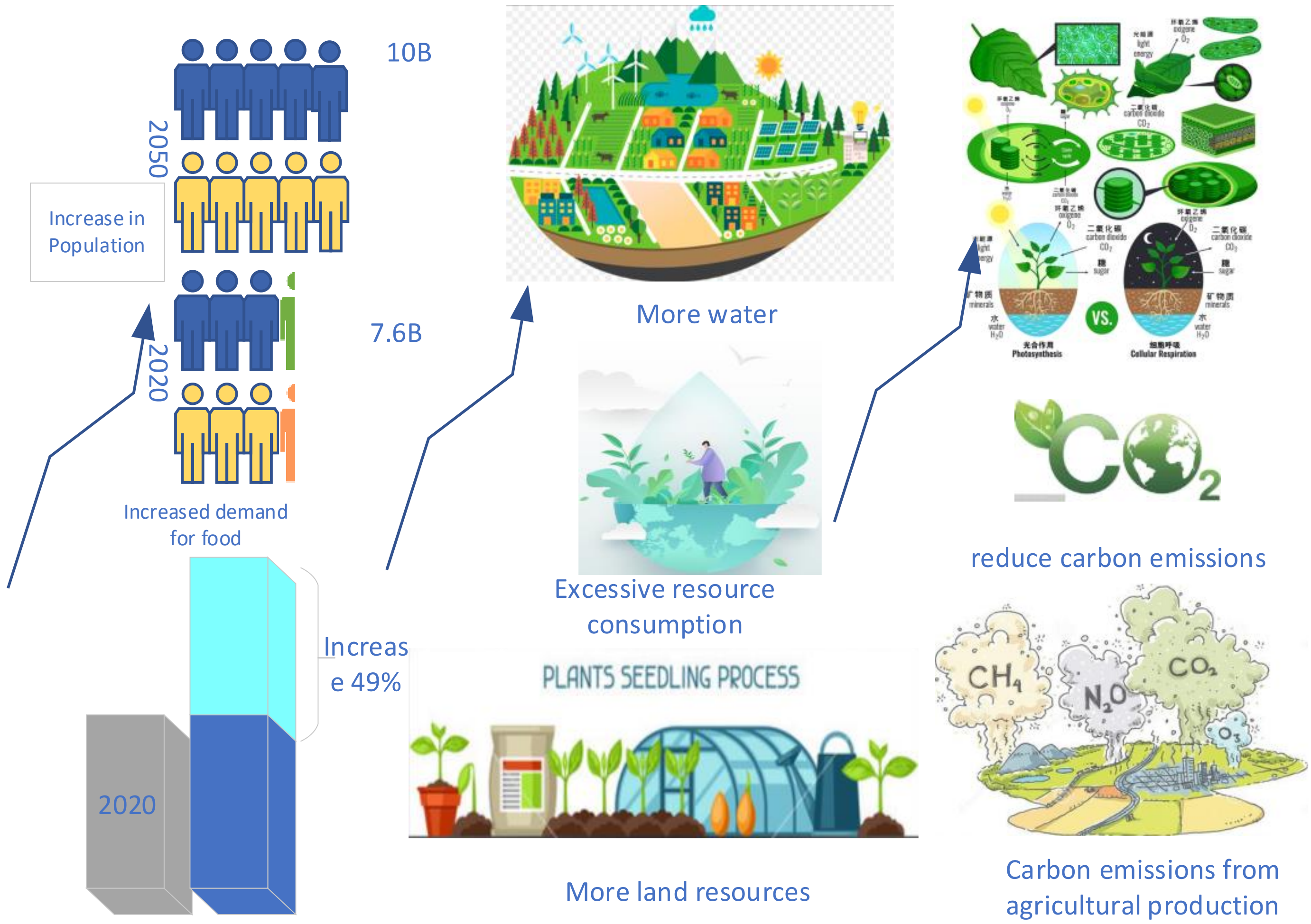

Figure 1. Challenges to sustainable agricultural development in the future.

1.1. Smart Agriculture

There are many kinds of agriculture, including water-saving agriculture, facility agriculture, ecological agriculture, three-dimensional agriculture, organic agriculture, precision agriculture, and so on. Smart agriculture is a new agricultural production mode with the core element of information and knowledge. By deeply integrating modern information technology such as the Internet, Internet of Things, big data, cloud computing, and artificial intelligence with agriculture, it realizes agricultural information perception, quantitative decision-making, intelligent control, precise input, and personalized service. Smart agriculture is an advanced stage of agricultural informatization development from digitalization to networking and intelligence [2,3]. Smart agriculture is a new agricultural production mode and ecosystem based on digital and precision agriculture, as well as a production form in the era of Agriculture 4.0. Figure 2 shows the evolution of agriculture from stage 1.0 to 4.0 [4]. This revolution that Agriculture 4.0 will completely change how people produce food and effectively help people cope with the future population explosion, ecological imbalance, food crisis, and other potential challenges [5].

Smart agriculture covers many categories and scenarios. This paper combines previous summaries [6,7] and summarizes them according to the large fields and categories involved in agriculture, as shown in the figure below. In this paper, smart agriculture is mainly oriented to the field of planting and breeding, including crop planting, animal husbandry, and aquatic products. According to the production mode of this agriculture, it can be divided into facility agriculture, field agriculture, precision agriculture, and so on. This includes most areas of agriculture. In addition, various types of agricultural production include multiple scenarios, such as moisture monitoring, pest management, harvesting, and so on. The crop or production facing each scenario may differ, but many of the key technologies involved are broadly similar, so they are also grouped together. The following is a summary of the key technologies involved in the scenario, as shown in Figure 3.

Figure 2. Smart agriculture and agriculture 4.0 evolution.

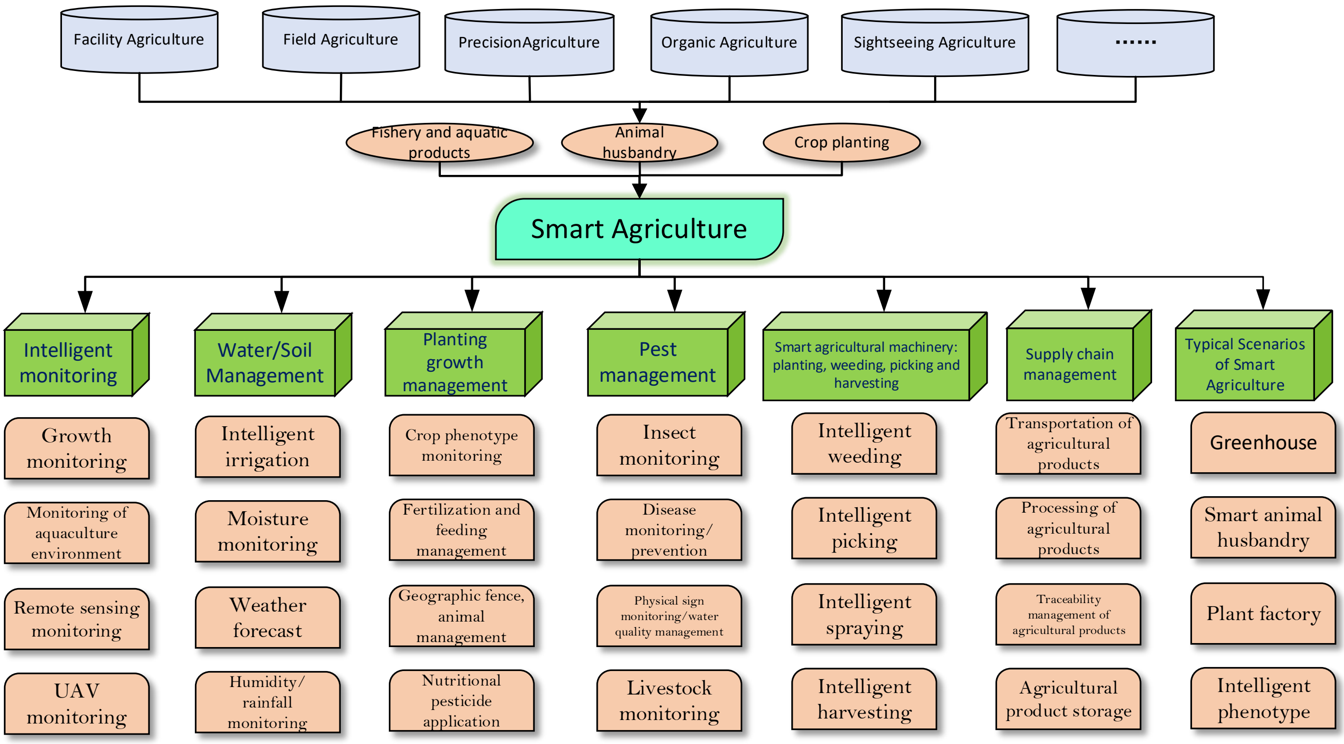

Figure 3. Smart agriculture field and classification.

The Internet of Things and other key technologies in smart agriculture, as well as the final target vision, are shown in Figure 4. The ultimate goal of intelligent agriculture is to realize intelligent, unmanned, precise, efficient, high-quality, and green. The key technologies needed to achieve the above goals include 5G, Internet of Things, big data, artificial intelligence, robotics, blockchain, drones, and so on.

The following introduces the research progress of 5G agricultural Internet of Things in relevant countries around the world, as shown in Table 1. It can be seen that the rapid progress of 5G commercial deployment in China has driven the development of 5G agricultural Internet of Things.

It is predicted that, by 2025, the proportion of 5G connections in the total number of connections will increase from 8% in 2021 to 25% in 2025. 5G is expected to account for nearly 60% of global mobile service revenue in 2026. With the commercial popularization of 5G worldwide, it will lay the foundation for the application of smart agricultural IoTs, bringing new opportunities.

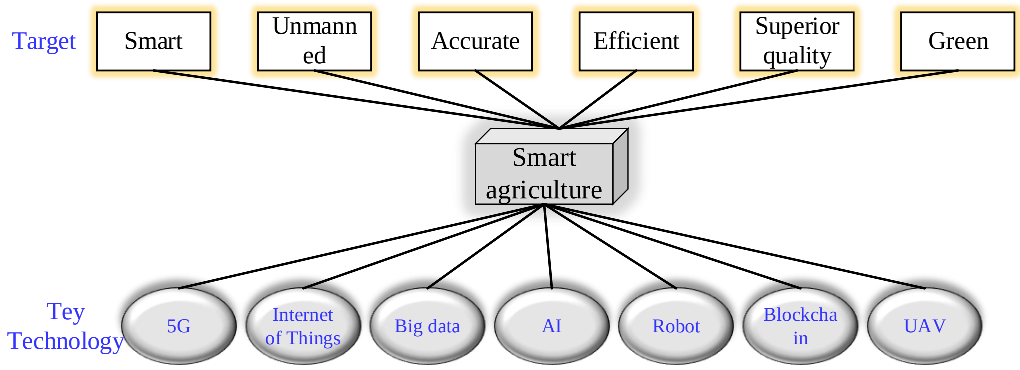

Figure 4. Key technologies and objectives of smart agriculture.

Table 1. Global 5G agricultural Internet of Things development [8].

Country	Agricultural Type	5G Agricultural Internet of Things	Development Representative/Development Characteristics	5G Policy
America	Large farms	5G + UAV + GPS+ satellite remote sensing	FarmLogs, Cropx	FCC—$9 billion 5G subsidy program
Europe	Precision agriculture	5G + big data + smart agricultural machinery monitoring and control, smart agricultural machinery	Holland, Switzerland, Huawei, Sunrise	5G commercial promotion
Japan	Green agriculture and ecological agriculture	5G + agricultural Internet of Things + smart monitoring	A new farming model with automation and intelligence	5G falls behind, 6G works
Israel	Facility agriculture	Intelligent depth sense + intelligent control	Innovative agriculture	5G networking
China	Mixed existence of various types of agriculture	Agricultural production is developing towards automation and smart agriculture by leaps and bounds	5G, smart agriculture, smart agricultural machinery	5G is being comprehensively promoted and demonstrated in agricultural application

1.2. 5G-IoT Smart Agriculture

The wireless communication capability of 5G with low delay, high density, and large bandwidth provides a communication guarantee for the application of other information technologies in the smart agricultural Internet of Things. Smart agriculture has relied on the fifth generation of information technology 5G, the Internet of Things, robotics, drones, big data, AI, machine learning, blockchain, and other key technologies to transform modern agriculture. It realizes the deep integration of the physical world and the information world, changing the current mode of agricultural production. Industry-oriented universal wide-area Internet of Things is becoming the main force [9]. It can promote the expansion and upgrading of IoTs in smart agriculture and expedite the landing application of big data in smart agriculture. It is the key to the in-depth application of UAV in agriculture and is an important booster for integrating artificial intelligence and robot blockchain in smart agriculture [10].

The Internet of Things continues to evolve with the evolution of information technology and sensors. It should not only perceive and transmit data but also have functions such as recognition, computation, service, semantics, and even cognitive decision-making [11]. The detection, management, and maintenance functions of the Internet of Things will also gradually become intelligent and unmanned. The in-depth integration of the Internet of Things, big data, and artificial intelligence will revolutionize the current form of the Internet of Things and generate huge social value [12]. As an important part of new digital infrastructure, the Internet of Things (IoT) is deeply integrated with 5G, big data, cloud computing, artificial intelligence, blockchain, digital twin, and other technologies, and is evolving into a smart IoT system (IoTs 2.0) [13], which is profoundly changing the process of the modern agricultural industry and promoting the rapid development of smart agriculture.

In the field of smart agriculture, the Agricultural Internet of Things (AIoT) is developing rapidly, but still faces many challenges. This includes the new application of the agricultural scene, the transformation of the new agricultural production mode, and the deep integration with other technologies. As a basic condition for the in-depth application of the agricultural Internet of Things, 5G communication technology will promote the in-depth application of the agricultural Internet of Things in smart agriculture. 5G can provide MTC communication with high reliability, low delay, and wide coverage, and its three typical application scenarios have broad prospects in smart agriculture [14]. 5G IoT technology can be extended to the scope of current, which cannot be achieved with the field, making IoT depth perception of the intelligent environment perception, enlarging the coverage of the Internet of Things of agriculture and the ascending scale, expanding the communication capacity, and realizing large-scale equipment interact with each other and data sharing so as to realize the agricultural decision-making process depth [15]. 5G-IoT is expected to provide real-time, on-demand, online, reconfigurable, and end-to-end coordinated capabilities for a variety of agricultural applications. It can provide logically independent network applications and configure networks on demand. According to the future agricultural needs, the integration of 5G with smart agriculture and the Internet of Things will be able to achieve network characteristics, as shown in Figure 5.

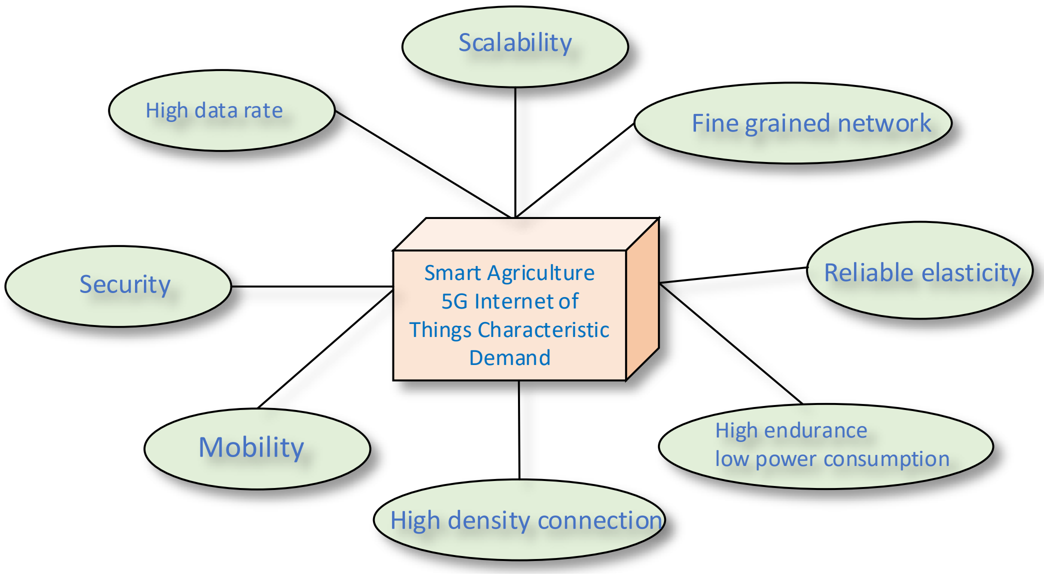

Figure 5. Characteristics of smart agriculture 5G Internet of Things demand.

The above content will be able to promote the landing of smart agriculture. At present, many scholars are paying attention to the opportunities and challenges brought by the commercialization of 5G to the Internet of Things and have carried out a series of review studies [16–23]. The relevant summaries are shown in Table 2.

Table 2. 5G-IoT review papers overview.

