Recent Trends, Emerging Opportunities, and Challenges of 5G-IoT in Smart Agriculture

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Abstract

The tremendous growth of the population globally is leading to a requirement for a revolution in food production to meet the demands. Hence, the agriculture sector is facing challenges like an increase in production via sustainable methods quantitatively as well as qualitatively. IoT has proved to be a promising technology in providing reliable and efficient solutions in this field. These methods have enabled the monitoring of agricultural farms distantly. However, the latency of wireless networks has turned out to be a significant challenge in such farming technologies. 5G has emerged as a cutting-edge technology that has revolutionized the sector of farming by making farming more productive, sustainable, and effective. This research paper delves into the progress domain of integrated 5G-IoT technology in Smart Agriculture. This paper provides an extensive survey of this emerging technology. The applications and open challenges have been discussed in depth. This study will be useful to researchers keen to add to the realm of Smart Agriculture.

Keywords Smart Agriculture. 5G. IoT, Intelligent farming. Applications. Challenges. 5G Technology

1. Introduction

Due to rapid growth in the world's population, a drop in natural assets, unpredictable environmental situations, and the demand for high-quality food products, the agricultural field is facing serious challenges. It is expected that by the year 2050, the gap between the supply of food items and their consumption will be huge, posing a serious challenge to the environment and natural resources. Fig 1 demonstrates the trend of population increase by the year 2050 with the decreasing land availability as the density in terms of persons per Km^2 is increasing [3]. These issues have motivated the transition from traditional agricultural methods to smart agriculture. Zhao Chunjiang [1] has claimed that the currently existing agricultural revolutions have entered the first phase of "Smart Agriculture". Smart Agriculture methods may incorporate various key technologies such as IoT (Internet of Things), Big Data, AI (Artificial Intelligence), Blockchain, Robots, etc. to meet the targets. These technologies can be used individually or in combination with each other as per the objective to be attained.

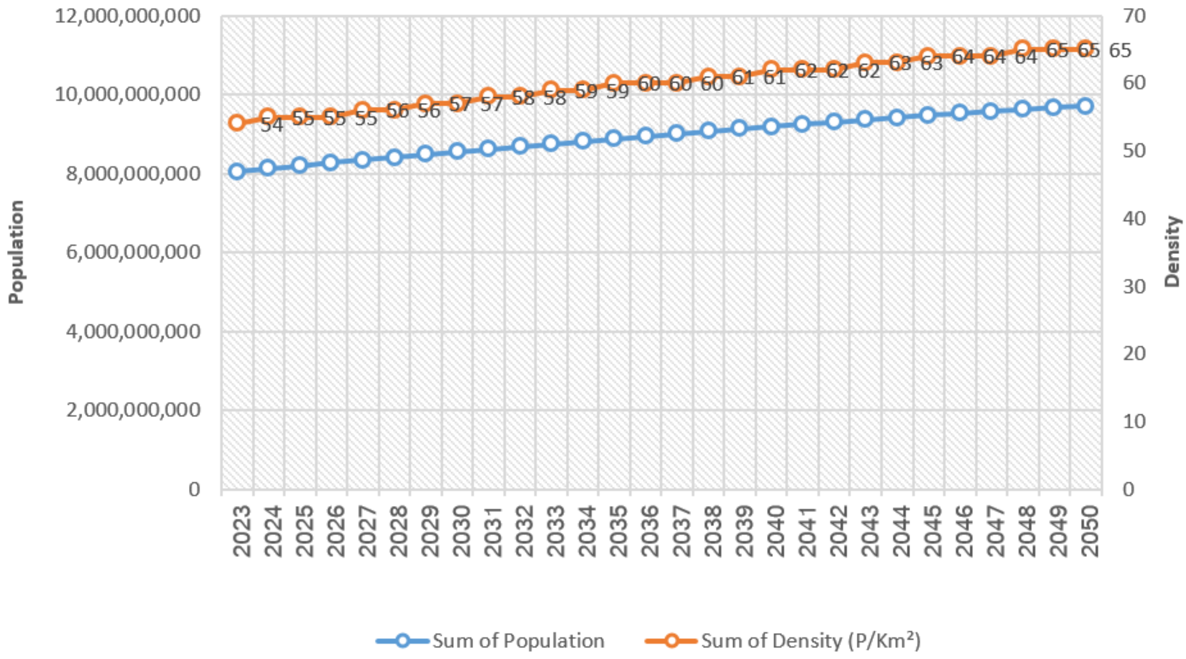

Fig.1: Predicted population trend till the year 2050.

The 5G mobile networks are superseding 4G around the world. The advancements in wireless communication and networking methods have converged 5G such that it can offer very high data rates, higher capacity, lower latency, and improvised security among other advantages. The telecommunication industry is targeting a fully interconnected mobile society by merging 5G technology with agricultural IoT.

The significant contributions of this paper are to present i) Concepts of Smart Agriculture in the modern scenario ii) the Convergence of IoT with the latest cellular technologies iii) To provide a comprehensive study of wireless technologies incorporated with IoT in Smart agriculture.

A comparison of this paper with recent cellular/ wireless technologies used for smart agriculture covered in the latest research literature has been provided in Table 1.

Table 1: Comparison of recent data communication technologies covered in literature and its comparison with this survey paper.

Author [Ref. No]	Year	IoT in Smart Agriculture	GPS	GPRS	LoRA	FOG/Edge	SigFox	ZigBee	RFID	Wi-Fi	3G/4G	5G
Jani, K. A. et. al. [8]	2021	✓	✓									
Placidi, P. et. al. [13]	2020	✓			✓					✓		
Payero J. O. et. al.[15]	2017	✓		✓				✓		✓		
Harun A. N. et. al. [17]	2019	✓								✓		
N.N Misra et. al. [78]	2020	✓										✓
Yascaribay G. et. al. [73]	2022	✓			✓							
Elijah O. et. al. [72]	2018	✓			✓				✓	✓		
Wang N. et. al. [70]	2019	✓										
Akhtar R. et. al. [68]	2022	✓	✓	✓								
Jawed. H.M. et. al. [61]	2017	✓	✓	✓	✓			✓		✓	✓	
Ojha.T. et. al. [60]	2015	✓	✓	✓						✓		
Jawad H. M .et.al. [27]	2017	✓			✓	✓	✓	✓		✓	✓	
Xu Wang .et.al.[28]	2018	✓	✓								✓	
Hassebo.et.al.[31]	2018	✓				✓					✓	
Jie Lin.et.al.[40]	2017	✓									✓	
A. Gupta .et.al.[43]	2017	✓										✓
Popovski P .et.al.[44]	2018	✓										✓
Mohamed E. S. Belal .et.al.[47]	2021	✓										✓
Ching-Kuo Hsu .et.al.[48]	2019	✓										✓
Wilson Arrubla-Hoyos .et.al.[49]	2022	✓										✓
Cristina-Mihaela Bălăceanu .et.al.[53]	2023	✓			✓							✓
This Paper		✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

As depicted in Table 1 this survey paper provides a study of most of the deployable data communication methods.

The structure of this paper is as follows- Concepts of 5G technology and convergence of this modern cellular technology with IoT for Smart agriculture have been discussed in section 2.

Section 3 explains the applications of 5G-IoT and some open challenges in this field. The study has been concluded in section 4.

Smart agriculture and 5G-IoT-enabled smart agriculture have been explained below.

1.1 Smart Agriculture

Smart agriculture methods have transformed traditional methods of crop planting, animal farming, and fishery & aquatic products. The inclusion of modern tools and techniques in these fields has decreased farmers' workload and increased their living standards by increasing their income. Smart agriculture refers to modern agricultural ways to manage agriculture production by using the latest technologies which increases the quality as well as quantity of produce with the least human effort. It is the modern agriculture method that integrates the latest technologies such as IoT, internet, cloud computing, machine learning, wireless technologies, etc. to realize intelligent decisions and precise data collection [2].

The farmers are majorly adopting modern technologies primarily for sensors (soil monitoring, humidity, light, and temperature sensors), software, wireless connectivity, location-sharing tools, robots, and tools for data analysis. Fig. 2 depicts the key technologies required for smart agriculture.

