Deep Dives and Case Studies for TELUS Priority Verticals: Agriculture

Prepared for TELUS Communications Inc.

Prepared by: Deetken Insight

30 June 2022

Deetken Insight

5.1 Deep Dives and Case Studies for TELUS Priority Verticals

5.1.1 Agriculture

Key Takeaways

- Key challenges faced by the agriculture industry include continuing population growth; changes in weather patterns induced by climate change; increasing soil degradation; pervasive water scarcity; and food wastage stemming from inefficient farming, transportation, and consumption practices.
- 5G will enable innovative applications that could help avert the expected food sustainability crisis and optimize farming practices. These digital 5G solutions include distributed arrays of wireless soil sensors that enable remote plant monitoring and smart irrigation; real-time monitoring and routing of livestock; connected farm machinery; predictive building and equipment maintenance and adjustment; remote drone surveillance and intervention; and smart greenhouses.
- These 5G solutions could increase farmland and human productivity; increase crop and livestock yields; optimize water, pesticide, herbicide, and fertilizer use; reduce farmer expenditures; decrease food wastage and increase traceability; mitigate environmental contamination; and enhance predictive maintenance of assets.

Industry Overview: The agriculture and agri-food industries, which account for approximately 9.7% of total global GDP[1] and 7.4% of Canadian GDP[2], will need to evolve rapidly over the next few years to meet the demands of global population growth and climate change. Over the next decade, 5G will play a critical role in the agriculture and livestock industries by improving crop yields, crop quality and the health of the livestock – while using fewer laborers. Smart farming/precision agriculture will allow farmers and breeders to be more informed and productive. IoE-based cloud computing service in the 5G network provides flexible and efficient solutions for smart farming that will allow the automated operation of various unmanned agricultural machines for the plowing, planting and management phases of crop farming. This will make farming operations more secure, reliable, environmentally friendly and energy-efficient, and enable unmanned farms. If 5G connectivity is implemented successfully in agriculture, the sector could add $500 billion to global GDP by 2030, amounting to a 7% to 9% improvement upon expected growth – alleviating much of the pressure on farmers.[3]

[1] Link to report: https://www.slideshare.net/IFPRI-PIM/beyond-agriculture-measuring-agrifood-system-gdp-and-employment
[2] Link to report: https://agriculture.canada.ca/en/canadas-agriculture-sectors/overview-canadas-agriculture-and-agri-food-sector
[3] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth

Challenges faced by the agriculture industry:

1. **Population growth:** The United Nations (U.N.) estimates the global population will increase by two billion people in the next 30 years to 9.7 billion in 2050 and could peak at nearly 11 billion around 2100.[4] According to estimates compiled by the U.N. Food and Agriculture Organization (FAO), we will need to produce 60% more food to feed a world population of 9.7 billion by 2050 compared to 2012 when the global population was 7.1 billion, based on current farming practices, techniques and technology, further straining our natural resources.[5]

2. **Changing weather patterns:** The variability of temperatures and precipitation and the rise in the frequency of floods and droughts because of climate change all tend to reduce crop yields.[6]

3. **Soil degradation:** The world's farmlands are becoming increasingly unsuitable for production. According to FAO, most of the world's soil resources are in fair, poor or extremely poor condition. Currently, 33% of the world's land is moderately to highly degraded due to the erosion, salinization, compaction, acidification and chemical pollution of soils.[7]

4. **Water scarcity**: Water resources are also highly stressed with 3.2 billion people living in agricultural areas with high to extremely high water shortages or scarcity. Approximately 1.2 billion people – roughly one-sixth of the world's population – live in severely water-constrained agricultural areas. This scarcity of land and water resources is putting additional pressure on the agri-ecosystem and increasing rural poverty in certain parts of the world.[8]

5. **Wastage of food:** Per estimates compiled by the Food and Agriculture Organization, approximately one-third of all food produced annually across the world, 1.3 billion tonnes, is wasted due to deficient farming, supply chain and consumption practices, while approximately 925 million people (1 in 7) are suffering from hunger.[9] Wasted food consumes approximately 30% of the world's agricultural land area and 25% of freshwater globally.[10,11] In Canada, approximately 58% of food produced is wasted according to the Canadian "Avoidable Crisis of Food Waste" study. This study found that of the 58% of food wasted, 24% is lost at the production level, 34% at the processing level and 13% at

---

[4] Link to report: https://www.un.org/en/global-issues/population
[5] Link to report: https://www.un.org/en/chronicle/article/feeding-world-sustainably
[6] Link to report: https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf
[7] Link to report: https://www.fao.org/3/i5199e/I5199E.pdf
[8] Link to report: https://www.unwater.org/water-facts/scarcity/
[9] Link to report: https://www.un.org/en/chronicle/article/feeding-world-sustainably
[10] Link to report: https://www.un.org/en/observances/end-food-waste-day/background
[11] Link to report: https://comparecamp.com/food-waste-statistics/#:~:text=Food%20waste%20also%20puts%20pressure%20on%20water%20resources.,in%20places%20with%20severe%20water%20shortage%20by%202050.

the manufacturing level. Distribution and retail waste accounts for 6% of total food waste and hotel, restaurant and institutions account for 9%.[12]

Smart farming is expected to drive significant enhancements in food planning, production, logistics, tracking, consumption practices and techniques. Technologies such as the IoE, AI, ML, and BDA, supported by a ubiquitous and resilient 5G network, can help harness the value of data. This would help avert the expected future food sustainability crisis while supporting the achievement of environmental and social suitability goals of enhanced productivity, water and fertilizer usage optimization, and GHG emission and food wastage reduction.

