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Sustainable Connectivity Design for IoT-Based Precision Agriculture

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Abstract

Agriculture is among the many industries that have undergone considerable change due to the Internet of Things (IoT). However, particularly in large-scale agricultural operations, IoT devices in the rapidly developing sector of smart agriculture frequently encounter significant issues related to energy consumption and network access. The growing world population—which is predicted to reach 9.7 billion people by 2050—and the unpredictable nature of natural disasters make this issue even worse. As a result, smart agriculture solutions that tackle the high energy consumption and connectivity issues that IoT devices face are required. By concentrating on the optimisation of energy-efficient connectivity options for Internet of Things-based smart agriculture systems, the study seeks to close this gap. The objective is to improve smart agriculture's sustainability and energy efficiency by utilising cutting-edge technologies, such as merging NOMA with narrowband IoT to reduce interference and deploying narrowband IoT for large-scale agriculture. Improving agricultural products' energy efficiency and productivity safely for a sustainable future is part of the research's broader aim.

1. INTRODUCTION

The advent of the Internet of Things (IoT), a conceptual framework that links digital systems to physical processes and enables automated operations, decision-making, and directed data analytics, has drastically changed the agricultural scene. Precision farming, a concept in which resources are carefully controlled and agricultural processes are optimised to give optimal output while minimising input and environmental damage, has become more popular in agriculture thanks to the development of the Internet of Things.

When farmers started experimenting with sensor technology to track variables like soil moisture, temperature, and other environmental parameters in the early 2000s, the Internet of Things (IoT) in agriculture took off. The foundation for the eventual revolutionary change in farming methods was laid by these early IoT implementations [1]. Farmers saw a dazzling opportunity in the Internet of Things (IoT) as sensor technology advanced and prices decreased. They used a range of sensor solutions to obtain a solid grasp of daily operations and significantly increase the effectiveness of resource allocation.

IoT, a paradigm that combines the digital and the physical, is currently spearheading a significant agricultural revolution. A new era of hyper-efficient farming and more sustainable, intelligent agricultural management is being fuelled by the widespread availability of sensor technologies, which enable farmers to track and measure every facet of their farming operations [2] However, several new management difficulties have emerged because of the volume and complexity of data generated by IoT sensor networks. The last mile, or the link between the farmers and the backend systems that crunch numbers, is essential; without it, the data is essentially worthless.

With the world's population approaching 9 billion, there is a greater demand for food than ever before, and farmland is limited due to the constant need for correct and efficient resource management. Sensors are typically deployed in plants, soil, or livestock, and with the Internet of Things, these devices

are constantly creating data, relaying minute-by-minute information on their environment, creating mounds of information, 90 percent of which did not exist five years ago. The fact that sensor data is only valuable when it is being used poses a big problem as well as an opportunity [2]. In addition to outlining the potential future of IoT in agriculture, this paper will discuss the difficulties in handling and utilising the unmanageable amount of IoT data in this sector. For most Indians, agriculture is the primary source of income and the foundation of the country's rural growth. Although IT has significantly impacted many businesses, environmental monitoring, and everyday life, it has hardly touched the surface of India's traditional agricultural practices. Due mostly to a lack of real-time data, conventional irrigation techniques have traditionally been time-consuming and vulnerable to significant water loss via evaporation, spills, and mismatched soil moisture profiles. By continuously monitoring soil moisture, temperature, humidity, and wind speed, Wireless Sensor Networks (WSNs), which are a subset of Information and Communication Technologies (ICT), have revolutionised irrigation techniques and elevated agriculture to the forefront of the Internet of Things [3]. In the diverse agricultural landscape of a country like India, these IoT-enabled solutions will provide a solid foundation for increasing productivity and efficiency at a reduced cost with a little environmental impact.

However, there are difficulties associated with the widespread use of WSNs in the agricultural sector, most of which are related to energy efficiency. Agricultural contexts involve sensor nodes functioning in farmland, which frequently lacks basic infrastructure, as opposed to industrial scenarios where sensor nodes have direct access to power sources[2] They are therefore solely dependent on battery power and manage their own energy source throughout their operational life. Energy consumption is also vital in this case with the focus on the. design and optimisation of innovative connectivity solutions to increase network lifetime and promote eco-friendly business. Focusing on the design and optimisation of the energy efficient connectivity in Energy Harvesting (EH) Internet of Things (IoT)-based smart agricultural system in the entire of India.This research paper gives a complete description of WSN structures, communication, Non-Orthogonal Multiple Access (NOMA) methods and protocols. The main framework relay-aided NOMA system model in uplink transmission, the uplink transmission of WSN in agriculture, performance analysis, and numerical results are analyzed in the following sections.

2. LITERATURE SURVEY

With the growing scope of the IoT in agriculture, several research works have been carried out in alignment with the rising technological advancements and the changing agricultural challenges. As an example, a recent report by Hu et al. (2019) has shown the value of wireless sensor networks (WSNs) in smart agriculture, especially to track the state of the soil and activate an accurate irrigation process. The IoT devices in agriculture can transform the conventional farming practices since the devices provide access to the real-time data inputs that can be used to optimise the way resources are managed in the farms. Similar research activities have reported the implications of IoT applications in data collection and analysis in terms of crop health indicators, temperature fluctuations and soil moisture. Overall, these papers demonstrate that the IoT technology is setting the stage of the data-driven agricultural decision-making process. The use of IoT in agriculture has been reported by earlier research to possess several

advantages. The IoT devices have now enabled farmers to access the information they require regarding the environmental conditions, trend of crops development, and the health of their soil. Precision agriculture is effective in water management, fertilization, and improved pest management methods since it involves real-time monitoring, meaning that farmers can easily control water and optimise fertilization and pest management methods. [2]. Through the predictive analytics features of IoT technology, farmers will be able to prevent and reduce prevalent losses on lost crops and reduced yields. Such analysis of the research results illustrates how the transformative IoT technology will be able to increase agricultural productivity and sustainability and make it resistant to external factors. As much as the future of IoT in agriculture is promising, there exist some challenges especially in terms of connectivity and energy consumption. The use of the IoT solutions that generate and process large amounts of big data leads to the aggravation of these issues and increases energy consumption of the systems. The scientists have therefore proposed a variety of energy-saving concepts in order to contribute to IoT-based smart farm systems. As an example, Zhang et al. (2020) have spoken about duty cycling as the method of decreasing the volume of energy consumed by IoT-powered devices in farming settings. Similarly, other studies have explored the means of optimizing routing schemes and communication schemes, which can facilitate in reducing the energy cost of data transmission in WSNs. The purpose of such programs is therefore to make sure that operational performance and energy saving co-exist in harmony. This will ensure that the IoT devices have reliable connectivity besides extending their battery life. Various factors (such as the application requirements, the network topology, and the deployment context) have a significant effect on the usefulness of the strategies such as duty cycling with regard to the lifespan of the IoT devices.This is because the frequency and length of communication activities may have an impact on duty cycling. In the meantime, certain trade-offs between network performance and energy saving must be considered when optimising communication protocols and routing algorithms. However, even while these solutions offer several observable advantages in terms of energy efficiency, much more can be done to refine and enhance them so that they can meet the various demands of the agricultural industry.