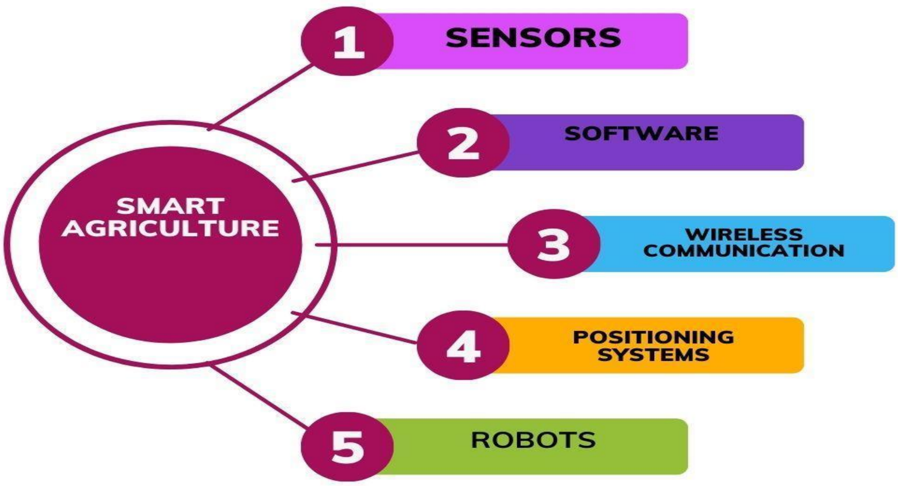

Fig.2: Key Technologies for Smart Agriculture

With the advent of Smart agriculture, agriculture has entered into stage 4.0 of agriculture.

Fig .3 depicts the evolution of agriculture from its 1.0 era to the 4.0 era. It is evident from this figure that the evolution stages in agriculture have completely transformed the ways of farming from stage 1.0 when farming was dependent solely on the physical strength of humans and animals to 4.0 where it is smart agriculture clubbing the latest technologies with management.

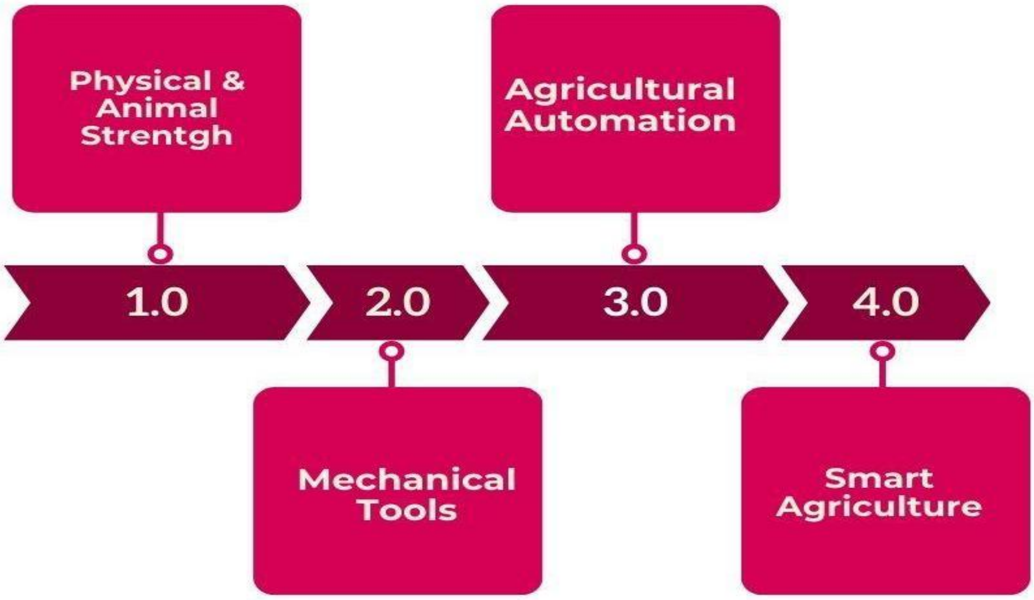

Fig.3: Evolution of the Agriculture Era.

The field “Smart Agriculture” is not only confined to farm agriculture but also includes Fishery aquatic farming and animal husbandry as shown in Fig. 4. The application areas of smart agriculture in these fields can be classified as

1. Intelligent Monitoring
2. Water & Soil Management
3. Pest Management
4. Plant Growth Management
5. Robots as Agricultural Machinery
6. Supply Chain Management

Intelligent monitoring can be attained with the help of UAVs/ Drones. These devices can be utilized for monitoring farms from the air as well as from the ground. Applying this mode of monitoring saves time, enhances crop quality, and eases the management of various resources involved. Such drones can be used for the analysis of fields and soil, spraying of pesticides, seed plantation, scouting of crops, and monitoring livestock [7-8]. To monitor moisture, humidity, luminosity, and temperature of the soil real-time monitoring needs to be done so that any variation in the required condition for the growth of the crop can be caught. For this, such wireless sensors that can capture the changes in real-time are needed.

The objective of smart agriculture is to cultivate Smart, unmanned, superior-quality products in a green and efficient manner [4-5, 80]. The modern technologies adapted to the realization of such agriculture are- Wireless Communication (such as 5G), IoT, AI, Blockchain, UAV, Robots, etc. Various existing wireless technologies such as Wifi, LoRaWAN, ZigBee, SigFox, LTE, and 5G have been compared in Table 2. It has been observed from this table that 5G technology is capable of providing real-time data collected from the farms due to its low latency.

Table 2: Comparison of various Wireless Technologies.

Technology	**Protocol**	**Frequency Range**	**Bandwidth**	**Speed**	**Range**	**Implementation Cost**	**Energy Utility**	**Reliability**	**Latency**	**Mobility**
LoRaWAN	LoRaWAN R1.0	915 to 928 MHz	100 Hz	50kbps	up to 5 km	Low	Very Low	No	High	No
Wi-fi	IEEE 802.11	5GHz to 60 GHz	20 or 40 MHz	10Mbps	up to 100m	Low	High	Yes	High	No
ZigBee	IEEE 802.15.4	2.4GHz	2MHz	250kbps	less than 1 km	Low	Low	No	High	No
SigFox	SigFox	200kHz	100Hz	100-600bps	30-50 km	Low	Low	No	High	No
LTE-M	Cat-M1 and Cat-M2	1.7–2.1 GHz	5MHz	4Mbps	up to 12km	Medium	Medium	Very Low	Low	Yes
5G	5G NR	UDP/IP	20–60 GHz	1Gbps	1.6 to 5 kilometers	High	High	Yes	Very Low	Yes

Smart agriculture has become a hot tracking area of research. Many researchers have published their findings in this area. Fig 5 demonstrates the number of research publications in this field from the year 2007 to 2022 [6]. This figure depicts the steep rise in the number of publications in the past five years. Despite a large amount of research in this field, very little research has been done in intelligent agriculture adopting 5G and IoT. Many developed countries like America, China, Europe, Israel, and Japan have already established their agricultural infrastructure using the latest mobile communication protocol i.e. 5G and they have progressed towards opting for smart agriculture using 5G and IoT at a very fast pace.

