Application of mobile networks (5G and beyond) in precision agriculture – draft

Lechosław Tomaszewski* [0000-0003-3836-7900]
Robert Kołakowski*◇ [0000-0002-5451-8847]
Mirosław Zagórda‡ [0000-0002-4514-1048]
*Orange Polska, ◇Warsaw University of Technology
Warsaw, Poland, ‡University of Agriculture in Kraków

Abstract

The multiple capabilities offered by the 5G network have significantly accelerated the expansion of the service portfolio of telecommunication operators. The future mobile network is expected to elevate these possibilities to an even higher level. Enormous data rate, near-to-zero latency and gigantic density of devices will allow for building robust and innovative ecosystems providing specialized services to the vertical industries. Moreover, the progress in network expansion towards the edge has facilitated the provisioning of services with stringent requirements much closer to the interested parties. One of such demanding field of services, which is recently gaining much economical significance, is Precision Agriculture (PA). The goal of the paper to present and assess the possibility of application of 5G and next-generation mobile networks to facilitate PA use cases. After the requirements assessment and 5G network capabilities analysis, the assignment of currently defined slice types and 5QI to the typical PA services is proposed. Moreover, the readiness of the 5G network as well as missing features with regards to PA are identified and addressed to 5G-Advanced and future 6G mobile networks.

Index Terms

5G, 5G-Advanced, 6G, Precision agriculture, Smart agriculture, Vertical services, Network slicing, UAV, V2X, MIoT, URLLC, eMBB, Augmented Reality, mMTC, HMTC, Sensors, MEC

I. Introduction

The 5G System (5GS), since its very first vision formulated by the International Telecommunication Union (ITU) [1], has been expected to introduce massive benefits to wireless communication-based services. One of the main targets of the new mobile generation was to provide one common solution that could address stringent and robust requirements of different vertical sectors. Several innovative mechanisms have been proposed by the Standards Developing Organizations (SDOs), with the most notable and revolutionary concept of network slicing – splitting a mobile network into a federation of several ones, each architecturally adapted to support a specific service. So far, five Slice/Service Type (SST) categories have been defined, each targeting a specific range of services characterised by common priority requirements, namely, Enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLLC), Massive Internet of Things (MIoT), Vehicle to Everything (V2X) and High-Performance Machine-Type Communications (HMTC) [2]. Additionally, the mechanisms that allow for data processing at the edge of the network have been also devised. The ETSI Multi-access Edge Computing (MEC) platform [3], integrated with the networks slicing-enabled 5GS, opens up a plethora of new possibilities regarding local-level provisioning of the low-latency and high-bandwidth services. This trend is expected to be further enhanced by the introduction of 6G System (6GS) featuring near-to-zero latencies, Tbps data rates and advanced mechanisms supporting even the most demanding use cases.

One of the relatively new field of application of 5G-based communication – important in the context of the continuous improvement of the efficiency of food production with minimization of its environmental footprint – is Precision Agriculture (PA). Its main goal is to utilize high-end technologies, including wireless communication, as well as control loop-based systems to optimize agricultural processes, e.g. by avoiding excessive fertilization or pest management and optimizing the agrotechnical treatments, thus contributing to sustainable use of natural resources and limiting the natural environment contamination.

The goal of the paper is to outline the application of the 5G and future mobile communication technologies in the field of PA emphasising demands heterogeneity – so far poorly recognized in the telecommunications sector – and a need to integrate multiple communication approaches to enable implementation of efficient End-to-End (E2E) systems. The paper is structured as follows. In Section II, the specificity of the PA sector is presented. Section III describes the work related to the 5G advancements relevant to this sector. In Section IV, the characteristics of the PA processes and related data exchange are outlined. Section V is devoted to 5GS applicability to PA and identification of gaps. Section VI concludes the paper.

II. Specificity of the sector of precision agriculture

PA is a relatively new trend in the field of agricultural science and practice, proposed at the beginning of the 1990s, which is based on the computer-aided process of planning, conducting and analyzing the efficiency of plant production. However, the fundamental paradigm of PA is relinquishing from treating the field as a uniform area in terms of properties, and therefore

Supported by the Horizon 2020 project 5G!Drones (Grant Agreement No. 857031).

also subjected to agrotechnical treatments in a uniform manner, in favor of observing and measuring the spatial variability – with high resolution and accuracy of the order of single centimeters – of the properties of arable land (e.g. soil type, its abundance, reaction, the influence of the neighbourhood, terrain slope and its exposure, water conditions, microclimate, etc.), the occurrence of phenomena (e.g. properties of cultivated plants, their yield, presence of pests, damage due to violent weather conditions or caused by wildlife, etc.) and then adjusting the local point response to this variability. Consequently, e.g., the sowing rate can be adjusted locally to the soil properties, fertilizers' doses – to the nutritional requirements of plants, and pesticides' doses – to the local scale of infection or infestation [4]. PA is enabled primarily by the proliferation of Geographic Information Systems (GISs) and Global Navigation Satellite Systems (GNSSs), but also by the development of electronics (in particular, agriculture parameters metrology and ubiquity of embedded microprocessor systems), mechatronics, Artificial Intelligence (AI), and wireless data transmission technology to ensure continuous communication within the entire technical system of PA, thanks to which the spatial conditioning of agriculture and its processes is not an acute challenge.

