6G Internet of Things Communication - A Key to Futuristic and Sustainable Farming?

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***Abstract*—Preservation of the natural environment and resources is one of the biggest challenges faced by humanity today. Overpopulation, rapid degradation of the natural environment, climate change and urbanization has put enormous pressure on agriculture, pastoralism and forestry. Smart agriculture is the most prominent solution to address the pressures on agriculture, boosting production and improving the agroecological environment. The key to smart production is automation technologies like large-scale machine-to-machine communication (M2M), the Internet of Things (IoT) made possible through wireless communication. The 6th-Generation wireless would integrate a plethora of terrestrial, aerial and maritime communications to serve human-centric applications and connect the massive number of diverse devices, enabling robust Machine type communication. 6G could transform innovations introduced by 5G in the agricultural sector, such as real-time monitoring, UAVs, and predictive maintenance, by overcoming present limitations in latency, data rate, scalability and flexibility of 5G devices. This short technical report starts with a literature review of necessity, evolution and ongoing research on 6G-enabled agriculture, surveying the state-of-art 6G wireless communication techniques, use cases in Smart agriculture, followed by a SWOT analysis highlighting the merits and challenges and finally, commercial viability and future research directions of 6G-deployment for Smart Agriculture is discussed.**

***Index Terms*—6G, Smart Agriculture, Space-air-ground networks, Terahertz, Wireless Ai**

I. Introduction

Agriculture is changing. The world population is projected to rise by 10 Billion of which 70 percent will be urbanized. Amidst the challenges of climate change, freshwater depletion, and changing consumer preferences, conventional farming approaches need to be rethought. The marriage of biologics, data and technological innovations or the 'Agtech' has massive potential to achieve unrealized levels of food productivity, efficiency, and environmental sustainability. Agtech has given rise to Smart Farming, which is the application of technological resources to help in various stages of crop production. It derives from precision agriculture techniques and optimizes crop production by improving nutrient application, reducing water and electricity consumption, and monitoring disease and pest growth. Wireless communication technologies are essential to the realization of smart farming. Cellular communications and internet connectivity for smart farming applications need high processing power with minimum delays which is made possible by 5G networks that have entered a phase of mass commercialization and promise universal connectivity, minimum latency, and, specifically, the highest rate of data transfer. However, 5G is plagued with expensive infrastructure, low coverage per base station, lack of security mechanisms and integrated support for space, aerial and underground water communications. This has paved the way for the 6G revolution. 6G, while still in the research phase promises near-instant and unlimited full wireless connectivity, integrating sensing, communication, computing, caching, control, positioning, navigation and imagining in one system to gain almost human-like consciousness and usher into an era of both human and machine-centric applications.

This technical report summarizes the need and application of 6G technologies in agriculture, followed by a discussion on merits, challenges, and threats. We also discuss the potential scope of 6 in commercial establishments and bottlenecks and conclude by discussing future research directions in the implementation of 6G for smart agriculture.

II. Vision and Evolution of Mobile Networks for Agriculture

Researchers have described 6G as technology that will transform society in a "Ubiquitous Intelligent Mobile Society." The researchers have envisioned 6G to be supported by 5G infrastructure like Software-Defined Networking, Netowrk Function Virtualization and Network Slicing to facilitate super smart cities, Internet of Everything (IoE) and tactile communication. The 6G is expected to provide high reliability, data rate in order of 1 Tb/s, ultra-low latency lesser than 1 ms, high energy and spectral efficiency in secured and private manner while connecting everything and everyone in remotest corners. In Smart Agriculture, the main objective of 6G would remain to accelerate the progress acheived by 5G in developing intelligent predictive systems born from fusion of IoT and AI/ML techniques to predict and improve yield, crop quality, irrigation and fertilization schedule and crop health analytics.