Time	Overview Journals	Main Focus	Scene
2016	M. R. Palattella et al. [16]	From technology, standardization and market prospect	Market Paradigm
2018	Shancang Li et al. [17]	Key implementation technologies, main research trends and challenges	Key technologies and trends
2018	D. Wang et al. [18]	New paradigm of 5G intelligent Internet of Things (5G l-loT): big data mining, deep learning, and reinforcement learning	New paradigm
2018	G. A. Akpakwu et al. [19]	Application requirements of the Internet of Things and the development status of related communication technologies	Communications technology
2019	N. Wang et al. [20]	Physical layer security	Security
2020	K. Shafique et al. [21]	Prospects of 5G key technologies for the Internet of Things	5G Key Technology
2021	Yu Tang et al. [22]	Opportunities, challenges, and key technologies	Smart agriculture
2022	Ogbodo E U et al. [23]	5G and LPWAN-IoT for Improved Smart Cities and Remote Area Applications	5G LPWAN-IoT
2022	Khanh Q V et al. [24]	Wireless communication technologies for IoT in 5G: vision, applications, and challenges	Wireless communication technologies

Despite a great deal of research on 5G-IoT, there are few reviews on 5G IoT in agriculture. Secondly, there is a notable amount of research on smart agriculture, as shown in Table 3.

It can be seen that smart agriculture and the Internet of Things are both hot-tracking directions, and there are many review articles and rapid technological development. Many scholars have conducted research from various perspectives. Based on 5G, there is not much in-depth research, and the following method is to carry out in-depth research and discussion from this aspect.

Domestic literature research on 5G intelligent agricultural Internet of Things is also becoming a new hotspot. There is a rapid growth trend in related papers, and the main research fields include smart agriculture, the Internet of Things, 5G, and so on. The above distribution obtained from 5G, smart agriculture, and the Internet of Things retrieved from CNKI shows that research is increasing rapidly as show in Figure 6.

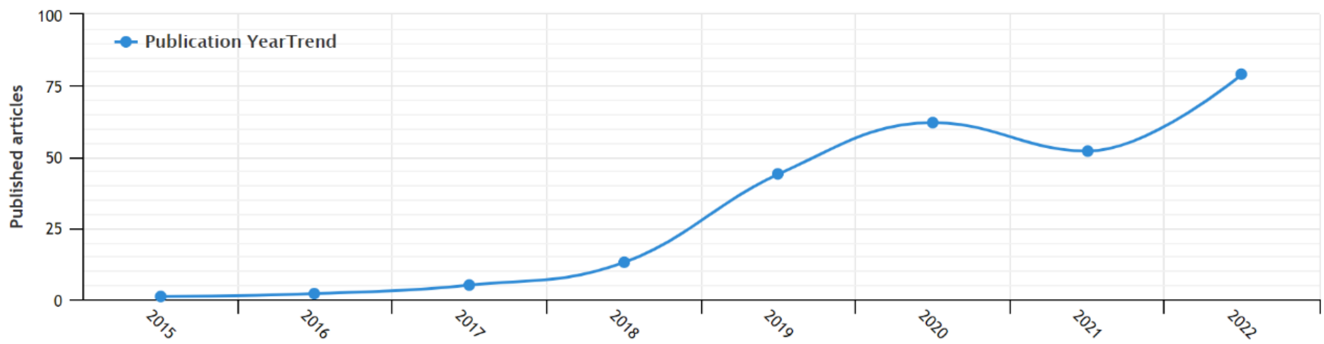

Figure 6. Shows the overall trend analysis of related papers.

Table 3. Summary of smart agriculture.

Time	Overview Journals	Theme	Key Words
2017	Mekala M S et al. [25]	Smart agriculture cloud computing	Smart agriculture, cloud computing
2018	Rahul Dagar et al. [26]	Intelligent Farm IoT	Smart Farm, IoT
2019	Farooq M S et al. [27]	Investigation on the Role of the Internet of Things in Smart Farms	Smart Farm, IoT
2019	Devare J et al. [28]	Crop generation detection and control	Detection, crops
2019	Fiona J R et al. [29]	Image processing and disease detection based on image detection in agriculture	Image processing, disease detection
2019	Bh Ag At M et al. [30]	Internet of Things in Smart Farm	Smart Farm, IoT
2019	Sarker V et al. [31]	Edge computing Lora in the Internet of Things	Edge computing, Lora
2019	Smart et al. [32]	Smart Farm	Smart Farm
2020	VIPPON et al. [33]	Progress of Internet of Things in Agriculture	IoT, Agriculture
2020	Friha O et al. [34]	New technologies of the Internet of Things for smart agriculture in the future	Future smart agriculture IoT
2021	Rayhana R et al. [35]	RFID sensing technology in smart agriculture	Smart agriculture, RFID, perception
2021	Xing Yang et al. [36]	Internet of Things for Smart Agriculture in the Future	Smart agriculture, IoT
2021	Ye Liu et al. [37]	Industry 4.0 to Agriculture 4.0	Agriculture 4.0
2021	Bhat S A et al. [38]	Big data and AI revolution for precision agriculture	Big data, AI, precision agriculture
2021	Godwin Idoje. et al. [39]	Progress and challenges of intelligent agriculture Internet of Things	Smart agriculture, IoT
2021	Wen Tao et al. [40]	Progress and challenge of intelligent agriculture Internet of Things communication technology	Smart agriculture, IoT, communication technology
2021	Godwin Idoje et al. [41]	Technological progress and challenges of smart farms	Smart Farm
2022	N. N. Misra et al. [42]	Internet of Things, Artificial Intelligence and Big Data in Agriculture and Food Industry	Food industry

1.3. Summary

1.3.1. Contribution

In this paper, the research and prospects of 5G joint IoT in smart agriculture are summarized. Firstly, it reviews the differences between 5G compared with current and previous communication technologies. Following that, combined with the characteristics of the agricultural Internet of Things, the reform and impact of 5G on it are summarized and prospected. Finally, combined with the application paradigm of 5G and smart agricultural IoT, the possible challenges are put forward, and some potential research issues are pointed out.

1.3.2. Organization

5G-oriented intelligent agricultural Internet of Things is an essential direction of smart agriculture in the future. This paper intends to summarize the relevant research status and possible research directions from the following perspectives. The rest of this article is structured as show in Figure 7. In this paper, the impact of 5G on the Internet of Things for smart agriculture is sorted out, and the potential application scenarios and existing challenges are summarized.

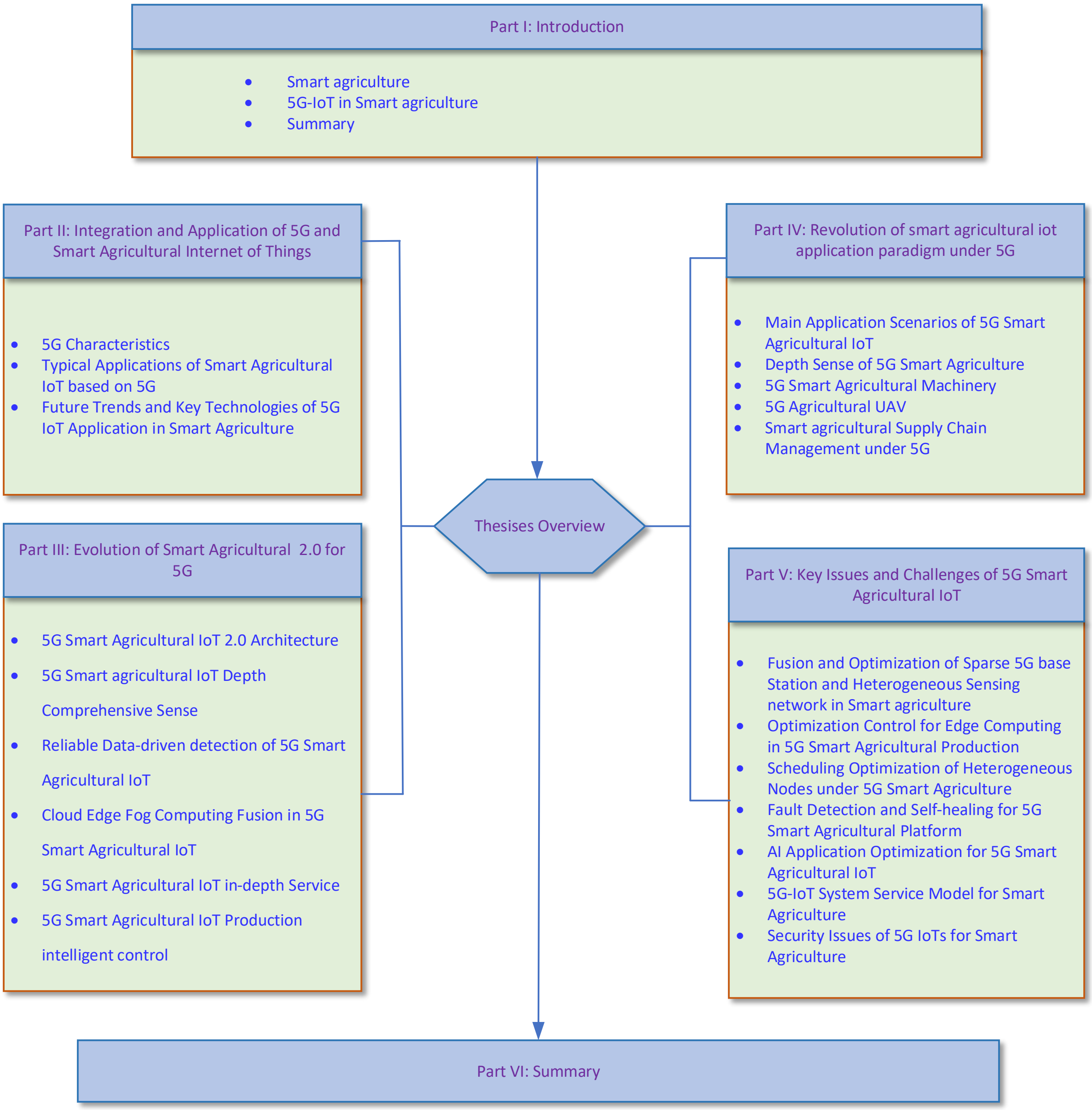

Figure 7. Structure of this article.

2. Integration and Application of 5G and Smart Agricultural Internet of Things

2.1. 5G Characteristics

The existing agricultural IoT uses various communication technologies in its application, including Zigbee, Wifi, Sigfox, and so on. As a new generation of communication mode, 5G is compared with the characteristics of other communication modes in agricultural scenes. Table 4 summarizes how 5G compares to other communication technologies commonly used in the Internet of Things. 5G has its own characteristics.

Table 4. 5G compared with other related communication technologies.

Parameter	Standard	Frequency Band	Time Delay	Data Rate	Transmission Distance	Energy Consumption	Cost	Network Size
5G	3GPP Release-16	3–6 GHz	Low	100 Mb/s–10 Gb/s	Base station signal coverage area	Medium	Medium	Infinite
4G	LTE	2.4 G/865 MHz	Medium	10 Mb/s–1 Gb/s	Base station signal coverage area	Medium	Medium	Infinite
Zigbee	IEEE 802.15.4	2.4 G	High	20–250 Kb/s	Within 100 m	Low	Low	Below 500
Wifi	IEEE 802.11	5 GHz-60 GHz	Medium	1 Mb/s–7 Gb/s	Less than 100 m	Medium	Medium	Below 100
NB-IoT	3GPP Release 13	850–900 MHz	High	160–250 kbps	Base station signal coverage area	Extremely low	Low	<50,000
SigFox	SigFox	200 KHz	High	100–600 bit/s	Base station signal coverage area	Low	Low	<50,000
RFID	ISO18000-6C	860–960 Mhz	Low	40–160 kbit/s	1–5 m	Low	Low	<1000

It can be seen that 5G has its own characteristics compared with other communication technologies, with incomparable advantages in terms of large bandwidth, large connection, and low delay. Therefore, the emergence of 5G may bring new changes and opportunities to the existing agricultural production mode in many agricultural application scenarios.

Compared with the 1G voice era, 2G text era, 3G picture era, and the recent 4G video era, the application scenarios of 5G will get a leapfrog development. Compared with 2G to 4G, which are born to connect "people", with the advent of the Internet of everything era, mobile communication networks need to evolve to connect "things". 5G is facing the common demand of large traffic and small data, mobile broadband on the one hand, and the Internet of Things on the other. Its main features are as follows in Figure 8.

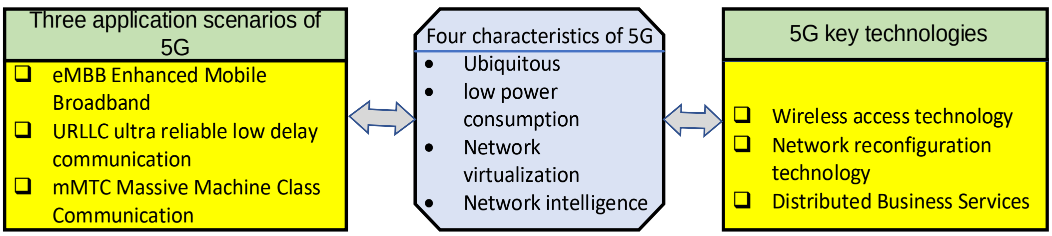

Figure 8. 5G technical introduction.

The development and deployment of 5G have provided the communication layer foundation for access and transmission to realize the "Internet of everything" in a real sense. Gb/S span will be realized not only in the field of mobile communication. It can also provide 3D, UHD video, AR/VR, cloud office, and other immersive interactive methods to upgrade. It will also give birth to more new agricultural application scenarios. The three major application scenarios of 5G application services include Enhanced Mobile Broadband (eMBB), Massive Machine Type Communications (mMTC), and ultra-reliable and Low Latency Communications (uRLLC). The latter two belong to the application scenarios of the Internet of Things [43,44], as shown in Figure 9.

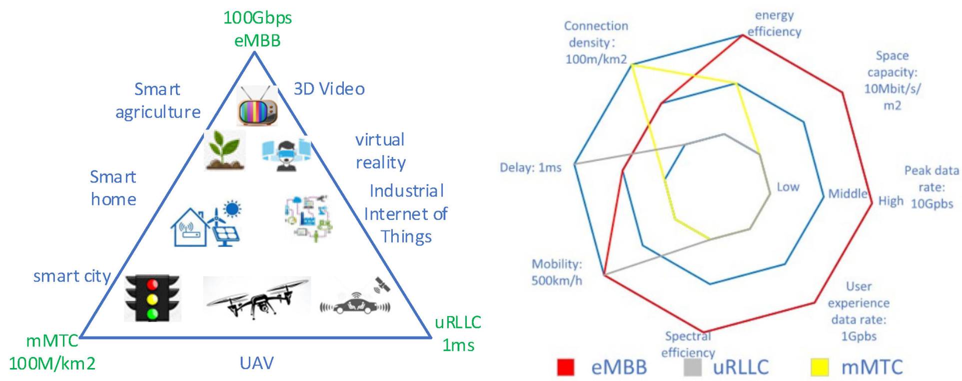

Figure 9. 5G: The three major application scenarios.

2.2. *Typical Applications of Intelligent Agricultural Iot Based on 5G*

Based on the above analysis, the three application scenarios of 5G, eMBB, mMTC, and uRLLC will be widely applied in smart agriculture. It will significantly improve the connectivity between smart agriculture stakeholders, user products, and data. The following Figure 10 shows the typical application scenarios.

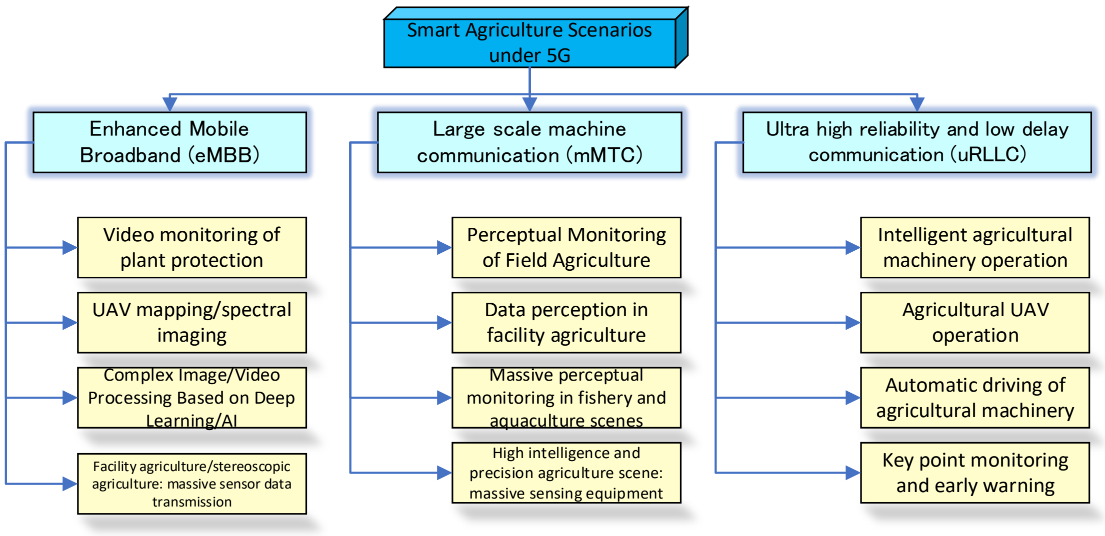

Figure 10. 5G application scenarios in smart agriculture.