PA is not an artificially sophisticated concept, but has strong economic, legal and social conditions and its development and implementation are motivated by an increase of: (i) efficiency of using the means of production in agriculture (10% fuel savings, even 85% pesticides' reduction [5]), (ii) yield, with a simultaneous reduction of production costs (100-300 EUR per hectare [6]), (iii) productivity of people and equipment (20-30% work time savings [6]), (iv) sustainability of the cultivation system by adjusting the treatments or dose of the means of production to the microhabitat, (v) quality of agricultural produce, and (vi) environmental protection by avoiding unnecessary or excessive application of fertilizers or pesticides. It is worth a mention that in the European Union, agriculture is under strong regulatory and legal pressure, e.g. control of the use of fertilizers [7] and pesticides [8]. In addition, the production of the chemical industry for agriculture is extremely energy-intensive. Therefore, in the current situation in geopolitics and the global energy carriers market, more efficient use of agricultural inputs and filling gaps in the supply of food and fertilizers from outside the European Union will be of vital importance for food security. These factors imply a rapid growth of the PA significance in the coming years.

Apart from plant production, the concept of PA may also apply (with appropriate modifications) to livestock production, forest management, and even fish farms [9]. Sometimes, the term Smart Agriculture (or "Agriculture 4.0"), in which the emphasis is on the rapid exchange of completely digitized information at all stages of agricultural production and also with external partners, as well as on advanced decision support by cloud-based expert systems, is presented as the next stage of the technological revolution in agriculture after PA. In this paper, both stages will be considered together.

III. Related work

The early visions of 5GS by ITU identified three fundamental usage scenarios: eMBB, Massive Machine Type Communications (mMTC), and URLLC – further commonly followed by the industry [1]. However, among the example applications, agriculture is not indicated, although previously listed as one of the fields of Internet of Things (IoT). The majority of scientific efforts and papers on the borderland of telecommunications and PA, share that vision and associate the PA needs and applications with "low-end" sensoric IoT, i.e. mMTC. Works beyond this approach are rare. The automated radio network planning framework for nomadic 5G campus networks, which optimizes the base station downlink (DL) coverage, is presented [10] for several receiver altitudes (0.1-1.5-3.5 m) relevant in an agricultural scenario. A platform of drones [11] constituted a flying *ad hoc* 5G network and provides acquisition of data from the agricultural IoT sensors located in rural areas with poor coverage. The drones can be also equipped with cameras and sensors for remote crop inspection. An iterative optimization method [12] to find the optimal drone's altitude and location, the antenna beamwidth, and the variable power and block length allocated to each robot inside the circular cell to minimize the average overall decoding error has been proposed for drone-assisted relay systems supporting the URLLC services for agricultural robots. In [13], the system for a big dairy farm (1000 cows), consisting of drones with cameras and 5G connectivity, the image recognition-based system for Real-Time (RT) individual dairy cow monitoring, behavior analysis and feeding, is presented. An electronic fence with 5G-connected cameras and image recognition is proposed for RT detection of unauthorized persons' access for reduction of damages and thefts on farms [14].

Within the EU Horizon program, there are several projects to deal with the PA needs. The IoF2020 project [15] has demonstrated the applications of IoT technologies in 19 agriculture use-cases around five trials (arable, dairy, fruits, meat and vegetables) in an operational farm environment all over Europe, but the connectivity for trials was provided with Radio Access Technology (RAT) types as LoRa and 3G/4G mobile network. The 5G-HEART project [16] deploys digital use cases involving healthcare, transport and aquaculture, i.a. (i) high bandwidth in-vehicle situational awareness and see-through for platooning based on bidirectional 80 Mbps Vehicle to Vehicle (V2V) connectivity with 99.99999% reliability, 5 ms latency, and 100 signalling messages per second; (ii) tele-operated driving based on 20 Mbps/20 ms connectivity; and (iii) remote monitoring of water and fish quality in aquaculture using eMBB, URLLC, and mMTC service slices for aquaculture remote health, sensoric and camera data monitoring as well as automation and actuation functionalities. The 5GENESIS project has shown the exemplary implementation of an agricultural use case, in which a 5G-connected camera in a drone or autonomous robot was feeding the image recognition system with crop images for weed detection and application of herbicide by a robot [17]. The 5G!Drones project [18] demonstrates an integrated ecosystem of aviation (drone control and traffic management) and telecommunications in a number of scenarios, i.a. infrastructure inspection, drone-enhanced IoT data collection and connectivity extension by a flying nomadic 5G base station. It is worth a mention that there is growing awareness in the EU bodies that the transformative 5G solutions in agriculture should go beyond the IoT area [19] and include Augmented Reality (AR), RT automation and remote operation.

The mobile network SDOs present different approaches. The 3rd Generation Partnership Project (3GPP) has not decided to separate the agricultural sector, in opposite to e.g. unmanned aviation or automotive sectors, but the general service requirements for 5GS [20] should be mapped on the PA needs. The most demanding PA use cases may be additionally addressed in the field of cyber-physical control applications in vertical domains [21] and video, imaging and audio for professional applications [22], both commonly classified by 3GPP as "Industrial IoT" supported by New Radio (NR), i.e. 5G RAT. The most important gap in the 5GS is related to location accuracy (30 cm precision/1 s latency, still far insufficient). The GSM Alliance (GSMA) presented the "Future of farming" case study in PA as the field of IoT, promoting 4G NB-IoT RAT (featuring low data rates and high latency) [23]. They also present the later case study, in which the image data captured by the on-board cameras are sent from the autonomous agriculture robot to a cloud-based edge computing server via a 5G connection for AI-based weed recognition preceding the selective application of herbicide. The decision cycle duration was ∼250 ms, where the transmission took 20-25 ms and the peak upload data rate was 120 Mbps [24].