The evolution from mobile networks from 1G to 6G has slowly but surely worked in the advancement of agricultural techniques, sharing of information, automation and improving the efficiency and reduction of wastage and global carbon footprint of agriculture. The first generation of mobile networks enabled farmers to communicate with each other and exchange information about weather, crop prices and market scenarios through voice calls and make informed decisions about their farming practices. The second generation of mobile networks enabled farmers to access the internet through their mobile phones giving them access to online resources and worldwide markets. The third generation of mobile networks brought faster internet speeds enabling farmers to access sophisticated techniques such as GPS mapping, remote monitoring of crops and equipment and real-time weather updates. The fourth generation of mobile networks helped farmers to use semi-autonomous vehicles, drones and sensors for precision agriculture, environmental monitoring and automated farm management systems, and early detection of plant diseases and pests. The fifth generation of mobile networks opened the doors of cutting-edge technologies such as augmented reality, autonomous robots, and machine learning for predictive analyses, optimization of crop yield and minimizing waste of resources. 5G with its promising technologies such as massive MIMO, network slicing, smaller cells and devices able to provide reliable high-speed connection to exchange large amounts of data while ensuring wide coverage, low-energy consumption and high spectrum efficiency has transformed traditional agriculture.

However, 5G does not offer a promising solution to tackle more critical challenges in population, resources and environmental management. Disadvantages of 5G technology include the high cost of 5G infrastructure, smaller coverage area per base station and the need for multiple base stations. Another crucial limitation is security risks. For instance, software-defined networks (SDNs) lack trust verification mechanisms between management applications and controllers. The main network structures in 5G such as HetNets (Heterogeneous networks) are restricted to ground-based networks. 6G promises to overcome these limitations and open up a new era of connection, intelligence and sensing to lead a comprehensive digital transformation and integration of biological, physical and digital worlds.

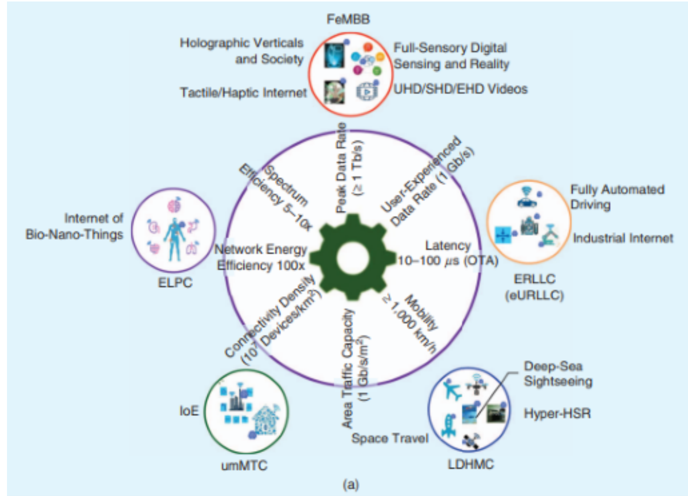

Fig. 1. Typical scenarios of 6G networks

III. Key Technologies in 6G for Smart Agriculture

A. Space-Air-Ground-Integrated Networks

As the scope of human activities has expanded to water, sky and space, the need for multi-dimensional networks has emerged to fulfil omnidirectional integration of ground and non-ground networks on the levels of physical, link, network and systems layer. Space and air-based networks integrated with ground networks in 6G aim to provide ubiquitous coverage on the surface along with three-dimensional space. This multi-dimensional network can effectively incorporate varied resources, intelligent network control and information processing units along with AI applications to handle diverse network requirements. Unmanned Aerial Vehicles (UAVs) have been deployed in smart agriculture for a long time in fertilizer spraying applications. They have also been used to provide communication services in natural disaster struck areas and monitor forest fires. Space-based networks like high–resolution satellites are also employed for soil and crop health diagnosis, meteorology and crop yield prediction using a combination of remote sensing and unsupervised learning. An integrated space-air-ground communication network includes base stations, drones and satellites to aid agricultural activities. For instance, integrated space-air-ground can be used to construct terrain-independent laboratories using drones, satellites and agricultural sensor networks for rapid and detailed field analysis compared to traditional schemes. Almalki et al. [53] designed a low-cost integrated real-time automatic monitoring platform to collect environmental parameters using UAV and IoT technology. These platforms can help farmers analyze and understand patterns of environmental data over large farmland areas with great accuracy to improve crop productivity and yield.