2.2.1. Enhance Mobile Broadband Applications (eMBB) in Smart Agricultural IoT

With the improvement of intelligence in smart agriculture, there is increasing data information, which needs the support of large data transmission rate. The high bandwidth of 5G will be able to support high-definition video transmission and massive data transmission. Successful real-time transmission of HD data will enable remote real-time detection, as well as the combination of machine learning algorithms to transmit HD video back for rapid analysis and computation. Secondly, massive data transmission can be combined with deep learning algorithms to analyze and calculate plant diseases and insect pests [45,46] and quick weed control.

The integrated application of 5G will promote the planting industry to realize intelligent planting technology, intelligent agricultural management, open planting process, and intelligent labor management. 5G network, artificial intelligence image recognition, satellite remote sensing [47], big data, and other technologies are used to drive all kinds of unmanned agricultural machinery equipment to realize automatic operation. Including aerial plant protection UAV, unmanned highland gap plant protection machines, rototiller, corn planters, unmanned sprinkler irrigation systems, etc., to achieve safe, reliable, environmental protection and energy-saving farm operations. It can also monitor agricultural production in real-time, realize rapid detection of crop diseases, pests, weeds, farmland water quality, and soil, provide fine-grained nutrition, ventilation, and water supply for crops, and improve productivity [48,49].

In the 5G smart farm [50], the shading system, fresh air system, cooling system, fertilization and watering system, data acquisition system, and light supplement system achieved 5G control. For example, intelligent glass greenhouse food production can also achieve substantial growth. Mobile robots based on 5G can complete panoramic collection. Along with the cultivation tank of the greenhouse, it automatically completes inspection, fixed-point collection, automatic return, automatic charging, and other actions. If there are obstacles along the way, it can automatically go around. Real-time acquisition of high-definition video data by video sensing nodes can solve the delay problem of massive data transmission based on edge computing devices and artificial intelligence, improve quick response ability, and realize front-end intelligent decision-making [51]. All kinds of intelligent agriculture applications based on video processing are shown in Table 5.

Table 5. Video image processing in smart agriculture.

Literature	Application Scenario	Data Type
Garcia [52]	Distributed precision agriculture	Video and Data
He Liu [53]	Video segmentation	Video
Sabzi S [54]	Monitoring of potato weeds in video	Video
He Jiang [55]	Fruit disease surveillance based on deep learning	Image

It can be seen that there are many intelligent agricultural applications based on video image detection at present. With the continuous development of video acquisition equipment, HD images and videos are becoming increasingly popular. Optimizing data transmission has always been a challenge. The integrated application of smart agriculture based on 5G is a big direction.

2.2.2. Large-Scale Machine Type Communication (mMTC) in Smart Agricultural IoT

Smart agricultural IoT is the next generation of agricultural IoT for smart agriculture. It needs a depth perception of the agricultural production process. Large-scale agricultural production scenarios require large-scale sensing nodes to transmit data [56]. Traditional sensor networks have some difficulties in networking reliability, energy efficiency, and deployment cost. However, large-scale machine-type communication based on 5G can achieve a smart agricultural IoT with low cost, high reliability, low power consumption, and convenient networking and deployment. For example, NB-IoT can be deployed to quickly monitor soil, fertilizer, and plants in farmland. In this way, the comprehensive perception and depth perception of agricultural production can be realized, providing support for the deepening application of smart agriculture [57].

5G-oriented NB-IoT enables dense sensing network deployment. Combining computer vision and other technologies can effectively extract plant phenotypic variation and its related information. Moreover, machine learning, artificial intelligence, and other cutting-edge technologies are used for processing [58]. Deep learning convolutional neural networks were used to evaluate crop phenotypic characteristics and soil conditions. Multispectral imaging in agricultural areas is based on IoT sensors and small unmanned aerial vehicles (UAVs). It identifies plant quality and leaf diseases.

2.2.3. Ultra-Reliable Low Latency Communication (uRLLC) in Smart Agricultural IoT

Such ultra-reliable low-latency communication applications are generally oriented to mission-critical, real-time transmission of critical data and control of major agricultural equipment [59]. Drones based on 5G networks can achieve precision operations. The flight trajectory and situation data of the UAV can be returned to the 5G network UAV management and operation platform in real-time through the 5G network. Flight status can be monitored in real-time [60]. Through the agricultural information collected by UAV and satellite remote sensing technology, the platform can intelligently and dynamically analyze the crop situation in the monitoring region, make a macroscopic estimation of the real-time seedling situation, environmental dynamics and distribution of crops, and output scientific reports [61]. According to the report, farmers can clearly grasp the growth situation of crops and soil moisture and manage production in response to problems so as to ensure more scientific and efficient farming activities.

The universal application of 5G will provide the communication basis for unmanned, intelligent, and intelligent agricultural machinery and equipment because 5G technology has the characteristics of high speed, short delay, low power consumption, ubiquitous network, and scalability. It will shine in the fields of agricultural Internet of Things, precision planting, agricultural products circulation traceability, agricultural drones, smart farming, agricultural industry services, and so on, and promote agriculture to be more informationalized and intelligent [62,63].

2.3. Future Trends and Key Technologies of 5G-IoT Application in Smart Agriculture

It can be seen from the above analysis that the integration of 5G and IoT has a wide application prospect in the scenario of smart agriculture. Agricultural IoT can be used to collect environmental monitoring information on crop growth and process this information to develop the production plan of precision agriculture. Precision agriculture requires the network to support the connection of massive devices and a large number of small data packets. Since agricultural IoT devices are often deployed in areas where signals are challenging to reach, such as mountains, forests, and waters, 5G can meet the requirements with stronger coverage capability, flexibility, scalability, and lower power consumption, delay, and cost. The future trends of intelligent agricultural IoT facing 5G mainly reflect the following:

1. Cloud edge collaboration: agricultural monitoring terminal and cloud collaboration.
2. Cloud computing/AI/big data/Internet of Things/digital twin and other agricultural integration.
3. Virtualization and servitization of perception/access/communication layer, software defined network.
4. Model-driven, cloud-native new application (APP) development environment for smart Internet of Things.
5. The deep integration of people, information space, and physical space will form a deep intelligent smart agriculture and achieve a harmonious ecology of human–machine symbiosis.

The key technologies of IoT applications in smart agriculture include vital information sensor technology, phenotype information acquisition technology, phenotype group data analysis technology, phenotype group big data management and database building technology, etc. [64,65]. All these technologies need the support of 5G. Among them, the life information sensor technology collects information about seeds and their propagation/seed production environment and obtains the corresponding physiological and ecological information through signal transformation and AI data processing. Phenotypic information acquisition technology automatically extracts important phenotypic features and logical relationships from massive amounts of information to realize automatic and accurate identification of phenotypic traits. Phenotypic data analysis technology covers the complete process from the initial data collection to the final refinement analysis. Phenotype group big data management and database building technology are used to manage, store, and share tabular data.

3. Evolution of Intelligent Agricultural IoT 2.0 for 5G

Intelligent Internet of Things (IoT 2.0) refers to a complex system that integrates "human, information space and physical space" [66] under the guidance of 5G and other communication technologies and AI technologies and intelligently interconnects and serves cooperatively. Among them, the new generation of AI technologies includes data-driven deep reinforcement learning intelligence, network-based swarm intelligence, hybrid intelligence oriented by human–machine and brain–computer interaction technology, cross-media inference intelligence, autonomous intelligent system, etc. The "wisdom" of the smart IoT system refers to the interconnection of people, information space and physical space, and the digitalization, IoT, servitization (cloud), collaboration, customization, flexibility, greenness, and intelligence of the layered and progressive system [67].

The Internet of Things is evolving into the next generation. Under the role of 5G, the Internet of Things combined with big data, machine learning, cloud services, and so on, will have intelligent characteristics. It can make the physical process and the information world deep integration. The network level of the Internet of Things mainly includes monitoring, detection, computing, service, and control from bottom to top, and these connotations will also undergo profound changes.

3.1. 5G Smart Agricultural IoT 2.0 Architecture

With the rapid development of video business and various vertical business applications in smart agriculture, centralized data storage and processing modes will face difficult bottlenecks and pressures. The existing Internet of Things architecture is difficult to meet the data return of big data, which easily deteriorates network indicators and affects user experience. In this case, data processing capabilities and services need to be provided near the edge of the network where the data are generated. With the development of 5G and the availability of relevant business requirements and network conditions, edge computing has gradually achieved great development. Agricultural IoT is evolving to Smart Agricultural IoT 2.0, where edge computing can alleviate these defects of centralized IoT, and transfer computing tasks to the edge service side to significantly improve delay and energy consumption, especially for delay and energy-sensitive IoT applications.

5G IoT for smart agriculture achieves optimal resource allocation through network slicing, SDN/VFN, and other technologies. However, due to a large amount of sensing data in the smart agriculture scene, the real-time requirement is high. With the increase in terminal computing power, the network architecture for smart agriculture will also change. The architecture of a smart IoT system is shown in Figure 11.

5G-based agricultural IoT can be implemented by deploying edge computing based on application needs. Edge computing migrates IT resources, such as computing and storage, from traditional cloud data centers to users. IT shortens the physical distance between users and IT resources, achieves lower data interaction delay, and saves network traffic. This provides users with low latency and high stability of IT solutions. Edge computation depends on edge nodes. The requirements of edge nodes for smart agricultural IoT are not strictly regulated. Compared with the general sensor node thought and its computing power, the communication ability is stronger. The deployment position is usually at the end of the network, that is, the application site. After IoT edge applications are deployed, edge nodes serve as extensions of remote IoT platforms on devices. Devices are managed through cloud-edge collaboration. Edge nodes can provide computing and management services for nearby devices, such as local management of low-latency services, local control, and rule execution when disconnected from the cloud. The device accesses the edge node and finally uploads data to the remote IoT platform through the edge node, as shown in Figure 12.

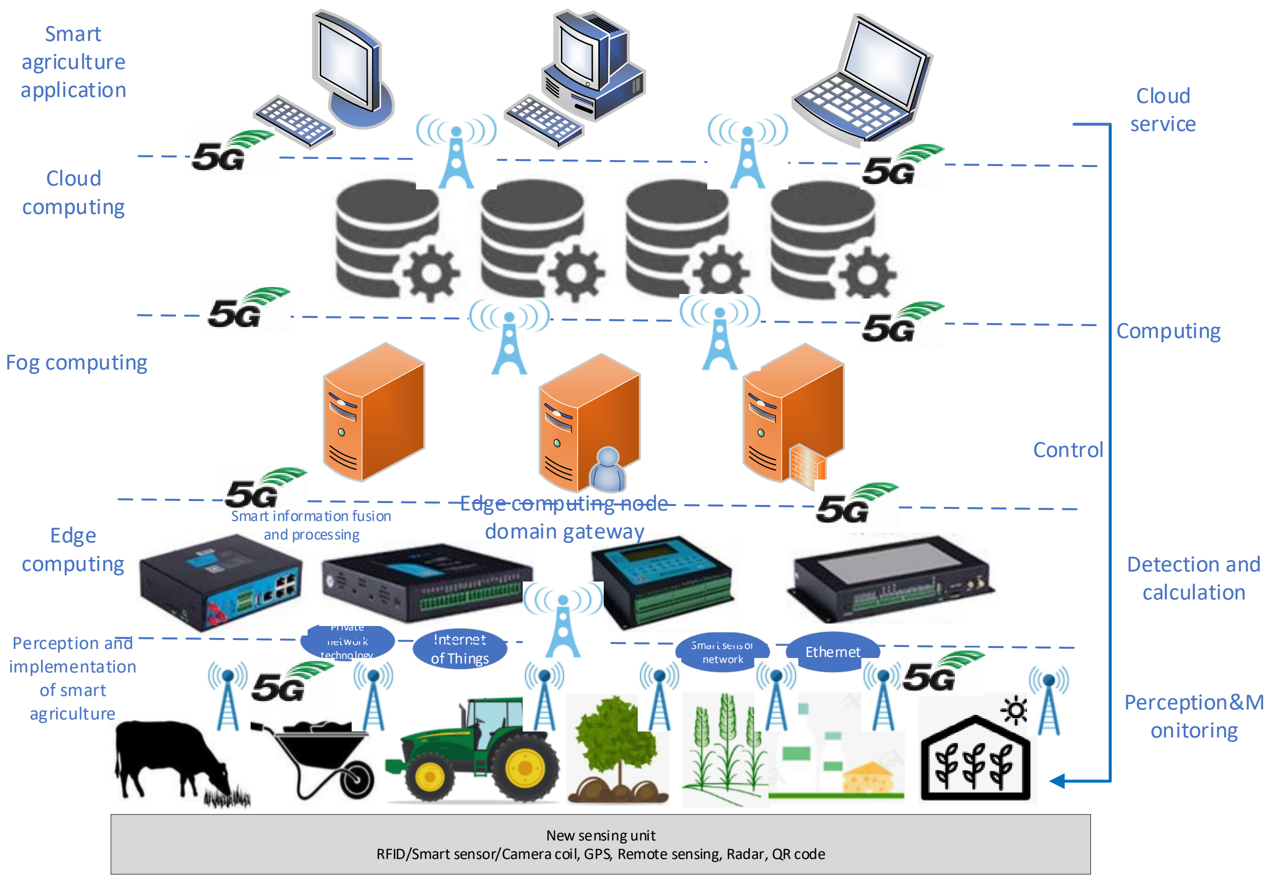

Figure 11. Architecture of the smart Internet of Things system based on 5G.

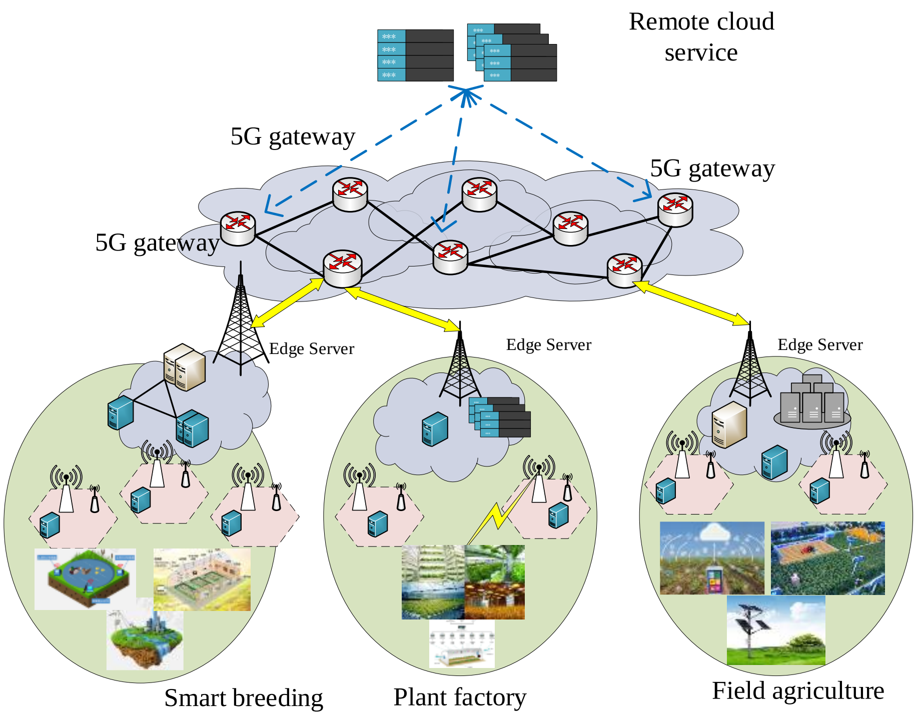

Figure 12. Application scenario diagram of the edge computing system of the agricultural Internet of Things.

3.1.1. Personalized Service Network Slice in 5G Intelligent Agricultural Internet of Things

Requirements on network characteristics (network speed, delay, number of connections, energy consumption, etc.) in different agricultural application scenarios are different, and some are even contradictory. For example, agricultural high-definition video surveillance cares about the picture quality, and the overall delay of a few seconds or even more than ten seconds is not felt. In remote agricultural machinery driving, a delay of more than 10 ms will seriously affect safety. Therefore, the purpose of splitting and refining the network is to respond more flexibly to the needs of smart agriculture scenarios. Based on 5G technology, Network Slicing can be implemented, and the Network can be divided into N logical networks according to application scenarios as shown in Figure 13. Different logical networks serve different scenarios. Because of the diversification of demand, networks need diversification. The network must be flexible because it needs to be sliced. Because they move flexibly, the connections between networks also change flexibly [68].

