AgriEdge: Edge Intelligent 5G Narrow Band Internet of Drone Things for Agriculture 4.0

Aakashjit Bhattacharya and Debashis De

Abstract The previous three industrializations had a major impact on the agricultural sector. There was a transformation from indigenous farming to mechanized farming. With the advent of Industry 4.0, the fourth generation of the Agriculture revolution has taken place with the introduction of precision farming, and the backbone of this revolution is mainly the Internet of Things. Edge Intelligence in combination with Agriculture Big-Data Analysis and modern evolving communication technologies like 5G Narrow Band (NB) IoT is going to play a significant role in the progress of Agriculture 4.0 through real-time applications as a simpler waveform like NB-IoT consumes less power, have high reliability, have wider deployment capability and have lower latency. Energy-efficient and Real-time application of technologies in the agricultural sector is the need of the hour for a smart green industrial revolution through Agriculture 4.0. The induction of Multilingual Voice User Interface control enabled drones in combination with dynamic sensors in 5G era, will prove to be a game-changer in the agricultural sector. Edge Intelligence enabled drones will introduce the concept of ubiquitous computing in the agricultural domain, will be quite beneficial for the farmers as it will provide real-time alerting, monitoring systems in addition to real-time precision farming.

Keywords 5G · NB-IoDT · Agriculture 4.0 · Precision Agriculture · Contactless Multilingual Voice User Interface · Edge Intelligent Drone

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Acronyms

3GPP	3Rd Generation Partnership Project
4G	4Th Generation mobile network
5G	5Th Generation mobile network
BSNL	Bharat Sanchar Nigam Limited
CoAP	Constrained Application Protocol
CS	Compressive sensing
DOS	Denial of Service
DTLS	Datagram Transport Layer Security
EU	European Union
GPS	Global Positioning System
GSM	Global System for Mobile Communications
IoT	Internet of Things
IoDT	Internet of Drone Things
LAN	Local Area Network
LDR	Light Dependent Resistor
LED	Light Emitting Diode
LTE	Long-Term Evolution
M2M	Machine-To-Machine
MQTT	Message Queue Telemetry Transport
NB	Narrow Band
NB-IoT	Narrow Band IoT
Node MCU	Node Micro Controller Unit
PAN	Personal Area Network
RAT	Radio Access Technology
TCP	Transmission Control Protocol
UAC	User Access Control
UAV	Unmanned Aerial Vehicle
UDP	User Datagram Protocol
URL	Uniform Resource Locator
WAN	Wide Area Network
WEP	Wired Equivalent Privacy
Wi-Fi	Wireless Fidelity
WPA	Wi-Fi Protected Access
WPA 2	2nd Generation WPA

1 Introduction

Agriculture is the source of livelihood for many countries and it plays a significant role in the economy of many countries. Other than growing crops, it is also associated with animal breeding, land cultivation. Agriculture is not only associated with food but is also associated with the fiber and medicine sector. Agriculture is a vibrant area for the nourishment of mankind. It is of significance to innovate techniques that help in the subsistence of agriculture. Blockchain based IoT can ameliorate the food chain.

Advancement in the field of agriculture in some countries took after an agriculture revolution took place in those countries. Like after the Green Revolution that took place in India in the earlier 1960s, led to an increase in higher-yielding varieties of seeds due to improved technologies in the agriculture sector. Similarly, after Golden Fiber Revolution that took place in India, jute was started to be used as a raw material in the fabric industry, and even today jute is used as a raw material in making strong threads and jute products. 5G is an evolving technology and is going to play a vital role in the field of Internet of Things (IoT) [1], Industrial IoT, Industry 4.0 [2], Precision farming [3], and Agriculture 4.0 as shown in Fig. 1 to provide real-time updates. Agriculture as a whole has been influenced by centuries of continuous cultivation of exotic plants in various regions across the world due to various historical events and human interventions [4].

Skylo's partnership with Bharat Sanchar Nigam Limited (or BSNL) to launch World's First Satellite-Based NB-IoT in India, is going to play a very vital role in the advancement of the implementation of the Digital India program in India. Through this partnership, program machines will be turned into always-connected smart objects. Through this NB-IoT project, millions of sensors and machines will be connected from space. This will help the business owners to make smart timely decisions as they will be able to understand, manage, and predict what is going to happen. To date, Skylo is integrating the system with trucks, tractors, trains, and buses. After the system is commercialized and available to the local public, this system can be integrated with Drones for smart agriculture, smart surveillance system, etc. In Skylo

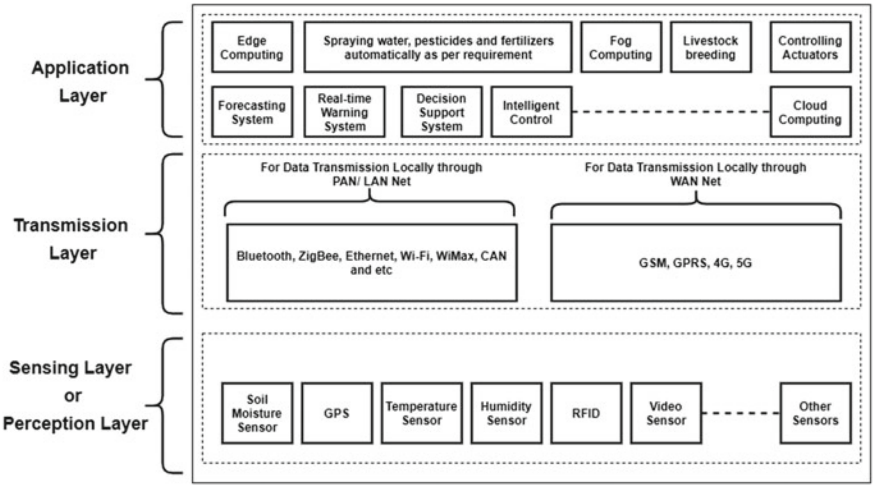

Fig. 1 Layers of internet of drone things in the application of smart agriculture

there are sensors fitted that transmit data to Skylo Satellite Network, and from there it sends data to the destined group of people. The Skylo platform provides cross-device support to visualize the collected data and based on the data received the end-user is given the ability to take a quick appropriate on-spot decision. From an economic point of view, Skylo provides the world's cheapest satellite-based solutions to connect sensors with machines [5].

The architecture of the Internet of Things can be divided into 3 layers mainly the Sensing layer, the Transport layer, and the Application layer. The Sensing Layer is responsible to collect real-time data from the surrounding through sensors, and with the help of the transport layer, the processed or raw data is forwarded to the Application layer. Compressive sensing (CS) based IoT has also a 3-layered architecture, but there is a slight difference in the second layer. Layer 1 is called the CS-Based Acquisition layer, Layer 2 is called the CS-Based Reconstruction Layer. In this layer, after the data is collected, the raw data gets filtered out and only the processed and important data are transmitted to reduce the bandwidth consumption. The next layer is Layer 3, and just like any other IoT architecture, this layer also deals with the application of the collected data through actuators and devices. Any project related to the Internet of Things domain means there is somewhere a hardware-software interaction within the system and with every passing day, the wireless sensor networks are getting famous for their simple form factor and lower cost of design. By the application of Agricultural Big Data, on Agriculture, there will be optimization in the agricultural economy, that will continuously promote to achieve sustainable optimization of industrial development. With the advent of advanced communication technologies like 5G, the combination of the internet of things, big data, artificial intelligence, mobile internet, and cloud computing is getting closer and closer. 5G will help in the rapid growth of smart agriculture. Various means of communications in form of PAN/LAN net or WAN net being used for transmission of data from the sensing layer to the application layer as shown in Fig. 1.