Potential Digital Solutions Supported by 5G[13]	Types of 5G Capabilities Leveraged
1. **Distributed soil sensors**[14] that measure parameters such as moisture or temperature, identify issues such as diseases or insects, and enable informed farming decisions. 2. **RFID, bar code and other identification technologies**[15] that build a safe traceability system for agricultural products and enhance the added value of agricultural products. 3. **Weed and crop monitoring**[16] provide real-time crop vegetation monitoring, which enables the ability to track positive and negative dynamics of crop development. 4. **Routing and monitoring of livestock**[17, 18] supports real-time management of livestock to monitor the location, health and needs of individual animals and to adjust their nutrition, thereby preventing disease and enhancing herd health; with this information, farmers can also identify sick animals so they can be separated from the herd to prevent the spread of disease. 5. **Smart irrigation**[19] through the use of controllers and devices which reduce water usage by using precise real-time and location-dependent information about site conditions; IoT sensors embedded in the soil can measure moisture levels and data captured from drones can help generate heat maps that highlight problem areas. Advanced machine learning algorithms can process this data and distribute water where it's needed most. 5G's	1. **Ultra-low and predictable latencies with quality-of-service guarantees (URLLC)** even with a heavy load and many users. 2. **Extremely high bandwidth for data transmission (eMBB),** enabling the transfer and download of massive data files, high-resolution images, videos and supporting AR/VR. 3. **Massive IoT (mIoT)** - 5G will be able to facilitate a large network of IoT devices and sensors. 4. **Fixed wireless access (FWA)** - ultra-low-cost networks in rural areas. 5. **More deployment flexibility** for sparse and dense options. 6. **Mobility capabilities to ensure a smooth handover** between base stations. 7. **Reliability of device interoperability** and low device cost at scale. 8. **Location awareness** for navigating, real-time locating and positioning.

[12] Link to report: https://www.secondharvest.ca/getmedia/58c2527f-928a-4b6f-843a-c0a6b4d09692/The-Avoidable-Crisis-of-Food-Waste-Technical-Report.pdf
[13] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
[14] Link to report: https://www.mdpi.com/1424-8220/21/5/1693/htm
[15] Link to report: https://www.barcodesinc.com/news/bar-coding-and-rfid-enable-food-supply-chain-traceability-and-safety/
[16] Link to report: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture
[17] Link to report: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture
[18] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
[19] Link to report: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture

speed and throughput facilitate the transmission of these large data sets. 6. **Connected farming machinery**[20, 21] that uses auto-steer GPS signals to automatically control the tractor in seeding, spraying, fertilizer application, and harvesting, thereby reducing the overlap of farming operations and leading to substantial fuel savings. Automated farming equipment (e.g., smart milking equipment) and vehicles (e.g., harvesting trucks) can be controlled remotely by a central operator. 7. **Building and equipment management**[22] through predictive maintenance and real-time environmental adjustments; this is aimed at improving performance and extending the useful life of farm equipment and other assets as well as decreasing the risk of mold, fire and other threats. 8. **Drones for farming**[23, 24] use drone surveillance and remote interventions based on image analysis and connected sensors communicating data with the drone to monitor fields, livestock or autonomous machinery (e.g., driverless harvesting trucks). Drones support the isolation of problem areas on a large farm through massive penetration of large-scale IoT sensor networks, aerial scanning and detection. Drones also enable autonomous, targeted (reduced) application of pesticides and herbicides, and can spray fertilizers, pesticides and herbicides 40 to 60 times faster than doing so by hand.[25] **9. Smart greenhouses** leverage IoE and connected devices to create a self-regulating microclimate conducive to crop production. These controlled environments eliminate the struggles of inclement weather and predators while delivering real-time insights to farmers for optimum efficiency. Farmers using smart greenhouse crop monitoring systems can leverage insights from big data and analytics to regulate crop spraying, irrigation, lighting, temperature, humidity and more.[26]	
Potential Operational Benefits	**Potential ESG Benefits**

[20] Link to report: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture
[21] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
[22] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
[23] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
[24] Lin to report: https://www.5gradar.com/features/ways-5g-will-change-farming-and-agriculture
[25] Link to report: https://www.businessinsider.com/smart-farming-iot-agriculture
[26] Link to report: https://www.businessinsider.com/smart-farming-iot-agriculture

