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Specification Of 5G Networks For Agricultural Use Cases Using The Example Of Harvesters Operated By Swarm Robotics

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Abstract

Feeding the growing world population is a scientific and economic challenge. The target variables to be optimised are the yield that can be produced on a given area and the reduction of the resources used for this purpose. High-wage countries are faced with the problem that the use of personnel is a significant cost driver. Developing countries, on the other hand, usually operate on much smaller field sizes, so that the work in the field is still strongly characterised by manual labour. One solution to meet these challenges is the use of smaller autonomous harvesting robots. These can be networked into a swarm of machines to work even larger fields. The networking of autonomous agricultural machines is a key use case for rural 5G networks. 5G technology can offer many advantages over older mobile communications standards and therefore make use cases more efficient or enable new ones. Various use cases are also conceivable in the field of agriculture, yet it is unclear how 5G networks can and must be specified for this purpose. In this paper, using the example of 5G-connected harvesters powered by swarm robotics, we present the challenges that have arisen and the specification that has been developed.

Keywords

5G; Swarm Robotics; Smart Farming; Information Technology; Agriculture

1. Introduction

5G technology continues to grow in importance since its introduction, as can also be seen from the increasing subscription numbers of mobile radio standard. According to Ericsson's Mobility Report, the number of subscriptions increased by 70 million in the first quarter of 2022 alone [1]. Ericsson expects an increase of over 1 billion in the whole of 2022. The general tenor is that 5G technology will affect almost all industries if it not already does. The biggest changes that 5G will bring are expected in consumer goods, manufacturing, logistics and agriculture. In the B2C sector for example, higher speeds and lower latency will enable the use of augmented reality and virtual reality, so that the customer experience can be enhanced, for example, cities can use AR or VR at landmarks or museums to provide more information, so-called points of information (POI). In industry, on the other hand, improved analysis of the available real-time data can reduce downtimes on machines and set production standards. 5G technology can also lead to major changes in the logistics sector, as individual vehicles can be networked with each other [2]. Agriculture will also be increasingly influenced by 5G technology, the keyword here being so-called smart farming. The term smart farming refers to the use of information and communication technologies in agriculture. From a technological point of view, Unmanned Aerial Vehicles (UAVs), Unmanned Ground Vehicles (UGVs) and Wireless Sensor Networks play an important role in smart farming [3]. With UAVs, for example, it is possible to observe and monitor large fields from the air. In this way, various status information regarding weed growth, hidden animals,

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insect infestation and water can be automatically obtained without the need for large staff. The usage of 5G promises plenty of advantages especially in combination with (semi-)autonomous vehicles due to low latency, high connectivity, and high data throughput features. As the technology is not yet well tested in real life applications, its validation would be beneficial.

Agriculture in general is faced with various challenges. The task of feeding the expanding global population necessitates both technological and economic solutions. The yield that can be produced on a specific area and the reduction of resources needed for this goal are the target factors to be optimized [4]. Countries with high wages and developing nations confront various difficulties. Particularly in the former, the use of personnel is a major cost-driver [5]. The COVID-19 epidemic has also shown that hiring foreign harvest workers is not a dependable strategy for protecting the harvest in times of distress and can create a significant bottleneck [6]. On the other hand, developing nations struggle with the fact that their farming operations take place on much smaller fields, necessitating a lot more physical labor [7]. Because of this, it is challenging to use economies of scale and standardize production methods. Using autonomous, modular harvesting robots that are smaller is one way to address these issues. These robots can be employed in smaller groups or alone to automate the harvesting process for small fields. They can also be networked into a swarm of devices that autonomously cultivates huge yet parceled regions and avoid personnel bottlenecks. Positive side effects include greater resilience due to using multiple small machines rather than a single large one (redundancy in case of failure scenario) and the potential for cultivation under glass due to the machines' lower dimensions (water and resource savings). Thus, the usage of 5G in conjunction with swarms made up of tiny harvesters has a direct impact on greater ecological sustainability, including expanding populations of small game and more diverse plant and insect life (e.g., pheasant, partridge or admiral). Due to the use of wireless sensor technologies, cameras and autonomous systems, there is an increased data throughput that requires the use of a 5G network. Swarm algorithms for autonomous robots require that calculations do not only take place on the machine itself, but also centralized. Information as position, velocities, detected obstacles and status need to be transmitted and analyzed in short time to fulfil security standards. Thus, a performant telecommunication technology is needed.

The research presented in this paper addresses the aforementioned issues by showing the current state of an ongoing research project and providing its exemplary solutions as benchmark and basis for further work. In the beginning, we will focus on the research gap concerning this subject. Then, we will describe the use case and the elaborated requirements and specifications for the fitting 5G network. Finally, we take an outlook on developments to come.