After the live data is transmitted to the Application layer, the collected data is then used for data analysis to predict the amount of water, fertilizer, pesticides required for different plants in various temperature and humidity conditions based on past observations. This type of data-intensive and computation-intensive task is generally performed in a Cloud Computing platform. Whereas the real-time application of the collected data for quicker response is done with the help of Edge Intelligence or Fog Computing. Edge means with a distributed computing paradigm to bring storage and computation close to the area of application. Although Edge computing devices have limited computational and storage capacity in comparison to cloud servers, it provides a quicker response to address an issue within a very short duration of time or instantly and saves network bandwidth. For instance, in the case of a forest fire detection system, these edge nodes will provide a quicker response and alert the authorities, so that the authorities can provide a quicker response and thus help in reducing the destruction caused through the forest fires in contrast to the alerting system which would be Cloud-based alerting system. Edge computing devices provide ubiquity thus helps to provide real-time computation on any device at any location.

With the evolution of 5G communication technology, drone-based smart precision agriculture based on the Internet of Drone Things (IoDT) [6] will get enhanced due to lower network latency and can provide Edge Intelligence enabled solution to Agriculture 4.0. With the help of Edge Intelligence and a ubiquitous network of drones, it will smartly, ubiquitously, and autonomously provide the right amount of water, fertilizer, and pesticides through image processing and other dynamic sensors as shown in Fig. 2 based on forecasting concept and agriculture big data analysis. Some of the parameters which will be taken into considerations are atmospheric humidity, temperature, crop condition soil type moisture level in the soil. It will also provide smart real-time farm monitoring especially during the night time to provide

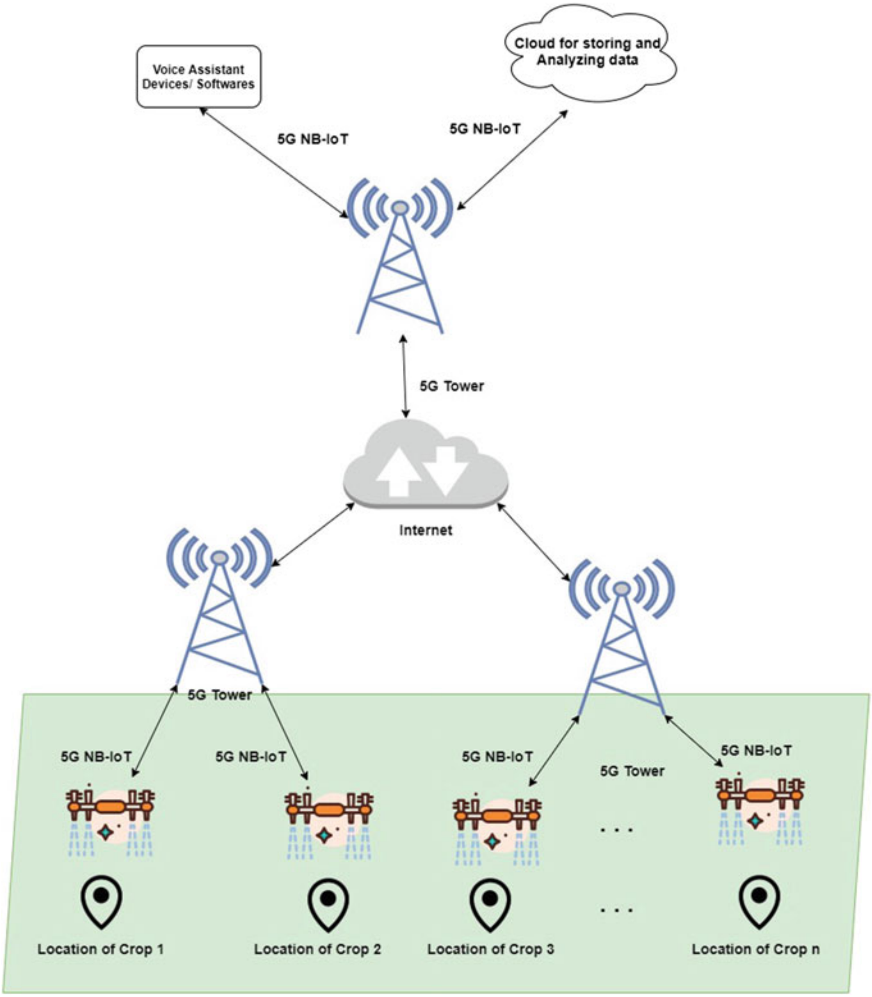

Fig. 2 Implementation of Agriculture 4.0 using 5G NB-IoDT

Table 1 5G NR Frequency bands and their Frequency Ranges [9]

Frequency Bands	Frequency Range in MHz
Band n77	3300–4200
Band n78	3300–3800
Band n79	4400–5000
LTE Band 46	5150–5925

Table 2 Countries and their Frequency Bands [9]

Countries	Frequency Range in MHz
US	3550–4200
China, EU, Japan	3600–4200 and 4400–4900

a secured farming experience to the farmers so that their crops do not get destroyed or affected by any unforeseen situation like a fire or unwanted human activities.

Ultra-low latency, low energy consumption, and reliable wireless communication support for a huge number of IoT devices gave rise to the concept of 5G NB-IoT. Evolution of Long-Term Evolution (LTE) and 5G technologies is expected to provide a newer advanced interface for the future IoT Applications, but currently, the development of the 5G technologies is in its initial stage and is aiming at using Radio Access Technology (RAT) for higher frequencies and re-architecting of the network [7]. 5G NR can be classified into two categories, based on Frequency Range. At first, there is Frequency Range 1, which includes sub-6 GHz frequency bands and the other is Frequency Range 2 that works in the frequency range of 24.25 GHz to 52.6 GHz [8]. 3GPP has approved some frequency bands below the Sub-6 GHz frequency bands, namely, Bandn77, Band n78, Band n79. The frequency bands of these approved frequencies are listed in Table 1.

These collections of frequencies range the future 5G NR spectrum that is catered from certain frequency ranges in the US, China, EU, and Japan as shown in Table 2. Recently for supporting Sub-6 GHz Frequency bands, an array antenna with dual-band operation has been reported [10–15].

With the evolution of Industry 4.0, the Internet of Things has got a wide range of applications in the industry because it can easily provide cross-platform and cross-device support, and help in device interoperability. Internet of Things enables easy communication among the products and their environment through machine-to-machine (M2M) communication. In this chapter we have discussed the various implementations of Agriculture 4.0, Precision Agriculture and what are the advantages of using 5G Narrow Band IoT (or NB-IoT) which is a 3rd Generation Partnership Project(3GPP) aiming towards supporting wide-area Internet of Things applications using licensed spectrum [16] in the Agricultural sector. We have also proposed an idea and have shown the prospects in the agricultural sector by using 5G NB-Internet of Drone Things (NB-IoDT).

NB-IoT can be categorized into several bands based on the frequency of its uplink and downlink. The main advantage of using NB-IoT is that it provides better connectivity to a massive number of devices along with longer battery life, low complexity, and low costing. Actuators or devices can be easily operated using various Bot APIs available like Telegram Bot, Line Bot, WhatsApp Bot, or Messaging Apps or websites in a real-time environment. Some of these bots are paid and some are available free of cost.