In summary, it can be concluded that in the field of telecommunications there is no comprehensive, sectoral approach to PA to allow the identification and dimensioning of its needs, as well as preparing network operators to provisioning of services, and the scattered approach obscures the picture. Moreover, many of the mechanisms that have already been proposed by SDOs and are direly needed in the field of PA have not been implemented yet in carrier-grade networks [25], which is another obstacle for creating E2E, 5G-based Precision Agriculture Support System (PASS).

IV. Characteristics of processes, touchpoints and data exchange in precision agriculture

The system of PA is related to a production process in which actions must be taken in response to numerous factors of varying variability in time and space. While soil properties change over a very long period of time, other phenomena, e.g. the nutritional status and hydration of plants, and especially the occurrence of an infestation with a pathogen, may require a very quick response. Additionally, the possibility of a reaction may depend on external factors (e.g. suitable weather, soil moisture, time of day, temporary legal limitations) and the availability of resources (e.g. personnel, farming machinery, production means). Moreover, in agriculture there is a strong spatial condition related to, e.g., the structure of the farm's land (concentrated or highly dispersed). Therefore, logistics will also affect the limitations of possible reaction scenarios.

PASS can be described by the classic model Monitor-Analyse-Plan-Execute based on Knowledge (MAPE-K) [26] (cf. Fig. 1) with highly spatially dispersed and diverse touchpoints, i.e. sources of process monitoring information and actuators used to influence the process. As PA acts within various perspectives (multi-year, growing season, the life cycle of the cultivated plant and RT), there will also be many management levels with individual MAPE-K loops, but based on a common knowledge module integrated with GIS, covering the spatially described current situation and history of land and crops, including the history of agrotechnical treatments, as well as models of analytics, inferences, solutions and execution orchestration, the goals of all time perspectives and the rules of arbitration between them. The data produced by lower level (short-term) MAPE-K loops will feed also the higher level (longer-term) ones.

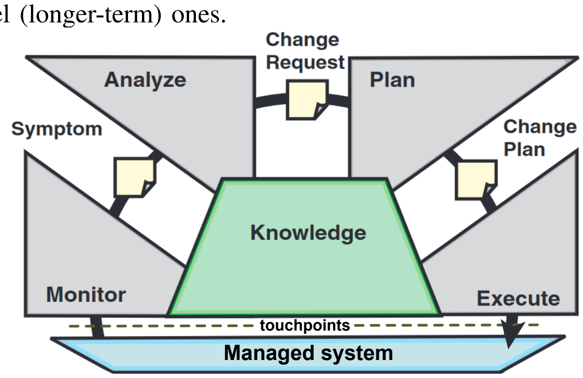

Fig. 1. IBM MAPE-K autonomous management loop (based on [26])

The basic requirement of PASS with regard to the responsiveness of the communication layer will therefore be that the communication between the MAPE-K chain and the touchpoints must not noticeably slow down, lengthen or stop MAPE-K processes at the level of their individual time scale, or force their rearrangement or additional logistic operations (e.g. passings, transits, etc.). Hence, the general principle is to avoid as much as possible manual data exchange, e.g. transferring data via USB memory, and to provide on-line connectivity for all elements of PASS.

The characteristics of the PA touchpoints and their data exchange is essential for determining the service requirements for the communication layer implemented by the mobile network. The use cases described below may refer to objects that are stationary or provide geospatially-stamped data ("on-the-go" acquisition). The majority of the PA equipment exposes the data after the end of the acquisition session (burst-like exchange of the acquired data files). Successive transmission of agricultural measurement data from PA objects is rather not used nowadays, but there are also cases of continuous transmission (RT processes, multimedia streaming).

UC1 Position sensing: As the typical GNSS accuracy of several meters is inadequate, the positioning correction has to be applied. The most commonly used is the Real-Time Kinematic (RTK) technology providing the accuracy of less than 3 cm. The typical maximum position readout frequency of GNSS receivers is 10 Hz, which corresponds to $\sim$13.9 cm spots spacing at 5 kmph. RTK enables RT position correction based on the information from the RTK reference station over the IP network using the RTCM SC-104 or CMR/CMR+ protocols. The required data rate typically ranges from 150 to 2400 bps.

UC2 Soil properties mapping: The class includes measurements of electrical conductivity (used to assess salinity, soil grain size and type, the depth of rock or hardly permeable layers and groundwater), reaction [pH], organic carbon content, and compactness (mechanical measurement, "stop-and-go" approach). Their common feature is the spot measurement of certain soil properties directly in the field with spot coordinates tagging. The typical time intervals between measurements are 1-25 s, so the approximate distances between measurement spots are 1.4-34.7 m at 5 kmph. There are also machines for automated collection of soil samples for laboratory analysis, but since the samples need to be unloaded on the farm, the spots information data transfer may be performed also there.