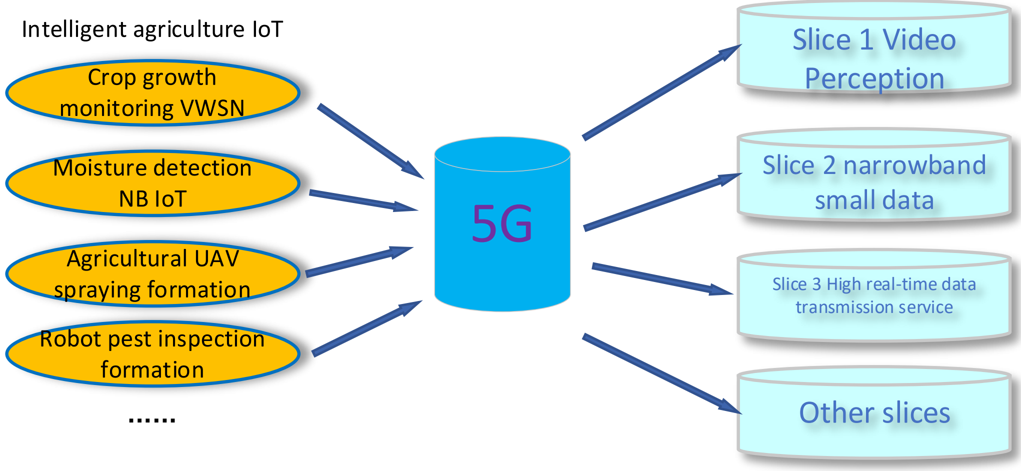

Figure 13. Smart agriculture 5G-IoT network slice.

Network slicing is a logical network partitioning scheme implemented to meet the different requirements of various applications, which can ensure resource isolation and service guarantee between slices where different services are located [69].

3.1.2. The 5G Intelligent Agricultural Internet of Things (IoT) System Is Integrated with "Cloud, Network, Edge, and End"

The impact of 5G on the Internet of Things for smart agriculture, including the system network architecture, will bring new changes. 5G intelligent agricultural Internet of Things will realize the integration of "cloud–network–edge–end" and profoundly change the agricultural production form [70].

Under the role of 5G, the future intelligent agricultural Internet of Things must be a system of cloud-net-edge-end deep integration as shown in Figure 14. Realize the deep integration and control of agricultural production and information world. The cloud realizes the cloud of services and data, and the network includes all kinds of networks represented by 5G. The self-consistency of intelligent agricultural IoT is realized by combining edge computing and terminal nodes [71].

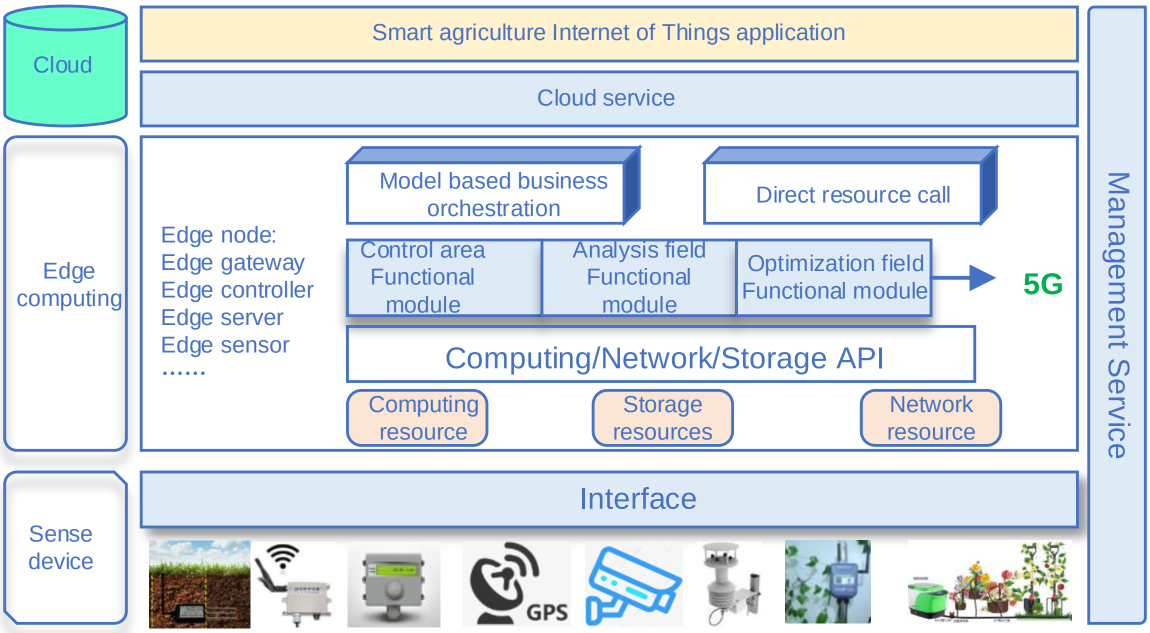

Figure 14. 5G-IoT service architecture of cloud-edge collaborative smart agriculture.

3.2. Perception of Deep Fusion of 5G-Intelligent Agricultural Internet of Things

Smart agriculture is a form of deep intelligence of agricultural production and a form of deep integration of the physical production process and information world. First, the smart agricultural IoT requires comprehensive and in-depth monitoring of agricultural production processes and objects. This requires the support of 5G, the intensive access of massive sensing devices, the transmission of large amounts of data, and the support of the operating system basic software platform suitable for the new generation of IoT systems. The end devices will evolve. Meanwhile, the communication modules and architectures will change.

3.2.1. Intelligent Agricultural IoT Sensing Device Based on 5G

In order to adapt to the performance of the smart agricultural Internet of Things and the advantages of 5G, such as high speed, high density, low delay, low power consumption, and wide coverage, the software and hardware of traditional sensing devices need to be changed.

The carrier bandwidth of 5G communication varies from 180 K to 200 M [72]. Communication rates also range from a multi-point uplink rate of 56 kbps for narrowband IoT to a maximum peak rate of 10 Gbps. The 180 K carrier bandwidth is specifically targeted at low-rate NB-IoT applications, featuring strong signal strength, strong penetration, and good coverage radius and depth coverage. It is mainly suitable for some IoT terminal applications with low data rates and most of the time in hibernation state. Such applications are widely used in smart agriculture and many other applications, such as ecological environment monitoring, because many plants and animals have long growth cycles and slow changes. There are four typical applications of NB-IoT, as shown in Table 6.

Secondly, such applications mainly change the hardware of sensor nodes in terms of antenna communication module and low-power design [73,74]. The module of the terminal node device based on NB-IoT will also change correspondingly, as shown in Figure 15.

Table 6. Four typical business types of NB-IoT.

Type	Describe	Scene
Autonomous exception reporting service type	For example, the notification of smoke and fog alarm detector and smart electricity meter power failure, the minimum data demand for uplink data (in the order of cross knots), and the cycle is usually in years and months.	Fishery breeding, precision agriculture
Business type of independent periodic report	For example, the measurement report of intelligent utilities (gas/water/electricity), intelligent agriculture, intelligent environment, etc., the uplink demand for small data volume (hundreds of bytes), and the cycle is mostly in days and hours.	Plant moisture, environmental monitoring, climate monitoring
Network instruction service type	For example, when the device is turned on/off, it triggers sending an uplink report, requests meter reading and requires minimal downlink data (in the order of cross knots). The cycle is usually in days and hours.	Automatic irrigation, automatic oxygenation, etc.
Software update business type	For example, software patches/updates require a large amount of data (kilobyte level) for uplink and downlink, and the cycle is usually in days and hours.	Remote System Update

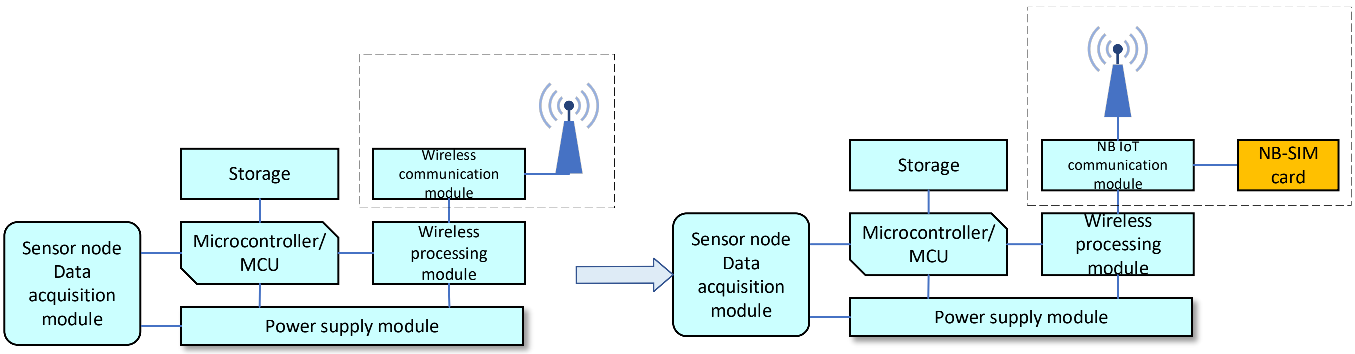

Figure 15. Sensing device communication module changes.

The communication module is usually made of off-the-shelf modules or selected chips for design. NB-IoT chips can be used by carriers of China Telecom, China Mobile, and China Unicom. At the same time, Sim cards are required to order corresponding data plans.

Many application scenarios facing smart agriculture also require large bandwidth data transmissions, such as video and VR. 5G-oriented sensor nodes can select 5G-oriented high-bandwidth communication modules. Its communication module baseband chips require specialized chips, such as Qualcomm, Huawei, etc. Due to the high data rate, the number and type of corresponding sensors can also be diverse. In the meantime, the corresponding processor, memory, and power supply modules are completely different, as shown in Figure 16.

Sensor nodes are equipped with 5G high-rate baseband chips for high-rate data communication. Multiple sensors can be integrated into appropriate scenarios to improve the integration degree, reduce the number of nodes and optimize the network architecture [75,76]. For example, the smart insecticidal lamp can integrate a variety of sensors, as shown in Figure 17. When multiple sensors are integrated, the bandwidth of the data stream changes. In the 5G scenario, the architecture of the Internet of Things changes accordingly, replacing the traditional Zigbee network, etc. [77]. The change of communication module will lead to an overall change of hardware. For example, low-power design, the architecture of the main control chip, software change, power supply system design, sensor integration, etc. [78].

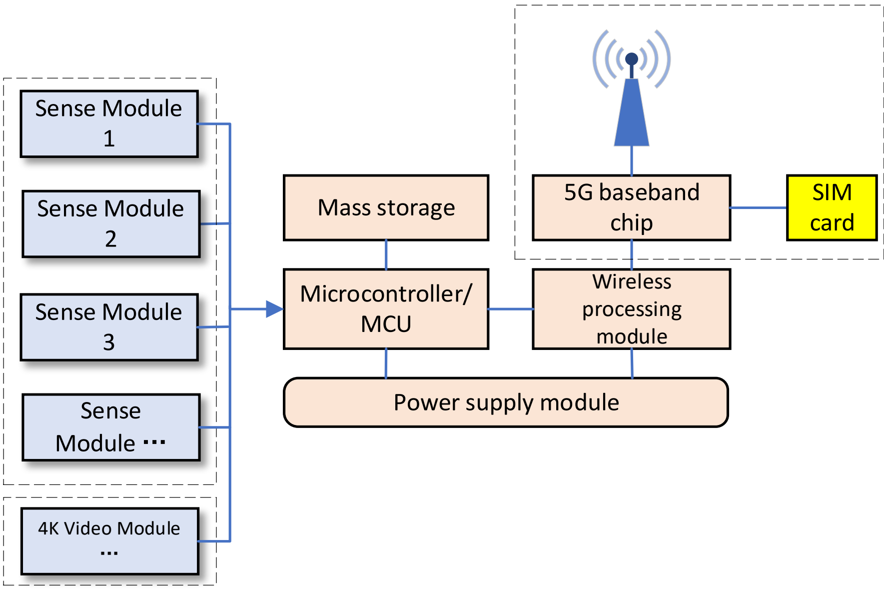

Figure 16. Sensor node composition model facing high rate facing 5G.

Figure 17. Multi-sensor system.

3.2.2. 5G Intelligent Agricultural IoT Operating System

With 5G, the hardware of IoT sensor nodes for smart agriculture has changed. In order to adapt to the application scenario, the corresponding software system will be affected and changed. The vision goal of the Internet of Things with 5G is the interconnection and interconnectivity of everything. However, the current operating system is difficult to support this goal, such as the lack of interoperability of a lightweight operating system [79]. The status quo of the Internet of Things operating system is shown in Figure 18.

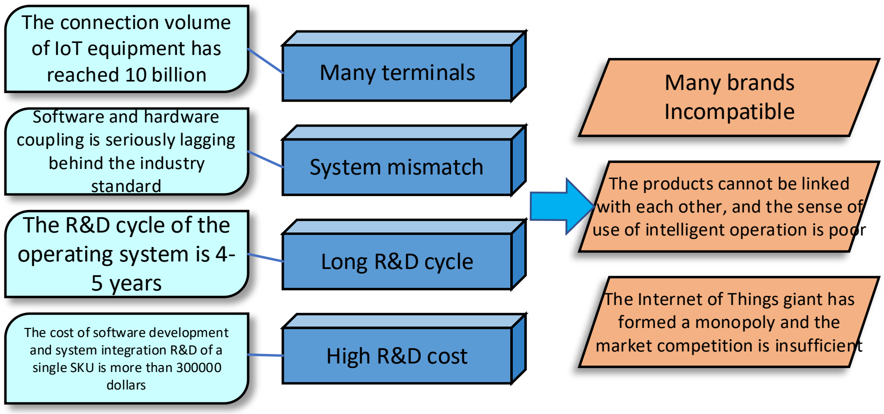

Figure 18. The status quo of the Internet of Things operating system.

The current Internet of Things operating system has made great progress [80]. Internet of Things operating system brands, and complementary compatibility, restrict the great development of the Internet of Things. In order to achieve the goal of the Internet of everything in the 5G scenario, its operating system will need to change in the future.

A typical IoT system is shown in the following Figure 19. Among them, the operating system is an important middle part applied to the bottom layer, which is related to the key to cloud interconnection and is the key to realizing the seamless interaction between people and things. Future IoT operating system requirements are shown in Figure 20.

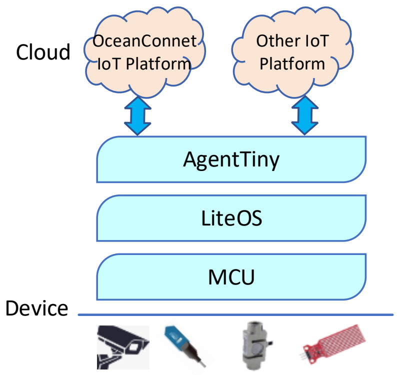

Figure 19. Huawei 5G IoT system.

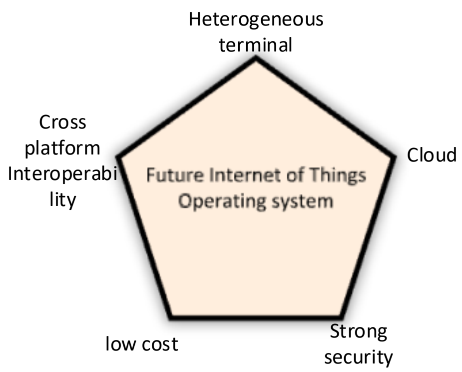

Figure 20. Future IoT operating system requirements.

Many scholars have conducted many beneficial studies on the operating system of the Internet of Things [81,82], mostly for applications, real-time scheduling, kernel design, and so on. Less attention is paid to the architecture of future sensor operating systems. It summarized the current major IoT operating systems in Table 7. In the future, under the condition that the data bandwidth is satisfied, highly intelligent is the due connotation of smart agriculture. The concept of a sensor node is more general, as there is not only a single perception function but it may also have an executive function, etc., based on edge computing, etc., to achieve node interoperability.

Table 7. List of IoT operating systems.

IoT OS	Description/Provider	Networked Operating System	Description/Provider
Brillo [80]	Google's solution for building connected devices	LiteOS	Huawei
mbedOS	ARM Internet of Things device platform	TinyOS	Tencent
RIoT [83]	Internet of Things friendly operating system	AliOS Things	Alibaba
Contiki [84]	Open source IoT operating system	RT-Thread	Real time operating system (open source)
Zephyr	Scalable real-time operating system for resource constrained systems	Windows 10 IoT Core	Windows
Nuttx	Standard compliant and small footprint real-time operating system	WatchOS	Apple

With an IoT operating system, from service connection to service application, the ultimate goal is service intelligence. In smart agriculture, with a 5G scenario, the operating system of the Internet of Things also needs to serve smart agriculture. Fuchsia OS and Harmony OS were developed by Google and Huawei. The goal is to be able to run on a variety of different hardware platforms, with distributed operating systems based on the microkernel structure and running more efficiently.

3.2.3. Large-Scale Terminal Access of 5G Smart Agricultural Monitoring Terminals

A large number of sensing devices will be deployed in the smart agricultural IoT for breeding moisture monitoring, fine agriculture, and other scenarios. How to access massive terminals in LPWA for 5G low-power wide area networks [85] is a challenging problem. With the continuous improvement of the capabilities of the air interface at the access end, the performance bottleneck of the whole system is gradually reflected in the core end, edge end, and other areas. Therefore, there must also be corresponding innovative technologies at the core or edge end to meet the nearly demanding requirements of 5G IoT applications in the future [86]. However, the existing cellular network core architecture is not suitable for the development of the Internet of Things.

The deployment of 5G has created the possibility for large-scale and intensive IoT deployment, but there are also challenges concerning reliable access and data transmission and processing, as shown in Figure 21.