B. Terahertz Technology

From 2016 to 2021, mobile data traffic grew by seven times. Wile communication technologies operation on higher frequency bands have become common, current technology is still struggling to support data transmission and communication at the Tbps level. Terahertz solution could solve these problems as it supports ultra-high bandwidth, extra-low latency and super-i data transfer rate. Terahertz lies in the frequency band from 0.1 Tz to 10 Tz, located between microwave and infrared bands. Therefore, it has both penetrating and absorbing properties of microwave and spectral resolution properties of infrared. As it uses terahertz as a carrier wave for wireless communications, terahertz band could support ultra-i communication rates and can be used for micro-sized communications, data return with ultra-high capacity, sort-range ultra-high rate transmissions and high-precision positioning and resolution sensory imagining of networks. Terahertz technology is one of the most commonly used 6G technologies in agriculture. Zaid et al. designed a system to detect pesticide residues in leaves by measuring water content using Terahertz technology and were the first to explore terahertz applicability in determining plant health. Usman et al devised an integrated communication-sending system to monitor plant nutrients at the nanoscale level and facilitate early detection of agricultural diseases or malnutrition. Wedage et al. investigated terahertz technology for weather prediction. Jian et al. researched on application of terahertz radiation to monitor rain storage quality. Thus, potential of terahertz in agriculture applications are in Pest detection: Due to few picometers wavelength of Terahertz waves, they have penetration capacity and low energy consumption. This could be used to wirelessly sense and detect plant pests and prevention of plant diseases. In Food Safety and Water Quality monitoring: Terahertz spectroscopy could identify weak intermolecular interactions and wavy metal substances. Hence, it could be used to detect pesticide residues and wavy metal traces in crops and quality check of irrigation water fed to crops.

C. *Reconfigurable Intelligent Surface (RIS)*

RIS is an artificial electromagnetic surface structure developed from metamaterial technology and have programmable properties. RIS has become an important research avenue in 6 technology due to its low cost, low power consumption, programmability and deployment ease. It is designed as a spatial electromagnetic wave modulator which intelligently reconfigures the wireless propagation environment in a communication system. It could be combined with terahertz frequencies to improve terahertz coverage. Due to propagation attenuation and molecular absorption of terahertz frequencies, the terahertz transmission is limited in distance and coverage. This limitation can be alleviated by interaction RIS with Terahertz. Zhang et al. explored backscatter communication in RIS for an agricultural sensor network which showed reduction in agricultural sensors' cost, power consumption and monitoring range. Liu et al devised solar harvesting along wit RIS sensing in agriculture to improve wireless energy transfer efficiency and increase the coverage to address poor sustainability and durability in agricultural sensing activities. The applications of RIS in agriculture could be summarized as: 1. Communication in remote areas: In remote areas, deploying base stations is not economical. In its place, RIS could be employed to improve communication systems quality by adjusting of propagation environment and low-cost deployment and maintenance. 2. Agriculture precision sensing: RIS can increase the number of communication links to improve accuracy and precision in wireless sensing.

D. *Wireless AI*

AI as multiple applications in wireless communications such as modelling, learning, prediction complex unknown wireless propagation environments, signal processing, intelligent scheduling, network state tracking, network deployment and optimization. AI-empowered physical layer technologies for 6 communication includes wireless environment modelling and sensing, channel estimation/production, channel compilation codes, modulation and waveform techniques, OFDM receiver design, multi-antenna transreceivers, multi-user access and active user detection and localization. The AI-empowered link layer technologies for 6G communications include power and channel allocation, access control, link scheduling etc. Wireless AI applications in agriculture include digital soil mapping, remote plant health monitoring and disease detection. Vijaykumar et al. designed an automated irrigation system which utillizes artificial neural network to analyze the environmental parameters and control the timings and amount of irrigation leading to a 8 percent reduction in water consumption. Dasgupta et al. designed a similar system to collect annual precipitation, and soil pH and deploy deep-learning models to recommend suitable crop precipitation to farmers intelligently. Somov et al. too employed the same system to early detect symptoms of any crop disease. To conclude, wireless AI can contribute in Resource Allocation Optimization by AI-based scheduling of wireless resources for low-power, sustainable agriculture. It would also integrate with wireless positioning for understanding crop, soil and vegetation distribution accurately through image recognition.