In the IoT domain, the two most commonly used fundamental protocols are CoAP and MQTT. These protocols are best suited for low energy consumption devices. These protocols have little overhead and huge extensibility. As both the CoAP and MQTT protocols are Internet protocols they both have transport layer security [17]. There is always a hardware-software interaction in the Internet of Things domain. MQTT protocol works in the Publisher-Subscriber model. In simple terms, it means that the publisher publishes content at a regular or a given interval of time. And the subscribers who are subscribed to that publisher will be able to receive the updates through a broker. CoAP (or Constrained Application Protocol) design helps simple constrained devices to join IoT through a constrained network that is having low bandwidth and low availability. It supports asynchronous message exchange with low overhead. Very simple syntactic analysis can be done using the CoAP protocol. It has proxy and caching capabilities also. CoAP protocols work where TCP based protocols like MQTT fails to perform. It supports networks having billions of nodes. The DTLS parameters used for security purpose in CoAP is equivalent to 128-bit RSA keys. CoAP is by default bounded to UDP (or User Datagram Protocol) and optionally to DTLS.

In recent years drones have got a wide range of applications across multiple domains and fields [18–24]. Sometimes it is claimed that the history of the first drone dates back to 1849 when the Australians launched around 200 pilot-less balloons against Venice [25, 26]. Again in [26, 27] it has been told that Unmanned Aerial Systems can be traced back to 1896 when Samuel Langley's unnamed drone flew over the Potomac River. It has got several applications in the field of military missions [25, 28], precision farming [29, 30], crop monitoring [31], disaster management [32], etc. The application of drones in these fields is comparatively quite cheaper in comparison to manned aerial vehicles [33]. With the introduction of drones in the agricultural domain, farmers need not have to get exposed to harmful pesticides, as pesticides and fertilizers get sprayed over the crops with the help of these drones. Again, these drones can be used for aerial surveying of the crops and detect un-towards incidents occurring in the field or farm, like forest fire detection. Thus, the overall introduction of drones in the field of agriculture has revolutionized the advancement of Agriculture 4.0.

2 Literature Review

Diverse types of sensors like temperature, humidity sensor, soil moisture sensor, water level sensor, LDR sensor, and various other actuators like LED, submersible water pump, along with an ESP8266 Wi-Fi module to transmit data to the ThingSpeak cloud platform has been used [34]. They have designed an automated system to maintain the moisture level in the soil. There are many disadvantages to the system, like when the main motive is just to maintain the level of moisture of the soil, they have unnecessarily used the DHT11 sensor. Readings taken from DHT 11 sensor do not have any contribution to the system, other than just collecting atmospheric humidity data unlike the LDR sensor which is used to sense the intensity of light in the surrounding and turn on and off the LED accordingly to provide an ample amount of light to the plants. In addition to this, their system is working to read available moisture in the soil from the soil moisture sensor and water the plants accordingly. They have used Way2SMS for notification purposes, which provides only 2 free SMS per day [35], which hinders the path of free 2-way communication between the user and the system. Overall, this system does not seem to be bandwidth-efficient, because they are at first sending data to the cloud and again fetching that data back to a local Web Server. So, their system is consuming a lot of network bandwidth. This 2-way journey of the data from the device to the Cloud and again back to the local Web Server is making it more and more time consuming and as a result of that, this system is going to send an alert notification to the end-user very late. Although they have said that by storing the data locally, they use the data for data analytics purposes, but they can export the dataset from the ThingSpeak Cloud platform for further research purposes and there is no other added requirement for this local web server. Using an additional web server is making the system less power efficient. If they wanted to store data locally, they could have parallelly transmitted the data to both Cloud and the local web server thus reducing the utilization of the network bandwidth. They have used Wi-Fi as a means of communication with the internet, but Wi-Fi connectivity will fail to provide a higher latency unlike 5G NB-IoT enabled devices.

Arduino Micro-controller along with ESP8266 Wi-Fi module for controlling the actuators and for communication purpose respectively [36]. They have a water flow sensor, soil moisture sensor, and temperature (ds18b20) sensor. Temperature (ds18b20) sensor can sense temperature from −55 °C to +125 °C [37]. This system can automatically toggle the state of their water pump and sprinklers from Power on to Power off state and vice-versa based on the level of moisture in the soil and temperature and can also be operated in manual mode through a website. The main disadvantage of this system is that multiple crop types are not supported in a single system. If the farmer plans to sow seeds of a different crop type, then the system will have to be reprogrammed with the new moisture level of the new crop variant. This system requires an active Wi-Fi connection for communication purposes. So, in case the Wi-Fi router gets compromised, hackers or cybercriminals can cause malfunctioning of the devices. They have also not implemented a simple authentication before sending any command to the device, so any unauthorized user can easily operate the system if they get the website URL or IP Address. Proper UAC could have been implemented to increase the security of the system and prevent unauthorized access to the system.

Smart Farm system in [38] has been divided into three components—hardware, web application, mobile application. The use of the hardware components comprising of DHT22, 1 channel relay module, Solenoid, Node MCU is used to control the actuators and collect the live data of the crops. The second component is the web application which has been used to visualize the collected live data from the IoT devices from various villages. This interface is used by an admin level user to manipulate the conditions of water needed for each of the crops. The real-time data that is collected will be used to monitor the level of moisture in the soil required for a particular crop and in the future, these collected data will be used to predict the amount of water that will be required for a particular variety of crops. The third component, that is the mobile application will be used by the farmers to operate the actuators in both manual and automatic mode of operation. In this project, they have used Node MCU for the transmission of the data to the server. They have used the Apriori algorithm available in Weka [39] to extract the association rules from the collected live data and have used linear regression to model the relationship between several inputs and outcome variables. The input variables include temperature, humidity, and soil moisture. The model is shown in Eq. (1):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots + \beta_p x_p + \in, \tag{1}$$

where y is the outcome of the variable. $B_n x_n$ represents the product of the change in y with a unit change in x_n for n = 1 to p-1.

In this system, they have used the Line Application for the notification purpose. But the main problem with this application is that the Line API is not available to free of cost, and there is a subscription charge, so this could be replaced with Telegram Bot as it's API is available free of cost and can address 30 requests per second. Nothing has been mentioned about the proper UAC of the system, which can make illegal users access the system.

UAV based mapping system for precision agriculture has been implemented using fog computing [40]. Both static and dynamic sensor deployment has been done to collect data. The data collected by UAVs are transmitted to a broker which sends the data to the other brokers to execute scheduled policies based on the analysis. Fog computing has been implemented for delay-sensitive applications, which has helped them to get early warnings and provided them data-driven monitoring system. This proposed work is based on INET5 and OMNet++4 which is the extension of FogNetSim++ [41]. The fog devices are tracked by a broker with the help of data collected from the fog nodes. This proposed framework provides a complete farming ecosystem inclusive of fog locations, UAVs, and sensors.

A new architecture of cloud-based autonomic information system named AgriInfo for agriculture domain [42]. This system has been designed to collect information from pre-configured IoT/ Edge devices at the user level and process it based on certain fuzzy rules and store the processed data in the cloud for future reference. These fuzzy rules are kept on updating based on future research and developments. This system collects mainly nine types of data, which are—weather, crop, soil, irrigation, fertilizer, productivity, equipment, and cattle. This system can automatically allocate resources at the infrastructure level after identifying the QoS requirement request of the user. In other words, AgriInfo has been designed to provide Agriculture-as-a-Service (AaaS) through web and mobile-based applications. AgriInfo has been broadly divided into two sub-systems:—User Subsystem and Cloud Subsystem. The User Subsystem provides an interface for the end-user to interact with the system. The users are classified into three categories- agriculture expert, agriculture officer, and farmer. Agriculture experts answer user queries and update the fuzzy rules. The agriculture officers are the government officials who provide the latest information regarding the new schemes, policies, and rules that are passed by the government. In this system, farmers are important entities, they take the advantage of the system by asking queries and getting automatic replies after analysis. At first, the users will have to do the registration to the system, and after that when they login into the system, the homepage of the user will be displayed. The users can monitor any data related to their domain and get benefitted from them without visiting the agriculture help center. All the queries asked by the users are updated on the database and after analysis, an automated reply is given to the user via their pre-configured devices. The main advantage of this system is that no technical expertise is required to use this system. This application has been developed on CloudSim [43] to validate the proposed system through real-time mobile and web applications. Table 3 gives a brief comparison of the surveyed papers.