3.3. Reliable Data-Driven Detection of 5G Smart Agricultural IoT

Based on the various kinds of data acquired by the massive sensing devices, they can be detected and processed to serve the upper-layer applications. These acquired terminal underlying data can be used to detect complex events in the process of agricultural production, provide intelligent decision-making for smart agricultural production, improving the degree of intelligence. Secondly, based on the breakthrough of current data volume acquisition, the breakthrough of machine learning algorithms, and the innovation of communication technology, all kinds of image processing based on machine learning are gradually popularized in smart agriculture. These lay the foundation for intelligent agricultural production.

3.3.1. Complex Event Detection in Agricultural Production

Complex event detection for agricultural production process [87]. Complex event detection abstracts business data into a sequence of events. Through the complex event description method, the potentially valuable composite data are described as a specific event-matching structure. The complex event detection engine then detects the event sequence satisfying the matching structure from a large number of event streams and finally outputs the data fusion results. The basic strategy of the event detection engine is that all Events in the time window are called candidate Events, and the candidate Events generate Matching sets according to the rules.

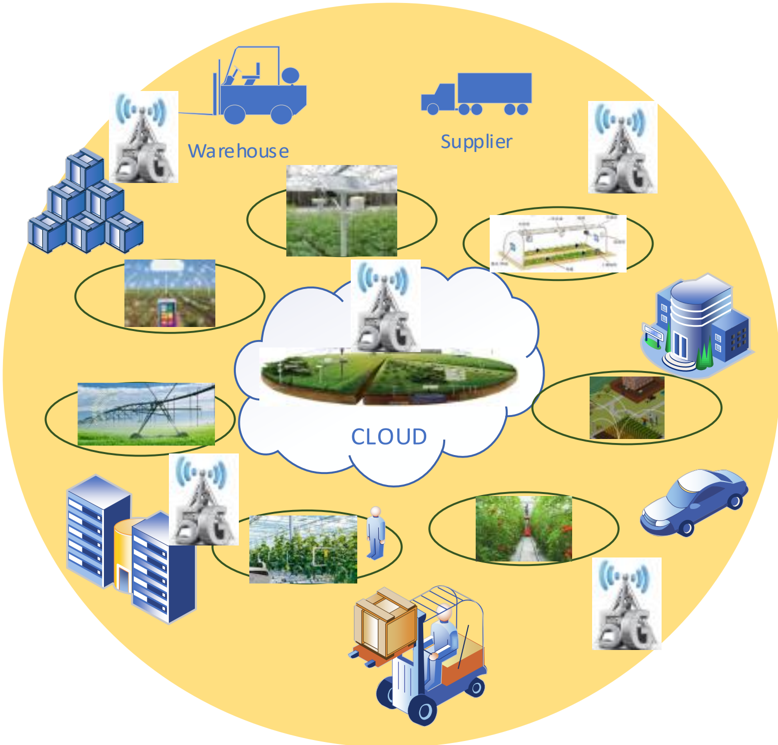

Figure 21. 5G large-scale access of smart agricultural Internet of Things perception terminal.

These data can be multimodal structural and unstructured types of data. They are widely used in smart agriculture scenarios. When the sensing data are rich enough, the complex event rules can be established through various moisture data and crop growth models to determine whether drip irrigation and fertilization are needed [88,89]. In fish farming, data collected by various sensor devices deployed in ponds are used to determine whether there is a lack of oxygen or other complex events, and so on.

The detection conditions of complex events firstly need rich physical world data, and enough sensing devices need to be deployed so that various relationships can be discovered. Second, complex computational processing power is required. For pattern matching and so on, we need quick calculation and judgment. In addition, some complex event detection is real-time, and these requirements become feasible with 5G.

3.3.2. Depth Detection of Pests and Diseases Based on Machine Learning

With the development of information technology, methods based on machine learning have been widely used in agricultural production in recent years. Many scholars combine image processing with pattern recognition, and widely use it in crop disease and pest recognition. The color, shape, texture, and other parameters extracted were screened and optimized. The linear classifier, Bayesian decision theory, fuzzy recognition, and other pattern recognition techniques were used to identify and classify various crop pests and diseases, which improved the recognition accuracy. Thus, the development of agricultural informatization and precision was further promoted [90].

As an important branch of machine learning, deep learning network is becoming a hot technology with its powerful data analysis ability. Deep learning networks can contain hundreds of hidden layers, and the features will be transformed a lot of times. Deep learning can be applied to identify crop pests and disease targets. For achieving the relationship fitting of complex sample data, the core idea is not only to automatically extract multi-layer feature representations from a large amount of data through a variety of linear and nonlinear transformations but also to complete the task of feature extraction and transformation using supervised and unsupervised combined training methods [91]. Due to the structure of a deep neural network, the error features extracted by the previous layer network can be weakened to a certain extent, and the complex function can be expressed with fewer parameters. The structure of the deep neural network will be more compact, which improves the efficiency and performance of the network.

It is obvious that the current methods with strong pattern recognition ability are particularly dependent on a large amount of data, which requires enough data to draw useful conclusions. The traditional agricultural IoT data are limited, which is challenging to support the data collection needs of future smart agriculture development. The introduction of 5G and smart agricultural IoT provides conditions for the collection of massive data.

3.4. Cloud Edge Fog Computing Fusion in 5G Intelligent Agricultural Internet of Things

In future smart agricultural IoT, data will be extremely abundant, and how to conduct analysis and calculation from these data to guide modern agricultural production is an important challenge.

Due to the limitations of volume and battery life, many mobile devices deployed in agricultural production cannot meet the requirements of these applications in terms of computing, storage, energy, and other resources. Therefore, Mobile Cloud Computing (MCC) technology has been proposed. It provides reorganized computing resources for mobile devices in the cloud platform, migrates data processing and storage to the cloud, and reduces constraints on its own resources. With the development of smart agriculture, massive data will be generated in the future to be analyzed, processed, and stored in the central cloud [92]. At the same time, there may be a large number of connections between sensing devices, and these MCCS cannot meet the demand. New computing methods, such as edge computing and fog computing, will be integrated into the intelligent agricultural IoT system [93]. Edge sensors no longer need to continuously transmit various sensing data to the data center. It can judge the sensing data on its own, contacting the data center only when there is a significant change in the reading to decide what action to take. Cloud computing is suitable for non-real-time, long-period data, and business decision scenarios, while edge computing plays an irreplaceable role in real-time, short-period data, and local decision-making. Edge computing and cloud computing are two important supports for the digital transformation of the industry. Their collaboration in the network, business, application, intelligence, and other aspects will help support the agricultural IoT to create greater value. Intelligent edge computing based on 5G power can use the cloud for large-scale security configuration, deployment, the management of edge devices, and the ability to assign intelligence based on device type and scenario, allowing intelligence to flow between the cloud and the edge. The edge computing model in smart agriculture is shown in Figure 22.

Secondly, with the continuous enrichment of data in smart agricultural IoT, the traditional forms of computing will become richer and richer. Distributed computing based on cloud computing, fog computing, and other forms will be deeply integrated with 5G communication capabilities and applied to smart agriculture. Agriculture, for wisdom in greenhouse cultivation, oriented precision fertilization, aquaculture, animal husbandry, and aquaculture, the scene such as plant monitoring, needs the edge of the Internet of Things system IoT terminal according to the scientific planting and breeding, fertilizers and other professional industry model, implement local sampling, local operations, and local decisions at the same time, according to the requirement of the center's continuously updated mathematical model and iteration. Therefore, the intelligent Internet of Things terminal should be based on the requirements of fog computing and edge computing architecture, rely on the machine learning and algorithm training of cloud computing center, complete, reliable real-time deep computing, accurately control on-site facilities and equipment, and achieve the purpose of scientific planting and breeding.

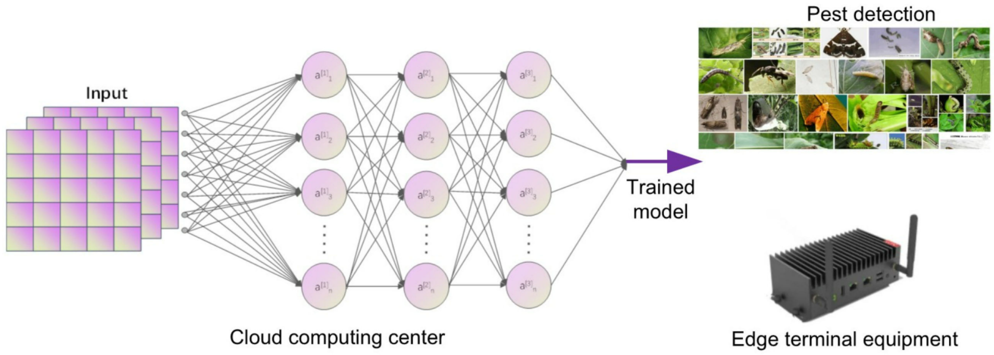

Figure 22. Smart agriculture edge computing model.

3.5. 5G Intelligent Agricultural IoT In-Depth Service

The intelligent Internet of Things platform under the 5G will provide personalized, customized, and in-depth services for agriculture. The smart agriculture IoT big data service platform is shown in Figure 23.

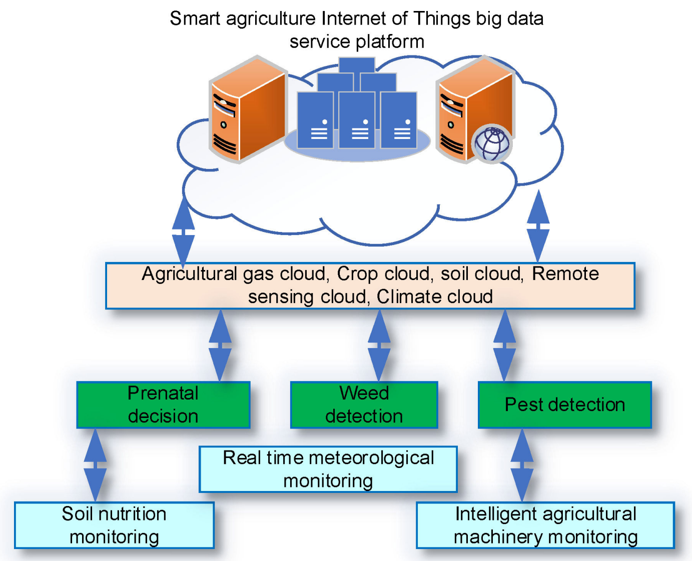

Figure 23. Smart agriculture Internet of Things service platform.

Based on the power of 5G and the improvement of computing power and storage capacity, combined with the latest service platform architecture SaaS, PaaS, IaaS, etc., the services of smart agriculture will be extremely friendly and convenient. By shielding the underlying details, users will be provided with QoS humanized services, as shown in Figure 24.

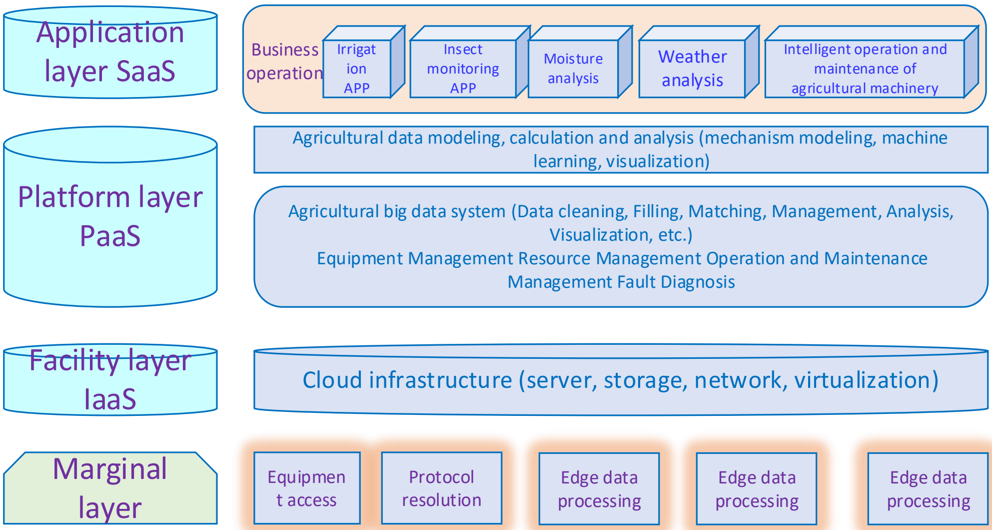

Figure 24. 5G smart agriculture Internet of Things service.

Concerning 5G, the Internet, the Internet of Things, big data and cloud computing, artificial intelligence, and other modern information technology and agricultural depth fusion, the implementation of agricultural information perception and quantitative decision-making, intelligent control, accurate, and personalized service, the new way of agricultural production is the agricultural informationization development from the advanced stage of digital to network and intelligent.

3.6. 5G Intelligent Agricultural IoT Production Intelligent Control

The application of intelligent agricultural IoT based on 5G is bound to involve production control, and control of various agricultural machinery such as irrigation and spraying [94]. The innate advantages of 5G have innate advantages for the control of smart agriculture—mainly low delay, high bandwidth, and other technical characteristics, as shown in Figure 25.

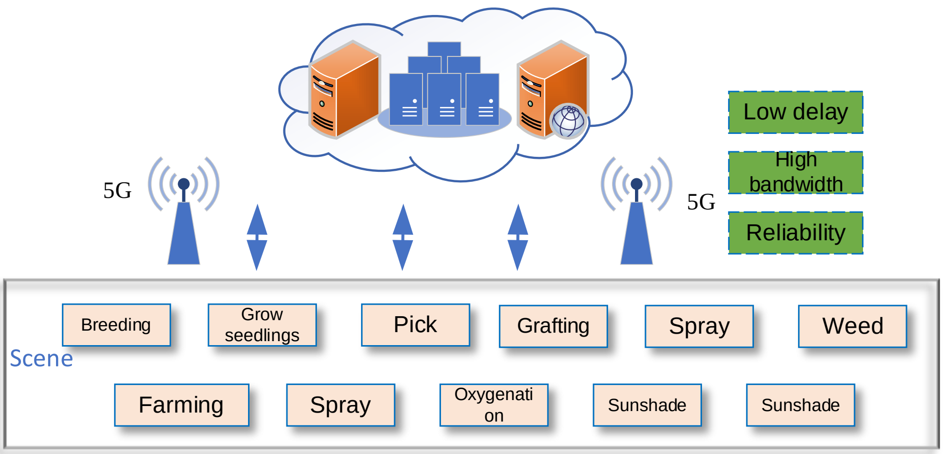

Figure 25. 5G of intelligent control of intelligent agriculture production.

For example, a project uses drones to take photos of farmland, and the raw data will be transmitted to the cloud via 5G network for real-time data analysis and identification. The results can then be re-matched to the field, and a tractor or farm robot, guided by GPS, can then navigate to the area where the weeds are growing and carry out precise removal. This could reduce pesticide use by up to 90 percent, with the possibility of replacing pesticides with hot water to remove weeds later. Neural networks and self-learning algorithms make plant identification more and more accurate, but they also generate a lot of data. Therefore, the combination of 5G and other technologies is crucial to the success of this innovation project [95,96].

4. Revolution of Smart Agricultural IoT Application Paradigm under 5G

4.1. Typical Application Scenarios of 5G Smart Agricultural IoT

The development of 5G network will provide the infrastructure needed for smart agriculture for agricultural production. The main application scenarios include the following aspects.

4.1.1. Smart Farm

The two characteristics of 5G network, high speed and large connection, will help the agricultural industry implement large-scale machine services. Centralized control of environmental sensors, planters, UAVs, and other monitoring equipment and real-time data transmission. Finally, the purpose of intensive farming, accurate fertilization, and reasonable irrigation is achieved [97]. Agricultural machinery automatic agricultural machinery equipment based on 5G was integrated to achieve rapid, large-area, efficient, and precise spraying operation [98].

4.1.2. Smart Forestry

Smart forestry utilizes 5G network video, UAV, and other monitoring equipment to carry out forest inspection, realize the monitoring of forest resources, forest pests and diseases, wild animals and plants, forest fire prevention, and provide guide and rescue services for staff and tourists [99].

4.1.3. Intelligent Animal Husbandry

5G intelligent animal husbandry can improve the production efficiency of animal husbandry, reduce the cost of breeding, prevent livestock epidemic and livestock loss, and protect animal husbandry ecology [100,101]. For example, the use of 5G drone technology, wearing 5G terminals on the necks of cows, and the use of Internet of Things technology to manage yaks have brought great changes to the traditional herding work of plateau herders.

4.1.4. Smart Fishing Ground

5G smart fishing grounds use monitoring equipment such as high-definition network cameras and underwater camera systems to carry out real-scene monitoring, aquatic product growth monitoring, and precise bait casting to improve the safety of underwater operations and save labor costs [102]. In the Marine ranch, 5G panoramic monitoring application is realized through 5G coverage. The panoramic high-definition camera equipment and 5G underwater camera system were set up to realize the 24-h panoramic monitoring of the ranch. Managers can observe the growth of aquatic products, including underwater observation, from their offices or homes through mobile phones [103]. Based on 5G technology, the intelligent control of the production process of Marine cash crops, including kelp and other seedlings, can also be realized, making it possible to have unmanned Marine ranching.