However, there are still several research gaps that must be filled in order to create energy-efficient IoT-based smart agriculture systems. For example, how can IoT-based smart agriculture systems include cutting-edge technology like edge computing and machine learning to maximise scalability and energy consumption? Prior research has mostly concentrated on network architecture and communication protocol optimisation for wireless sensor networks in smart agriculture. In order to determine the best course of action for reducing energy consumption in the Internet of Things system and increasing operational capabilities, future research should investigate novel design techniques that make use of data analytics and intelligent decision-making.Moreover, how can IoT-based smart farm deployments be maintained by integrating and utilising renewable energy sources (such as solar or wind)? It will be difficult to have a sustainable strategy that uses energy storage (such as supercapacitors) in addition to photovoltaics, wind, and mechanical harvesting mechanisms for energy efficiency because solar cells are duty-cyclable by nature and cannot keep a node on all the time. Finally, what multidisciplinary mechanisms and enabling policies must be created or made available to support IoT-based smart

agriculture practices that are more sustainable over the long term? [6][4] Without encouraging synergistic collaborations across various research facets, as well as among researchers, industry and key stakeholders, and policy makers, it is neither feasible nor feasible to address these questions. These collaborations have the potential to collectively influence our understanding and applications of these principles in smart agriculture.

3. METHODOLOGY

The theoretical frameworks supporting our research project to develop and improve energy-efficient connection solutions for the Internet of Things-based smart farm systems are thoroughly discussed and analysed in this section.

3.1. Efficient Path Selection and Duty Cycling

Duty cycle, a basic strategy that aims to carefully balance the trade-off between operational activity and energy preservation, greatly informs energy management for IoT devices. This method alternates between periods of low-energy operation during sleep intervals and times of high-energy operation during active intervals, such as when data sensing and transmission duties are being carried out. IoT devices are enabled and deactivated intermittently. The main goal is to reduce the energy consumption that IoT devices incur when they switch from active to sleep activities by carefully planning these duty cycles. This will increase the devices' operational lifespan. Therefore, duty cycling is primarily intended to improve the sustainability of IoT deployments, which is crucial in the context of continuous battery operation, like that found in the majority of IoT scenarios. In turn, efficient path selection aims to carefully choose the pathways to use for data packet transit inside a wireless sensor network (WSN); there are frequently several options available, and this decision is impacted by a variety of factors, such as latency, energy consumption, and data throughput. This technique significantly enhances the total lifespan efficacy of WSN deployments by identifying pathways that successfully balance energy savings with optimal performance. [3] It holds significant importance for agricultural settings, especially those with limited resources, which are common in much of the developing world. Duty cycling, on the one hand, is a basic way to preserve the little energy that an Internet of Things device has. This method can be used to meet the main need of energy conservation while guaranteeing the sensor node operates continuously. Our system, the Microclimate, provides an example of duty cycle in action, as we often transition from sensor node processing and data transfer to low-power sleep mode.In such settings, effective path selection is equally important; path selection that uses the least amount of energy overall can significantly increase the operational lifetime of sensor nodes. For instance, if energy-efficient path selection can be accomplished, subterranean soil moisture sensors in real agricultural fields can function for years on a single coin cell battery in precision agriculture. The combination of domain expertise, intelligent data analysis, and machine learning—including both traditional methods and contemporary data analytics, including machine learning algorithms—is important and will continue to be so in both duty cycling and effective path selection.

We emphasise that the foundation of our planned research efforts, which aim to provide energy-efficient connection solutions customised for IoT-based smart farm systems, is the cooperation of duty cycling and effective path selection techniques. In addition to lowering the energy overhead of data transmission, our goal is to provide dependable and prompt communication in agricultural IoT deployments by coordinating the functioning of these technologies. This, in our opinion, greatly extends the lifespan and resilience of IoT devices in the face of energy constraints and ensures the smooth transfer of critical agricultural data, giving farmers the tools they need to make wise decisions that maximise resource utilisation and sustainably raise agricultural output.

3.2 Wireless Sensor Network (WSN) Framework

A wireless sensor network (WSN) is a distributed network of sensing devices that are positioned spatially throughout a monitored area in order to sense the environment and gather data. Wireless communication protocols are used to connect these devices. A typical WSN contains a few sensor nodes that are distributed in the area of interest. These nodes in combination with each other gather, process, and transmit sensed data to a base station (usually an IoT gateway) where more processing and analysis can be performed. WSNs are the most important technology in smart agriculture because they allow real-time monitoring and control of such agricultural parameters as crop health, temperature, and soil moisture. This allows farmers to practice precision agriculture and make informed decisions (Cone & Cothren, 2011). Application of WSN models in smart agriculture is a radical change in the conventional methods of farming and the beginning of a new era of resource allocation and decision-making on the basis of sensor-data. WSN systems allow farmers to have a holistic view of the numerous details of their farms by linking sensor nodes to the arable land under their control [2]. These frameworks allow farmers to make informed judgments by installing sensor nodes across their fields, which allows them to determine when they need to schedule irrigation, fertilisation plans and pest control actions. Moreover, high-resolution geographical and temporal data can now be obtained by farmers due to the large-scale use of sensor nodes. It is possible then to apply them in identifying geospatially localised anomalies and applying specific interventions, which reduce agricultural risks and improve yields. Still, it can be concluded that the implementation of WSN structures in smart agriculture contributes to a better understanding of the complicated dynamics of agro-ecosystems and increases the sustainability and efficiency of agricultural activities, which will lead to the future of data-driven farming.

3.3. NB-IoT

A breakthrough in the cellular internet of things, narrowband IoT was created especially to satisfy the needs of low power wide area network solutions. Its extremely small channel bandwidth of 180 kHz, which is equivalent to a whole resource block of a 5G New Radio NR channel, is the key to its design. Although NB-IoT was proven to be most effective in a more constrained framework, the majority of 5G technologies function with wider digital channel bandwidths. It exhibits remarkable power efficiency, low complexity, and effective use of spectrum resources. Release 13 saw the identification of NB-IoT as a component of the 3GPP cellular standards, which went beyond the initial 5G limitations and demonstrated a more straightforward architecture for battery-powered IoT device applications.