Table 3 Comparison Table of Agriculture state of the art models

	Proposed model	[34]	[36]	[38]	[40]	[42]
GUI Based	✓	X	✓	✓	N.A	✓
Voice Interface	✓	X	X	X	X	X
Drones Used	✓	X	X	X	✓	X
Static Sensor	X	✓	✓	✓	✓	✓
Dynamic Sensor	✓	X	X	X	✓	X
Communication medium	5G NB-IoT	Wi-Fi	Wi-Fi	Wi-Fi	Wi-Fi, GSM Module, and short-range communication	Through JADE Agent
Contactless interaction with the device	✓	X	X	X	X	X

3 Advantage of Dynamic Sensors Over Static Sensors in Agriculture 4.0

In some of the smart irrigation and precision farming systems, static soil moisture sensors along with the water controllers are kept scattered in the field. This estimates the amount of water that is to be sprinkled on the field quite inaccurate.

As shown in Fig. 3, we have pictorially represented farmland in form of a square and divided the square into sub-squares representing multiple zones based on the level of moisture in the soil to demonstrate some real-world challenging scenarios in the case of smart agriculture. The yellow-colored square boxes represent the areas that are having less moisture content and the blue-colored square boxes represent areas that are having excess moisture content and the green-colored box represents an area with an optimal amount of soil moisture level. We have highlighted some scenarios to demonstrate the disadvantages of the existing systems.

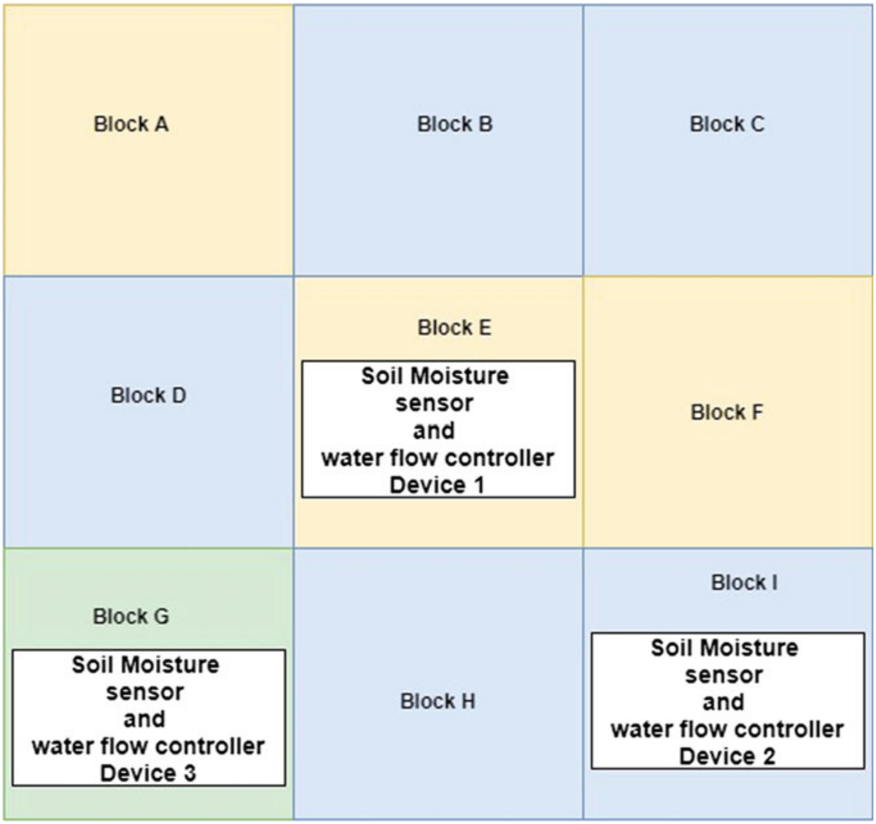

Fig. 3 Demonstrates the various scenarios that can affect the crops from existing smart irrigation systems

Scenario 1: When Device 1 in Block E, locally detects the soil moisture level in the soil, it finds that there is very less moisture content in the soil, so it starts pumping water in Block E. Now, Block B, Block C, Block D, Block H, Block I are already having a huge amount of moisture in the soil but they are adjacent to Block E. So, when the water pump in Block E starts pumping water, from the general property of water, it will flow to the adjacent areas as water does not get soaked in some types of soil quickly, which means that the adjacent block of lands which are already having high moisture level will get this excess amount of water. Now, this can adversely affect the crops, because with an excess amount of water in the soil, crops like wheat which does not require much water will get destroyed, and even if they do not get destroyed, we will get poor quality wheat, from which the farmers will not be able to earn much profit.

Scenario 2: Here we will assume that we are planting rice crops that require a huge amount of water. Suppose the device is installed in Block B or Block C or Block D or Block H or Block I, where there is an excess amount of water. Then this device will not pump in water. Now the blocks A, E, F which are having a low amount of water, will not get the desired amount of water for the rice crops planted in those blocks. This, in turn, will lead to the destruction of the rice crops, or poor-quality rice crops will grow as they require a huge amount of moisture in the soil.

Scenario 3: In this scenario as depicted in Block G of Fig. 3, the soil is having an optimal amount of moisture required in the soil for the type of crop planted in the soil. So, the problem will be when a scenario like a Scenario 1 will occur, excessive water will get flowed to these regions and will affect crop growth.

Thus, the existing systems are giving a locally best solution in terms of the moisture level of the soil for a particular block of land. In simple words, if there are N number of crops in the field, then N number of these devices has to be used and maintained, by the farmers or the horticulturist. This will become a quite tedious job for them to monitor the devices. Also, this solution will not be cost-effective, as there will be additional maintenance for these N devices. So, in this type of scenario, there is a need for drones in the domain of smart agriculture.

Another main problem that occurs with the systems designed in [34, 36, 38] is that this type of soil moisture sensors has metallic contact points, and when these sensors are used for a considerable amount of time, the metallic plates of the soil moisture sensors gets eroded and they give inaccurate readings, thus leading to incorrect results. People, in general, prefer to reduce the cost of peripherals, so when they will use low-quality soil moisture sensors, it will erode the terminals easily and will give wrong results. Several times while working with soil moisture sensors, these types of problems have been faced.

All the models mentioned in [34, 36, 38] are not giving fertilizers or pesticides to the crops, instead, the farmers or horticulturists or the gardener will have to go from one plant to other plants to give pesticides and fertilizers. Many farmers do not take any preventive measures before applying pesticides on the plants [57] which affects their health [58–62]. So, applications of these models of smart farming can prove harmful to the farmers. Another problem with the systems mentioned in [34, 36, 38] is that the sensors are fixed at a given location, so the sensors might fail when there is no power supply. In [40] they have used both static and dynamic sensors, and that makes maintenance of sensors much easier and less hectic in comparison to farmlands where all the deployed sensors are static. In [42], the proposed architecture AgriInfo is only able to process English and do not have multilingual support. So it will be difficult for the farmers who talk in local languages to communicate with the devices. Although handheld devices ease the access to a particular system, AgriInfo does not have the option for handheld devices.