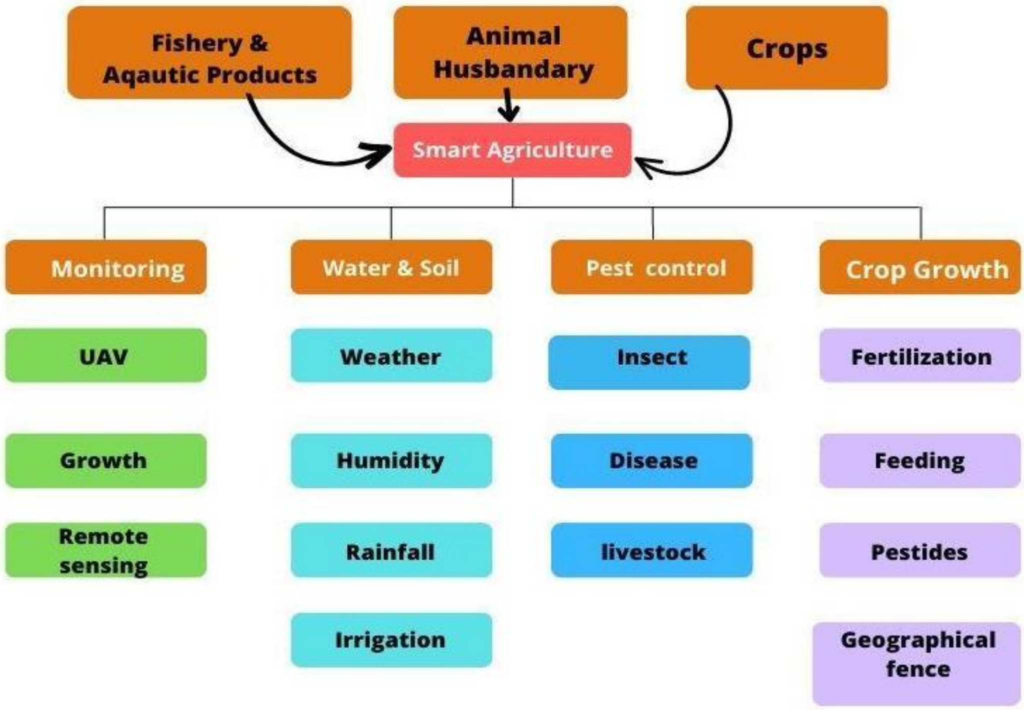

Fig.4: Classification of application areas.

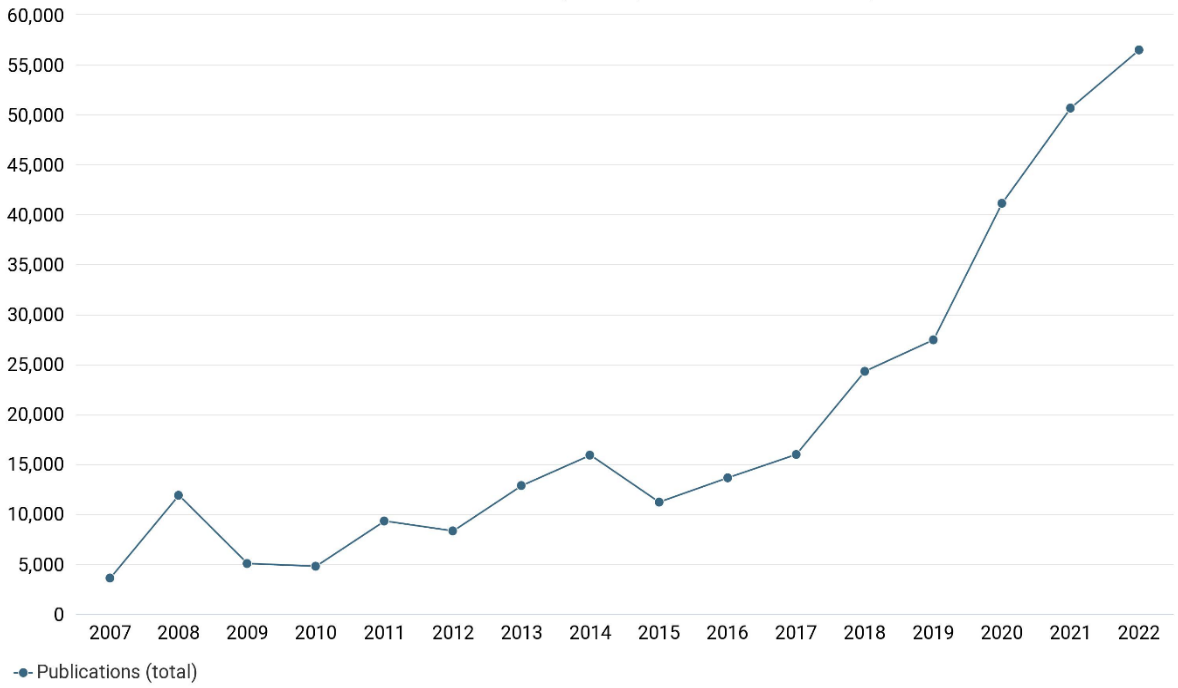

Fig.5: World Population Trend.

For agricultural IoT devices to function efficiently a fast and wireless internet is a foremost requirement. The previous generations of mobiles were not able to provide such high speed with less latency. 5G is the latest mobile communication tool with high data rates, higher capacity, lower latency, and improved security. There is not much research has been done in using this technology merging this with IoT for intelligent agriculture. This raises a requirement for in-depth research to be done in this hot tracking technology. This paper provides a systematic survey of the state-of-the-art work done in this field.

2. 5G-IoT in Smart Agriculture

Agricultural technology has been continuously developing for more than 10,000 years from the evolution of handmade tools during the Stone Age to the mechanical equipment development during the Green Revolution to today's era of smart farming. With the developments in 4G and 5G technologies, a new era of smart agriculture is emerging. The implementation and automation of new developments will offer numerous advantages not only for growers but will also result in transparency in the supply chain. With these developments and various environmental sensors, the impact of the environment on crops can be lowered. This is the beginning of a long-awaited period of very well-automated and established farming. The phenomenon of smart farming is being propelled by the commercialization and popularization of smart 5G technology in combination with the agile developments in IoT in convergence with various machine learning[10] and AI, UAV, robotics, cloud computing services, edge computing, blockchain and big data handling and statistical processes as shown in fig 6.

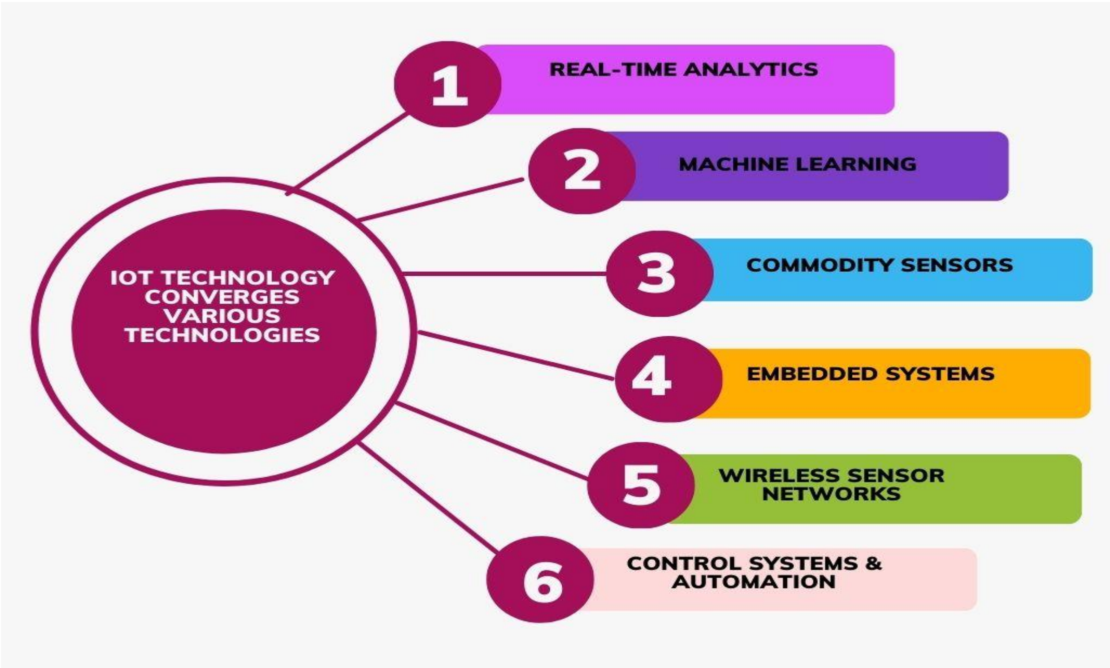

Fig. 6: Convergence of IoT with various technologies.