UC3 Contactless evaluation of soil and crop properties: The evaluation utilizes the image spectral analysis in the range of visible light (350-700 nm) and mainly near infrared (IR) (700-1000 nm, less often 700-2500 nm) resulting from the reflection of solar radiation (passive) or forced one (active). Depending on the shape of the spectral characteristics (so-called "signature"), it is possible to find the presence of a healthy plant, a dying plant, a dead plant, heavy and light mineral soil or peat soil within the image area, e.g. a pixel. The spectral analysis is based in particular on the observed phenomenon of a sharp change in reflection at the border of the red and near IR range ("red edge") characteristic of healthy plants. Spectral signatures will be specific for the plant species and the stage of their vegetation period, but the red edge effect always occurs. It is also possible to use thermography (9-14 μm) or the Light Detection and Ranging (LIDAR) technique (precise scanning of the shape of the land surface and evaluation of spatial variability of the shape and composition of the soil).

Image acquisition is done separately for narrow sub-ranges by means of narrow-band sensors included in a specialized camera (simplified solutions recording the image in RGB visible light channels and the IR range channel are also available), thus creating a set of images of the same area (bands) to make orthophotomaps for further analysis with specialized software to deliver a land map showing qualitatively and/or quantitatively the occurrence of some phenomenon of interest. The process of such a map delivery is multi-stage and computationally complex. In particular, various vegetation indices with different and complementary properties can be used for better identification.

Contactless sensing with the use of aerophotography can be carried out with the use of various flying objects, but from the point of view of this paper, important is the use of drones taking pictures along an optimal flight route adapted to the shape of the field, and then transmitting them for further processing in the terrestrial information system. Alternative local contactless sensing with the use of sensors operating at close range (passive or active, manual or mounted on a tractor or a cultivation set, e.g. on booms) is usually associated with an immediate calculation of the selected vegetation index by the device; this value with a time-spatial signature may be continuously transmitted to PASS. In the case of the autonomous RT MAPE-K loop in the on-board subsystem during the trip (e.g. a sprayer with an infestation detector), both the spot values of the tested indicator and of the applied product will be recorded, thus creating the legally required documentation of the procedure.

UC4 Yield mapping: Used for evaluation of the final efficiency of all agrotechnical treatments in a season, will depend on the specifics of the harvested crop and the combine-harvester design, but may consist of multiple on-board sensors (1-5 s readout resolution) to measure various yield and harvesting process parameters. The yield monitors are implemented as on-board subsystems of combine-harvesters to visualize current process data and even show current maps against the background of archival maps. The continuous transmission of yield monitoring data may be irrelevant or required by the farm management model – in large farms, central monitoring of all activities within the farm may be necessary.

UC5 Telemetry and telematics: Collecting telemetry data other than previously discussed is aimed at continuous remote monitoring of the machinery operation in the field, RT collection of diagnostic importance data, as well as fleet management. Moreover, communication will be bi-directional and may enable the following functions (depending on the manufacturer's policy): (i) mapping the current and historical location of the fleet components for the continuous optimization of its use; (ii) optimization of travel routes, adapting them to e.g. the location of a petrol station in case of prediction of soon refueling; (iii) reporting the working mode (driving, stopping, idling, loading/unloading, etc.) and the load weight; (iv) geo-fencing and working hours limitation; (v) informing about the following events: starting/stopping the engine, vehicle movement (including unauthorized use and location), opening the fuel filler, occurrence of diagnostic events represented by appropriate codes; (vi) insight to the machine's dashboard and its basic operating parameters: battery voltage, engine speed, operating fluids and fuel tank levels, ambient and machine system temperatures (engine oil, coolant, oil in the hydraulic system, air in tires), pressure in the hydraulic system; (vii) RT insight into CAN bus communication of the machine [27] and live transmission from information panels installed in the machine; (viii) identification and registration of the operator driving the machine. In most cases, the information from the machine (measurements, events) can be time/geospatially tagged to enable mapping their occurrence, advanced analysis against the background of maps describing the work area or route, etc.

UC6 Stationary or quasi-stationary sensing: In a PA farm, sensors installed permanently in the fields may also be used, enabling continuous, independently to agricultural treatments, remote insight into the local situation, e.g., weather stations or soil moisture sensors arranged in a grid (they can also cooperate with an irrigation system installed in the field). In the case of free grazing animals on pastures, monitors of life processes (e.g. temperature, heart rate, etc.) may be worn. It is also potentially possible to install cameras providing situational awareness with a 360° viewing angle in remote fields. Apart from the latter case, stationary and quasi-stationary data sources will be data from IoT sources with a discontinuous, cyclical pattern of daily activity, a relatively low required transmission speed and a relatively small data volume.

UC7 Actuators programming: Considering the agrotechnical operations, the actuators will be all mechatronic elements and systems, i.e. electronically controlled sprayer valves, actuators for the gate or tilt of the trailer's load box, spreader motors, etc. However, their direct remote control is rare, and they are controlled by the on-board machine controller, executing an operation program to send the appropriate control signals at the appropriate machine location or time. The same logic will also apply to programs or maps of routes, application or sampling spots. Communication with actuators takes the form of uploading the configuration file at an arbitrary moment and should be completed within a subjectively and contextually short time, i.e. not causing a downtime.