4 Security Issues in Agriculture 4.0

All the models mentioned in [34, 36, 38] are using Wi-Fi for communication purposes. For encryption purposes, Wi-Fi uses popular protocols like WEP, WPA, and most recently it uses WPA2 for encryption purposes. Wi-Fi, which is a wireless connection possesses various cybersecurity threats [44–53]. Several tools are available in the market to hack into Wi-Fi networks. The most common and advanced tool in Kali Linux [54–56]. So, if anyone hacks into the Wi-Fi router, then the hacker can easily compromise all the systems that are connected to the Wi-Fi. If the hacker is having some ill intentions, he/she can easily make the device malfunction without the knowledge of the farmer and in turn will destroy the crops. These systems have not implemented proper User Access Controls, so any unauthorized user can access the system with ease in case they get access to the Mobile App or the website URL.

5 Advantage of Using 5G NB-IoDT Over Wi-Fi and Wi-Fi 6 in Agriculture 4.0

5.1 Comparison of Download Speed Among Wi-Fi, 4G, and 5G Network

In the latest analysis by OpenSignal it has been found that in the USA, UK, Spain, Australia, Kuwait, Switzerland, South Korea, Saudi Arabia, 5G download speed is better than Wi-Fi connection. It has been forecasted that cellular technology will improve faster than fixed networks and Wi-Fi connections [63]. Data collected between January 22- April 21, 2020, is shown in Table 4.

From Fig. 4, we can graphically see that the average download speed of 5G is more than that of 4G and Wi-Fi connectivity. So, the initiatives to implement smart agriculture systems using 5G Narrow Band Internet of Drone Things is of utmost importance to provide a smart, ubiquitous, latency-free communication between the end-user and smart agriculture devices.

Table 4 Average download speed in Mbps across Wi-Fi, 4G, and 5G connections [63]

Countries	Wi-Fi Download Speed	4G Download Speed	5G Download Speed
USA	59.8	27.7	52.3
UK	34.1	24.9	138.1
Spain	47.0	28.8	146.8
Australia	25.6	44.1	163.9
Kuwait	26.7	16.7	185.1
Switzerland	73.9	45.0	201.9
South Korea	74.5	53.7	224.0
Saudi Arabia	21.4	24.4	291.2

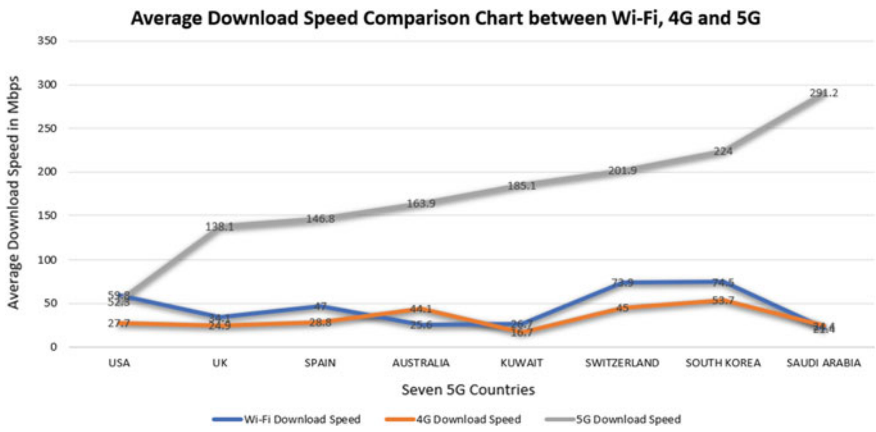

Fig. 4 Graphical representation of Average download speed across seven 5G countries

5.2 *Advantage of 5G NB-IoDT Over Wi-Fi and Wi-Fi 6 from Cyber Security Perspective*

Although we know that Wi-Fi 6 [64] is also one of the evolving technologies with 5G networks with a significantly higher speed of operation in comparison to the current Wi-Fi connectivity, it can have certain aspects from the cybersecurity point of view. Wi-Fi 6 is the future generation implementation of Wi-Fi connectivity that follows IEEE 802.11ax [65–71] standards and works in the frequency range of 5925–7125 MHz. But the main disadvantage of using Wi-Fi 6 is that if the router gets compromised then it will not take much time for the hacker to hack into all smart irrigation systems that are connected to that particular Wi-Fi 6 router and make the devices malfunction. Popular cyber-attacks like flooding DOS [72, 73] (or Denial-of-Service) attacks on these connected smart irrigation systems can be done through flooding requests through the compromised Wi-Fi or Wi-Fi 6 router as shown in Fig. 5.

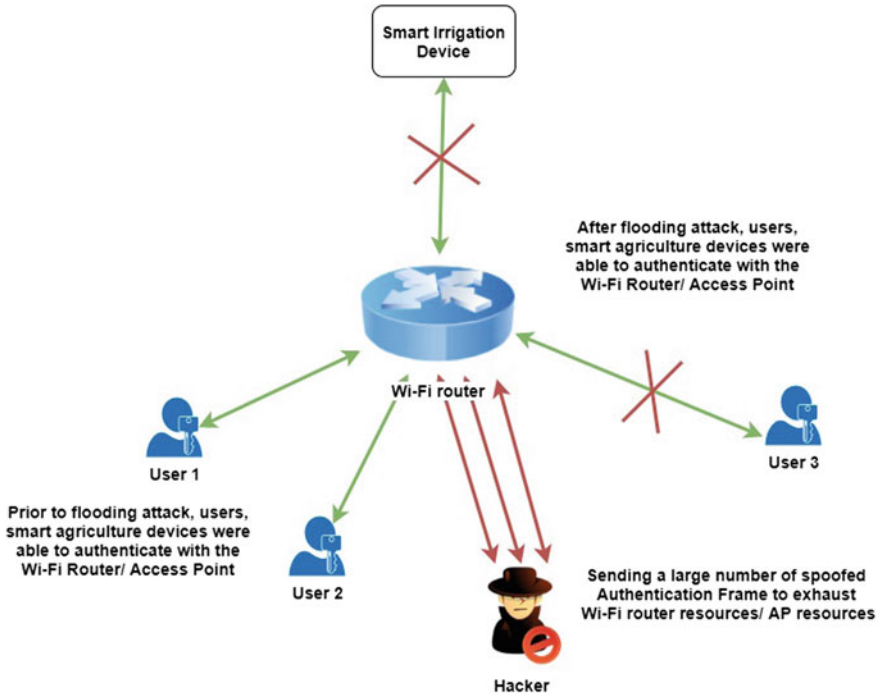

Fig. 5 DOS attack on the Wi-Fi router using flooding attack

This will not only make the smart irrigation devices inaccessible by the farmers but can also lead to quick drainage of the batteries that are fitted on those smart irrigation devices through the flooding of illegal requests sent by the hackers. Remote Code Execution attack can be performed on a Wi-Fi router [74–76] to which multiple smart irrigation devices are connected. Once the attack is successful, through the Wi-Fi router, the attacker can perform Man-In-The-Middle Attack [77] and can either make the smart irrigation devices malfunction by modifying the requests sent by the user to the smart devices or modify the live data that is being sent to the end-users from the smart irrigation device as shown in Fig. 6.