4.2. Deep Sense of 5G Smart Agriculture

4.2.1. Agricultural 5G Image Processing

In smart agriculture, a large number of scenes need to realize monitoring or identification and detection of various targets. With the rapid development of machine learning technology in image processing, many problems in agriculture can be solved by video monitoring and image detection. This paper summarizes the typical application scenarios of agricultural image processing, as shown in Figure 26. It mainly includes three categories: plant pest and disease identification [104,105], crop growth analysis and detection [106], and livestock and aquaculture monitoring [107,108]. Each category is divided into many specific problems. The core mode is to collect image data and then combine data with an artificial intelligence machine learning algorithm to train the model and then detect the model.

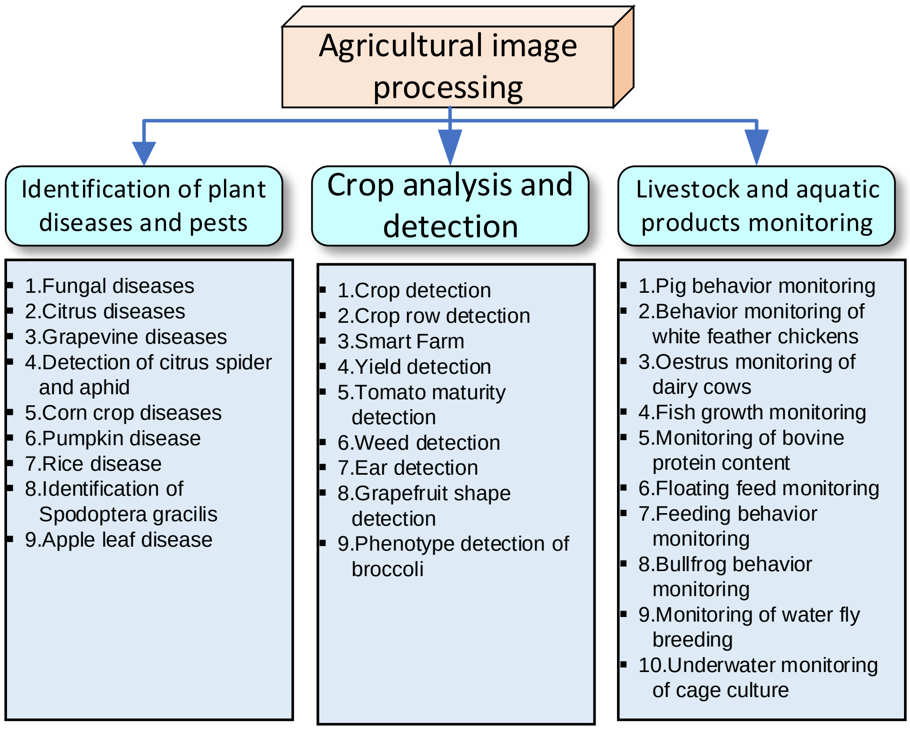

Figure 26. Image processing in agriculture.

With the popularity of high-definition cameras, more images need to be transmitted in agricultural IoT. The transmission of these high-definition images poses a challenge for the network. Second, many scenarios require real-time detection and processing. With the popularity of 5G technology, the effective transmission and real-time processing of video and image big data can be realized by building a 5G-oriented heterogeneous Internet of Things.

4.2.2. Agricultural Intelligence Detection Based Machine Learning

The development of artificial intelligence machine learning has brought new opportunities for smart agriculture. Many researchers have conducted a great deal of research by combining machine learning algorithms. The main goal of machine learning is classification and detection [109,110]. In agricultural application scenarios, machine learning mainly realizes agricultural sensing data, including video, image, text, and other multi-modal data, and trains models for data detection. The following figure shows the general model processed by machine learning, as shown in Figure 27.

However, the autonomous training model is limited by the resources and computing power of the sensing device, and the effect is not always ideal. At present, there are many open-source deep learning platforms for artificial intelligence, which can optimize model training and provide detection accuracy with the help of platform capabilities. The open AI deep learning platform is shown in Figure 28.

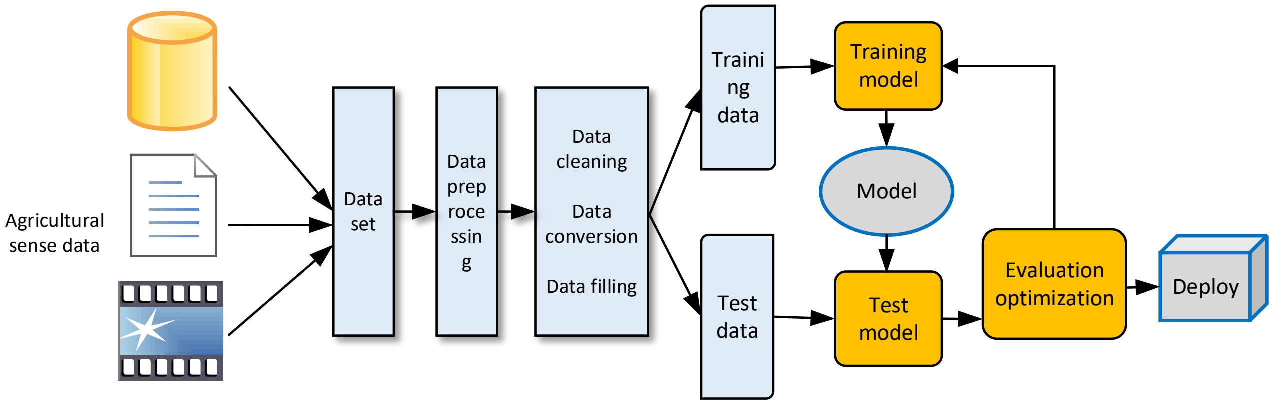

Figure 27. An agricultural intelligence detection framework for machine learning.

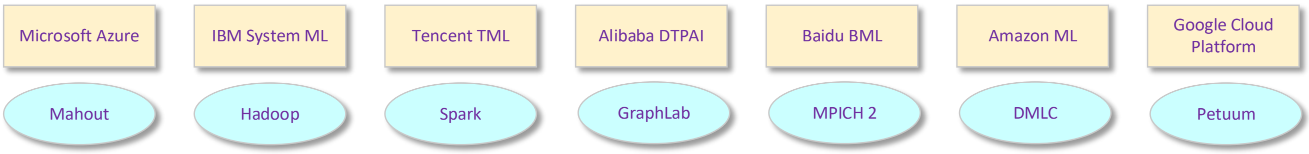

Figure 28. Open artificial intelligence deep learning platform.

Deep learning is an important branch of machine learning. It can automatically and efficiently extract target features and recognize targets through model training. The application of deep learning technology combined with image processing to the recognition of crop diseases and insect pests is an inevitable trend in the future development of precision agriculture. The performance of deep learning networks is very dependent on data sets. High quality, high correlation, complete annotation, and large-scale agricultural data sets are of great significance for model training. In the application of crop disease and pest recognition, in addition to color images taken by cameras and mobile phones of sensing devices, multimodal agricultural data such as hyperspectral, near-infrared, and infrared images are becoming a trend, and their acquisition provides support for model training, as shown in Figure 29. In addition to publicly available data sets, an important source for data set sources is self-collection. However, it is very difficult to collect graphs of crop diseases and insect pests, and there are some problems, such as page occlusion and victim area concealment, which require multi-angle sensing equipment to collect at the whole time, which requires a large amount of data collection and transmission. Based on 5G, high-speed transmission of data from terminal sensing nodes to the platform can be realized, real-time detection of data can be realized, and the degree of intelligence can be expanded [111].

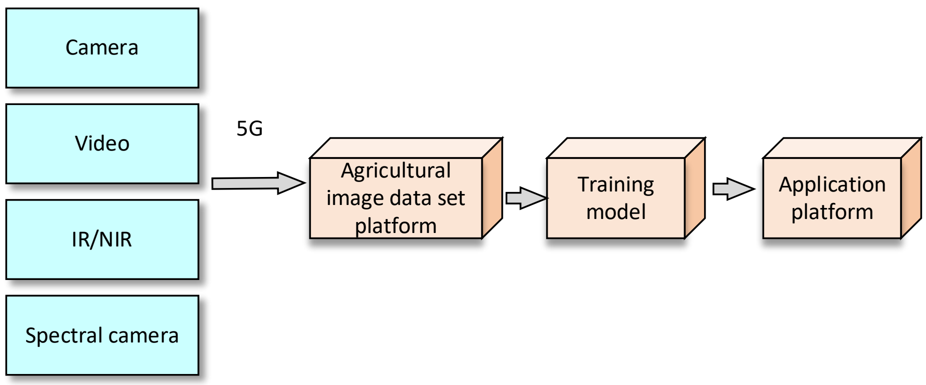

Figure 29. Machine learning detection platform based on 5G.

4.3. 5G Intelligent Agricultural Machinery

Under the conditions of high speed and low delay of 5G, intelligent agricultural machinery can realize deep real-time perception, such as the state information collection, fault location, and operation monitoring of agricultural machinery can be displayed online in real time. The system can diagnose the failure of agricultural machinery in real-time and schedule the cooperative operation of multiple agricultural machineries. The advantage of low latency is that route decisions can be made in time, increasing the speed of sowing or harvesting and making the operation more accurate. Secondly, agricultural robots are mainly divided into two categories. First, walking robots. The second is the robotic hand robot. The robot is mainly based on visual recognition technology to identify and locate plants and then plant and pick them. 5G technology enables robots to receive commands faster, transmit high-definition pictures and videos, and promote the development of robot visual recognition technology. 5G has increased the number of robots that can be accessed, allowing multiple robots to be remotely controlled to work and improving operational efficiency.

4.3.1. Intelligent Agricultural Machinery

Agricultural machinery plays an important role in agricultural production practice. It can effectively improve the efficiency of agricultural production to promote large-scale and industrial planting. All kinds of machinery used in the process of agriculture, forestry, animal husbandry, deputy, and fishery production are collectively referred to as agricultural machinery. Agricultural machinery can be broadly divided into two categories: power machinery and working machinery. The following diagram summarizes the classification diagram of agricultural machinery and equipment according to different functions [112,113], as shown in Figure 30.

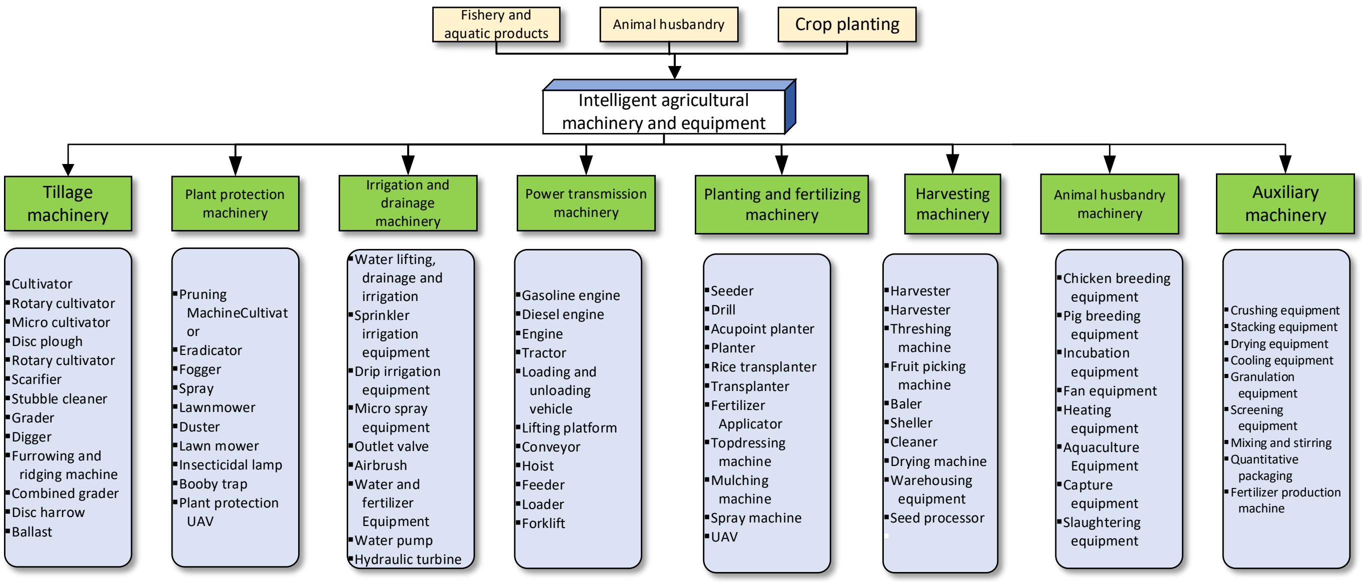

Figure 30. Classification of agricultural machinery and equipment.

The trend of intelligent agriculture development is necessarily intelligent. With the development of technology based on automated equipment, the intelligent operation of agriculture will be realized by means of sensors, information transmission, and information integration processing, which are based on the Internet of Things, big data, and artificial intelligence [114].

For example, the intelligent agricultural machine can form a highly intelligent operating system by configuring various sensing devices and computing chips on the agricultural machine, combined with satellite positioning detection terminal equipment, digital integration module, and IoT system. Intelligent agricultural machinery can also display information on agricultural machinery operation through the management center information platform. The perception information will be monitored for statistics and management, agricultural machinery macro management, command scheduling, and operation statistics. Information technology and agricultural machinery chain integration, through data analysis, get a scientific decision.

Higher intelligent agricultural machines require more sensory data intake for computational processing decisions. This requires a smart agricultural Internet of Things. For example, the irrigation system of farmland can be completed by simple operation of farmers. However, the question of when and how much to irrigate depends on people's experience. The intelligent irrigation system can be judged comprehensively through the monitoring data of crop production status, temperature, and humidity, meteorological conditions, etc., which saves manpower and ensures the health of crop growth.

The problem is that the traditional Internet of Things cannot meet the requirements of real-time transmission of large amounts of data. With the integration of 5G, smart agricultural machines can achieve a data communication rate, which is expected to change the production mode of smart agricultural machines and the degree of wisdom, as shown in Figure 31 and Table 8.

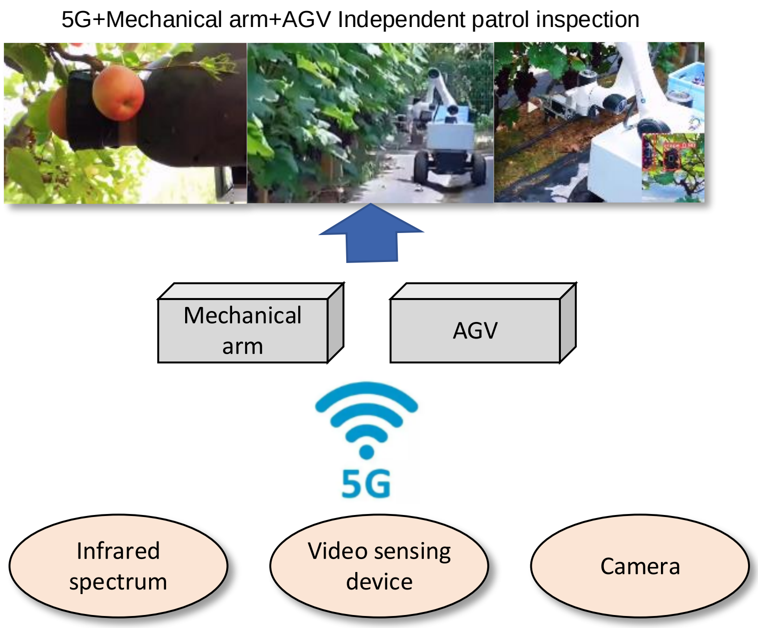

Figure 31. 5G + robotic arm + AGV independent inspection.

Table 8. Image recognition and detection of intelligent agriculture.

Literature	Content	Field	Type
B. Bose et al. [115]	Diagnosis, detection, and classification of cannabis diseases	Plant protection	Classification algorithm
D. Brunelli et al. [116]	Identify and kill apple pests	Plant protection	Neural network
R. Medar et al. [117]	Crop yield prediction	Plant protection	Machine learning
N. Gobalakrishnan [118]	Plant disease detection	Crop diseases and insect pests	Image processing
M. Merchant [119]	Various nutritional deficiencies of mango leaves	Crop protection	Image processing
Q. Feng [120]	Tomato harvesting machine	Harvest	Image segmentation processing

Under the background of 5G, the smart agricultural IoT will transform the existing agricultural machinery equipment and make it more intelligent. Intelligent agricultural machinery can perceive its position, surrounding environment relationship, and the internal working state of machinery by building machine vision, multi-dimensional perception, and satellite positioning based on 5G agricultural Internet of Things. It can achieve good cooperation and scientific implementation, effectively improving the effect of agricultural mechanization by controlling and operating each process. Intelligent agricultural machinery 5G-based agricultural Internet of Things can realize real-time monitoring of agricultural machinery's own condition, operating state of machinery and tools, meteorological conditions, and operating environment. It can also guide agricultural machinery to adjust the operation plan in time according to the obtained information and effectively reduce the industrial machinery in the process of operation failure, such as machine damage, poor quality, and other problems. In addition to the above, intelligent agricultural machinery will reduce the amount of ineffective operation of industrial machinery. Energy efficiency has been significantly improved. The precise operation also realizes the precise application of pesticides and fertilizers and truly realizes the requirements of energy-saving and environmental protection.