All the operations and decisions for smart farming based on IoT can be taken by collecting real-time data using various environmental sensors that are spread all over the field. This vast network of sensors allows the farmers to obtain a detailed view of various parameters of weather, soil composition, moisture in soil, fertilizers and pesticides, disease detection, harvesting, and yield prediction and monitoring [11] at the remote end using smartphones and the internet. Also, agricultural drones help in collecting information related to topographic maps of the agricultural land and different types of resources available in the region. This collected data is compared with the historical data available for cropping, use of fertilizers and processed using smart machine learning techniques, which enable farmers to perform a comprehensive analysis of soil, such as the temperature, acidity, nutrient status, and other properties and improve almost all farm operations like water/ soil management, pest management, planting, and growth management, etc. [12-16]. Very well and planned coordination is required in precision/smart agriculture. The automation process desires well-developed apps for a proper analysis of the data collected from soil scans using drones or land cameras, which helps AI [17] enabled decision support systems to come up with a final decision to manually or automatically select the number of sprayers and fertilizers to be spread using drones or robots without manual intervention. Further, with the advancement in technology traditional irrigation methods are preferably replaced by IoT-based irrigation to fight against the scarcity of water. Also, the wastage of water can be avoided by deploying IoT-based water control systems that allow a precise flow of water to fields [18-20]

In the year 2001, CWSI (Crop Water Stress Index) was developed [21] to measure stress and to avoid the effects of environmental factors causing variations in the temperature of the plant and its stress. The authors have deployed IoT devices to quantify the mixing of soil with fertilizers to enhance plant quality. Data such as the nutrition level of the plant and weather conditions have been collected through sensors and analyzed further to calculate the exact amount of chemical composition of fertilizers. According to FAO (Food & Agriculture Organization) reports pests and crop diseases cause a loss of around 40% of crop yield annually. This can be avoided by deploying precise farming wherein IoT Technology along with drones, sensors, and robots can be employed to identify the diseases in the plant and quantify an exact number of pesticides to be used. There is much-dedicated software such as - Pynco to monitor weather conditions, Smart Element, farm OS, etc. for monitoring, collecting, and analyzing the farm data.

Advantages of 5G over existing technologies

Automation of farming techniques, optimum utilization of available resources and minimizing risk, weather forecasting, required manure/fertilizers spay by soil monitoring, pest control, weed control, livestock management with video data, sensor-based smart agriculture, soil health monitoring, remote crop yield optimization, smart warehousing, distribution, greenhouse monitoring with real-time data, predictive analytics for crop sustainability can be achieved with IoT.

The collected data from IoT-based smart devices is communicated for precise assessment and accurate estimation using various wireless network technologies like RFID, SigFox, ZigBee [22-24], NB-IoT [25-26], Wifi [27], 3G/4G [28] and 5G [29-31] Characteristics of various communication technologies that are frequency band used for communication, data rate, network size, time of data transmission termed as time delay, distance of communications and installation cost is shown in fig 7. All these technologies have their advantages and limitations.

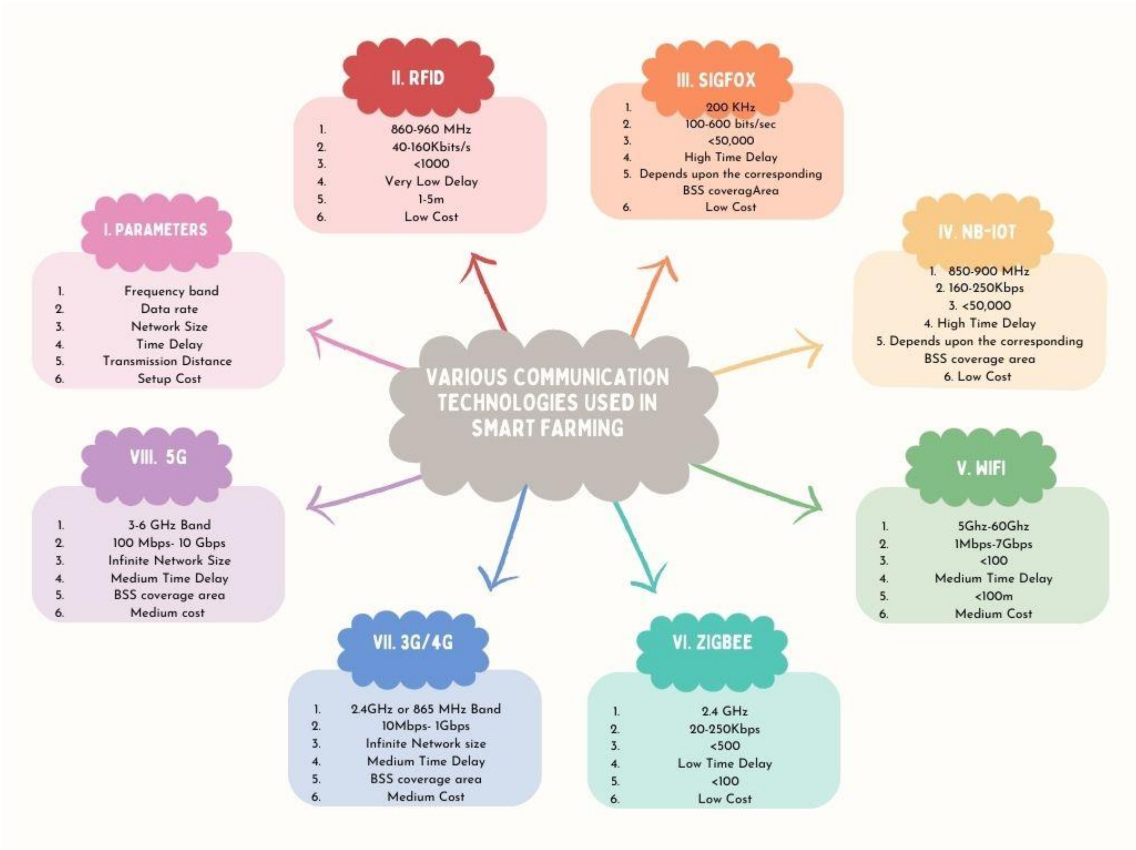

Fig.7: Various Communication Technologies Used in Smart Farming.

Technologies like RFID, Zigbee, Sigfox, NB-IoT, and Wifi provide wireless connectivity at low cost but these can't be deployed for very large amounts of data as these provide lower bandwidths and also can be accessed over small areas. Although the connectivity, network size, and speed provided by 3G/4G are promising due to the existence of certain limitations of these technologies they could not be implemented in smart farming. One of the biggest constraints is the operating area. Remote areas especially farms do not have a complete excess network so the implementation of sensors, and collection of data would not be useful if that data could not be transferred at the remote end. Also, resource allocation, channel conditions, changing data rates, and handoff issues along with network connectivity in the case of 3G/4G networks pose the biggest challenge in smart farming.

Since in smart or automated farming, many battery-operated devices like drones, robots, and sensors are used, these can't be operated for long durations. The massive amount of data from several sensors, and devices for smart farming is continuously increasing and requires more speed intelligence, secure communication capabilities, scalability, and high processing power to accomplish heavy computational tasks. To achieve low costs, and high and fast performance for IoT devices, high connectivity combined with ultralow latency is essential. The current 4G network (LTE) that allows IP-Packet-based connectivity cannot support such features [32-33]. All these constraints of 3G/4G cellular networks will be overcome by transitioning to 5G.

Characteristics of 5G

In comparison to the 1G -voice era, 2G-text era, 3G- image era, and 4G- video era which were meant to connect people, the development, and deployment of 5G will be evolving to connect things. So, it demands large traffic and small data, IoT on one hand and mobile broadband on the other. The basic characteristics required for smart agriculture are ubiquitous, low power consumption, network visualization, and network intelligence. The key technologies of 5G are Wireless access technology, Network configuration technology, and Distributed Business services, and three main application scenarios include- eMBB Enhanced Mobile Broadband, URLLC Ultra Reliable Low Delay Communication, and mMTC Massive Machine Class Communication.