This is possible because when an IoT device gets connected to a Wi-Fi router it's IP Address, and MAC Address is stored in the Wi-Fi router, and by just hacking into a single router [77–79], a hacker can easily get details of all the connected IoT devices and can easily plant those malicious codes in them without the idea of the farm owner or horticulturist. By malfunctioning of these IoT devices, the attacker can hinder the growth of good quality crops. So, these attacks can be minimized by individually connecting each smart irrigation device to the internet through independent GSM modules connected to each smart irrigation device. So even if the hacker hacks into a single device, the chances of hacking into another adjacent device are negligible. So, although Wi-Fi 6 is having better connectivity in comparison to the current Wi-Fi

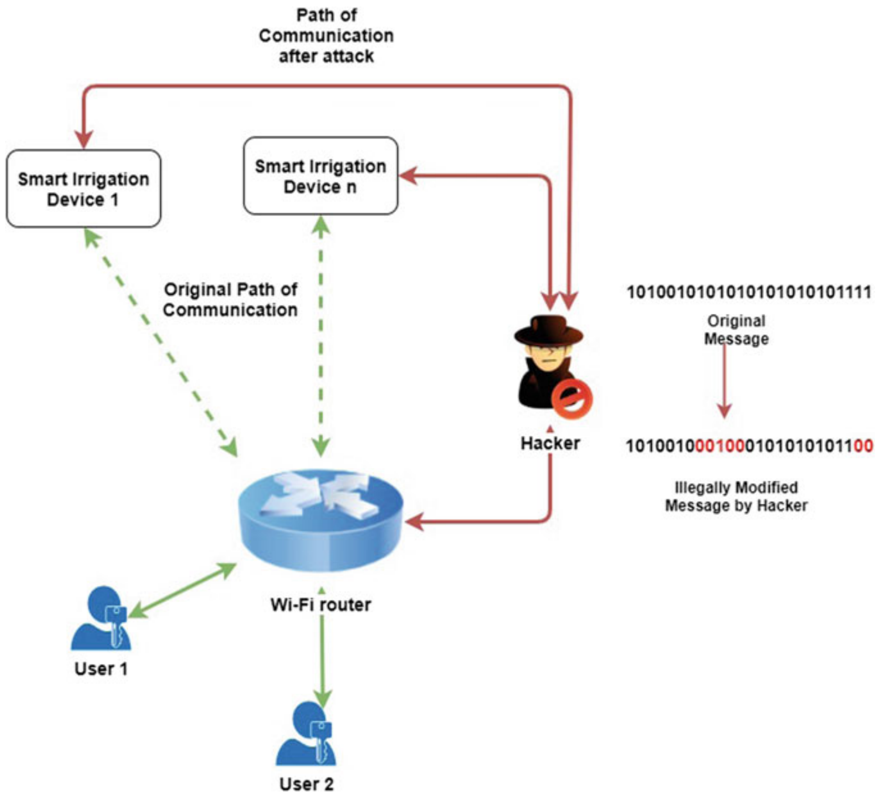

Fig. 6 Man-In-The-Middle Attack on Smart Agriculture System after compromising Wi-Fi router

connections, using it can be quite challenging from the security point of view. So, there is a need for 5G NB IoT connectivity of individual devices.

5.3 Contactless Voice User Interface for 5G NB-IoDT

There are many popular voice assistants available in the market like Apple Siri, Google Assistant, Microsoft Cortana, Amazon Alexa [98]. The help of various other smart home devices like Google Nest, Google Nest Mini, Amazon Echo to name a few. We can combine the power of both 5G NB-IoDT along with that of the voice assistants to make a much faster and cheaper approach in controlling drones for precision agriculture, which means giving the right amount of fertilizer, water, pesticides, etc. at the right time and at the right plant or crop in right quantity based on several parameters like temperature, soil moisture, humidity, etc. through several sensors using various computing models [80–92] as shown in Fig. 7. Precision Agriculture provides better quality of crops [93–97].

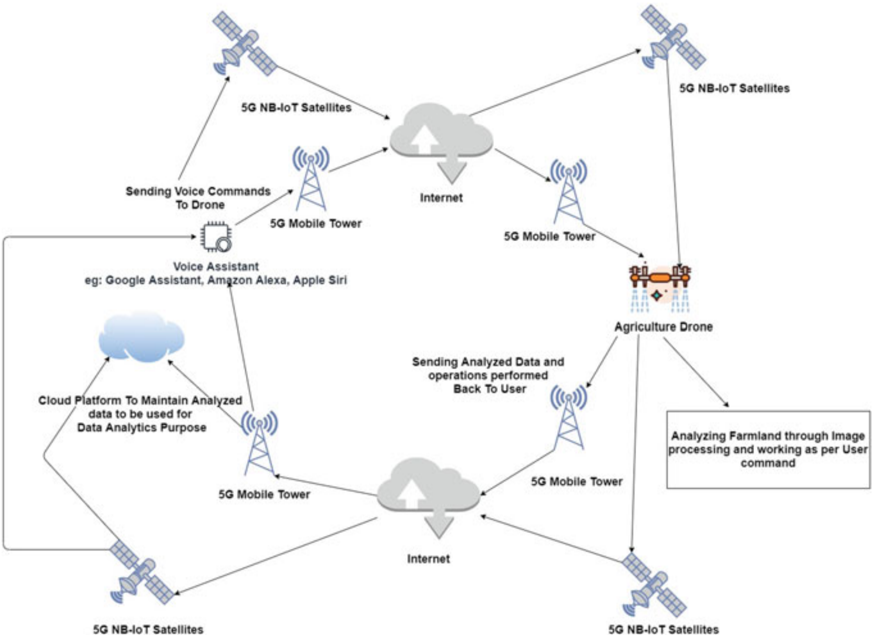

Fig. 7 Block diagram of contactless Voice User Interface enabled Agriculture 4.0 through 5G NB-IoDT

APIs and SDKs of these popular assistants like Apple's Siri, Amazon's Alexa, Microsoft's Cortana, Google's Assistant [98] are available, which can ease the process of controlling devices with voice commands. Using these popular services offered by Amazon, Google, and Microsoft, or any other organization, we can provide a Voice User Interface to a Smart Precision Agriculture system. Some of these Voice Assistant provides multilingual support, so these voice-assistants can be used to provide multilingual support to the proposed model. As the voice-based user interface has become a very popular User Interface, using this system will help the end-users not to rely on common user interfaces like Graphical User Interface or Command Line Interface which requires physical contact. During this global outbreak of CovID-19 pandemic where the e-commerce companies and food delivery apps are switching towards contact-less delivery just to reduce the spread of CovID-19 through physical contact [99–101], this approach will be quite helpful to reduce the spread of similar types of harmful diseases from contact, and this play a very vital in reducing the spread of contaminating diseases like CovID-19 through the food supply chain or product supply chain since the farmers or the horticulturists may be infected with CovID-19 and from that, it might lead to the spreading of this virus. If required any farming organization can either design their Voice Assistants or make use of the readily available voice assistants to control the drones. Another major advantage of using these Voice Assistants is that they provide multilingual support, so it will be easier for the farmers or the horticulturist to control the drones in their native language using these voice assistants as shown in Fig. 7.