It is clear that smart agriculture combined with the Internet of Things and machine learning algorithm big data can transform traditional agricultural machinery and equipment, making them more intelligent. In addition, the operation of intelligent detection and sensing equipment can realize the functions of agricultural machinery positioning, real-time statistics of agricultural machinery working area, and real-time calculation of operation quality. The system supports a variety of agricultural machinery operations such as sowing, transplanting, plant protection, harvesting, deep loosening, and land preparation, straw returning, and so on. It can measure fuel consumption and obtain the working condition information of agricultural machinery in real-time. This facilitates the control of agricultural production progress and facilitates the real-time control of the working area, working quality, and working power consumption. Being based on geospatial remote sensing technology, multi-sensor fusion technology, 5G technology, and big data technology, the system realizes the comprehensive upgrading of smart agricultural machinery.

4.3.2. Automatic Driving of Agricultural Machinery

The automatic driving technology of agricultural machinery is to use high-precision satellite positioning and navigation information and controls the hydraulic system of agricultural machinery by the controller so that the agricultural machinery can drive automatically according to the set route (straight line or curve). It can effectively improve the working accuracy, improve the land utilization rate, reduce the labor intensity of machine hands, and extend the working time (field work can also be carried out at night). Moreover, it is easy to operate and reduces the requirement for the driving ability of the manipulator [121,122]. Based on the Beidou Navigation Satellite System (BDS) [123,124], a global Positioning system (GPS) can achieve intelligent driving of all kinds of agricultural machinery, including rice transplanters, seed drills, combine harvesters, etc. The high-precision positioning and navigation technology, image recognition, and transmission technology are applied to the intelligent driving of these machines to realize the precise navigation of agricultural machinery driving and automatically complete the land tillage, sowing, field management, and harvest, as shown in Figure 32.

Intelligent agricultural machinery automatic driving system uses satellite positioning, mechanical control, inertial navigation, and other technologies so that agricultural machinery, according to the planned route, automatically adjusts the direction of travel. Operation precision can reach the centimeter level, and can be used for ditching, raking, sowing, ridge, fertilization, spraying, harvesting, transplanting, and other agricultural operations.

Unmanned agricultural machinery has many problems to be solved, such as real-time control, low speed, and complex scenes. Sensing data do not easily meet the needs of intelligent control. The high bandwidth and real-time performance of 5G will be able to meet the above requirements of unmanned agricultural control operations.

Figure 32. 5G unmanned agricultural machinery model.

4.3.3. 5G Automatic Coordination of Multiple Agricultural Machines

The 5G agricultural machinery unmanned operating system is deployed on the 5G cloud network fusion platform. With the intelligent agricultural machinery equipment docking, we realized the agricultural machinery from the hangar, and machine plough way to the operation plot of the whole process of unmanned operation. It covers all the production links of rice cultivation, seed, pipe, and harvest. In the hangar and on the road, the location map modeling is first carried out, and the application equipment deployment based on RTK differential GNSS positioning technology, IMU data, and UWB precise positioning technology were used to achieve the indoor and outdoor centimeter-level positioning accuracy. Secondly, the core control system deployed in the edge cloud and the visual and radar terminals installed in the agricultural machinery were combined to sense the surrounding environment intelligently. Finally, the AI deep learning algorithm was used to complete the mark line recognition and obstacle detection when agricultural machinery is moving forward and backing up. In this way, unmanned driving, parking, obstacle recognition, and automatic obstacle avoidance can be realized, as shown in Figure 33.

4.4. 5G Agricultural UAV

UAVs require a high time delay of network signals. 5G networks give UAVs important capabilities such as ultra-high-definition video transmission, remote networking, and autonomous flight. 5G technology makes it possible for fleets of drones to work together and around the clock. It has huge development space in agriculture, security, electricity, and other industries [125]. The plant protection UAV is small in size, light in weight, flexible for flight control, and has good applicability to different plots and crops. At the platform end, the networked UAV can be remotely controlled to set functions such as assigning tasks, designing routes independently, sending back spraying data in real time, and automatically returning after an operation. Plant protection UAVs reduce pesticides, save water consumption and improve pesticides [126]. The steady wind field generated by the rotor of the UAV can penetrate the bottom of the crop, and the atomization effect is good, reaching the back of the blade.

Live broadcasts of rice by unmanned aerial vehicles are relatively popular in south China, which can sow 300~600 mu per day, 3~5 times that of ground machinery. At the same time, it eliminates the process of seedling, raising, transporting, and transplanting. The drone can adjust the nozzle size according to the size of the seed. Spray the seeds in rows and columns as needed. The UAV can also spray granular fertilizer and pesticides. According to the difference in particle density and quality, it can automatically adjust the parameters of the medicine box to provide efficient and intelligent fertilization and application schemes.

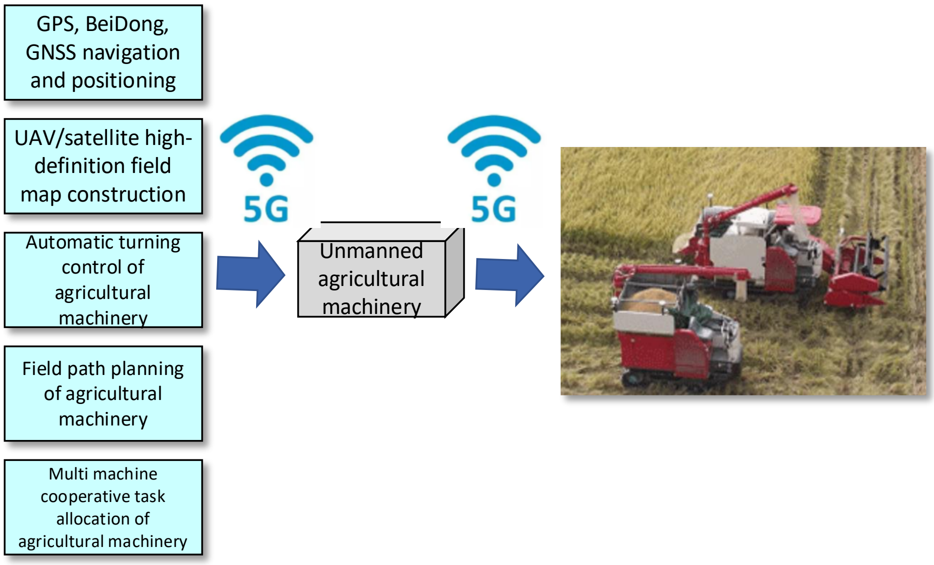

Figure 33. Schematic diagram of unmanned agricultural machinery collaboration based on 5G.

The drones carry a range of remote sensing equipment that can photograph the growth of crops. Remote sensing images combined with extensive data analysis can realize the functions of crop monitoring, fertilization advice, and pest and disease prediction. Different yields reflect different infrared spectra, which can be used to measure the area of crops. Pests and diseases can be analyzed by infrared spectroscopy and high-definition photographs.

For forest management, 5G drone ground stations will be deployed around the forest farm, covering an area of about 100 km. The drones are equipped with equipment, such as optical cameras and high-definition cameras, to monitor vegetation growth and forest cover. Through big data analysis of tree varieties and survival rate, replanting suggestions can also predict the occurrence of forest pests and diseases and put forward prevention and control suggestions. In terms of forest fire control, inspection routes can be planned according to daily needs, and the UAV will automatically alarm if there is any abnormality [127]. If the forest is on fire, drones can be sent to check the fire, and the fire can be used to identify the point of fire.

According to the different functions of agricultural UAVs, as shown in Figure 34, they can be divided into two categories: agricultural operation and farmland information collection. Agricultural operation refers to the use of unmanned aerial vehicles (UAVs) to replace some human agricultural operations and to solve the shortage of human operations in quality, efficiency, and labor, as well as the safety problems of operations. The collection of farmland information refers to the timely and accurate collection of field information using remote sensing detection technology, including photosynthetic quality, soil moisture, and crop population growth [128,129].

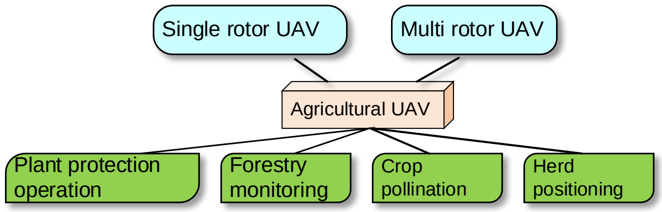

Figure 34. Type of agricultural UAV.

Several challenges remain in the current application of agricultural drones:

First, the endurance time of agricultural UAVs is short, which cannot adapt to multiple types of complex operations in the field.

Second, it is difficult to control. Most of the intelligence degree is low, and anti-collision and other functions are lacking.

Third, the precision application control technology based on agricultural information is not mature enough. During aerial spraying operations, agricultural information such as crop growth, pests, and diseases in different operating areas were obtained by aerial remote sensing technology, and prescription maps were generated to determine the pesticide preparations and dosage required for aerial spraying in different areas. The precision application of plant protection UAVs was realized by variable control technology.

All the above have put forward new requirements for the intelligence degree of UAVs, mainly including intelligent control, precise operation, better function, and optimization of spraying equipment. For the precise control of UAVs, it is necessary to consume more abundant information to meet its control needs. Secondly, the real-time control needs to be strengthened and satisfied, and the large bandwidth and low delay of 5G can meet the above requirements. It can be expected that the popularity of 5G will be expected to promote the further development of agricultural drones.

4.5. 5G Intelligent Agricultural Supply Chain Management

Agricultural products have various production processes, long cycles, and numerous factors, so it is challenging to realize standardized production and management [130]. The supply chain of agricultural products is in all stages of agriculture before, during, and after production. Participants participate in different roles of producers and consumers to realize the supply and circulation of agricultural products among agricultural producers, agricultural materials/agricultural service enterprises, wholesale and retail markets, regulatory agencies, and end consumers. It connects the production, processing, transportation, sales, and other links of agricultural products and integrates logistics, capital flow, and information flow. It is important to establish a chain structure network composed of agricultural product suppliers, manufacturers, distributors, retailers, and end consumers [131]. Traditional agricultural supply chain participants mainly use the Internet of Things technology to achieve information collection, transmission, processing, processing, and other businesses. However, as IoT systems are built in different participant systems, they belong to different platforms. For the seemingly interconnected network, the business is relatively independent, unable to quickly and effectively complete the exchange of information, the real realization of the whole process of sharing, presentation, and other difficulties.

The traditional Internet is to reduce intermediate links, reduce transaction costs, expand the scope of service, improve service quality, and so on. Embedding blockchain technology may deepen the meaning of the Internet. It can form credit by recording, storing, transferring, verifying, and analyzing information data programmatically. Blockchain can save a great deal of labor costs and intermediary costs, and the recorded credit information is completer and more difficult to fake. The internal structure of the network architecture of each subsystem is different. The network slice network virtualization of 5G can realize the isolation and organic combination of each sub-platform. An agricultural products supply chain management schematic diagram of 5G block chain is shown in Figure 35.

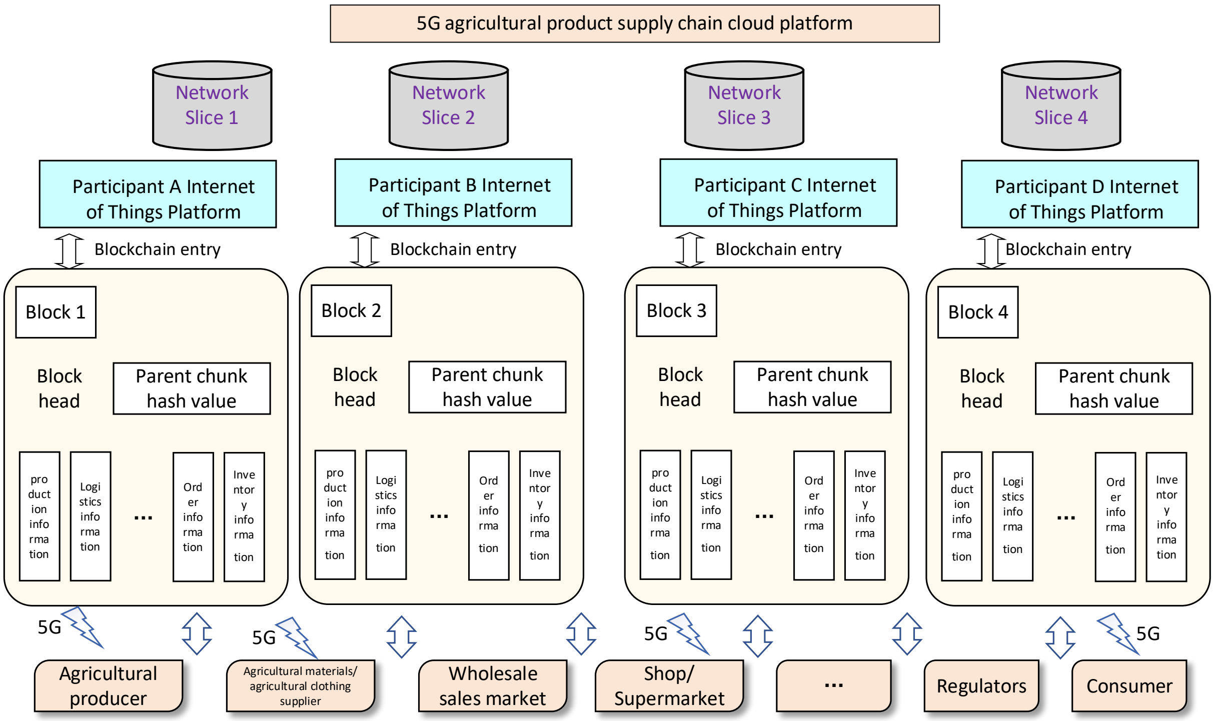

Figure 35. 5G block chain agricultural products supply chain management schematic diagram.

5. Challenges of 5G Smart Agricultural IoT

5G will bring new development opportunities to agriculture, making the smart agricultural IoT evolve in a smarter direction. At the same time, it also brings many new problems, and smart agriculture faces new challenges, as shown in Figure 36.

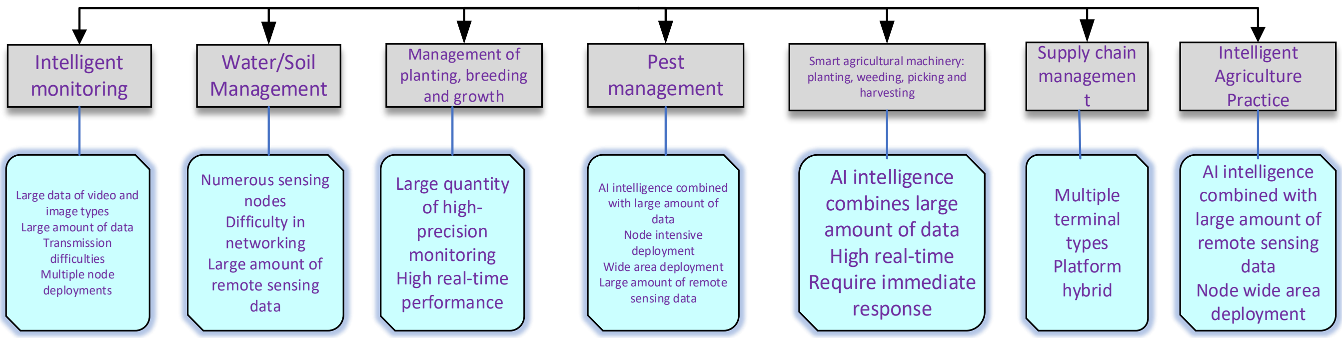

Figure 36. The new problems in the smart agriculture Internet of Things.

These new problems bring new challenges to the application of smart agriculture. Many of these key issues may be partially solved with the introduction of 5G technology.

5G is the infrastructure of the intelligent era. Its characteristics of "extremely high speed, enormous capacity and extremely low delay" can provide basic support for meeting the development needs of smart agriculture in the future. Compared with the 2–4G era, the demand for base stations and network control equipment has increased significantly in 5G. The large-scale application of 5G technology not only increases the cost of network infrastructure, but also the cost of power and operation, and maintenance is much higher than that of 4G, which brings challenges to the field agricultural production with low added value. However, 5G technology still has limits when it comes to applications such as virtual reality, intelligent production, and driverless driving. First, the deployment of 5G base stations is not balanced. As many 5G base stations are distributed in sparsely populated areas, such as fields, agriculture, and farming, there may be only a few 5G base stations in these areas, which cannot effectively cover all of them, which brings challenges to the popularization and application. Secondly, the introduction of 5G will bring a change of the whole smart agriculture application paradigm. The architecture, perception, transmission, computing, service, processing, and application mode of 5G Internet of Things for smart agriculture will bring changes, and there will be challenges.

5.1. Fusion and Optimization of Sparse 5G Base Station and Heterogeneous Sensing Network in Smart Agriculture

5.1.1. Optimization of Hybrid Deployment of 5G and Sensing Network

According to the analysis, the characteristics of 5G network in agriculture are sparse, uneven, and they have low coverage of network base stations and slow deployment of farm base stations in remote areas. This brings challenges for the application of 5G in field agriculture and plantation agriculture.