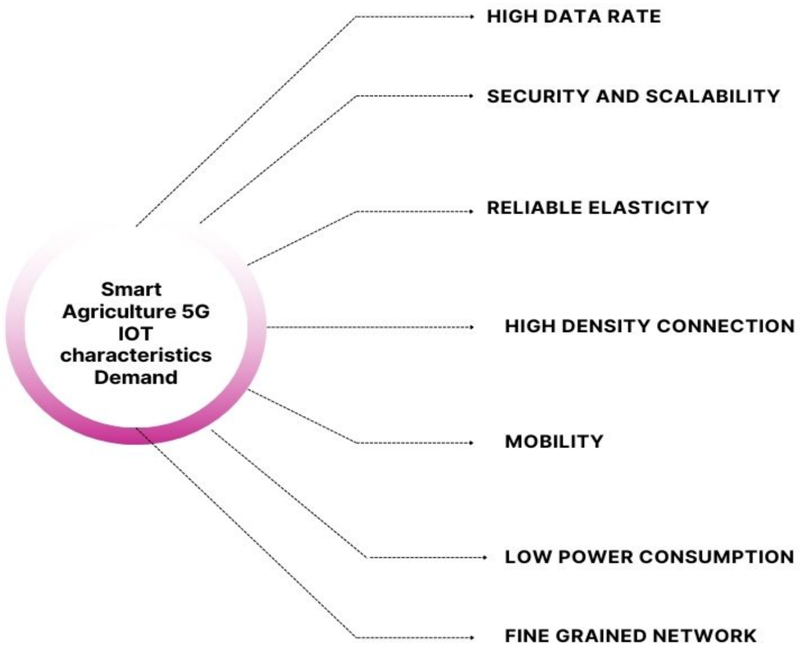

Fig.8: Demand of characteristics of 5 G-based Smart Agriculture.

3GPP established the 5G standard in December 2017 to define the specification of the 5G network and 3GPP Release 16 the second phase of 5G is expected to be released soon. The use of a high-band spectrum or milli-meter wave in a 5G mobile network is responsible for very high speed and low latency [34-39]. The capacity to connect billions of devices, high data capacity, and speeds faster than 10 Gbps are resultant of the higher bandwidth provided by 5G. Its uploading and downloading speeds are 100 times faster than 4G with an uplink data rate of 10 Gbps and a downlink rate of 20 Gbps per mobile station. However, for user calls, the actual upload speed is 50 Mbps, and the download speed is 100 Mbps. More than 1 million devices can be connected within a square km that too when they are moving at very high speeds and each device can be differentiated by using the cognitive radio technique which has the characteristic of allocating dynamic channels for each device. The major advantage of 5G over 4G which lags connection issues, is the delivering latency which is very low approximately 1 ms, [40-43]. Carrier waves that are used in 5G are microwaves (MWs) which cannot cover larger distances. Therefore, mobile towers need to be placed approximately 250 m distance apart to provide undisturbed connectivity. The antenna height for these towers is small and can be put on trees, street lights, roofs, vehicle tops, etc. Therefore, it is possible to distribute the 5G network to remote locations also.

The latest 5G IoT-based smart agriculture can be classified into three groups based on the application scenarios of 5G: enhanced mobile broadband (eMBB), massive machine type communications (MTC), and ultra-reliable low latency communications (URLLC) [44-46].

Smart Agriculture Scenario under 5G is summarized in Table 3.

Table 3: Smart Agriculture Scenario under 5G.

Enhanced Mobile Broadband(eMBB)	**Massive Machine-type Communications (mMTC)**	**Ultra-reliable low latency communications (URLLC)**
Video Monitoring of plant protection against livestock, weeds, etc.	Perceptual Monitoring of Field Agriculture	Intelligent Agriculture Machinery Operation
Mapping with UAV/Spectral imaging	Data Perception in Facility Agriculture	Agricultural UAV operation
Use of Complex Image and video processing techniques based on Deep Learning/ AI	Massive Perceptual Monitoring in Fishery and Aquaculture Scenes	Automatic driving of Agricultural Machinery
Massive Sensor Data Transmission	High Intelligence and Precision Agriculture	Key Point Monitoring and Early Warning

The primary goal of eMBB is the performance metrics of human-centric interactions like video monitoring of plant protection against livestock, and weed, mapping with UAV/spectral imaging, use of complex image and video processing techniques based on deep learning/ AI, and massive sensor data transmission. The primary goals of mMTC are high connection density, low complexity, and cost with minimal battery consumption. mMTC focuses on perceptual monitoring of field agriculture, data perception in facility agriculture, massive perceptual monitoring in fishery and aquaculture scenes, and high intelligence and precision agriculture. Deployment of dense sensing networks and their data visualization with computer vision and other technologies can efficiently extract soil conditions, plant phenotypic variation, and characteristics. It also helps in identifying plant diseases at the initial stages. The primary goal of URLLC in smart agriculture is to provide real-time transmission of critical data and control of major agricultural control equipment and robots like Intelligent Agriculture Machinery control, Agricultural UAV operation, Automatic driving of Agricultural Machinery, Key Point Monitoring, and Early Warning. 5G IoT-based smart agriculture will give a new shape to agriculture.

3. Contribution of 5G in the development of IoT-based Smart Agriculture model

Implementation of 5G in the area of smart agriculture has enabled farmers to link the IoT, equipping them with real-time data on farming and their livestock. This will help in lowering the number of inputs, simultaneously leading to a rise in production and improved quality of output.

5G also has incorporated the use of autonomous vehicles and drones for efficient farming. This advancement is helping in crop mapping, monitoring, and inspection. The operations could be completed with a lesser manpower force leading to reduced costs. This merger will meet the growing demands of farmers and consumers at the cost of few resources [47].

3.1 Application areas of 5G in Smart Farming and Agriculture

As the population worldwide is on the hike, there's immense pressure on farmers to meet the requirements. Meanwhile, consumers also demand high-quality agricultural food. To meet both these requirements the farmers are looking forward to smart farming which will help them to increase their yields without compromising on food safety and quality.

Smart Farming Technologies

IoT smart farming when clubbed with 5G manages agricultural fields with the latest technologies, which leads to better quality, and increased quantity of agricultural food. This provides farmers with sensors to study the quality of soil, its water requirement, and weather parameters [48]. Monitoring equipment allows real-time data access and both ends, robotics machinery for processing and data analysis using large data recovered from real-time analysis. Also, farmers have a weather forecast that allows them water usage and waste management [49].

Livestock raising and selective breeding

5G plays a pivotal role in increasing the efficiency of animal husbandry, making breeding cost-effective, managing crises like epidemics and loss of lives of cattle stock, and maintaining the ecology [50-51]. The implementation of 5G tags on animals, 5G-applied drones, and the application of IoT.

3.2 5G-based farming machinery

5G offers high speed along with short delays, making it useful in various fields. Smart agriculture machinery is one of those fields. The major advantages of using 5G in intelligent machinery are as follows [52]:

i. High efficiency: Since a large number of devices are integrated into machinery and 5G allows high-density connections
ii. Low latency: As compared to previous existing technologies 5G is the fastest and offers minimum delays during data transfers this makes the communication between the machinery fast and efficient.
iii. High Capacity: Each mobile station offers high capacity for data transfer. Data uploads and downloads are in Gbps.
iv. High connectivity: Millions of devices are connected to a single access point in a small area.
v. Easy identification and allocation: 5G tags all transmission channels easily for identification and allocation

3.3 Role of image processing in Agriculture

The entire process of smart agriculture is divided into three sections, first monitoring, identifying, and detection. All three processes include a large amount of data in the form of images and videos. To sort these kinds of data image processing is very useful [53].