Another advantage of using drones is that there are many smart agriculture systems available, but those are using static sensors in place of the dynamic sensors. Now static sensors are those sensors whose locations are fixed and mostly work on fixed battery supply and stop working when the battery gets discharged which makes the maintenance of those sensors quite a hectic task. Dynamic sensors on the other hand are not fixed to a specific location, so their maintenance is not much hectic in comparison to that of the static sensors. We can easily fit various sensors like IR camera, night vision camera, thermal imaging camera on the drones to capture images of the field and by then by applying Edge Intelligence and image processing on the set of farm images collected along with the corresponding GPS location, we can easily apply the right amount of water, fertilizer, and pesticides, etc. on the crops as shown in Fig. 8. At the same time, they can also alert the farm owner in advance regarding any unwanted scenarios that have taken place on the farm along with its GPS location. For instance, it can warn the farmers regarding crop fire, or any other unusual incidents that are taking place in the farmland or horticulture. Let's cite an example, in the case of grapevine owners, whose wines spread a huge amount of area, it is quite difficult for few individuals to be continuously vigilant over the vineyard throughout the day and especially at night. So, by implementing 5G NB-IoDT with a night vision enabled camera, the farm owner will be able to get real-time data about his or her vineyard and will be alerted as soon as any unusual or unwanted scenario takes place like fire in the grape vineyard.

After the collection of the images and sensor data, we can process the data in the drones, using the concept of Edge computing [102–110] as shown in Fig. 8 as Edge

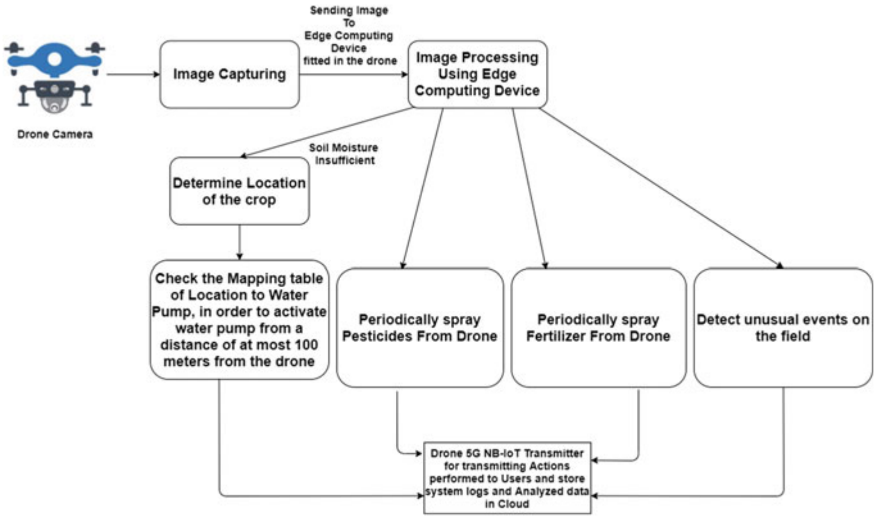

Fig. 8 Edge Intelligence for processing the Images and Sensor data using

computing plays a very crucial role in handling real-time challenges [111]. These drone-based systems can even detect events like forest fires or fires in the wines or farmland and alert the owners in advance to reduce further damage. If there are fixed sensors that will detect forest fires, there is a high chance that these systems might fail if there is a huge fire and the batteries fixed in these systems can fail and the farm owner or the grape wine owner may not be even informed about the fire in the initial stage and that can cause a huge loss to the owners.

5.4 Satellite-Based 5G NB-IoDT Implementation

With the introduction of Satellite-based 5G NB-IoDT, the monitoring of crops in the areas where there is no proper network coverage has also been made possible as shown in Fig. 9 through satellite communication. In the remotest of the islands, where there is no network coverage, Satellite-based 5G NB-IoT enabled drones can be used for smart alerting and monitoring of the crops. The drones can be designed in such a way that they will try to communicate with the nearest 5G mobile tower, but in case there is no nearby 5G mobile tower, it will automatically switch to another mode of operation where it will use satellite-based 5G NB-IoT. This will add flexibility to the ubiquitousness of the drone sensors by providing network connectivity in the remotest of places where there is no proper network connectivity.

Satellite-based 5G NB-IoT network will provide a very fast, reliable communication with a very low latency, which will make it an ideal choice over 4G and Wi-Fi to

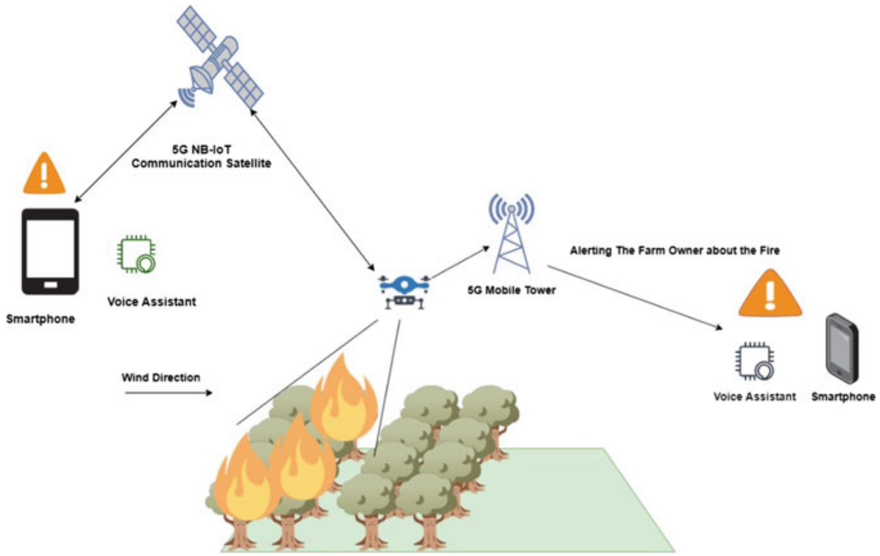

Fig. 9 Forest Fire Detection System Using Smart Farming Drone

be used in real-time applications like this, especially in areas where there is no mobile network available. By applying Machine Learning, our system will understand that what action is required to be performed by the drone and the analyzed result will be sent back to the drone and the drone will perform the required task and forward both the analyzed data and the action performed both the user and store the results in the Cloud platform for future reference. For notification purposes, we can use Telegram Bot as it's APIs are all available free of cost. The Telegram Messenger API supports at most 30 messages per second [112]. Its APIs are available free of cost to use unlike Line and WhatsApp APIs.

6 Future Open Research Challenges

Challenge 1: Smart water pump. The main disadvantage of the agriculture system is that, if there is excess water in the farmland, there is no backup system to pump out the excess water. So, water pumps can be installed in the farms that can pump out excess water from the farmland. The point of contact of the input of these water pumps should be placed at a certain height above the soil so that only the excess water gets pumped out of the soil. The output of the water pumps should be done on a specific channel to conserve the excess water that is getting pumped out and use the water later. This will prove to be quite beneficial, especially in the desert areas, where there is not much moisture content in the soil and also have a scarcity of water. IoDT based smart watering sprinkling systems needs to develop for proper water distribution.

Challenge 2: BOT based Adaptive sensing for Agriculture 4.0. Problems with static sensors like soil moisture sensor and water sensor is that they have metallic contact points and when there is an excessive amount of moisture content in the soil, their point of contact with the micro-controllers may start to malfunction, thus giving incorrect results. So, a high-resolution and zoom-in capability camera can be fitted on the drones, to detect the level of moisture in the soil and start the water pumps to pump out the excess water from the soil. Popular bots like Telegram Bot can be used to send live notifications to the farmers. As the APIs of these bots are available free of cost, it will not cost the farmers a single penny to use its APIs. Other popular messaging platform-bots of Line and WhatsApp are also available but they are not available to free of cost. The main advantage of using these bots is that they provide cross-platform and cross-device support for future generation Agriculture.

Challenge 3: Green Agriculture 4.0. Energy-efficient techniques of IoDT using zonal thermal pattern analysis and adaptive crop health monitoring system towards green IoT needs to design for smart agriculture [113–117].