For this imbalance and sparsity feature, it can be configured from two aspects. One is to optimize the deployment of sensing nodes, and the other is to deploy in combination with heterogeneous networks. The hybrid deployment strategy for field agriculture, for example, 5G sensing nodes are deployed in key areas, and other sensing nodes are deployed in other areas, and sensing deployment optimization is realized through network resource virtualization and other technologies. When the communication nodes of large-scale intelligent agricultural sensor networks are deployed in three-dimensional space under the background of 5G, the traditional random node deployment mode has the problems of high energy consumption, high cost, and node disconnection. Firstly, by taking advantage of the characteristics of the high bandwidth of 5G communication, a hierarchical communication scheme can be designed, and a hierarchical node optimal deployment model, a communication energy consumption model, and a fully connected sensor information transmission network model are established. On the premise of ensuring the full connectivity of sensor communication network nodes in farmland, the life cycle of communication network nodes is improved.

(a) 5G sparse deployment based on field agricultural planting scenarios.

Combined with the actual field agricultural planting scene, the 5G base station has a high working frequency band and a large signal attenuation, and its coverage radius is only 0.3–0.5 times that of the 4G base station. It is difficult to meet the goal of low cost and high benefit of network construction only by deploying a macro base station. The micro-base station has a small coverage radius and low construction cost. In order to optimize the deployment cost of 5G base stations, the heterogeneous network architecture of "macro and micro collaboration" can be adopted. How to combine smart agricultural business for optimal deployment is an important issue. Heterogeneous networks can optimize the cost of 5G signal deployment while realizing the coverage of agricultural operation areas and optimizing the perceived cost.

(b) Intensive deployment optimization of 5G and sensing nodes in fine agriculture.

In fine agriculture, there are many parameters to monitor, many types of business, and the need for intensive sensing equipment, which generates an explosion of mobile data. How to realize intelligent and efficient green deployment planning of intelligent nodes such as base stations and gateways with large area coverage for various intelligent agricultural applications is one of the key issues. By deploying small base stations with lower cost and closer to users, it becomes a feasible solution to construct ultra-dense heterogeneous networks centered on monitoring objects.

5.1.2. Optimization of 5G and Sensing Network Gateway Deployment

Previously, the deployment optimization of sensing nodes and 5G base stations were proposed in fine agriculture. In the integration of 5G and sensing devices in deployment, it is necessary to combine the collaboration of the Internet of Things gateway to realize the high-low speed switching and transmission of sensing data.

(a) The deployment of edge gateway in the Internet of Things. The conditions of edge gateway coverage and service terminal traffic generator, the factors affecting the offloading delay of computing tasks, and the constraints of edge gateway capacity allocation. Following that, the edge gateway deployment optimization model was established and optimized.

(b) To solve the problem of base station deployment in the Low Power Wide Area Network (LPWAN), the received signal values of all terminal test points can be predicted by combining the terminal receiving signal prediction module. Then, the prediction results are transformed into the weight values of all terminal test points during clustering, and the terminal test points are clustered. In addition, the location of the base station was adjusted to achieve the optimal coverage effect and realize the deployment optimization in the whole application scenario.

5.2. Optimization Control under Edge Computing in 5G Intelligent Agricultural Production

The popularization and application of 5G intelligent agricultural Internet of Things will bring major challenges to the traditional cloud computing model, such as high latency and jitter, no support for location awareness and mobility, and non-adaptive communication types. The production of smart agriculture often needs to deploy edge computing to achieve real-time computing and reasonable allocation of resources.

5.2.1. Automatic Phenotype Monitoring Based on 5G Internet of Things

By monitoring and sensing plant growth phenotype, the analysis of crop traits is of great reference significance for cultivating crop varieties with excellent traits such as drought resistance, poison resistance, lodging resistance, high nutrient rate, and salt and alkali resistance. It helps researchers select seeds of good quality for the next generation of breeding objects. There are many common image-based phenotyping methods in the field of plant phenotype. Among them, the image recognition method based on visible light has lower requirements on experimental equipment, higher practicability, and can collect large-scale plant image data. Therefore, the current deep learning can be better applied to those algorithms that use visible light images. All these require high-speed data transmission, and how to collect and control real-time data in multi-source sensing devices is a problem worth studying. At present, the main concern of plant leaf recognition methods based on visible light images is that there are not many kinds of recognition methods. There are many researchers working on automatic phenotypic sensing platforms, which require automatic sensing data pickup. Combining the advantages of high bandwidth and dense deployment of 5G to realize automatic measurement and real-time computation of phenotype is a problem worth studying.

5.2.2. Intelligent Sensing Real-Time Control for Intelligent Agricultural Machinery

More intelligent agricultural machinery will participate in the future smart agriculture. They can combine 5G Internet of Things and edge computing to realize smart agricultural production. Among them they face the real-time control of equipment, which requires rapid data collection and processing.

In the operation of smart agricultural machinery, sensors deployed on the roadside of farmland can sense all kinds of environments and obtain important traffic information. For example, fixed sensors such as vision sensors and millimeter wave sensors are installed on the side of the road, and the information collected by the sensors is sent to the edge server for processing to extract information such as vehicle location and vehicle trajectory. According to the multi-source information obtained by roadside sensors, crop sensors, and smart agricultural sensing equipment, real-time data processing is carried out to analyze the operation status and calculate the results. Mobile edge computing provides powerful computing and storage capabilities. The side camera and millimeter wave radar are fused based on the edge server. Through data preprocessing, space synchronization, time synchronization, and tracking algorithm, they can cooperate with each other, jointly building an intelligent agricultural machinery environment sensing system to make it more stable and reliable.

During the operation of intelligent agricultural machinery, target tracking should focus on the following points: (1) Object association: radar detection should be associated with camera detection, while the current fusion detection must be associated with the existing trajectory; (2) Tracking link: appropriate filter should be selected for tracking; (3) Tracking management: tracking object database needs to be maintained.

5.3. Scheduling Optimization of Heterogeneous Nodes under 5G Smart Agriculture

How to optimize the scheduling of sensing nodes in different rates, resources, and networks is a problem to be studied in the intelligent agricultural IoT under 5G.

5.3.1. Sense Scheduling for 5G Smart Agriculture

Under such circumstances, how to optimize the deployment of network resources and nodes to achieve better overall network performance is a problem worth studying.

(a). Sensing task collaboration based on 5G: Sensing task collaboration is a hot issue in sensor networks. Based on the connectivity, coverage, survivability, and task completion requirements of the network, this paper proposes a collaboration mechanism based on the limited energy, computing, and storage capacity of the sensing nodes and the task completion requirements. The network topology is reconstructed by adjusting the transmit power of nodes, neighbor selection, sleep scheduling, or mobile node location. The decomposition, assignment, scheduling, and execution of tasks are accomplished cooperatively by coordinating the behavior of mobile sensor nodes. Topology reconstruction optimization is mainly carried out in edge nodes and load balancing. In smart agriculture, the perception equipment is more diverse, and the perception task is more complex.

(b). Cooperative scheduling of large agricultural machinery equipment: agriculture-oriented large agricultural machinery includes unmanned aerial vehicles (UAVs), mutual sensing, and task coordination of multi-aerial robots. For example, building the social Internet of Things creates a dynamic social network for each object connected to the Internet of Things. Social networks are extended through node profiles and trust levels to find objects that contribute to IoT applications and solve resource management problems. Assign sensitive tasks fairly to objects in the social network. How to optimize the sensing task of massive heterogeneous sensing devices in the Internet of Things for smart agriculture. It is still a challenge to realize the efficient collection of sensing data and the maximum efficiency of network resources by abstracting network resources.

5.3.2. Optimization of 5G Network Signal Coverage Scheduling for Agricultural UAV

In addition to the upstream and downstream rate, end-to-end delay of services, end-to-end delay of control, and positioning accuracy, the coverage height of wireless signals is one of the most important requirements for 5G networks in agriculture.

According to the requirements of UAV network indicators in each scenario in IMT-2020 (5G), Advance Group—White Paper on 5G UAV Application, the coverage height requirements of wireless signals of networked UAV in the application field are shown in Table 9.

On the basis of the existing network, it is technically feasible to deploy a small number of base stations for the 5G communication requirements of agricultural UAVs. However, the actual network planning still needs to focus on several issues.

(a) Adjacent area planning.

In order to make connected UAVs fly continuously in the air, in addition to seamless 5G wireless network signals, civil UAVs also need to be able to switch smoothly between different cells and different base stations. In this way, it is necessary to cover the high level of the community to have a reasonable neighborhood relationship. In addition, the UAV communication terminal needs to switch from the low-level 5G wireless network to the high-level 5G wireless network when taking off. This also requires reasonable neighborhood planning between the 5G cell covering the high-rise and its neighboring 5G cell. Similarly, the UAV communication terminal needs to switch from the high-level 5G wireless network to the low-level 5G wireless network when landing. It is also necessary to make reasonable neighborhood planning between the 5G cell covering the low layer and its adjacent high-rise 5G cell. Its switching band is controlled at about 100 m in the air.

(b) Interference problem.

5G wireless networks are also self-interfering systems. All base stations share a bandwidth of 100 MHz. Therefore, it is necessary to control the coverage of the signal through reasonable planning and optimization. In this way, it is necessary to avoid discontinuous coverage or blind coverage caused by insufficient signal, and to avoid interference in other communities due to over coverage. At the same time, the mutual interference between the 5G cell covering the lower layer and the 5G cell covering the upper layer should be avoided. Of course, this will require a long period of experimentation and exploration.

Table 9. Requirements for coverage height of wireless signals of networked UAVs in application fields.

No.	Application Area	Business Attribute	Cover Height/m	Coverage
1	Agricultural and forestry plant protection	Spraying pesticide	10	countryside
2	Agricultural and forestry surveying and mapping	Agricultural land survey	200	countryside
3	Agricultural inspection	1080p Video return	100	Patrol inspection covers field agriculture
4	Agricultural formation flight	UAV formation flight	200	countryside
5	Future cloud AI	UAV cloud-based autonomous flight	300	countryside
6	Agricultural and forestry monitoring	Crop growth monitoring	100	countryside

5.4. *Fault Detection and Self-Healing for 5G Intelligent Agricultural Platform*

Smart agriculture 5G-IoT faces increasing network scale and density, dense terminal connections, and higher intelligence, and the failure rate will increase. The production efficiency of large-scale smart agriculture is an important issue. With the integration of 5G, many intelligent applications will be gradually popularized. These apps are built around the 5G Internet of Things. How to quickly identify the faulty node or device and the self-healing ability of the platform are important research issues.

5.4.1. Node Fault Identification and Early Warning Based on Heterogeneous Sensing Data Fusion

Combining the collected sensing data for computational analysis and network topology to identify node faults is a problem worth studying. Due to the mixed deployment of 5G and various sensing devices, mixed data sources, multi-hop communication, and transmission route changes, how to realize the fault identification of sensing nodes and possible fault detection is an important research issue.

5.4.2. Research on Fault Tolerance Based on 5G Heterogeneous Fusion Sensing Network

Traditional perceptual networks generally assume unreliable perception. The actual agricultural production will appear to be all kinds of failures. Because of the intensive deployment, the cost of ensuring all reliable operations is high. Therefore, it is worth studying that fault tolerance can guarantee the normal operation of the whole agricultural production in a certain period of time under limited fault.

5.4.3. Self-Healing Mechanism Based on 5G Heterogeneous Fusion Sensing Network

In smart agriculture, production is blocked due to the failure of the sensing equipment network, which affects efficiency. Therefore, it is necessary to study how to self-heal after faults occur, such as network topology self-healing, to guarantee node pathways. For example, perceptual repair under dense nodes. An additional example is 5G gateway coverage self-healing.

5.5. AI Application Optimization for 5G Intelligent Agricultural Internet of Things

The application of 5G brings new opportunities for smart agriculture, which is expected to solve the problem of data transmission and storage. With the development of artificial intelligence, it is an important issue to study lightweight deep artificial intelligence algorithms or platforms combined with various scenarios of smart agriculture.

Artificial intelligence algorithms represented by deep learning have laid the foundation for many scenarios of smart agriculture applications. With the popularization of 5G, the range of application scenarios of smart agriculture will be greatly expanded. However, the current existence represented by deep learning will face the important challenge of how to achieve reliable and effective operation under the condition of small cost in the scenario of smart agriculture, relying on massive data and powerful computing power.

5.5.1. Lightweight Deep Learning Algorithm Based on 5G-IoT Edge Computing

Edge computing equipment has some computing ability, but its computing ability is not enough for massive data model training. The challenge is how to design deep learning or machine learning algorithms suitable for agricultural production. Better results can be obtained by training on small sample data, reducing the amount of data transmission, reducing the cost of communication resources, and improving the real-time accuracy, which is a problem worth studying.

5.5.2. Multi-Source Data-Sensing Machine Learning Algorithm for Smart Agriculture

In the 5G scenario, sensing nodes are densely deployed, and heterogeneous sensing data need to be calculated and analyzed to serve the upper layer. However, there are often low data quality, multi-source, heterogeneous, and multi-modal sensing data, and changes in network topology. How to calculate these mixed and redundant low-quality data by clustering, statistics, Bayesian, and other machine learning methods is an important research problem.

5.6. 5G-IoT System Service Model for Smart Agriculture

An important means to promote the implementation of smart agriculture is the information physical fusion system based on 5G. The typical application mode of smart agriculture is to comprehensively perceive agricultural information through the agricultural Internet of Things. Massive sensing devices for agricultural IoT are deployed in the whole process of agricultural production and processing. Various information (environmental temperature and humidity, soil moisture, carbon dioxide, images, etc.) is collected through various networks, including 5G. Traditional agricultural models will be changed by means of cloud computing, big data, edge computing, and artificial intelligence. It can realize intelligent perception, intelligent warning, intelligent decision-making, intelligent analysis, and expert online guidance of agricultural production environment to provide precise planting, visual management, and intelligent decision-making for agricultural production. This is to realize the intelligent management of agricultural visual remote diagnosis, remote control, disaster warning, and so on, and gradually establish the visual communication and application mode of agricultural information services. Relying on the knowledge of agricultural experts stored in the knowledge base, reasoning, analysis, and other mechanisms were used to guide the production and circulation of agriculture and animal husbandry. It promotes the transformation of traditional agriculture, which is human-centered and relies on isolated machinery production mode, to modern smart agriculture, which is based on information and software production mode. How to construct an appropriate application service paradigm and model for intelligent agriculture 5G-IoT is an important issue to be studied.

5.7. Security Issues of 5G Internet of Things for Smart Agriculture

The future of intelligent agriculture is highly intelligent, informationized, and unmanned, and security issues should be a concern. Due to the application of 5G technology, there are many data flows and information flows which are prone to data deception, etc., which will lead to serious consequences, such as the death of crops or the poor quality of animal husbandry objects caused by incorrect pesticide spraying.

At present, there are many research results on the security of the Internet of Things. In general, attacks in IoT applications are classified using the following two criteria: (1) internal or external attacks and (2) passive or active attacks. Therefore, the threat model can be classified into attacks targeting privacy, authentication, confidentiality, availability, and integrity attributes based on the characteristics of attacks that attempt to compromise IoT agricultural nodes, namely IoT devices, fog nodes, and cloud nodes. 5G itself is relatively secure. However, due to the specific application scenarios, the security problems of smart agriculture have their specific characteristics, which require joint analysis and research.

5.7.1. Information Traceability of the Whole Process of Intelligent Agricultural Production Based on 5G Blockchain

Food safety has always been a matter of great concern to the public. The traditional tracing system has some shortcomings, such as information opacity, data easy to be tampered with, poor security, and relative closure. In the future, the development of 5G, combined with blockchain technology and its unique advantages, will provide a new solution for the reliable traceability of the agricultural supply chain. In combination with the communication capability of 5G, blockchain technology can be combined with the sensing equipment of the agricultural Internet of Things for semantic segmentation and tracking to achieve high security.

5.7.2. Intrusion Detection for Intelligent Agricultural Production Based on 5G

With the popularization of 5G Internet of Things in smart agriculture, the degree of intelligent and networked agricultural production is getting higher and higher, and more and more security issues need to be paid attention to. Unique security issues and vulnerabilities may arise, including network, control, communications, services, etc. How to combine the agricultural production process and the structural characteristics of 5G IoT to establish a security mechanism, rapid detection, and early warning of the intrusion of key steps in the production process is an important challenge in the future.

6. Summary

In the future, smart agriculture, after 5G technology transformation and upgrading, will show the following characteristics: unmanned operation, precise production, refined cultivation, standardized production, and intelligent supervision. Due to its low latency, massive data transmission, and massive connectivity, 5G is contributing to the development of IoT in agriculture. The combination of 5G with other technologies has spawned a number of agricultural applications to reduce the environmental impact of pesticides, protect natural resources, improve animal welfare and help farmers increase yields and save costs. This paper summarizes the impact of 5G on the Internet of Things, smart agriculture, and related technologies. The key technologies and scientific issues affecting the development of 5G-IoT were analyzed to provide some ideas for the development of 5G in smart agriculture. The scope of smart agriculture is relatively large, and many details have not been discussed in-depth. Further efforts will be made in the future.

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