2. Methodology

The present methodology of this research work results on the one hand from practical methods within the project and on the other hand from accompanying theoretical research. Figure 1 illustrates the procedure.

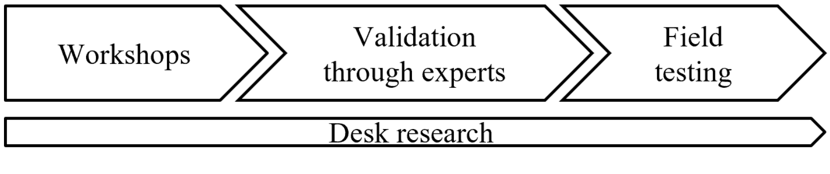

Figure 1: Illustration of the methodology

The sub-objectives of the project are to create a 5G specification and system architecture for the agricultural use case of swarm robotics harvesters, to implement the network and to test the technology in practice, with the result that the benefits and limitations of 5G technology can be demonstrated. Different methodologies were used for the various sub-objectives. The 5G specifications are based on the various use cases. These were determined during several workshops within the project team. The goal was to completely capture the various scenarios in which the 5G network becomes relevant for the harvesting robot. These use cases were validated by the robotics experts from the extended project team. Based on this, the requirements for the 5G network were defined for each defined use case. The requirements specify the latency frame, the data throughput, the need for real-time transmission and the required data rates. The specifications were discussed and validated with various 5G providers. Furthermore, a 5G short-term licence was applied for an agricultural test field to be able to test the defined use cases and the 5G specifications in a real laboratory. In the process of these field tests, the various use cases are carried out in realistic harvesting situations with the harvesting robot. Instead of getting the data directly, desk research is the act of gathering information that is already published [8]. Desk research methodology is particularly suitable for building up knowledge on new topics and substantiating existing statements or hypotheses with facts. Desk research enables a resource-saving and efficient gain of knowledge. In this case, different research papers were considered to get a holistic overview of the state of research and to identify the research gap. This is highlighted in the following chapter.

3. Research Results

In the following, we will present the results of our research.

3.1 Research Gap

As early as 1995, there was initial research into an autonomous robot that harvests fragile vegetables and fruit. In recent years, there has been a great deal of research on this, including describing the navigation and positioning of individual harvesting robots [9]. Despite the need for strong communication between machines, there has not been research on outdoor 5G communication for robots.

The existing research on 5G in agriculture covers specific topics, such as security [10,11] or it is only mentioned as an enabler for IoT applications [12,13]. Overall, there are only a few sources that deal with the design of 5G networks. One exception is Valecce et al. 2019, who specify the requirements for a 5G network for UAVs (Unmanned Air Vehicles) and UGVs (Unmanned Ground Vehicles). However, these are of a qualitative nature and are not precisely matched to the hardware used by the autonomous robots [14]. Another exception is Tomaszewski et al. 2022, where the network requirements were determined for several 5G use cases in agriculture. However, this is not based on requirements for the 5G network developed jointly with the user but based on 3GPP-defined classes of service. Further on, only the deliverability by 5G networks is discussed and no 5G network architecture is presented [15].

As can be seen in table 1, the design and functionality of the network layer is discussed with similar frequency in the agricultural sector compared to the physical layer in the field of the Internet of Things (IoT). However, it should be noted that the topic of 5G as an enabler technology is rarely supported. As described above, high importance has been attached to the technology. Consequently, several research papers have already been published on this topic, albeit being concerned with different conditions as the surroundings. Most of the work is on enclosed spaces, such as factory floors with use cases such as augmented reality and analysis of real-time data. In these areas, there are already requirements for the 5G networks and, as a result, the corresponding network specifications [16,17]. Overall, there is a deficit in research on 5G in an agricultural context [18].

Thus, we deduct a research gap for the practical specification and system architectures of 5G networks for agricultural use cases on an outdoor field especially for robotics applications.

Table 1: Surveys to physical and network layer for IoT applications in agriculture [19]

Survey	Talavera et al. [20]	Ray [21]	Tzounis et al.[22]	Elijah et al. [23]	Khanna and Kaur [24]	Shi et al. [25]	Ruan et al. [26]	Feng et al. [27]	Shafi et al [28].	Ayaz et al. [12]	Farooq et al. [29]	Radoglou-Grammatikis et al [30]	Ferrag et al. [10]	Liu et al [13]
Year	2017	2017	2017	2018	2019	2019	2019	2019	2019	2019	2019	2020	2020	2020
Physical layer	○	●	●	●	○	●	●	●	●	●	●	●	●	●
Network layer	●	●	●	●	●	●	●	●	●	●	●	○	●	●
5G considered	○	○	○	○	●	◑	◑	○	●	◑	○	○	●	◑
5G Specification	○	○	○	○	○	○	○	○	○	○	○	○	○	○

●: Supported; ◑: Partially supported; ○: Unsupported.