UC8 Drones: The use of drones in PA is a fragment of the overall area of their possible applications; some general characteristics will apply. In the case of large-scale farms or ones with spatially dispersed land structure, Beyond Visual Line of Sight (BVLOS) flights will be of particular importance, thus requiring a ubiquitous communication platform for: (i) Command and Control (C2) aspect: directly controlled flight or autonomic one along the uploaded route (cardinal points, azimuth, altitude, etc.) with in-flight drone parameters monitoring and with direct control – providing the pilot with First Person View (FPV), i.e. RT video streams from the high-definition (4K/8K) camera with a 360° viewing angle; (ii) active connection to the Unmanned Aircraft Systems Traffic Management (UTM) system for airspace management and flight coordination (telemetry data transmission: position, azimuth and flight speed, etc.); (iii) use case-specific data transmission (photogrammetric data collection, crop and infrastructure monitoring, crop pest control by air discharges of pest antagonists, etc.).

UC9 Communication between machines: The complementary functionality applicable to large farms may be the synchronous operation of multiple machines, e.g. in line formation of a group of combine-harvesters with the simultaneous transfer of the threshed grain to the next machine, and finally to a truck at the end of the array. In consequence, the use of machinery is optimized through minimizing stoppage during unloading and U-turning, and the excessive soil compaction by loaded machines is avoided. To enable this approach, mechanisms for communicating between machines are necessary, e.g. broadcasting their location, azimuth and ground speed information, and optionally FPV.

UC10 Autonomous agricultural robots: With mechanisms of autonomy (detection of plant rows or driving on the basis of a plant map from sowing, supported by high-precision GNSS positioning), the manual remote control is not required for their operation. The communication will be needed for e.g. remote transmission of the action plan, changes in the base knowledge (patterns of weeds, pests or infestations to be detected), use of remote computing in the cloud for off-loading the local processing as well as sending information (including video stream) to the operator. In terms of the model of communication needs, there are similarities to drones. The difference will be the speed of movement (the maximum speed is much lower than in the case of drones), as well as work near the ground, as opposed to drone flights at altitudes of up to 120 m.

UC11 Support for people performing agrotechnical activities in the field: To support field workers, AR technology may be used. For a simple workaround, a personal terminal (e.g. a tablet), based on the current position, would receive information from GIS of the farm in the form of maps of soil properties and water relations, sown plants, history of treatments, photos taken previously, etc., to quickly familiarize the farm worker with the current situation even without prior on-site presence. True AR allows adding contextual information to the observed image, e.g. names or legends of recognized objects, information about their properties, instructions on how to proceed, etc. The transmission requirements for AR are characterized by a very high quality of RT video streaming and a maximum Round-Trip Time (RTT) of 20 ms for good Quality of Service (QoS) perception [28]; for RTT $>$ 40 ms a cybersickness may occur, significantly intensified for RTT $>$ 75 ms [29].

UC12 Architecture and implementation approach to PASS: At present, there are no comprehensive solutions to cover 100% of all functional needs of a PA farm; it is necessary to use various PASSs and interchange data, using commonly recognized formats. There exist PASSs prepared for local installation and – more and more popular – network ones run in the cloud. In the latter approach, the system architecture aims to optimize the information processing and data transferring, leading to distributed computing, in particular edge computing.

In Tab. I, the exemplary characteristics of selected PA touchpoints with burst-type data exchange is presented for comparison.

V. Precision agriculture use cases' support by 5G System

Based on the general assumptions and descriptions of the use cases presented in section IV, an analysis of service requirements was carried out against the background of the relevant 3GPP Stage 1 documents for 5GS [20], [30], [31]. The results have been presented in Tab. II. The intensity and type of data exchange (burst/stream), required data rate, maximum delay and reliability were determined for individual use cases through mapping to identified service classes defined by 3GPP. On that basis, it was proposed to assign the relevant SST to each of the use cases.

TABLE I
EXAMPLES OF BURST-TYPE DATA EXCHANGE AT VARIOUS PA TOUCHPOINTS

Use case type	Data volume per spot	Data volume per hectare	Notes
Soil properties mapping	384 B	37,5 KB	Conductometer, induction-based measurement, 100 spots per hectare
Soil properties mapping	143 B	–	Tensometric frame, possible different working widths
Contactless crop evaluation	255 B	51,9 KB	Handheld vegetation index meter, ∼200 spots per hectare
Actuator programming	303 B	41,6 KB	Mineral fertilizer application map, 140 spots per hectare
Yield mapping	115 B	166,3 KB	Wheat combine-harvester, 5 s intervals
Drone photogrammetry	–	37,4 GB	1 cm per pixel, 42.4 MP RGB+IR camera, 14 bits per band, necessary images overlapping included

TABLE II
PA USE CASES' REQUIREMENTS MAPPING TO 5GS SERVICE REQUIREMENTS

Use case ID		Exchange intensity	Exchange type	Data rate	Max. delay	Reliability	SST
UC1		high	stream	2.4 kbps	–	high	URLLC
UC2		low	burst	≤ 1 kbps	–	low	MIoT
UC3	photogram-metry	high	burst	∼1 Gbps	200 ms	low	eMBB
UC3	local sensing	low	burst	≤ 1 kbps	–	low	MIoT
UC4		low	burst	≤1 kbps	–	low	MIoT
UC5		high	stream	1 Mbps	20 ms	high	eMBB
UC6	sensors	low	burst	≤ 1 kbps	–	low	MIoT
UC6	video streaming	high	stream	120 Mbps	20 ms	99.99%	eMBB
UC7		low	burst	∼ Mbps	–	low	eMBB
UC8	C2	low	stream	28 kbps	40 ms	99.9%	URLLC
UC8	UTM	low	stream	∼ kbps	500 ms	99.9%	URLLC
UC8	FPV, video streaming	high	stream	120 Mbps	20 ms	99.99%	eMBB
UC9		high	stream	65 Mbps	20 ms	99.99%	V2X
UC10		high	burst	1.1 Gbps	2 ms (1)	99.9%	HMTC
UC11		high	stream	0.1-1 Gbps	10 ms	99.99%	eMBB