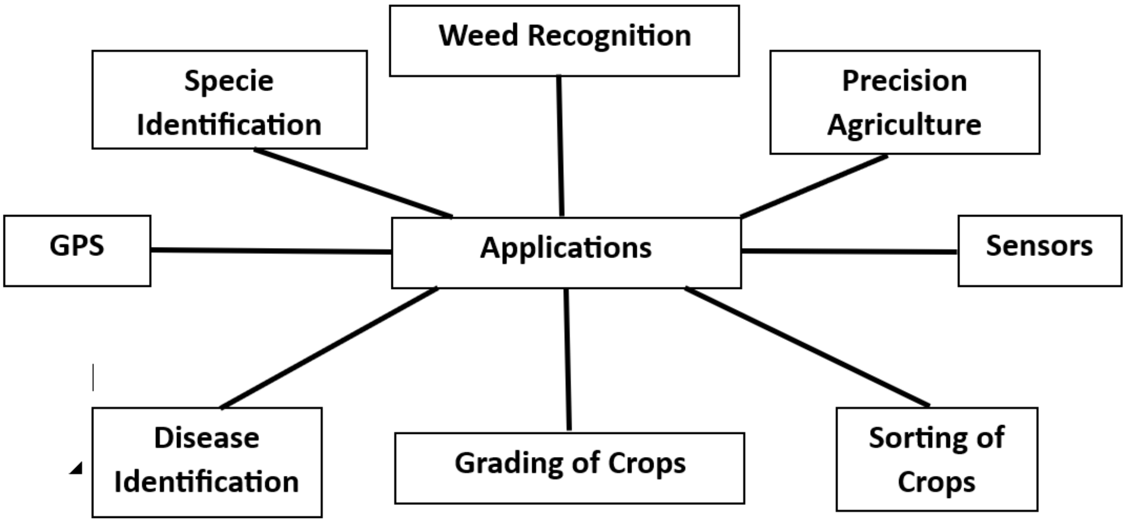

Fig.9: Applications of Digital Image Processing in Smart Farming.

Areas of application of digital image processing in smart agriculture are as follows:

Monitoring: The entire growth of the crop is monitored keeping a record of its development process. During the process, if any abnormality is observed, it can be eradicated at the earliest. Crop monitoring includes the measurement of the thickness of the leaves of the crop. Water level required to be maintained for healthy crops and length of rhizome. Monitoring reports the maturity of the crops and fruits, whether they lack any kind of nutrition or water content.

Diagnosis: Diagnosis of the crop includes whether the crop is affected by any disease or not, if it is done at the initial stage the entire crop can be saved. Also, to find if there is any attack of pests and insects on crops, they damage the crops to the root level. Early detection of such attacks is very important. Weeds are parasites that grow on crops and steal all the sunlight and nutrients from the crop. All three issues are easily resolved by image processing, whenever any such issue develops on crops their image matching is found with data stored and it is easy to control and treat at an early stage. Digital image processing helps in saving time and resources for farmers.

Inspection: During the growth time of a crop, it is important to figure out the nutritional value present in the crop. This can be done by comparing the size of the leaf and the thickness of the rhizome with data of healthy leaves and rhizome thickness stored in the data bank of image processing. If some discrepancy is found on lower grounds it is easily and on time rectified leading to healthy crops. Also, it is very helpful for fruit crops. This image segregation helps to identify which fruits are ready to be plucked or are decaying. This helps in increasing the efficiency of the production

Identification: In farming, not all production is of the same quality. Digital image processing helps in grading the production. This way high-quality crops can be distinguished from lower qualities.

3.3 Application of Machine Learning in Smart Agriculture

The latest and most efficient trend in the field of smart agriculture is the implementation of machine learning using the latest technologies. It is very useful in finding water content in the soil, soil quality, insects, pest and weed effects, and protection. Machine learning operates in five steps [54]:

i. Data collection from agricultural land
ii. Data Library
iii. Pre-processing of data
iv. Training of the model
v. Performance evaluation

3.4 5G-based UAV

Unmanned Aerial Vehicles (UAVs) play an important role in smart agriculture. 5G has increased the capacity and task of UAVs by providing UHD transmission of images and video data, and autonomous flight and they are capable of working in remote and rural areas. Previously, it was a challenging situation to synchronize many UAV drones at a time for a longer duration, 5G made it possible in agricultural fields where UAVs of small size and light weight are required for plant protection [55]. These UAVs help in lowering water usage and reducing the quantity of pesticides. They reduce human roles while seeding, growth, transportation, and transplantation. It dispatches seeds in the desired pattern in soil, it sprays fertilizer and pesticides when and where required.

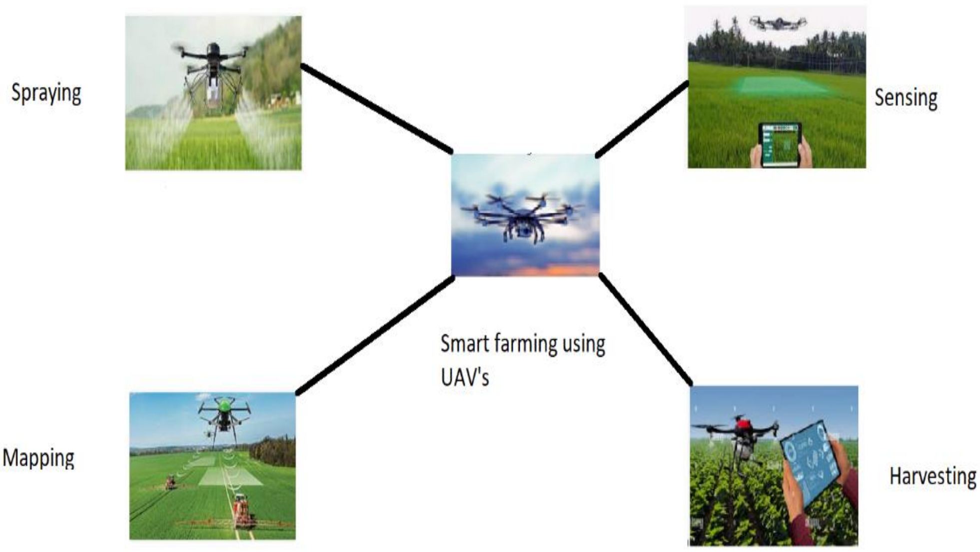

Fig. 10: Smart farming using UAVs.

Based on application area UAV's are two types-

Farm information collector UAV: These types of UAVs collect data from the fields. The data is in the form of videos and images. This requires high storage capacity. High transmission rates without data being lost and highly secured connection. All these requirements are fulfilled by 5G.

Agricultural UAV: This UAV has a specific role on farmland and they are as follows-

i. Protection of plants: This is done by spraying pesticides and fertilizer on the crops at the desired time.
ii. Pollination: Pollination is an important aspect of vegetable and fruit farming. 5G-based UAVs help find the correct time and resources to do the same
iii. Animal positioning: UAVs help locate the cattle stock in a large field. It also helps in finding whether any cattle is missing and later locating it in the fields.
iv. Farm monitoring: The UAVs monitor the entire agricultural land against attacks by insects, and natural calamities like heavy rainfall, strong winds, and hail storms. 5 G provides weather forecasting for the same.

5G overcomes all the challenges faced by UAVs in the real-time fields like endurance time, difficulty in control, and high precision control technology by managing high data rate, large bandwidth, and transfer data with minimum delay

3.5 Intelligent Demand- Supply chain distribution using 5G

The crop goes through various processes of plantation by farmer, production, transportation seller, and sales, and finally reaches the user. So, there's a direct connection between the user or consumer and the producer. This demand-supply chain between the two is made more efficient by the usage of 5G. Previously IoT was used but it had drawbacks as it's different for different platforms. 5G has bridged this gap by embedding blockchain at super high speed which previous technologies couldn't provide.

4. Challenges of IoT-based 5G Smart Agriculture

5G opens doors to immense opportunities in the field of agriculture, to make smart agriculture smarter than the prevailing techniques. Advanced techniques with brighter results end up in new challenges to be overcome. These challenges are partially solved by the inclusion of 5G. 5G is capable of handling over 100 times traffic along with high network efficiency. Simultaneously, it offers super-fast speed with minimum delay. All these characteristics are a boost to the development of smart agriculture.

There's an increase in the cost of the application of 5G technology as it requires a greater number of base stations as compared to 2-4G technology, resultantly there's an increase in the cost of operations and power consumed, which further results in high maintenance costs. All these parameters imbibe new challenges in the field of smart agriculture. The biggest challenge of 5G is the placement of base stations where there's a limited population, when smart agriculture is concerned the base station cost is high in such areas, and resultantly the cost is to be borne by existing customers which are farmers in this case. If cost-cutting is done by placing fewer numbers of base stations will result in fewer coverage areas.