Furthermore, NB-IoT operates in regulated frequency bands where no other wireless communication can interfere because it was especially made to be resistant to channel interference. It also integrates easily with the current 5G infrastructure, however adjustments are need to account for the limited capacity. Its core radio interface architecture is unaltered, guaranteeing adherence to 5G NR requirements. To capitalise on previous investments and enable consistent integration with current networks, NB-IoT uses the 5G NR principle of Orthogonal Frequency Division Multiple Access (OFDMA) for downlink and Single Carrier Frequency Division Multiple Access (SC-FDMA) for uplink. It is also perfect for critical Industrial Internet of Things IIoT applications because it has data encryption and authentication mechanisms integrated into the radio interface as part of the 5G NR architecture [5]. It allows the sharing of data safely which is critical in the development of smart agriculture. It has three different modes of operation, namely: guard-band, in-band and stand-alone. Both of these modes can be used in a variety of applications and different use cases in the 5G spectrum [6]. 5G NR architecture is also suitable in applications of the critical Industrial Internet of Things IIoT as it combines data encryption and authentication, in the radio interface[4]. In order to create smart agriculture, it is necessary to facilitate safe data transfer. It has three different operation modes, namely stand-alone, in-band and guard-band deployment. Each of those are applicable in a variety of use cases and applications in the 5G spectrum [9].The design goal of expanding the coverage by 20 dB for each mode was accomplished using a sequence of message broadcasts, adaptive modulation and coding techniques, and configurable transmission power. Sequence of message transmission, adaptive modulation and coding schemes, and adjustable transmission power were used to achieve the design aim of increasing the coverage by 20 dB for each mode. With this increased coverage, support is now available in additional locations that were previously unconnected or had poor signal strength. Additionally, 5G-compliant features like improved Discontinuous Reception eDRX and Power Saving Mode PSM to manage energy consumption—which allows for a longer working period as less power is used—benefit the device-independent deployment. The Internet of Things will thus be redefined by NB-IoT, a revolutionary technology that offers enhanced security, increased coverage, and high efficiency. As a result, the NB-IoT technology has a great deal of promise to improve farming methods in developing countries like India. Due to a lack of monitoring equipment, resources are largely underutilised in a variety of sectors, especially in agriculture. Water scarcity, for instance, is a major problem in many regions of India and is essential to creating effective water management strategies for successful crop production [10]. Sensors that are linked to NB-IoT devices contact the soil in agricultural fields in order to determine its moisture content. Indian farmers can use the soil moisture data to save water by precisely irrigating their farms. To improve application accuracy and proximity to the crops, the NB-IoT technology sensor is also installed in fields to work in tandem with sensors for pesticides, fertilisers, and humidity levels. The farmer can manage resources and make decisions remotely thanks to the real-time data these sensors provide. Additionally, Indian farmers can now afford the NB-IoT devices due to their low energy consumption. All of these combinations enable farmers to practise efficient farming and maximise harvest yields by appropriately applying nutrients to the crops.These agricultural routes have been found in several countries across the world and have produced favourable results [11]. These solutions will become more effective and

efficient in Indian agriculture as NB-IoT technology develops, supporting sustainable agriculture in the country.

3.4. Non-orthogonal multiple access

Wireless sensor networks installed in agricultural areas are a good fit for the suggested relay-assisted non-orthogonal multiple access strategy. The goal is to use NOMA's capabilities, which include a large number of connections and enabling different symbols to use the same REs through power-domain multiplexing, to address the issues of scarce resources and the high-rate requirement of uplink transmission to a central sink node. Assume first that the centre sensor nodes are able to send data straight to the sink, and that the relay will help the other peripheral sensor nodes. Since devices like WiFi, ZigBee, and Bluetooth can easily interfere with communication between the sink node and the chosen centre sensor node, the chosen sensors are initially theoretically kept within a specific radius so that no other device detects that the unlicensed spectrum is being used. Second, the relays help the transmission inside the seed sub-cluster, and the sensors are arranged into sub-clusters according to their actual locations in the field. Nomadic usage guarantees that the sub-cluster shares the same REs and that distinct sub-clusters have distinct REs [5].Relays are strategically placed between the centre sensors and the sink to increase the data transmission rate. This way, the centre sends from a NOMA set and shares the same relay in the uplink transmission. The sensors are positioned as SN1, SN2, and SN3 in the system model of the suggested relay-aided Non-Orthogonal Multiple Access scheme, which is depicted in a block diagram. By taking into account interference, energy conservation, and the restricted transmission power of the centre sensors, this method seeks to improve the rate and data dependability of uplink transmission for wireless sensor systems in a farm environment. Due to the high reliability of NOMA, the presence of interference from many devices, such as WiFi and Bluetooth, does not reduce the quality of the data delivered. Furthermore, NOMA transmits more data than interference; therefore, the data is still accurate [12]. Therefore, the use of NOMA enhances wireless communication in the agricultural sector. Consequently, the agricultural sector will employ more environmentally friendly farming practices.

3.5. SWAFM, or Smart Water and Fertiliser Management

The Smart Water and Fertiliser Management System, or SWAFM System for short, is an Internet of Things (IoT)-based smart irrigation system designed to optimise fertiliser management and freshwater use in agriculture. According to the farmers themselves, the old water irrigation approach created a number of serious problems, including over- and under-irrigation as well as a failure to take into account the best time to maximise crop yield. The SWAFM system was created to control fertiliser and water supplies, distribution, and consumption automatically and independently at different levels in order to address these problems.

To effectively manage water and fertiliser, the SWAFM system consists of a number of components, including sensors, computing tools, and services [13]. First, using IoT technology for NPK sensors, nitrogen, phosphorus, and potassium sensors collect vital soil data like temperature, moisture, and

nutrient content needed for plant growth. The information provided by these vital sensors is enough for farmers to remember the nutrient levels of their farms and to apply the appropriate amount of water and fertiliser to each farm in the future. Temperature and water level sensors are examples of utilities that can improve measurement precision. In order to monitor soil conditions, the SWAFM system uses Primary Data Collectors, or PDCs. One of these PDCs may support roughly ten NPK sensors. Virtual Entity (VE) representations of physical entities are created using the sensor data that has been obtained and annotated with contextual metadata. Furthermore, two massive initializations—the Cloud and fog node system—run by IoT Cloud Service manage the enormous volume of sensor data in a distributed database node. The IoT and cloud service provides online services for managing IoT data, including devices, processing, and storage. Desktop and mobile users can use these clouds to control and manage the data. In order to cut costs and ensure that the IoT components of SWAFM are correctly identified and connected, open-source clouds are utilised in this study. [14] Lastly, water channel design involves planting GPS sensors on the field to create a slope and field structure that allow water to flow following crop development. IoT valves regulate water flow to multiple tiny channels in the field to regulate fertiliser and water deployment controls when necessary, maximising nutrient distribution with water flow.

SWAFM is a major project that essentially restructures traditional systems, such irrigation, by combining fertiliser management with a particularly integrated smart irrigation technology.