Challenge 4: Realtime connectivity for Agriculture 4.0. for Narrowband characterization of the near-ground radio channel for wireless sensor networks for smart farming at 5G-IoT bands is crucial [118]. This will help to provide better connectivity to the static sensors that are installed on the ground and are sending real-time data to the Cloud or the End-Users. And with the inclusion of 5G NB-IoT, unlike 4G connectivity, there will be no network congestion and network interference issues. Besides 5G NB-IoT will provide support for satellite communication, which means the smart devices can work in sync with the end-users and cloud in places where there is poor network connectivity through satellite communication. 6G technology is under development for ultra-low latent network.

Challenge 5: 6G Smart Agriculture Appliances for IoDT. IoDT-enabled smart appliances development under industry 4.0. References [119, 120] will be developed for real-time machine Learning and ubiquitous computing-based solution for agriculture. 6G network research is on to provide better connectivity and better bandwidth efficiency.

Challenge 6: Sensor Cloud for Agriculture 4.0. Deployment of AgriEdge based on sensor mobile Edge computing/ sensor cloud platform. Sensors can increase agricultural productivity. Hence, a collaborative approach of the sensor cloud can be most effective in agriculture. Agri sensors increase the agricultural yield, so a collaborative method of sensor edge cloud can be most effective in agriculture [116, 121–123].

Challenge 7: Geospatial Mobile Edge Computing(GMEC). GMEC is used for developing a ubiquitous sensor network platform using IoT in precision agriculture [124, 125]. The geographic information is collected from various sources and with this, IoT establishes communication to the entire world through the Internet. The information will be helpful in the maintenance of the farmland by applying the required amount of fertilizer at the right time in the right place. The main goal in combining the Geospatial technology with IoT for precision is to monitor and predict the critical parameters such as water quality, soil condition, ambient temperature and moisture, irrigation, and fertilizer for improving crop production. It can be expected that with the help of Geospatial and IoT in smart farming, the prediction of the amount of fertilizer, weeds, and irrigation will be accurate and it helps the farmers in making decisions related to all the requirements in terms of control and supply [126]. The application of groundwater for domestic and agricultural uses has increased day by day. However, geology and anthropogenic activities can impact groundwater quality. But information on quality evaluation and suitability classification of groundwater based on water quality index (WQI) is limited. Thus, study evaluated the spatial variability of groundwater quality and its suitability for potable and irrigation purposes. Water samples will be collected from wells across the study area and analyzed for physicochemical properties. Suitability for domestic and irrigation uses will be determined. Regular quality monitoring of the groundwater is recommended to avert likely deterioration indicated by some quality parameters [127].

Challenge 8: Edge Intelligence for Agriculture 4.0(EI Agri 4.0). For precision agriculture, intelligence at the edge level provides a real-time solution for agriculture problems [128].

Challenge 9: Qos for Agriculture 4.0. QoS aware Internet of Agricultural Things needs to implement an autonomous system [6, 129–131]. QoS level is implemented in the MQTT protocol and it functions with different parameters provide a grade of IoT system to set the cost parameters QoS_0, QoS_1, and QoS_2 [132].

QoS_0—at most once: The minimal QoS also known as “fire and forget” level is zero. This service level guarantees a best-effort delivery for agriculture data with no guarantee of delivery as the recipient does not acknowledge receipt of the message and the message is not stored and re-transmitted by the sender. It provides the guarantee as to the underlying TCP protocol.

QoS_1—at least once: QoS level 1 guarantees that a message is delivered at least one time to the receiver of agriculture devices. The sender stores and retransmits the message multiple times until it gets a PUBACK (Publisher Acknowledgement) packet from the receiver.

QoS_2—exactly once: QoS_2 is the highest, safest but slowest level of service in MQTT for agriculture 4.0, which guarantees that each message is received only once by the intended recipients by at least 2 requests or response flows a secured four-way handshake between the sender and the receiver. Harmonization between the sender and receiver is performed by packet identifier of the original PUBLISH message to deliver the message of agriculture data. Ensuring proper QoS level of IoDT ensures proper quality of Experience (QoE) of farmers.

Challenge 10: Blockchain for Agriculture 4.0 (BCAgri 4.0). BCAgri 4.0 for 5G-enabled IoT for industrial automation for food supply chain management is essential [133–138]. Blockchain-based e-agricultural systems with distributed ledger systems for storage organization, agricultural conservation data integrity is protected in information administration [136–138]. IoDT and Blockchain technology as two rapidly emerging fields can ameliorate the state of the food supply chain [139–143]. Blockchain ensures security of IoDT based Agriculture 4.0. 6G enabled futuristic Quantum blockchain will provide higher security for IoDT in near future.

Challenge 11: AgriDew. Dew computing based smart IoDT will be used for future Agriculture even if the internet connectivity is not stable [144–146]. Lightweight dew computing paradigm needs to design to manage heterogeneous wireless sensor networks with various types of UAVs [147].

Challenge 12: Drone Swarm optimization. Particle swarm optimization (PSO) and Glowswarm optimization (GSO) based flight path optimization is important area of research to provide edge intelligence to autonomous IoDT [148–156].

7 Conclusion

With the increase in World population, there is a higher demand for operational efficiency in almost all spheres of life, especially in the agricultural sector. Thus, this is compelling us to shift towards a smarter approach to agriculture with the evolution of the Internet of Drone Things in agriculture domain. 5G NR can be classified into two categories, based on Frequency Range. At first, there is Frequency Range 1, which includes sub-6 GHz frequency bands and the other is Frequency Range 2 that works in the frequency range of 24.25–52.6 GHz. This frequency band varies from country to country. So, there is a need to shift to these latest network architectures as they have lower latency and helps in developing real-time applications. We have proposed an implementation of a smart agriculture model using 5G NB-IoDT. This comprises of implementation idea, basic system architecture, etc. We address certain challenges of the surveyed models in the area of smart agriculture.

During this CovID-19, when there is a global pandemic, we have suggested a contact-less idea of smart irrigation using 5G NB-IoDT, voice assistants, edge computing, and Machine Learning techniques. The recent introduction of satellite-based 5G NB-IoT by Skylo and BSNL will play a significant role in the field of smart agriculture by providing 5G NB-IoT connectivity even to the remotest of the places where there is network connectivity or the network connectivity is very weak. In the remotest islands where there is no proper internet connectivity, the introduction of this satellite-based 5G NB-IoT will prove to be a boon in the arena of smart agriculture. We hope that crops will grow with the help of cyber-physical systems, will reduce human interaction between the food supply chain.

Glossary

Agriculture 4.0 4th Generation Agricultural Revolution using cyber-physical systems, internet of things, cloud computing, machine learning, artificial intelligence

DHT Sensor to calculate atmospheric temperature and humidity

Drone/UAV An unmanned flying vehicle that is either autonomous or is manually controlled from distance by an operator

Fuzzy Logic It is a form of many-valued logic in which the truth values of variables may be any real number between 0 and 1 both inclusive that is where the truth value may range between completely true and completely false

Industry 4.0 4th Generation Industrial Revolution that includes automation and data exchange via Cyber-Physical systems, Internet of Things, Cloud Computing

LDR Sensor to detect light intensity

Multilingual Knowing multiple languages

Real-time When an operation is to be performed in a time-bounded way

WEP Security algorithm for IEEE 802.11 wireless networks

Wi-Fi Used for wireless internet connectivity

Wi-Fi 6 6th generation Wi-Fi connectivity

WPA Security standard for users of computing devices equipped with wireless internet connections

Ubiquitousness Capability to physically move computing services and devices with us

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