(1) Achievable in low area campus networks only

The primary observation based on the analysis is the huge data rates variety range as well as the appearance of immensely challenging delay limits. Moreover, for UC8-UC11, these very and extremely high data rates are associated with the uplink (UL) transmission. Compared to other applications, e.g. medical monitoring or smart grids, the required levels of reliability are not particularly high. However, the support of all use cases by the mobile network will require the use of all SST classes, and due to the further differentiation of the QoS requirements for use cases mapped to some SST, the separate Network Slice Instances (NSIs) with use case-relevant QoS parameters – traffic priority, (non-)guaranteed data rate, packet error rate and delay budget, etc. [2] – will have to be implemented, particularly for different tenants or differentiated User Plane (UP) architectures. Creation of NSIs implies the 5G Stand-Alone (SA) architecture [2] (almost all 5G networks in the world are still working in the 5G Non-SA architecture) and advanced automated network management algorithms for which the 3GPP standardization is currently still not advanced enough. The proposal for allocation of 5G QoS Identifiers (5QIs) to analysed PA use cases has been presented in Table III. In each case except UC10, the relevant 5QI can be assigned. It has to be noted that 3GPP does not provide the 5QI that ensures delay < 5 ms, which might be an obstacle in demanding URLLC cases.

TABLE III
3GPP 5QIS [2] SUPPORTING THE ANALYSED PA USE CASES

5QI	Resource type	Priority level	Delay	Packet error	Max. data burst volume	Use case ID
6	Non-Guaranteed Bit Rate (GBR)	60	300 ms	10^{-6}	N/A	UC2 UC4 UC7
6	Non-GBR	70	100 ms	10^{-3}	N/A	UC3: photogrammetry UC6: video streaming
8	Non-GBR	80	300 ms	10^{-6}	N/A	UC3: local sensing
70	Non-GBR	55	200 ms	10^{-6}	N/A	UC8: UTM UC6: sensors
80	Non-GBR	68	10 ms	10^{-6}	N/A	UC6: video streaming UC8: FPV UC11
82	Delay-critical GBR	19	10 ms	10^{-4}	255 bytes	UC1 UC5
83	Delay-critical GBR	22	10 ms	10^{-4}	1354 bytes	UC9 UC8: C2

The above requirements are in fundamental contradiction to the 3GPP basic service requirements for rural macro scenarios (cf. [20], clause 7.1) where the maximum user-experienced data rates are 50 Mbps for DL and 25 Mbps for UL, while the traffic capacities are respectively 1 Gbps/km^2 and 0.5 Gbps/km^2. The traffic capacities for urban macro scenarios are respectively 100 Gbps/km^2 and 50 Gbps/km^2, and for dense urban scenario 750 Gbps/km^2 and 125 Gbps/km^2. Thus, according to the current 3GPP vision, rural areas will be too impaired in capacity to cope with some PA use cases, as well as those for some drone applications. This seems to be the evidence of how far the complexity of sectoral service needs of agriculture, in particular of PA, is unrecognized, which may have general economic consequences. It is also an expression of the need for SDOs in the field of telecommunications to transform the approach to the agriculture sector into a comprehensive one.

The application layer support by edge cloud computing (UC12 for UC2-UC4, UC6, UC8, UC10-UC11) can be provided by the European Telecommunications Standards Institute (ETSI) MEC [3] implementation. It should be remarked, however, that the standardization of MEC integration with 5GS is still ongoing. Moreover, important issues related to the necessary adaptation of both architectural frameworks, taking into account the problems of duplicated functionalities and their potential conflicts or competition, scalability, simplification of the integrated architecture, etc. [32], have still not been resolved.

From the above considerations, it can be noted that for the implementation of 5G services for PA in a rural environment, the density of PA-related devices will not be a problem. The main barriers will be the network capacity, the maximum achieved data rates and latency levels. Hence, the provided support can become insufficient especially for latency-critical and extremely high UL data rate use cases (e.g. UC3, UC8, UC10, UC11). Moreover, the typically adopted network planning strategy in rural areas (high diameter macro-cells) as well as operation in “rural” sub-GHz frequency bands having inherently low capacity (e.g. in Europe the 700 MHz band with maximum channel width of 15 MHz) result in limited resources and non-100% coverage. The temporary palliative solution for the rural coverage and capacity issues may be the advance of integration of Non-Terrestrial Networks (NTNs) – especially High Altitude Platform Systems (HAPSs), having relatively low delays – with the 5GS as well as UL coverage enhancements, which are currently envisioned in the scope of the 3GPP Release 18, named “5G-Advanced” (to be concluded in the first quarter of 2024) [33].