E. *Integrated Sensing and Communications (ISAC)*

Integration of radar and wireless communication system on the hardware platform for sharing of hardware, software and radio resources to facilitate sensing and communications is referred to as Integrated sensing and communications (ISIC). The two sub-fields of ISAC are communication and sensing-centric systems. Communication-centric systems prioritize communication functions and improve communication indicators such as spectral efficiency, channel capacity, signal-to-noise ratio and bit-error-rate before the sensing applications. Sensing-centric systems ensure that communication system functions do not interfere with sensing performance by degrading accuracy, detection and recognition probability. Millimetre wave technology is a great example of the application of ISAC in agricultural research areas like the prevention of plant diseases where cameras are not efficient in capturing images due to high humidity and shade. As millimetre wave imaging has a high penetration capacity, it could penetrate foliage to detect microbial or pest infestations. The communication part of ISAC can support sharing of monitored environmental data to alert abnormal plant appearance and resource consumption.

F. *Digital Twins*

Digital twin technology involves mapping or cloning a physical entity on a virtual digital space. The digital twin consists of a physical object and its digital clone which can be simulated to enhance the performance of physical objects. Ghandar et al. researched into low-cost, high precision digital twin framework for farms with environmental wireless sensors and cloud server. This enables real-time monitoring of farmlands making Digital twin technology suitable to implement on multiple large farms. Batty et al. used deep learning and digital twin technology in aquaponics to decrease water, soil and light consumption. In a similar approach, Howard et al. used digital twins, big data and IoT in greenhouse to predict future state of greenhouse according to present and past conditions. Jans-Singh too designed a farm on Digital twin approach to automatically set optimal environmental conditions for plant growth while acheiving low resource consumption.

IV. Merits and Challenges of 6G in Smart Agriculture

6G technology is an emerging concept with a lot of research ongoing in distributed networking technologies, secure endogeneity, arithmetic and programmable networking, immersive multisensory networks and semantic communication. Merits of 6G include connectivity at ultra-fast speeds and low latency Ultra-fast speeds and low latency will allow for real-time monitoring and analysis of crops, soil conditions, and weather patterns.

The challenges to 6G includes compatibility at the hardware level. It is proposed of that AI would transform wireless networks into intelligent entities. However, it would exponentially increase the need of processing power to analyze large amount of data and AI algorithms. New semiconductor chips have been introduced to support Terahertz communication but more research is required to understand its utilization in practical scenarios. There is also a need of standardization of new protocols or update of existing protocols for 6G communications. To aid easy commercialization, it is necessary that these protocols are economical. One important aspect is also the development of infrastructure and if emergence of 6G would need a rehaul of existing wireless network supporting protocols and technologies. It is clear that to facilitate a ubiquitous communication a 3D network architecture combining satellite, UAV, underwater and terrestrial network would be required. The present infrastructure would be either rehauled or improvised to accommodate RIS, CubeSats, and Massive MIMO. ks, or will there be new Infrastructure? Not certain. It is not yet clear if there will be a complete overhaul of existing wireless networks with a new architecture for 6G. As 6G has been proposed to combine communication, computing, control and localization, it is a deviation from previous generations which focused solely on wireless communications. Therefore, there is lack of prior models and blueprints in enabling intelligent control in stringent application is a priority research focus. 6G is thought to usher a new era of haptics communication with technologies like teletouch and bidirectional brain communication. Wide adoption of haptics may render devices of smartphone era useless. However, for haptics to be widely adopted, psychological concerns of users need to be looked upon. There is also a need for new networking protocols or an upgrade to the existing ones to be compatible with the new technologies such as the THz frequency spectrum, which are enablers of 6G. As stated earlier in this paper, communicating at a higher frequency spectrum is prone to high path loss. Therefore, there is a need for hardware to improve the transmission range of THz communication. There is also a need for a robust system and algorithm for handover management in UAV/CubeSat communication. It is as well crucial that these hardware architectures are low-cost and energy-efficient. Additionally, as stated earlier, compatibility with existing infrastructure is desirable.