A summary of the requirements of 5G along with the challenges associated are as follows:

1) Intelligent monitoring: Smart Agriculture requires intelligence. Monitoring the fields for good results. But this comes with the cost of managing large sizes of images and videos, further, these video and image data sets are needed to be transmitted and received. Also, there's a requirement to deploy multiple nodes for efficient transmission [56-57].
2) Hardware: Implementation of hardware setup based on IoT with 5G faces severe challenges. The hardware setup is to be placed in real-time scenarios bearing the hardships of direct climate changes like extreme temperatures, severe humidity, mild to

heavy rainfalls and hailstorms, and wind blowing at an intense speed. All these climatic parameters are enough to destroy any hardware setup which generally includes electronic circuits. Besides facing these challenges, the end devices require powerful battery resources. Since the implementation is in open fields instant replacement in case of battery failure becomes a challenge. [58].

3) Supervision of soil and water operations: This requires several sensing nodes which are needed to keep track of soil and water required for agriculture. Being placed in remote areas there's difficulty in maintaining good networking and managing large data from rural areas [59].
4) Networking: Besides hardware challenges smart agriculture faces challenges in the network layer even. Since wired communication is not possible due to high cost, wireless communication is preferred, moreover to go wireless is the requirement of the hour. However, the drawback associated with wireless networks is that they have a short range, so there's a need for multiple node deployments. For the transfer of data in open areas robust and reliable technology is demanded. This becomes a major challenge in smart agriculture [60-61].
5) The growth management of farms: Continuous supervision of plants in the field is very important which records the planting, breeding, and growth. To do this a large amount of high-precision data and real-time performance is required [62].
6) IoT-based agriculture architecture: IoT-based agricultural base is way more complex than any other IoT transmission between end devices. Most important of all it requires a real-time monitoring system, this kind of monitoring has its own inflexible needs. This kind of platform requires real-time libraries. At times there's a need to create a service-oriented approach for a needful platform. These real-time libraries and frameworks are required by agricultural developers [63].
7) Pest Control: The major challenge in the agriculture field is the control of pests. This can be monitored by AI mechanisms, where large data is needed. It also needs multiple nodes deployed over a small area with large remote sensing data [55].
8) Commercialization: The commercialization of smart agriculture is still not a boom worldwide because of the major challenges faced in its implementation at the ground level. Since this is a very expensive technology to be implemented it needs commercialization so that it becomes affordable making it a challenge to be accomplished [64].

9) Propagation Losses: There are propagation losses from sensors at the farm during transmission and reception. This is a challenge that needs to be addressed for productive farming [65]

10) **Security:** Smart agriculture deals with an enormous collection of data at various levels making it difficult to protect. The use of 5G has resolved this challenge to a level but still, it's a concern. Data stealing and manipulation by unauthorized users is still a possibility [66].

11) Interference: Since the implementation of smart farming demands multiple node deployments. These multiple nodes lead to interference with each other especially when ZigBee, WiFi, and LoRa are used. This kind of hindrance results in high data loss resulting in reduced reliability. To completely eradicate these challenges is still a task for researchers [67].

12) Physical Safety of Devices: Since the entire setup of smart farming is to be placed in open fields, there's a severe impact of environmental conditions on the expensive sensors and electronic circuits. This leads to damage or theft of the circuitry and further results in failed communication. So, it is a mandatory requirement to safeguard the setup on a large level against damage and theft. Again, this is a major challenge in remote and rural areas [68].

13) Adaptability: In smart agriculture billions of smart devices related to agriculture are implanted, these devices are to be connected so there's a need for devices to be adaptable with each other. To do this an ample number of protocols and associated gateways are needed to support the system. This results in a highly complex system at the back-ends to sustain. This becomes a major challenge to be overcome [69].

14) Maximize the resources available: In smart agriculture, there's a need to maximize the available resources for the farmer. This maximization helps in measuring multiple node deployments, protocol and gateways required, cloud storage capacity, and quantity of data that is to be transmitted. Since the implementation is to be done on variably large fields, monitoring different crops or cattle becomes a challenging task because it requires a variety of devices and sensors. To maximize the resources, intricate algorithms and models are required. This remains to be a big challenge for high productivity [70].

15) Cost Effective: Smart agriculture requires the establishment and maintenance of expensive devices, sensors, infrastructures, and protocols. This majorly affects the profit margins, which is an important parameter while implementing smart agriculture. This is

still a major challenge to reduce the cost of set up or increase the profit margins of agriculture production [71].

16) Insufficient knowledge of the latest technology: It’s well observed that agricultural lands are a part of rural areas. The farmers are mostly uneducated and have very little knowledge of the latest technologies, their implementation, and maintenance. This becomes a major challenge to implement smart agriculture [72].
17) Implementation of low power wide area technology: Since smart agriculture is implemented over a large area, multiple devices are required at transmission and reception ends. At each layer power consumption becomes a major challenge. There’s a dire need to implement low-power wide-area technology [73, 79].
18) Standard platform: Smart agriculture is to be applied in variable geographical areas, various sizes of fields, variety of crops, monitoring of livestock, and fulfilling their needs. So, it’s a challenge to develop a standard platform that could be modified as per the requirement and applied to various conditions, simultaneously this should be simple and convenient at the user’s level [73].
19) Accessible: Smart agriculture networks should be capable enough to handle farmers’ mobility. From any location and at any time the farmer should be able to access the network and remain connected [74]
20) Quality of service: Various studies highlight the need for quality of service at each layer of smart agriculture architecture [75-76]. Maintaining the quality of service in all the network layers in this field is still a deeply studied topic of research.
21) Machinery: Smart agriculture requires smart machinery for plowing, sowing, irrigation, pest control, and harvesting. For all these tasks AI is clubbed with traditional tasks of farming which requires a large amount of data. This should be in real-time for immediate responses [77].
22) AI-based Agricultural tasks: This requires large data and wide area node deployment [78].
23) Computational complexity: The rapid advancement in intelligent heterogeneous Internet of Things [81], VR video caching and delivery framework for edge-enhanced next-generation wireless networks [82-83], task scheduler nodes, and robotic nodes within the Internet of Things [84] increases the computational complexity in implementation of 5G in IoT.

5. Conclusion

Researchers are evolving new methods to find solutions to increase productivity in the agriculture sector. The implementation of 5G wireless technology along with IoT has revolutionized this sector worldwide. The integration of IoT devices like UAVs, drones, sensors, etc. with faster wireless technology has improved yields in the farms and profitability of farmers. This modern technology has made it possible to take virtual consultations, robotic assistance, and smart monitoring of fields with reduced human labor. This technology offers better solutions to major challenges like limited resources of water, utilization of finances, and high production under natural weather conditions. IoT along with 5G implementation has offered better production at low cost. Not only productivity IOT helps in field management, soil and crop monitoring, movement of an unwanted object, attacks of wild animals, and thefts, etc. IOT offers user-friendly, convenient and cost cost-effective, and organized scheduling through secure and unblemished connectivity for all kinds of monitoring related to farming and farming.

IoT in smart agriculture monitors the moisture content of the soil, dampness in crops, weather conditions like airflow under soil, temperature and humidity, productivity, animal health, fertility, feeding, ruminating, and resting. Based on the requirement a server, gateway, and database are created to meet the users demand. Several state-of-the-art literature in this context has been discussed in this paper. A summary of this survey has been presented in Table 4. The combination of IoT smart agriculture with 5G cellular communication has been presented in detail. The need for smart agriculture in the current world population scenario, open challenges [81], and application areas of this area have been discussed extensively. Finally, it is anticipated that this work will be useful for researchers, agriculturists, and everyone keen to contribute to 5G, IoT, and the agricultural sector.

Table 4: A summary of recent literature with challenges and future trends.

Author	Year	Proposed Objective	Technology Adopted	Advantages	Challenges and Future Trends
Jani, K. A. et. al. [8]	2021	To optimize resource utilization using IoT in smart agriculture	IoT, GPS, sensors	Farmer's intervention is minimized by automating irrigation, fustigation, and detection of pests.	Implementation of the proposed method on real farm fields with optimum resource utilization.
Placidi, P. et. al. [13]	2020	Use of Low-Cost Capacitive Soil Sensors for IoT Networks	IoT, capacitive soil moisture sensor	Low-cost distributed nodes for IoT applications	Error bars are relatively wide.