According to the early visions, 6GS will not only fulfill the above gaps, but also promises the headroom for the development of future PA services. One of the expected benefits is network ubiquity and full convergence of fixed, mobile networks and NTNs, which can significantly contribute to service provisioning in rural areas. New service classes targeting more specialized use cases are proposed, i.a. Human-Centric Services (HCS), Multi-Purpose Services (MPS), reliable eMBB, Mobile Broadband Reliable Low Latency (MBRLLC), Massive Ultra-Reliable Low Latency Communication (mURLLC) [34]. Also, a considerable boost of system performance is anticipated – 10× lower latency (0.1 ms in radio link) and 10× better spectrum efficiency implying the respective capacity growth [35].

VI. Conclusions

In this paper, the application of mobile networks in the field of PA has been discussed, presenting the complexity and variety of needs and use cases of this economic sector, the importance of which will grow dynamically in the coming years. Based on the use case analysis, the service requirements related to the communication layer of PASS have been identified. Contrary to the stereotypical vision that equates PA with the “low-end” IoT class, the needs of this sector will be a big challenge for the Mobile Network Operators (MNOs) in terms of the required QoS, involving a variety of service architectures and NSIs. Additionally, the approach of SDOs to PA should be changed to a comprehensive sectoral one, and the development of standardization of 5G networks and the next generations should take into account the PA service needs to fill the gaps identified here that may hinder the support of PA by MNOs’ communication services.

References

[1] ITU-R, “IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond,” International Telecommunication Union – Radiocommunication Sector, Recommendation ITU-R M.2083 (09/15), Sep. 2015. [Online]. Available: https://www.itu.int/rec/R-REC-M.2083

[2] 3GPP, “System architecture for the 5G System (5GS),” 3rd Generation Partnership Project, Technical Standard TS 23.501, ver. 17.4.0, Mar. 2022.

[3] ETSI, “Multi-access Edge Computing (MEC),” [Website], Last accessed 22 Apr 2022. [Online]. Available: https://www.etsi.org/technologies/multi-access-edge-computing

[4] V. I. Adamchuk, “Precision Agriculture: Does it make sense?” *Better Crops with Plant Food*, vol. 94, no. 3, pp. pp. 4–6, 2010.

[5] European Parliament, Directorate-General for Parliamentary Research Services, R. Schrijver, K. Poppe, and C. Daheim, *Precision agriculture and the future of farming in Europe: scientific foresight study*. Publications Office of the European Union, 2019, doi: 10.2861/175493.

[6] H. Auernhammer, “Precision farming – the environmental challenge,” *Computers and Electronics in Agriculture*, vol. 30, no. 1–3, pp. pp. 31–43, 2001, doi: 10.1016/S0168-1699(00)00153-8.

[7] European Communities, “Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources,” pp. 1–8, Official Journal of the European Communities, L 375, 31 Dec 1991. [Online]. Available: https://eur-lex.europa.eu/eli/dir/1991/676/oj

[8] European Union, “Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides (Text with EEA relevance),” pp. 71–86, Official Journal of the European Union, L 309, 24 Oct 2009. [Online]. Available: https://eur-lex.europa.eu/eli/dir/2009/128/oj

[9] R. P. Beluhova-Uzunova and D. M. Dunchev, “Precision farming – concepts and perspectives,” *Zagadnienia Ekonomiki Rolnej/Problems of Agricultural Economics*, vol. 3, no. 360, pp. pp. 142–155, 2019, doi: 10.30858/zer/112132.

[10] A. Krause, W. Anwar, A.-B. Martinez, D. Stachorra, G. Fettweis, and N. Franchi, “Network planning and coverage optimization for mobile campus networks,” in *2021 IEEE 4th 5G World Forum (5GWF)*, 2021, pp. 305–310, doi: 10.1109/5GWF52925.2021.00060.

[11] G. Faraci, A. Raciti, S. Rizzo, and G. Schembra, “A 5G platform for unmanned aerial monitoring in rural areas: Design and performance issues,” in *2018 4th IEEE Conference on Network Softwarization and Workshops (NetSoft)*, 2018, pp. 237–241, doi: 10.1109/NETSOFT.2018.8459960.

[12] A. Ranjha, G. Kaddoum, and K. Dev, “Facilitating URLLC in UAV-assisted relay systems with multiple-mobile robots for 6G networks: A prospective of Agriculture 4.0,” *IEEE Transactions on Industrial Informatics*, vol. (early access), 2021, doi: 10.1109/TII.2021.3131608.

[13] J. Zhang, R. Zhang, Q. Yang, T. Hu, K. Guo, and T. Hong, “Research on application technology of 5G Internet of Things and Big Data in dairy farm,” in *2021 International Wireless Communications and Mobile Computing (IWCMC)*, 2021, pp. 138–140, doi: 10.1109/IWCMC51323.2021.9498643.

[14] C.-K. Hsu, Y.-H. Chiu, K.-R. Wu, J.-M. Liang, J.-J. Chen, and Y.-C. Tseng, “Design and implementation of image electronic fence with 5G technology for smart farms,” in *2019 IEEE VTS Asia Pacific Wireless Communications Symposium (APWCS)*, 2019, pp. 1–3, doi: 10.1109/VTS-APWCS.2019.8851659.