Because SWAFM relies on a whole system approach to the distribution and use of fertiliser and water, it can be viewed as distinct from these conventional methods. Three key pillars form the foundation of the project's structure: Water and fertiliser reserves, distribution, and consumption. The gathering and upkeep of water and fertiliser supplies might be considered the first block's area of expertise [7]. However, the active use of farmer resources is not assumed in this block. To maintain gradual development based on variables like crop needs, soil nutrient levels, and temperature, the second block oversees monitoring the distribution of farmer resources. To influence water flow and fertiliser application rates Sensors and controllers are used. With a longer-term outlook, this block can concentrate on creating and executing distribution plans. A response is a crucial component of the third block, which is primarily focused on the actualised real-time technology. Operations of SWAFM To adjust the frequency of fertilisation and irrigation, keep an eye on the crop's health, nutrient concentration, and soil moisture. To optimise agricultural output and reduce waste, Data is used in SWAFM's operational approach[8]. A novel feature of SWAFM is how it integrated water and fertilizer management. Distribution systems reallocate water and fertilizers based on changes in consumption. For instance, the distribution will control resource redistribution if the sensor identifies increased crop requirements or increased evaporation in a particular region.

3.6 OPERATIONAL BLUEPRINT

Wireless Sensor Networks (WSNs) are responsible for the transition from conventional farming methods to smart agriculture. Important data from agricultural fields must be collected by these networks and sent to a central control centre for intelligent data processing. They permit us to lower related expenses,

improve agricultural operating methods, and boost crop output and quality. WSNs are also applied to other production chain segments in the agro-industrial supply chain such as food processing, cold storage, and retail by ensuring traceability and security in the entire supply chain. The technique enhances the food safety and quality. The operation and implementation of WSNs within an agricultural environment demands the strategic positioning of sensor nodes within the farmland at the operational scale. They are the eyes and ears of the system, monitoring the metrics of crop growth, soil and environmental conditions, and other significant variables. The sink node is the central node of this network architecture, the main center of collecting and transmitting data. This node receives data of the scattered sensor nodes and sends it to the cloud networks or user apps where further processing and visualisation can be done [9]]. With the help of cloud technology along with the usage of a sink node, the system can be made more scalable and flexible, as well as readily integrated with the existing infrastructure, and offer access to virtually unlimited computing power to perform more complex data analytics and processing operations. WSNs have sensor nodes that operate in a relatively fixed network topology, unlike a conventional cellular network. This is not only due to their immobile deployment but also due to their multi-hop communication feature which has a low range.

To reduce energy consumption and guarantee timely data transmission, WSNs use well-defined patterns for communication. The farmland's edge is home to sensor nodes, which are used for data collection and monitoring, as well as data relaying to the sink node. However, performance on this communication scheme with resource constraints, notably limited available resources (REs) for communication, are not very attractive[10]. Performance optimisation and resource allocation strategies are crucial for effective uplink transmission from the sensor nodes to the sink node with high connectivity and low data rate.

WSNs serve as the benchmark for one of the most interesting sectors of the modern economy: providing farmers with real-time data and information so they can make quick decisions. In addition to cloud technology and its interface to sink nodes, addressing various communication challenges in an agricultural environment and continuously enhancing and optimising such networks for performance and scalability are prerequisites for our continued investigation and subsequent development of WSNs. By connecting WSNs with cloud computing paradigms, this enhances the advantages of scalability and effective data transmission and storage. This results in smart agricultural systems that are more reliable and efficient.

A.Using NOMA in IoT for Intelligent Farming

Using Internet of Things (IoT) technologies, smart agriculture has transformed modern farming methods, greatly increasing crop yields and optimising farming operations, including fertiliser and water use. These are accomplished through several interconnected infrastructure layers, including agricultural sensor networks, which are effectively enhanced by the use of Non-Orthogonal Multiple Access (NOMA) in IoT for smart agriculture. This section discusses the possible methods for successfully integrating this into agricultural IoT infrastructure, along with how it can address the opportunities and challenges associated with this process [11]. The user multiplexing and power domain multiplexing techniques in

NOMA in agricultural IoT networks provide innovative methods of enhancing connectivity and maximising resource utilisation. NOMA essentially enhances spectral efficiency and enables efficient utilization of radio spectrum by allowing a number of sensor nodes to share a time-frequency resource block [5]. Moreover, the power domain multiplexing capability of NOMA that minimizes the impact of the interference and enhances the overall connection enables the sensor nodes having superior channel conditions to have higher power levels. Consider a farm containing a large number of sensor nodes, each of which is required to transmit data to a central base station to be analyzed and decisions made. The sensor nodes would have sent their data progressively in a traditional orthogonal multiple access scheme that would have resulted in high latencies and significant reduction in spectral efficiency.

The agricultural IoT networks based on the use of NOMA have demonstrated the user multiplexing and power domain multiplexing techniques that offer new approaches to improving connectivity and optimising resource use. NOMA is basically a spectral efficiency and efficient use of radio spectrum, which allows multiple sensor nodes to share a time frequency resource block [5]. Also, the multiplexing capability of NOMA of power domain that reduces the effects of the interference that maximizes the overall connection allows the sensor nodes with better channel conditions to experience higher power levels. Take an example of a farm with a high number of sensor nodes, and all of them need to send data to a central base station to be processed and decisions taken. The sensor nodes would have transmitted their data sequentially in a more conventional orthogonal multiple access system which would have incurred high latencies and cause a severe spectral efficiency loss.An example of this is the management of interference, which is crucial to achieving high spectral efficiency at NOMA users. Interference from many nearby cells as well as interference from the intended signal consumer is the primary issue restricting communication performance and system reliability.

There are numerous chances to increase modern farming techniques' resilience, sustainability, and productivity through the integration of NOMA into the current agricultural IoT infrastructure. NOMA's enhanced connection and spectrum efficiency will allow for more effective use of limited radio resources, lower communication latency, and improve the overall performance of agricultural IoT networks. Therefore, NOMA can result in the smooth coordination and communication of sensor nodes, actuator nodes, and control systems with proper design and optimisation, facilitating better decision-making and increasing efficiency across a variety of farm management techniques. Numerous important advantages can result from the use of NOMA in agricultural IoT networks, including: (i) a notable boost in crop yields as a result of better irrigation and growing techniques; (ii) a huge decrease in the amount of water, fertiliser, and pesticides used; and (iii) an outstanding improvement in environmental sustainability, including a notable decrease in CO2 emissions, among other things.

Farmers may actually monitor almost every facet of their farm operations in real time with NOMA. As a result, they may decide how best to distribute resources, when to discard or reduce waste, and ultimately when to maximise overall output based on accurate and current information.

The support for the integration of cutting-edge sensing and automation technologies, such as autonomous farming systems and precision agriculture, is another unanticipated but welcome benefit of this complete solution. These technologies can further improve the efficacy and efficiency of every single one of a farmer's everyday tasks.