Payero J. O.et. al. [15]	2017	To develop a low-cost system for monitoring soil water potential using Watermark 200SS sensors using IoT.	IoT, LoRa radios, WiFi, Watermark 200SS soil moisture sensors	Successfully tested under field conditions by installing Watermark sensors at four depths in a wheat field	The power efficiency of the system can be increased by taking advantage of the sleep-mode capabilities of the microcontroller device
Harun A. N. et. al. [17]	2019	Improved Internet of Things (IoT) monitoring system for growth optimization of Brassica chinensis	IoT, LED light spectrum, GPRS, ZigBee, Wifi	The quality of plants is enhanced under different LED intensities.	Optimization of controlling LED parameters for better plant growth as well as producing higher yields can be done.
Jawad H. M et.al. [27]	2017	State-of-the-art approaches of IoT in agricultural applications and Comparison of different wireless technologies like Wifi, Zigbee, etc, and protocols for agricultural applications.	WiFi, Bluetooth, ZigBee, GPRS/3G/4G, LoRa, and SigFox	Comparison of various wireless communication protocols, their challenges and limitations in the agriculture domain, and identification of several power reduction and agricultural management techniques for long-term monitoring.	Help farmers with smart agricultural management techniques by observing different agricultural climates from remote ends with special low-power consumption WSNs.
Xu Wang et. al. [28]	2018	To set up an acquisition system for farmland by taking low-altitude remote sensing technology for observation and multi-rotor UAVs as carriers	GPS,4G	Developed a system for the collection of information related to crops that perform various operations like field operation management, monitoring of data, Baidu map, API map display, and exploring data	Evolution of unmanned aerial opportunities for monitoring in the agricultural sector with low cost and low power consumption.
Hassebo et. al. [31]	2018	Latency Analysis of 4G cellular network for various IOT applications	4G	Performance analysis and feasibility assessment of commercial LTE cellular networks for emerging IoT applications where latency can't be compromised or where mass connectivity of devices is required.	4G LTE systems suffer from latency issues, so used for IOT applications where latency requirements are > 150 ms.

Jie Lin et. al. [40]	2017	To explore the relationship between cyber-physical systems and IoT, to realize an intelligent cyber-physical world	IoT, Fog/Edge	Addressed architectures, enabling technologies, and security and privacy issues in IoT and its integration with fog/edge technologies.	IoT and fog/edge computing resulted in the improvement of QoS for smart agriculture, smart grid, smart transportation, and smart cities.
A. Gupta et. al. [43]	2017	To explore 5G cellular network architecture and key emerging technologies that help improve the architecture and meet users' demands.	5G, IOT	5G cellular network architecture is proposed that incorporates small cell access points, network cloud, D2D, and IoT.	spectrum sharing with cognitive radio, multi-radio access technology association, ultra-dense networks, full duplex radios, millimeter wave solutions, interference management for 5G cellular networks
Popovski P. et. al. [44]	2018	To design a communication-theoretic model that accounts for the heterogeneous requirements and characteristics of enhanced mobile broadband (eMBB), massive machine-type communications (MTC), and ultra-reliable low-latency communications (URLLCs) in 5G.	5G, IOT	Identified advantages of allowing for non-orthogonal sharing of RAN resources in uplink communications from a set of eMBB, mMTC, and URLLC devices to a common base station.	The use of H-NOMA techniques would help in the development of efficient smart agriculture with the implementation of power-efficient WSNs with reduced latency.
Mohamed E. S. Belal et. al. [47]	2021	Importance of using a 5G mobile network in developing smart systems, as it leads to high-speed data transfer, up to 20 Gbps, and can link a large number of devices per square kilometer.	5G, IoT	Implementation of smart farming, harvesting, seedling, weed detection, irrigation, spraying of agricultural pests, livestock applications, etc. using various techniques like r IoT, artificial intelligence (AI), deep learning (DL), machine learning (ML), and wireless communications.	Challenges faced by developing countries (work mainly focused on Africa) in implementing smart farming, implementation of Smart Decision Support Systems (SDSS) that support the real-time analysis, and mapping of soil characteristics and also help to make proper decision management.

Ching-Kuo Hsu et. al. [48]	2019	Development and implementation of image recognition techniques over fast 5G networks for intelligent monitoring of the growth of crops, reduction of agricultural damages, protection of crops from being stolen, and reducing the manpower of farms.	5G, IoT, Image Processing	With the availability of vast bandwidths in 5G networks, huge amounts of data collected at remote locations can easily be transferred and crop monitoring can be done from distant places, reducing manpower.	Growth in crop production as regular monitoring of the farms can be done from remote locations and advice from agriculture experts can be taken for weed or disease reduction in farms, by using the images captured.
Wilson Arrubla-Hoyos et. al.[49]	2022	To present an overview of the 5G technology landscape in Colombia and possible solutions for the implementation of 5G/IoT for smart farming, especially in remote locations in Colombian fields.	5G, IOT	The use of IoT and AI tools along with 5G will surely improve agriculture with the projection of SF applications at every stage of production, from soil preparation to planting, harvesting, and post-harvest processes.	High initial infrastructure cost for implantation of 5G especially in rural areas of Columbia is the biggest challenge.
Cristina-Mihaela Bălăceanu et. al. [53]	2023	To find a solution for precision agriculture by developing and implementing monitoring platforms to enhance product quality and productivity by implementing IOT, UAV, and 5G technologies.	5G, IOT,WSN, UAV, LoWPAN	A highly efficient model is designed with the use of specialized high-precision WSN sensors are transfer data to the Cloud platform through the use of 6LoWPAN end-to-end protocol.	Data collected through WSN and UAV is analyzed through Random Forest and Support Vector Machines to determine the risk of disease incidence that will improve the quality production.
Kamienski C. et. al. [59]	2019	Smart water management in precision.	SWAMP Project	Development and application of SWAMP architecture.	Adaptability, deployment, scalability, and complexity
Ojha.T. et. al. [60]	2015	Review of the state-of-the-art in WSN in agricultural applications.	The terrestrial WSNs and underground WSNs.	Imbibing WSNs in smart farming and related industries will help soar to new heights in the development.	Implementation of IoT in Indian Scenarios

Jawed. H.M. et. al. [61]	2017	Review of WSN-based agricultural applications	WSN	A rigorous comparison between state-of-art technology, such as WiFi, Bluetooth, ZigBee, GPRS/3G/4G, LoRa, and SigFox.	Power consumption and battery life, Communication range, Propagation losses, Routing, Localization and tracking, Reliability, Scalability, Cost, etc.
Grossi. M. et. al. [67]	2019	The impact of advancement in the field of sensors and sensing systems and its effect on smart agriculture.	Embedded System	Design of low-cost embedded sensor systems for low-cost, high-precision, and real-time suitability	Making sensors used in smart farming of low cost and high precision
Akhtar R. et. al. [68]	2022	Prediction model of Apple diseases	Machine learning using IoT data analytics	Computation of power and potential of computing techniques.	Implementation of technologies in the traditional farming approaches.
Wang N. et. al. [70]	2019	Impact of 5G wireless technologies on physical-layer Threats and PLS Solutions in 5G Networks	PLS solutions in 5G networks	Evaluation of security threats at the physical layer.	To overcome security threats of 5g IoT
Elijah O. et. al. [72]	2018	Literature survey to highlight the latest work going on in this field to enhance efficiency and productivity.	NB-IoT, LPWA, and 3GPP	Deployment of low power wide area communication technology for agriculture purposes.	Several issues to be addressed to make IoT affordable for small and medium-scale farmers. The major challenges are security and cost
Yascaribay G. et. al. [73]	2022	Analysis of the performance of communication systems in smart farming	LPWAN, LoRaWAN	Comparative analysis to show the impact on packet delivery ratio with state-of-the-art technology. The relationship is studied for the distance between nodes and the packet delivery ratio	Enhance the efficacy of the communication system.
Misra N. N. et. al. [78]	2020	Summary of IoT, big data, and artificial intelligence (AI).	IoT and AI	Role of data analysis in enhancing social, economic, and environmental parameters in the field of agriculture and food industry.	To make farmers more efficient, intelligent, and connected. Also to make the food chain authentic and of high quality.

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