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Impact of NextGen Wireless 5G Network on Agriculture

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Abstract*: The advent of next-generation wireless networks, particularly 5G, presents a transformative opportunity for the agriculture sector. The potential impact of 5G technology on agricultural practices, highlighting the opportunities it brings and the challenges that must be addressed for successful integration. Smart and precision farming allows farmers to be more informed and productive. The advent of 5G will considerably change the nature of jobs in farming and agriculture. The internet of things (IoT)-based cloud computing service in the 5G network provides flexible and efficient solutions for smart farming. This will allow the automated operation of various unmanned agricultural machines for the plowing, planting, and management phases of crop farming and will ultimately achieve secure, reliable, environmentally friendly, and energy-efficient operations and enable unmanned farms.*

Keywords: 5G, Smart Agriculture, IOT, Monitoring, Deep learning, Cloud-edge.

I. INTRODUCTION

The demand for smarter and more efficient agriculture is on a never-ending rise as farmers seek to maximise yields and minimise costs. Agricultural businesses seek to source high quality agricultural production, taken to market efficiently, and of sufficient quantity to sustain their market and profits, as well as to minimise the environmental footprint of their supply chain and operations. In this respect, according to the International Food Policy Research Institute, data-driven. The associate editor coordinating the review of this manuscript and approving it for publication was Mostafa Zaman Chowdhury. techniques can support the agricultural and food sectors to achieve the expected doubling of demand for food by 2050 by increasing farm productivity by as much as 67% and cutting down agricultural losses. The size, scale, and unstructured nature of future data-driven agriculture and Internet of Farming (IoF) require the usage of new analytical tools and frameworks to be developed and employed. These frameworks need to be flexible enough to weave together data from millions of hectares and from various sources, such as weather data, yield data, satellite imagery, small unmanned wireless sensor networks, aerial imagery, planting prescriptions, embedded intelligence in equipment, and equipment diagnostics. Once in place, these solutions enable the creation of predictive modelling and better models to manage crop failure risk and to boost efficiency in crop production. Hence, data-driven agriculture is a driver to provide predictive insights to future outcomes of farming, drive real-time operational decisions, reinvent business processes for faster innovative actions and game-changing business models. If these goals are achieved, it has the potential to be the next agricultural revolution of smart products utilizing precision application of inputs, yield monitors, and other sites specific sensors to a point where the system can be evaluated. Within this context, mobile technology is increasingly leading to the creation of innovative services and applications that are used throughout the agricultural value chain to help farmers make the most of the resources available to them. Considering just one example, field trials have shown thattechniques that use sensor measurements to apply site specific amount of irrigation water can maintain yield while reducing the water intake by 32% on a regional scale and on field scale by 25%. Similar techniques to vary other farm inputs like seeds, soil nutrients, etc., have proven to be beneficial. The advent of aerial inspection systems has enabled agricultural advisory services and Farm Management and Information Systems (FMIS) to get richer sensor data. Over time, all this data can indicate useful practices in farms and make suggestions based on previous crop cycles; resulting in higher yields, lower inputs, and less environmental impact. A key challenge in many locations for the further development of data- driven agriculture is the lack of seamless connectivity. Without ubiquitous network availability, the agricultural sector falls at risk of not progressing at the same pace other more digitized industries do, causing an impact not only on the supply chain, but also on the overall customer satisfaction. Therefore, the IoF and data-driven agriculture are about connectivity. Beyond the introduction of new tools and practices, the real promise of data-driven agriculture in terms of productivity increase, resides in the ability to remotely collect, use, and exchange data. Without sufficient wireless data transfer service, automated real-time communication between farm equipment and online servers is not possible, forcing producers to rely on manual data transfer, which may nothappen until after the season is over. By then, opportunities to adjust management practices are missed,significantly affecting farm profitability, productivity, andenvironmental benefits. In addition, agricultural areas that lack adequate connectivity may lead to geospatial data not being sufficiently backed-up in a timely manner, therefore increasing the risk of this valuable data being lost or destroyed. In this respect, agricultural areas are slowly benefiting from the evolution of communication technologies. The advent of the Internet of Things (IoT) came with associated development of new solutions based on Low Power Wide Area Network (LPWAN) technologies which, together with Wi-Fi, satellite, and cellular 4G communications, are the main connectivity options applied to smart agriculture applications nowadays. This set of available communication technologies will be complemented with 5G. By design, 5G technology will be capable of providing higher capacity, higher data rates, lower latency, and increased energy efficiency than previous generations of mobile cellular technologies. Therefore, 5G is expected to be an enabler for more flexible and efficient solutions for smart farming. The research presented in this paper aims at exploring the applicability of 5G technology to the IoF and data-driven agriculture. To do this, a number of relevant technology use case scenarios with emphasis on farm machinery are defined and described together with their associated connectivity requirements. The feasibility of operation ofthese use cases over 5G is evaluated based on the empirical results obtained in an extensive live 5G trial thatwas carried out in a representative agricultural area in the south of Denmark. Further, a reference methodology to accurately measure Quality of Service (QoS)-related parameters for evaluation of 5G performance in a data- driven agriculture context was developed. The main contributions of this paper are listed as follows:

- Reference list of data-driven agriculture scenarios and use cases and related communication requirements.
- Summary of the state of the art in communication technologies for data-driven agriculture, including current 5G perspectives.
- Reference methodology for measuring 5G QoS in the context of data-driven agriculture, including Mult connectivity schemes.
- Report and discussion of results from an early 5G trial with focus on data-driven agriculture scenarios, including an overview of the current suitability of early 5G networks for operating advanced agricultural use cases. The rest ofthe paper is structured as follows: Section

II addresses the definition and characterization of data- driven agricultural scenarios, and surveys the state-of- the-art communication technologies applied to agricultural operations. Section III describes in details thedevelopment of the 5G QoS measurement framework, together with the measurement equipment and scenario considered in the live 5G trial. Section IV details the 5G measurement results with focus on the relevant QoS parameters for evaluation of the suitability of data-drivenagriculture use cases. Section V presents an analysis of the 5G trial results and elaborates on the current capabilitiesof early 5G deployments to provide data-driven agriculture and IoF services.

II. WHAT IS 5G?

5G is the next generation of wireless cellular technology. It will provide speeds faster than any previous generationup to 3000 Mbps (3 Gbps) in the real world, depending onthe conditions and the tech being used competing even with those delivered via Fiber-optic cables. Movies that took minutes to download with 4G will take seconds with 5G. While smartphones and other mobile devices are the obvious use cases for 5G, there are many other applications for the technology. The internet of things (IoT), for example, will benefit tremendously from the speed and bandwidth provided by 5G, especially as the industry grows. In 2020, there were an estimated 12B IoT connections globally, according to IoT Analytics. By 2025, it is anticipated that there will be more than 30B IoT connections around the world, more than 4 IoT devices for every person on Earth. Autonomous vehicles, robotic surgery, and critical infrastructure monitoring are just a few of the potential applications of 5G-enabled IoT.

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Agriculture and Applications Supported by the 5G Network

Currently, the agricultural industry is facing challenges to support farmers to take full advantage of new technologies, with 5G being one of the main innovations. According to expert considerations, 5G will be responsible for generating major changes in farm productivity. In this context, innovation in agriculture emerges as a crucial priority and an essential component of the post-COVID-19recovery.

It is expected that 5G-supported SF will enable the deployment of many sensors to measure and monitor in real time the state and quality of the soil, moisture, nutrients, etc., providing answers to various questions that will improve efficiency and generate savings in agricultural production costs, among other advantages. A brief description of the main agricultural activities showsthat there are opportunities for the use of 5G technology at every stage of production, including land preparation, planting, harvesting, and post-harvest. However, currently, the processes developed in the production stages are limited by the fact that data are collected manually (offline), making them difficult to analyse, plan,and make decisions about crops and animals. This and other limitations of the sector can be improved with the use of 5G.