[15] “Internet of Food & Farm 2020 (IoF2020),” [Website], Last accessed 22 Apr 2022. [Online]. Available: https://www.iof2020.eu/

[16] “5G HEalth AquacultuRe and Transport validation trials (5G HEART),” [Website], Last accessed 22 Apr 2022. [Online]. Available: https://5gheart.org/

[17] A. Fornes-Leal, R. Gonzalez-Usach, C. E. Palau, M. Esteve, D. Lioprasitis, A. Priovolos, G. Gardikis, S. Pantazis, S. Costicoglou, A. Perentos, E. Hadjioannou, M. Georgiades, and A. Phinikarides, “Deployment of 5G experiments on underserved areas using the Open5GENESIS suite,” in *2021 International Conference on Smart Applications, Communications and Networking (SmartNets)*, 2021, pp. 1–4, doi: 10.1109/SmartNets50376.2021.9555428.

[18] “5G!Drones: Unmanned Aerial Vehicle Vertical Applications’ Trials Leveraging Advanced 5G Facilities,” [Website], Last accessed 22 Apr 2022. [Online]. Available: https://5gdrones.eu/

[19] F. Gilles and J. Toth, *Accelerating the 5G transition in Europe: How to boost investments in transformative 5G solutions (main report for the European Commission)*. European Investment Bank, 2021, doi: 10.2867/252427.

[20] 3GPP, “Service requirements for the 5G system; Stage 1,” 3rd Generation Partnership Project, Technical Standard TS 22.261, ver. 18.6.0, Mar. 2022.

[21] ——, “Service requirements for cyber-physical control applications in vertical domains; Stage 1,” 3rd Generation Partnership Project, Technical Standard TS 22.104, ver. 18.3.0, Dec. 2021.

[22] ——, “Service requirements for Video, Imaging and Audio for Professional Applications (VIAPA),” 3rd Generation Partnership Project, Technical Standard TS 22.263, ver. 17.4.0, Jun. 2021.

[23] GSMA, *The future of farming: How mobile IoT technologies can help agriculture feed the world*. GSM Association, 2018. [Online]. Available: https://www.gsma.com/iot/resources/chunghwa-nhr-agriculture-iot-case-study/

[24] ——, *Smart Farming: Weed elimination with 5G autonomous robots*. GSM Association, 2020. [Online]. Available: https://www.gsma.com/iot/resources/smart-farming-weed-elimination-with-5g-autonomous-robots/

[25] L. Tomaszewski, I. P. Chochliouros, R. Kołakowski, S. Kukliński, and M.-A. Kourtis, “High mobility 5G services for vertical industries – network operator’s view,” *IFIP Advances in Information and Communication Technology*, vol. 628, pp. pp. 71–84, 2021, doi: 10.1007/978-3-030-79157-5_7.

[26] IBM, *An architectural blueprint for autonomic computing*. IBM Autonomic Computing White Paper, Fourth Edition, Jun. 2006.

[27] S. L. Stevan Jr. and F. A. Farinelli, “CAN-bus remote monitoring: Standalone CAN sensor reading and automotive diagnostics,” *SAE International Journal of Connected and Automated Vehicles*, vol. 2, no. 1, pp. pp. 27–46, Feb. 2019, doi: 10.4271/12-02-01-0003.

[28] X. Hou, Y. Lu, and S. Dey, “Wireless VR/AR with edge/cloud computing,” in *2017 26th International Conference on Computer Communication and Networks (ICCCN)*, 2017, pp. 1–8, doi: 10.1109/ICCCN.2017.8038375.

[29] P. Caserman, A. Garcia-Agundez, A. Gámez Zerban, and S. Göbel, “Cybersickness in current-generation virtual reality head-mounted displays: systematic review and outlook.” *Virtual Reality*, vol. 25, pp. 1153–1170, 2021, doi: 10.1007/s10055-021-00513-6.

[30] 3GPP, “Unmanned Aerial System (UAS) support in 3GPP,” 3rd Generation Partnership Project, Technical Standard TS 22.125, ver. 17.6.0, Apr. 2022.

[31] ——, “Service requirements for enhanced V2X scenarios,” 3rd Generation Partnership Project, Technical Standard TS 22.186, ver. 17.0.0, Apr. 2022.

[32] L. Tomaszewski, S. Kukliński, and R. Kołakowski, “A new approach to 5G and MEC integration,” in *Artificial Intelligence Applications and Innovations. AIAI 2020 IFIP WG 12.5 International Workshops*, I. Maglogiannis, L. Iliadis, and E. Pimenidis, Eds. Cham: Springer International Publishing, 2020, pp. 15–24, doi: 10.1007/978-3-030-49190-1_2.

[33] “3GPP: Release 18,” [Website], last accessed 22 Apr 2022. [Online]. Available: https://www.3gpp.org/release18

[34] A. Yazar, S. Doğan Tusha, and H. Arslan, “6G vision: An ultra-flexible perspective,” *ITU Journal on Future and Evolving Technologies*, vol. 1, no. 1, pp. pp. 121–140, 2020, doi: 10.52953/IKVY9186.

[35] A. L. Imoize, O. Adedeji, N. Tandiya, and S. Shetty, “6G enabled smart infrastructure for sustainable society: Opportunities, challenges, and research roadmap,” *MDPI Sensors*, vol. 21, no. 5, p. 1709, 2021, doi: 10.3390/s21051709.