B. Better NB-IoT Link Adaptation

In the context of Narrowband-IoT (NB-IoT), a crucial technology for the Internet of Things (IoT), the principles of Non-Orthogonal Multiple Access (NOMA) can aid in enhancing uplink coverage, dependability, and latency. Adaptive link adaption solutions developed with NOMA principles are shown to be advantageous for NB-IoT networks. Better resource allocation results from this, which can significantly boost system performance, especially when it comes to coverage enhancement. NB-IoT, a licensed low-cost Power Wide Area Network (LPWAN) technology, meets the requirements of Internet of Things applications, such as low power consumption, long-range connectivity, deep indoor penetration, and low cost. Some methods for increasing coverage, such as reducing bandwidth and using repetitions, have been proposed and have shown some degree of success. NOMA's user multiplexing and power domain multiplexing can be applied to NB-IoT as additional coverage-enhancing techniques. For example, NOMA can provide more efficient use of radio spectrum and improved spectral efficiency by enabling several devices to use the same time-frequency resource block. According to the paper, NB-IoT facilitates both single-tone and multi-tone uplink transmission. There are choices with 12, 6, and 3 subcarriers in the case of multi-tone. There is only one subcarrier in a single-tone system, spaced either at 15 kHz or 3.75 kHz. In order to increase coverage and dependability, this demonstrates how NOMA concepts can be applied to enable dynamic tone allocation based on user requirements and channel conditions [19].

In NB-IoT, the link in question needs to be optimized by adjusting it to the maximum level of efficiency. It also adjusts to channel conditions to improve performance of the system by modulating the MCS (modulation and coding schemes), tones, and repeats. The link adaptation mechanism is depicted in Fig. 7. This adaptation is done on the SNR which the SRS (Secondary Reference Signal) gives. The MCS, tones, and repeats are altered in an adaptive way to produce a specific block error rate (BLER). The link adaptation strategy with the use of NOMA enables more dynamic allocation of resources, which incorporates multiplexing of power resources, and user multiplexing. We will be able to set the tones and repeats as per the channel conditions and traffic load. The potential options of the uplink data repetitions include 1, 2, 4, 8, 16, 32, 64, and 128 [11]. The decline of tones and MCS depending on the tone number of repeats shows that poor channel conditions decrease the link adaptation strategy depending on NOMA and shows the criticality of flexibility in link adaptation to NB-IoT. The optimization of the NB-IoT systems in terms of maximizing the available performance is crucial in changing and diverse environments. This can be utilized to create effective algorithms and protocols to allocate resources adaptively to improve the performance of a system based on the NOMA principles to achieve better performance in terms of coverage, reliability, and latency. The NS-3 simulator allows to assess the performance of link adaptation strategies in the open space and in urban conditions through random

scenario generation.. This methodology monitors how various parameters, such as MCS, repeats, and tones, respond to user distribution patterns and the prevailing channel conditions. The simulations demonstrate that there are great trade-offs between the latency, coverage, and reliability and the importance of adaptive resource allocation algorithms in the optimization of the system performance. Also, there are adaptive resource allocation techniques with NOMA which significantly enhance the overall system performance, demonstrated by the graphs representing the Packet Delivery Ratio (PDR) and average delay/latency at various regions of open and urban settings [9].

C. SWAFM Connectivity with NOMA-capable IoT

A major development is the integration of NOMA-based Internet of Things (IoT) with Smart Water and Fertiliser Management (SWAFM) into an agricultural system to achieve maximum water and fertiliser management.. Within an agricultural environment, this integration improves the overall system performance, efficiency, and reliability of data transmission.

The SWAFM platform gains a number of important advantages from NOMA-based communication. NOMA maximises the utilisation of available radio spectrum and improves system spectral efficiency by enabling many devices to use the same time-frequency resource block. As a result, cloud services, Primary Data Collectors (PDCs), and nitrogen, phosphorus, and potassium (NPP) sensor nodes communicate much more reliably and effectively.

How may the SWAFM platform's NPP sensors benefit practically from NOMA-enabled IoT connectivity? On the other hand, communication between the NPP sensors and the adjacent PDCs is crucial for monitoring the soil conditions that are necessary for each plant's growth. NOMA enables the NPP sensors to safely and efficiently transmit their data, first to the PDCs and then to the cloud services. They can use additional field sensors, such as temperature and water level sensors, to determine the right power depending on the NOMA connection. This would allow them to obtain precise and fast data from the farmers for well-informed decision-making.

Numerous problems must be resolved to properly integrate NOMA principles into the SWAFM platform. To improve the effectiveness of NOMA-based communication and guarantee simple interaction with the current SWAFM platform, they consist of power allocation, user grouping, and interference reduction. Because system performance must be optimised and the adoption of the current SWAFM architecture must be seamless, these strategies and protocols are essential. First of all, they may have user grouping and dynamic power allocation to optimise NOMA-based communication efficiency. In order to optimise the power for closing the Real communication throughout the user normalisation process, the IoT devices whose connection has been nominated would dynamically regulate their transmission power to adjust to the changing channel conditions [20]. Additionally, they would control the procedures for managing interference and allocating resources necessary to smoothly integrate the NOMA principles into the SWAFM platform, which would put water and fertiliser management under control. The SWAFM platform's water channel design could also benefit from IoT technologies. Where IoT-enabled valves and GPS sensors are used, agricultural fields are likely to experience free water flow, improving irrigation

efficiency and promoting greater water conservation. Water channels in agricultural fields can be precisely designed because of the exact field structure data provided by GPS sensors. IoT-enabled valves regulate water flow in real time, enabling more accurate and efficient irrigation techniques when combined with NPP sensor and PDC data. Water is eventually saved because of this more effective use of water. Sensors and PDCs make sure that their data reliably reaches cloud services with NOMA-enabled IoT technologies, which leads to more data that provides more precise feedback in fertiliser and water management methods.

5. RESULTS AND DISCUSSIONS

5.1. Performance Assessment and Field Deployment:

A comprehensive performance appraisal and practical testing would be required to transition the NOMA-enabled NB IoT solutions to smart agricultural applications beyond just a promising concept to deployed technology and figure out their actual effectiveness in the context of agricultural applications. The prototype systems with the proposed NOMA-based communication features should also be integrated into the real agricultural settings to correctly evaluate the key performance indicators and comprehend the effect of NOMA on the productivity and efficiency of smart agricultural processes. This would require carrying out field tests in real life environments to confirm the effectiveness of NOMA-powered IoT systems within real life agricultural environment. Test systems, which employ the suggested NOMA-based communication technology, i.e., NPP sensors, PDCs, and cloud services are used during these trials in various places in actual agricultural field. The suggested NOMA-based IoT solutions are tested in diverse geographical areas and environments to collect as much data as possible on their performance in the agricultural fields in different regions. The variety of the soil types, types of crops, and climate patterns are covered in this study to present the variety of opportunities and challenges related to the implementation of NOMA-based IoT systems in the real-life smart agriculture settings. An example of such initiative is the implementation of NOMA-enabled IoT-based systems in real agricultural plots in diverse regions and measuring the real performance of the systems with a range of the environmental factors, such as different kinds of crops, type of soils, and weather conditions. In order to have the most comprehensive analysis of the actual impact of the NOMA integration on the performance of the proposed IoT solutions in smart agriculture, some key performance indicators are measured in the course of these field tests. This project, once again, would seek to investigate the functional possibility and challenges associated with the implementation of the NOMA-based IoT-based solutions in the field of smart agriculture through the deployment of such systems in actual farms in different regions and investigate their functionality under different environmental conditions, including the types of crops, types of soil, and weather patterns. In order to comprehensively estimate the practical impact of an integration of NOMA on the functioning of the suggested IoT-based solutions in smart farming, a set of key performance indicators are measured during these field tests. As a case in point, the supplementary data that can be transmitted within a particular time can be evaluated by examining the data transmission rates between the NPP sensors, PDCs, and cloud services using NOMA. This would result