3.2 Results

To exemplify the utility of 5G technology for application in the agricultural space using harvesting robots linked by swarm robotics, we will first outline the use case, explain the challenges that have arisen in the first half of the still ongoing research project, and present the requirements and chosen 5G specifications and system architecture.

3.2.1 Description of use case

The use case can be divided into two sub use cases referring to the two types of agricultural machinery: a harvesting robot and a logistics unit. Physically, there will be two harvesting robots in the field and one logistics unit. The speed of both machines is approximately 2 km/h. There is also a control station at the edge of the field, which is also to be integrated into the 5G network. The control station will consist of a computer and desktop to connect the machines with the system and monitor them.

The harvesting robot is manually transported to the field. It starts in the home position; from there it must be connected to the 5G network. It connects to the platform and retrieves relevant data, such as a map in which the field to be harvested is divided into a starting point, an end point, rows of fields to be harvested and a route. It drives to the starting point and autonomously drives and harvests from there. For various reasons, e.g., because of an obstacle or a full harvest box, the harvesting robot can stop in the process. Depending on the reason for the stop, different procedures are followed. Either the problem is solved by a third party, by itself or by technology. The machine may then resume the harvesting process, or it waits for the logistics unit (see below) in case of a full harvesting box to continue harvesting after the harvesting box has been replaced. Otherwise, it drives to the home position to complete the harvesting process there or to resume harvesting after refueling.

The logistics unit is transported manually to the field. It starts in the home position; from there it must be connected to the 5G network. It connects to the platform and navigates to an empty harvest box, which is then picked up. The logistics unit now waits in a waiting position. If there is no demand, it returns to the home position and ends the process. If necessary, the logistics unit navigates to the harvesting robot. If no error occurs on the way there, the logistics unit exchanges the empty harvest box with the full harvest box in cooperation with the harvesting robot, navigates with the full harvest box to the storage location and places it there. The logistics unit then navigates back to the empty boxes, picks up one and waits in the waiting position. If an error occurs on the way of the logistics unit to the harvesting robot, it stops and, depending on whether the problem is fixed by a third party, by itself or by technology, it can either resume the process or drive to the home position and end the process.

3.2.2 Emerging challenges in the first half of the research project:

Numerous challenges arose whilst planning and testing. The most important ones are discussed below, stating a need by future end users towards the industry:

1. Lack of clarity as to which commercially existing hardware can (already) perform which 5G features and which cannot: although 5G theoretically offers many features and thus enables a wide range of specifications, not all of them can yet be offered in the currently existing, commercially available products. This severely limits the scope of action, but the overall situation is unclear.
2. Exact requirements for the 5G network are difficult to define in advance and change during the development of a use case. Agile methods can only be transferred to a limited extent, as expensive hardware is selected, purchased, and installed once in the field. The question is how to define requirements for a 5G network a priori to meet later demands.
3. Providing the necessary infrastructure in the field for a campus network proves to be difficult. This applies particularly the power supply, network coverage, and protection of all hardware from wind and weather.
4. Finding test networks is not easy. There are only a few providers and the costs for them quickly skyrocket. Especially if testing is to be done over a longer period (>1 week), the costs quickly exceed the five-digit euro range.
5. The knowledge about technical details of the design is not always easy to obtain, e.g., about the prioritization of data streams and Quality of Service (QoS).
6. The actual network coverage in the country on the exact location is unknown.
7. Required information from the 5G hardware vendor is not freely available.
8. A service catalog complementary to vendor hardware is not freely available.

3.2.3 5G-specification and system architecture

By having identified the macro and micro processes of the use cases, we were able to assess the 5G requirements that are needed to deduct the 5G network specifications. One example is the arm/fork lift alignment (micro process) of the box replacement (macro process) within the logistics unit: the latency shall not exceed 20 ms, the data rate is expected to be 17 MBps with a packet size of 0.28 MB *2, the packet loss may not exceed 10% and the process is not security critical. By combining all micro process information, the total data rate sums up to a maximum of 92 MBps for three robots in the swarm and a connected control station. The lowest latency allowed exceeds to 20ms and a package loss of <1%. Due to unclear and often insufficient network coverage and for security reasons, we chose to use a private network (campus network), instead of a public one.

Further requirements that are considered:

- Place of operation: As the hardware will be partly next to a field and only partly within a covered hut, it will be exposed to wind and weather and thus needs to work under these circumstances.
- Redundant networks: Most likely not needed.
- Set-up and dismantling: no special requirements for the hardware but needs to be dismantled after each harvesting season.