Although the benefits of 5G are numerous, many technical issues still need to be resolved to achieve an efficient deployment of this technology to ensure reliable data transmission in SF scenarios. Given that transmitted bits are susceptible to errors caused by phenomena such as noise, fading, or interference, and that the propagation of radio waves in the millimeters bands represents a real challenge from the point of view of coverage and data reliability, one of the challenges facing 5G is related to theoptimization of channel coding and, consequently, error correction codes. In this regard, the replacement of traditional turbo codes with other techniques such as low- density parity check (LDPC) or polar codes has been considered. The former have better performance characteristics, but are difficult to implement due to theircomputational complexity, while polar codes are easier toimplement thanks to less complex algorithms, but at the cost of sacrificing performance.

Another challenge for 5G/IoT deployment in smart farms is the power consumption of user terminal equipment (UE), which are often located in rural or remote areas and, therefore, need to extend the charging time and lifetime of their batteries. In 5G, the cyclic prefix orthogonal frequency division multiplexing (CP-OFDM) waveform is used in the downlink, while CP-OFDM or discrete Fourier transform orthogonal frequency division multiplexing (DFT-OFDM) can be used in the downlink. Since the peakaverage power ratio is lower in DFT-OFDM, its adoption will decrease the power consumption in UEs, which is necessary for IoT systems in SF. In addition, the possibility of using higher-frequency bands (e.g., above 70GHz) in the future in 5G and the future 6G makes it necessary to consider single-carrier waveforms.

Agriculture (real time monitoring & automation of agriculture machinery & Systems)

5G could have a major impact on the agricultural sector, especially on improving crop yield - an essential task, given that the world will need 70% more food in 2050 than it did in 2009 due to population growth, per the UN Food and Agriculture Organization.

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5G could provide real- time data for farmers to monitor, track, and automate their agricultural systems, resulting in increased profitability, efficiency, and safety. In a high-risk industrysuch as agriculture, these increases in production and precision are vital, especially as climate change poses newthreats to farmers around the globe. Autonomous tractors, for example, may eventually use 5G to pair with drones to guide their work, like identifying which parts ofa field need fertilizer. Similarly, machinery manufacturer Blue River Technology uses chip maker NVIDIA's 5G- enabled edge platform to power its AIbased "See & Spray"technique. This method equips tractors with cameras thatcan discern a weed from a crop and can then spray the appropriate solution to kill or nurture the plant. 5G couldalso drive the adoption of IoT devices for farming, which will improve agricultural processes such as water management, irrigation, livestock safety & maturity monitoring, crop communication, and aerial crop monitoring. The Food Resiliency Project is an example of an initiative that has brought together different stakeholders to find ways to apply 5G to farming. For instance, the project has combined edge computing technology, IoT deployments, and 5G networks to improve crop yields by continuously analysing soil conditions.

III. 5G MEASUREMENT METHODOLOGY

Specific 5G QoS testing methodology and testing equipment and setup were developed. The testing methodology was based on the previous cellular networkcharacterization work done by the authors in, while the dedicated equipment was built on top of the reference design (originally designed for 5G Industry 4.0 manufacturing applications) reported by the authors in [34]. To empirically assess the 5G network capabilities, the primary focus was the implementation of a measurement device able to monitor and record the relevant communication QoS parameters: link latency, PER, and throughput (data rate). For further reference, the device was designed to also record timing, Global Positioning System (GPS) position, and 5G signal strength(as received power in dBm), and 5G signal quality in termsof Signal-to Noise Ratio (SNR). Recording and analysing allthese parameters over a specific measurement route, allows for direct assessment of the 5G capabilities for providing data-driven agriculture. This is also enabled bythe fact that the overall setup and flows of data in the test resemble the main IoF system architectures, where different application end-point farm machines collect andsend/receive data via wireless Internet connection to a cloud-based server. Under these flow considerations, a 5G-capable user test device, which also serves as measurement device, and a dedicated cloud server hostedby Aalborg University and accessible via Internet (located in Aalborg, Denmark, approximately 250 km from the location of the test). All measurements were performed between these two devices, meaning that the data traffic from the 5G user device to the cloud server will traverse the 5G radio network, then the 5G core network and Internet Service Provider (ISP)'s backbone (located in Copenhagen, 300 km from the location of the test), then the general Internet, and finally the Aalborg University intranet. Effectively, the measurements include combined communication effects from both the wireless 5G network, the fixed network infrastructure, and server processing performance impact; shedding some light on the end-to-end performance of cloud-based agricultural systems. The 5G measurement setup was further designed to support advanced multi-connectivity, which isa simple connectivity solution based on hardware duplication that might be of interest for farming and agricultural technology verticals requiring reliable wireless support for their industrial applications. Multi- connectivity is implemented by considering two 5G network modem interfaces (instead of one as is normallydone) at the user device to increase the availability and reliability of the 5G connection by using the best of the two or a combination of both. Multi-connectivity schemes, rely on the uncorrelation in time and space of poor network performances or failures on the different interfaces [33]. This means than when one of the interfaces might be experiencing long delays or transmitting low data due to high number of connected users, long distance to the serving cell, or is performing a cell change; the other might be connected to a nearer different cell and, thus, experiencing a better connection enabling the possibility of having better latency or higher data rate transmissions. Hence, the methodology developed for assessment of the suitability of 5G for data-driven agriculture and IoF will consider not only the standard 5G user performance, but also the one that could.