in the faster decision-making process in smart agricultural operations. Reliability: The capability of NOMA-enabled Internet of Things systems to regularly interchange information and communicate in different settings. On measuring reliability, the loss of packets, signal strength, and interference levels are considered. • Energy efficiency: Since the IoT gadgets deployed in remote farming locations may receive power supply with limited resources, energy efficiency is critical. The power usage of the NOMA-enabled IoT devices is compared to the ability of such devices to prolong battery life and reduce energy costs. Latency: This is an important factor of the NOMA-enabled IoT systems since it entails the time interval between the time when data sent and received. In smart agriculture applications where real-time monitoring and control are needed, e.g. crop health monitoring and irrigation scheduling, latency is to be minimized. This comparison examines the potential effects of NOMA-enabled IoT technologies on fertilizer and water management: because the technology is able to transmit data more efficiently and accurately, it may result in increased efficient irrigation patterns, lesser use of water and more efficient delivery of fertilizers to crops, which can in turn improve agricultural productivity and yield. B. Optimization and Scalability: In case of smart agriculture, the scalability and optimization of NOMA-enabled IoT solutions play an important role in terms of their effective operation in large-scale agricultural environment. This part provides the scalability of NOMA solutions, such as Smart Water and Fertilizer Management and Narrowband IoT technologies, and the opportunities provided by optimization strategies. • Dynamic Power Allocation: In the NOMA-based IoT networks, dynamic power allocation plays a crucial role in enhancing the best communication facilitation to SWAFM. This will be achieved by allocation of SWAFM power in which the device power resources are distributed according to the necessary communication and channel conditions to optimize the spectrum utilization and reduce power consumption. Consequently, the complex algorithms to be created to assist in real-time communication with authority distribution during peak and off-peak times will necessitate the implementation of SWAFM devices based on the NB-IoT technology. User Grouping: With the user grouping capabilities of NOMA-based Internet of Things networks, one can optimize SWAFM devices based on NB-IoT in a number of ways: SWAFM can use multipath fading and user diversity to achieve spectral efficiency and system capacity by dynamically grouping devices with similar communication properties or spatial connections. Moreover, more sophisticated clustering algorithms that meet the needs of SWAFM and the NB-IoT capabilities can be successfully used to combine devices and to maximise the performance of the system and control the interference. • Interference Management: In the agricultural environment in which there is dense vegetation and a number of IoT devices are running concurrently, coordinating the interference is pivotal in improving the performance potential of SWAFM.

. Moreover, advanced mitigation techniques such as beamforming and interference alignment are effective strategies for minimizing co-channel interference when employed in conjunction with NB-IoT technology. To provide increased throughput and dependability in high-interference situations found in agricultural use cases, SWAFM cleverly aligns transmission beams and controls interference with beamforming.

• Analysis of Trade-offs: In addition, a careful examination of trade-offs is necessary to optimise utility in spectrum efficiency over system complexity and energy consumption to maintain an acceptable link

between SWAFM and NB-IoT technology [21]. For instance, the spectral efficiency and capacity would be significantly improved by the possible increased throughput with NOMA. But there's also a chance that energy usage and system complexity will rise significantly. To preserve scalability in actual large-scale applications within the agricultural domain, SWAFM's optimised SWAFM techniques would need to balance the trade-offs between maximising spectral efficiency over system complexity and energy consumption.

6. CONCLUSION

• This paper has discussed the introduction of NOMA into the Internet of Things networks in smart agriculture with particular focus on the SWAFM platform and NB-IoT technology. We discussed the potential of NOMA to enhance spectrum efficiency, optimisation of fertiliser and water, and size the application of NOMA-enabled IoT technologies in massive agricultural environments. Through our studies, we have found that NOMA has the potential to significantly improve spectrum utilization and connectivity of agricultural sensor systems, enabling more reliable, scalable and efficient powering of sensors and associated data. Also, the inclusion of NOMA in SWAFM has made it possible to manage water and fertilizers better, which is essential to boost agricultural productivity and sustainability. Additionally, we find that the implementation of the NOMA concepts to NB-IoT has resulted in significant improvements in uplink coverage, reliability, and latency parameters which are crucial towards the implementation of advanced IoT services in the agricultural sector. Our study has far-reaching and far-reaching implications to smart agriculture. The introduction of NOMA-based IoT technologies in agricultural projects will most probably lead to greater resource use, which will lead to higher yields and to a better ecological sustainability. Moreover, the combination of NOMA and the SWAFM platform will help to manage the water and fertilizers more efficiently and give farmers access to real-time data and analytics to make better decisions. More advanced coverage and reliability of NOMA-enabled NB-IoT networks will enable farmers to have more control over the operation of the fields, hence precision agriculture.. RECOMMendations to the next research. In this paper, we have provided preliminary details of the implementation of NB IoT based on NOMA to support smart agriculture. In order to completely exploit NOMA to IoT networks to serve the smart agriculture, there are some other aspects that would be valuable to explore more. Some of the areas we would recommend to be studied further include: • Dynamic Resource Allocation: More advanced algorithms and protocols to dynamically allocate power, group users, and control interference are under investigation, to be better suited to the dynamic nature of agricultural environments, with the use of NOMA-enabled IoT networks.• Field experiments and Validation: To validate SWAFM integration and NB-IoT enhancement for NOMA-enabled IoT systems in various agricultural settings, real-world field experiments and performance assessments should be carried out using realistic time and space situations.

• Optimisation and Scalability: To solve network densification and scalability challenges, various optimisation and scalability strategies for implementing NOMA-enabled IoT solutions should be suggested in expansive agricultural areas and networks such as 5G.

• Interdisciplinary Collaboration: As part of future research, telecommunications engineers, agronomists, and IoT developers should collaborate to co-design and implement more creative solutions that directly address the crucial problems that modern agriculture needs to solve.

DECLARATIONS

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are included in this published article and its supplementary information files.

Declaration of Interest Statement

The author, **Dr. Vineet Kumar**,**Deepak Sharma** declares that there are **no known competing financial interests or personal relationships** that could have appeared to influence the work reported in this paper.

This research was conducted **independently**, without any financial or non-financial support that could lead to a conflict of interest. The author affirms that the views expressed in this manuscript are solely those of the author and do not necessarily reflect the views of the affiliated institution, **Noida Institute of Engineering and Technology (NIET), Greater Noida**.