V. Commercial Viability of 6G in Smart Agriculture

6G technology is still in the research and development stage, and its commercial availability is not expected until the mid to late 2030s. However, it is believed that 6G could have a significant impact on agriculture by enabling more efficient and precise farming practices.

One of the key benefits of 6G technology in agriculture is its ability to provide ultra-fast, high-bandwidth connectivity. This could enable farmers to collect and analyze data from a wide range of sources, including sensors, drones, and satellite imagery, in real-time. This data could then be used to optimize crop yields, reduce waste, and improve overall farm productivity.

In addition, 6G technology could enable the use of advanced robotics and automation systems in agriculture, such as autonomous tractors and drones. This could reduce labor costs and increase the efficiency of farm operations.

However, the commercial viability of 6G in agriculture will depend on a number of factors, including the availability of infrastructure and the cost of implementing new technologies. It is also important to consider the potential risks and challenges associated with the use of new technologies in agriculture, such as data privacy concerns and the impact on rural communities.

Overall, while 6G technology holds great promise for the agriculture industry, its commercial viability in this context remains to be seen and will depend on a variety of factors.

VI. Conclusion

4. Conclusions In this report, we introduced the Smart Agriculture and its evolution with the changing generations of mobile networks. We reviewed the state-of-art technologies in 6G to enable smart agriculture and their merits, demerits and commercial viability. These techniques though pretty advanced have their own shortcomings and more research, especially pilot projects to test efficiency and impact on social, commercial and environmental level is needed. But, it is clear that Smart Agriculture will be defined by secure endogeneity, arithmetic networking technologies, programmable networking technologies, trusted data services, immersive multisensory networks, and semantic communication which would not only improve yield and quality of crops, but make farming a profitable venture and transform the livelihoods of farmers.

References

[1] Zhang F, Zhang Y, Lu W, Gao Y, Gong Y, Cao J. 6G-Enabled Smart Agriculture: A Review and Prospect. Electronics. 2022; 11(18):2845. https://doi.org/10.3390/electronics11182845

[2] Yu Tang, Sathian Dananjayan, Chaojun Hou, Qiwei Guo, Shaoming Luo, Yong He, A survey on the 5G network and its impact on agriculture: Challenges and opportunities, Computers and Electronics in Agriculture, Volume 180, 2021, 105895, ISSN 0168-1699,https://doi.org/10.1016/j.compag.2020.105895.

[3] Naqvi, Syed Muhammad Saleem, Shoaib Tahir, Naveed Li, Shixin Hussain, Saddam Haq, Syed Ijaz Ul. (2022). Role of 5G and 6G Technology in Precision Agriculture. Environmental Sciences Proceedings. 23. 10.3390/environsciproc2022023003.

[4] H. Tataria, M. Shafi, A. F. Molisch, M. Dohler, H. Sjöland and F. Tufvesson, "6G Wireless Systems: Vision, Requirements, Challenges, Insights, and Opportunities," in Proceedings of the IEEE, vol. 109, no. 7, pp. 1166-1199, July 2021, doi: 10.1109/JPROC.2021.3061701.

[5] Imoize AL, Adedeji O, Tandiya N, Shetty S. 6G Enabled Smart Infrastructure for Sustainable Society: Opportunities, Challenges, and Research Roadmap. Sensors. 2021; 21(5):1709. https://doi.org/10.3390/s21051709