- Scaling: In this use cases for testing purposes no scaling is planned, although would need to be considered for real operation.
- Migration: Most likely not necessary between private and public networks, but not ruled out in principle.
- QoS: It is desirable that the hardware supports the QoS (Quality of Service) feature but is not a must. It is wished for a signal, that needs transmitting prioritization before other signals.
- Service: A service agreement for setting-up, implementation of the network and in operation problem support must be negotiated.

These requirements will be newly considered with the results of the field tests, for which a prototype 5G network is used. Derived therefrom, we developed the following system architecture (see Figure 2) for this agricultural outdoor use case:

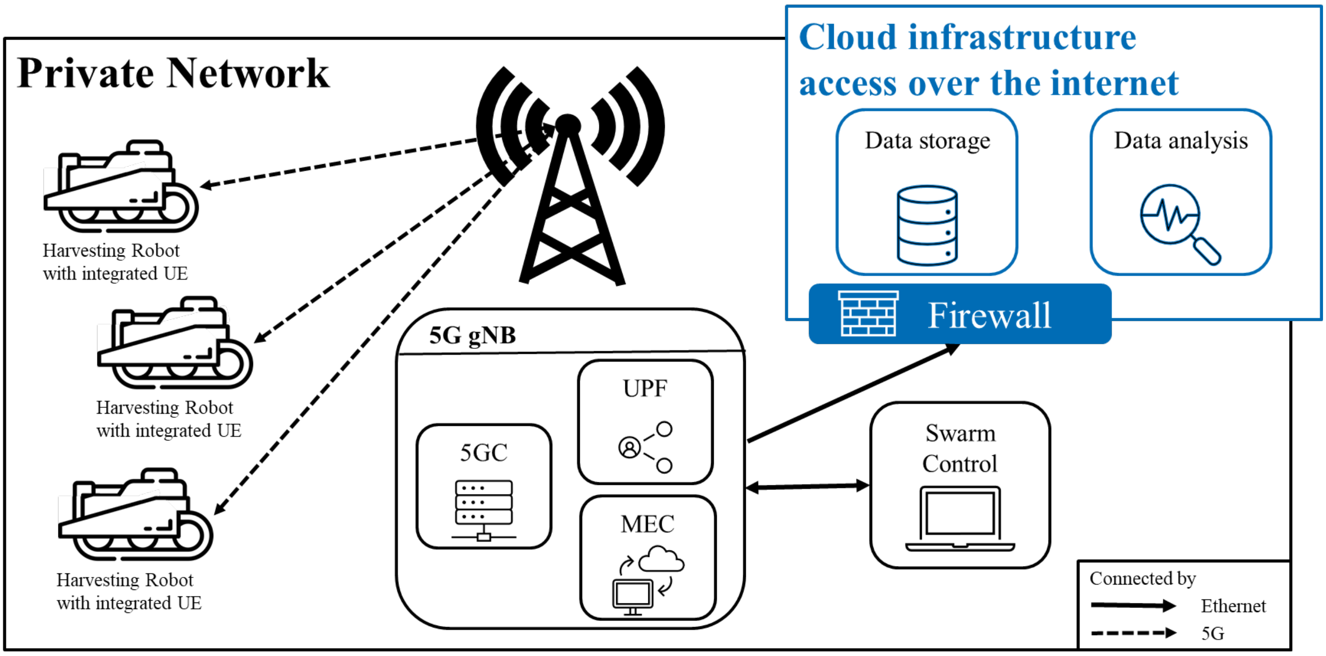

Figure 2: Proposed system architecture of the 5G network for linking harvesting machines via swarm robotics

The overall chosen structure is a private network (campus network). Within the Radio Access Network (RAN) all harvesting machines and logistic units are connected via user equipment (UE) to the base station with an antenna. The base station is a 5G next Generation Node B (5G gNB). It is connected with the Core Network containing the 5G Core (5GC), the User Plane Function (UPF) and the Mobile Edge Cloud (MEC). The Core Network is connected via ethernet to a computer on which the swarm algorithm is located and which steers and controls all processes. Furthermore, machine and video data are sent into a cloud infrastructure. There it is stored and used for analysis to improve the swarm algorithm.

4. Outlook and Conclusion

The validation of the 5G network is still ongoing. There will be several months of field testing to gain results and insights both for the swarm algorithm and the 5G specifications. After a first testing phase with a prototype 5G Network, we will go into discussions with 5G suppliers to finalize the system architecture and implement the final network on the field. By the end of 2023 we will have held several tests for the overall use case. Moreover, we plan to publish a business-case-calculator; its purpose is to give interested farmers or agricultural companies a sound calculation for which agricultural use case a 5G network delivers value in several dimensions (e.g., financial, sustainable).

Concluding we described an outdoor swarm robotics use case using 5G for connectivity. We highlighted the concrete challenges that arouse during the testing phase. Finally, we derived the requirements for the specification of the needed 5G network and proposed its system architecture.

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