Competing Interests

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Ethics and Consent to Participate declarations

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Not applicable

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Figures

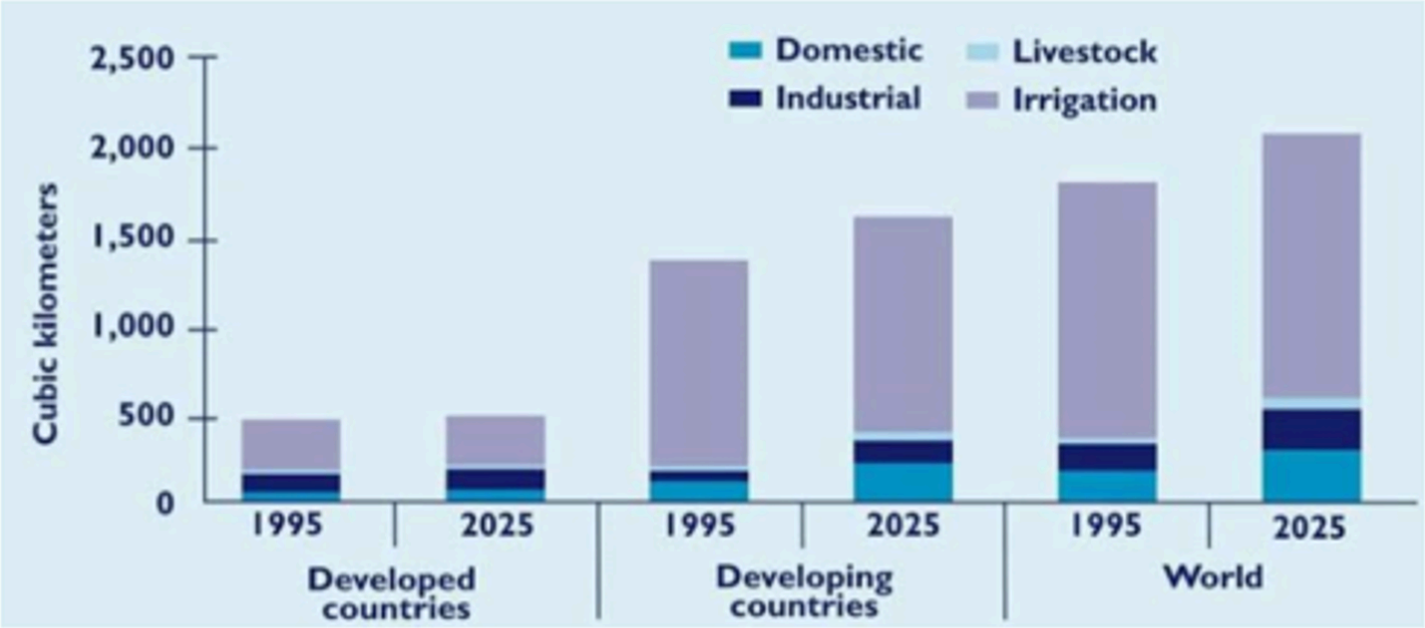


Fig. 1. Upcoming water needs for Agriculture

Figure 1

See image above for figure legend.