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

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

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

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

5G Networks in Medicinal Farming

According to forecasts, the global herbal medicine market is expected to experience substantial growth, increasing from $165.66 billion in 2022 to an estimated $347.50 billion by 2029. This growth signifies a significant compound annual growth rate (CAGR) of 11.16% over the forecast period. Private 5G networks are poised to revolutionize medical farming across the globe, offering numerous benefits in terms of connectivity, automation, and data-driven decision-making. In this article, we will explore some compelling use cases and provide relevant statistics to highlight the potential impact of private 5G networks in different parts of the world.

Smart Greenhouses: Private 5G networks enable the creation of smart greenhouse environments, where environmental factors can be precisely controlled to optimize plant growth. The Asia-Pacific smart greenhouse market is projected to grow at a CAGR of 10.2% from 2020 to 2027, according to a report by Grand View Research.

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Efficient Resource Management: By leveraging private 5G networks, farmers in Asia can optimize resource utilization by monitoring water usage, fertilization levels, and energy consumption. This leads to cost savings and environmental sustainability. The Asian Development Bank estimates that Asia will require an additional $800 billion in annual food investments by 2030, highlighting the need for advanced farming technologies. synchronized via GPS. This means that both ends in our 5G measurement setup are fully-synchronized, allowing for accurate link latency measurements.

V. CONCLUSION

Advanced wireless technologies, such as 5G, offering highreliability, high data rates, and low latency are expected tobe an enabler for new applications of digital technology in agriculture. Through this paper, a number of verticals, which have the potential to exploit such new communication technologies to optimize agricultural outputs have been identified. Such vertical lead to the definition of a number of related use case scenarios, together with their associated communication requirements. Based on the requirements, the use cases were classified according to their service types: Extreme Mobile Broadband (xMBB), Massive Machine-Type Communications (mMTC) and Ultra-reliable Machine-Type Communications (uMTC). An extensive 5G drive testwas performed in a representative rural area in the Southof Denmark to evaluate the suitability of operation for the defined use cases. The trial results, obtained over an early 5G Non-Stand-Alone (NSA) Release 15 deployment, revealed median Quality-of-Service (QoS) performancevalues of 24.5 ms for Round-Trip Time (RTT) link latency, 0.21% for Packet Error Rate (PER) reliability, and 80.1/35.5 Mbit/s for Downlink (DL)/Uplink (UL) data rate, respectively. Such early 5G network performance, indicates that mMTC use cases can be reliably operated inapproximately 99% of the cases, while certain xMBB use cases (those requiring data rates up to 10-50 Mbit/s) can be reliably operated in 65.8-97.7% of the cases. The measurement results suggest that uMTC use cases cannotbe supported in early 5G deployments, as they demand extremely low latency (lower than 10 ms), which is not achievable by design over NSA Release 15 configurations. Simple 5G device multi-connectivity schemes, based on the use of two interfaces as opposed to single modem approaches, are proven to enhance the early 5G system performance, and can be of great help for digital agriculture technology integrators. As telecom operators will continue the 5G rollout and network evolution towards Stand-Alone (SA) and the support Release 16 features, future 5G networks are expected to reliable provide support to all the listed data-driven agriculture use cases for continuing the technological development ofthe Internet of Farming (IoF).

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