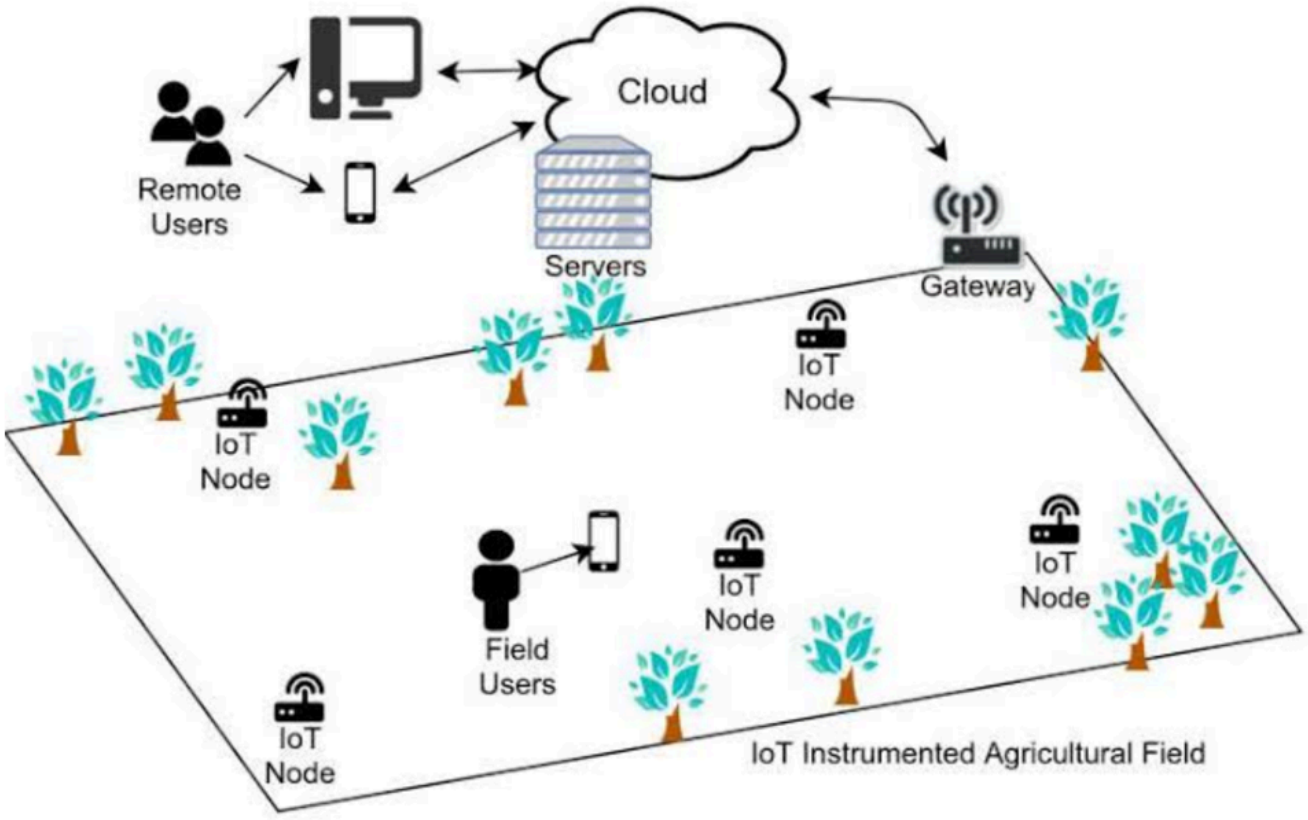


Figure 2

IoT Instrumented Agricultural Field

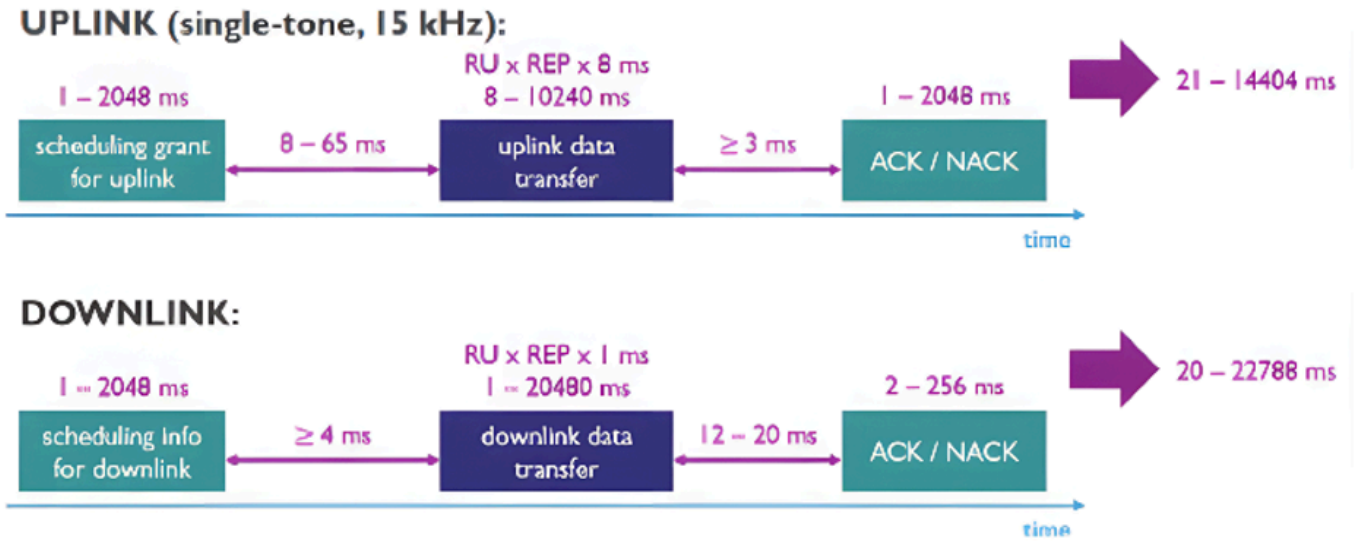


Figure 3

NB-IoT data transfer and scheduling

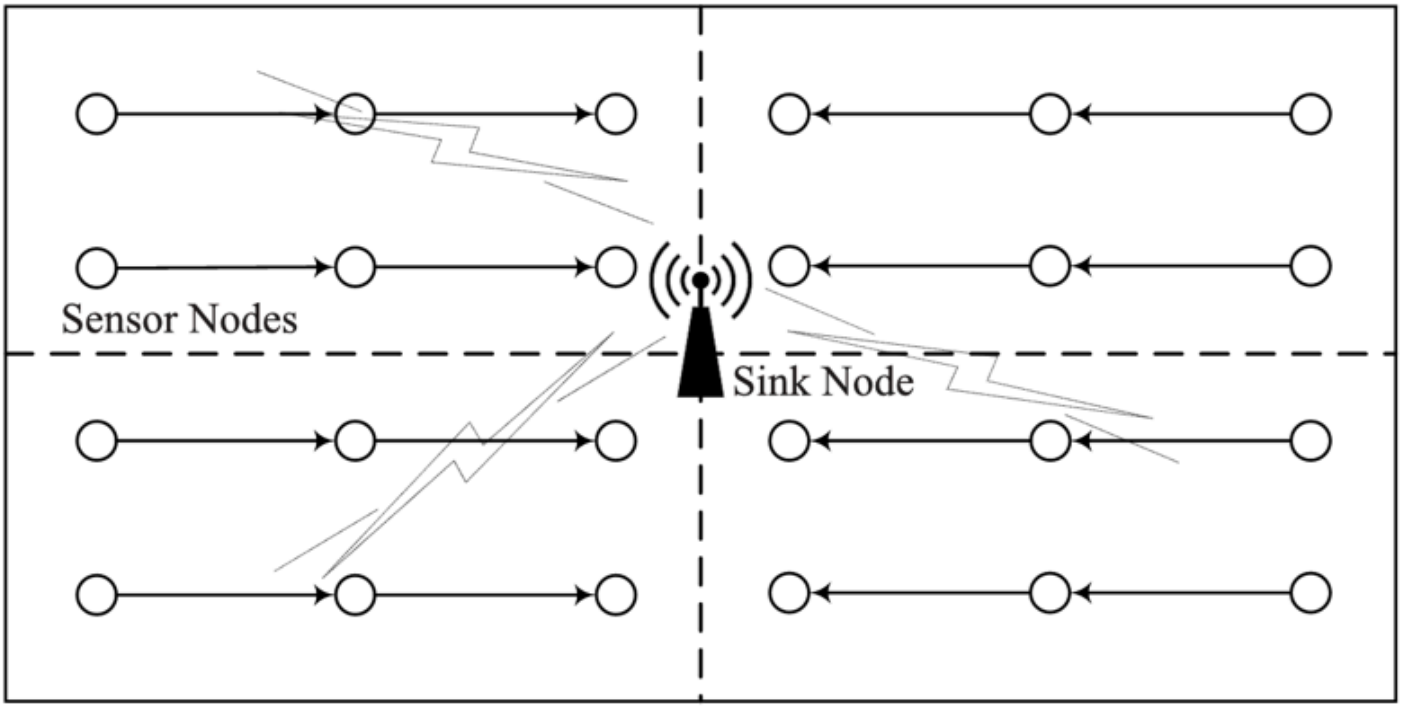


Figure 4

6 shows a rectangular farm field with WSNs in agriculture.

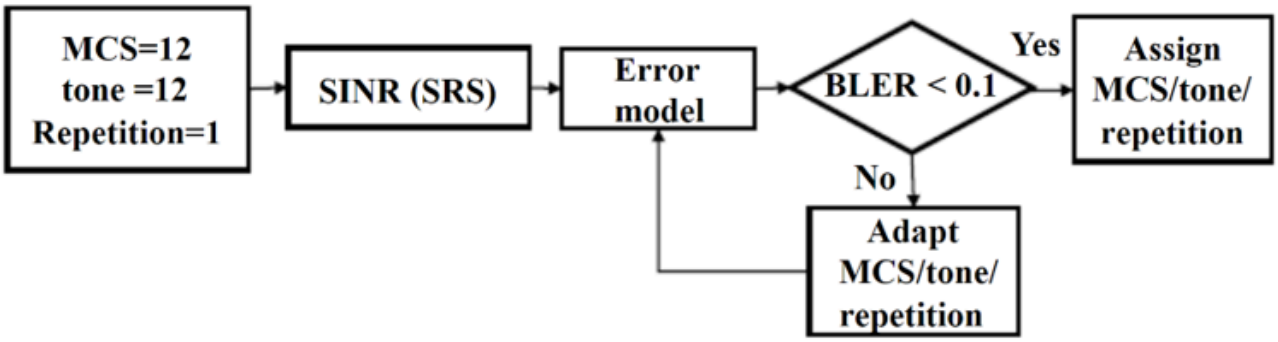


Figure 5

7: The Mechanism of Link Adaptation