1. **Increase in farmland productivity** by an estimated 4% because of current 4G technology adoption and the potential to increase productivity to 6% with 5G technology and application adoption.[27] 2. **Improved fertilizer placement (right source, right rate, right time and right place) has increased efficiency** by an estimated 7% and has the potential to improve efficiency by an additional 14% with 5G technology and application adoption.[28] 3. **Significant savings and simultaneous protection of the fragile farm ecosystem.** For example, a study conducted by the European Parliamentary Research Service found that early, accurate detection and localized pest and disease treatment have the potential to reduce pesticide costs by up to 85%.[29] Similarly, herbicide usage is estimated to decrease by 9% and can be reduced by a further 15% from current levels with 5G technology and application adoption.[30] 5G adoption is also expected to result in a decrease in seed, fuel and energy, labor and asset maintenance costs.[31] 4. **Increased human productivity and performance** and decreased level of unnecessary human intervention; the average number of employees working on the farm will fall over time as farmers add more technology, however, other jobs will be created by 5G in data analytics and farm management. 5. **Enhanced cyber and physical security** through real-time security monitoring and threat assessment via drones and industrial cameras.	1. **Ensured food security and resilience and reduced dependency on imports** by increasing crop and livestock yields, decreasing food spoilage and waste, and increasing food quality and access. [U.N. SDG - 1 and 2] 2. **Alleviation of the remote/rural digital divide** in rural communities which have been negatively impacted in many ways, including a lack of telehealth, remote/rural work opportunities and online workforce training; The agricultural community also suffers decreased productivity, such as food spoilage, which can be mitigated with the help of 5G-powered precision agriculture. 5G-enabled technologies will also support the alleviation of poverty, inequality and digital exclusion while increasing financial inclusion and market access, and competitiveness. [U.N. SDG - 1, 2, 5, 8, 10 and 14] 3. **Decrease in fossil fuel use** by an estimated 6% as a result of current 4G technology and application adoption and the potential to further decrease fossil fuel usage by 16% with 5G technology and application adoption.[32] [U.N. SDG - 12] 4. **Reduced water use** by an estimated 4% as a result of current 4G technology and application adoption and the potential to further reduce water usage by 21% with 5G technology and application adoption.[33] [U.N. SDG - 6] 5. **Improved worker health and safety** with the use of autonomous agriculture vehicles and drones for tasks where human involvement may be tedious or dangerous. [U.N. SDG - 3] 6. **Improved access to connectivity and integration into the end-to-end food value chain** will drive an increase in food safety and traceability and a reduction in food waste, thereby reducing GHG emissions and supporting global climate change goals. [U.N. SDG - 2, 8, 9, 10, 12 and 14] 7. **Shift of skills** and access to better professional jobs; in-field AR support for e-learning and expert advice in remote areas. [U.N. SDG - 8]

[27] Link to report: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf
[28] Link to report: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf
[29] Link to report: https://www.europarl.europa.eu/RegData/etudes/STUD/2016/581892/EPRS_STU(2016)581892_EN.pdf
[30] Link to report: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf
[31] Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
[32] Link to report: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf
[33] Link to report: https://newsroom.aem.org/download/977839/environmentalbenefitsofprecisionagriculture-2.pdf

Estimated Economic Benefits	Example Metrics Potentially Impacted by 5G
1. 5G applications in agriculture could add an estimated US$500 billion[34] to global GDP by 2030.	1. Access to the 5G network 2. Number of 5G-enabled digital solutions implemented 3. Estimated total value realized from 5G enabled digital solutions that are implemented 4. Increase crop and livestock yield 5. Decrease in fertilizer, pesticide, and herbicide use per output 6. Decrease in water and energy use per output 7. Decrease in crop storage and transportation costs 8. Increase in farmland utilization rate 9. Decrease in food crop wastage and livestock deaths 10. Decrease in GHG emissions 11. Decrease in workplace injuries 12. Increase in labor force skills index

Select case studies:

Precision Canola Farming[35,36]	
Background	▪ Roughly 90% of Canada's total canola production is exported to foreign markets. In 2018, Saskatchewan harvested over 12 million acres of canola, with total production of over 10.9 million tonnes.[37] ▪ Canola operations make use of fertilizers and pesticides on cropland to combat invasive plants, harmful insects and disease and promote higher crop yields. Larger operations use several tractors or manned aircraft to administer fertilizers and pesticides, which often under- or over-spray certain areas. This places not only crops at risk, but also human health and the environment.
Improvement areas	▪ Aerial scanning and detection by unmanned drones, in combination with large-scale IoT sensor networks, allows for autonomous, targeted and subsequently reduced application of fertilizers and pesticides.
Economic and societal impacts	▪ Precision agriculture can reduce the use of pesticides by up to 85%.[38] In addition to cost savings, precision agriculture would result in health and environmental benefits, as well as higher crop yields. [U.N. SDG 12] ▪ For Saskatchewan's canola industry, this reduction in pesticide usage would equate to up to $360 million in annual savings. Once 5G networks are established and precision agriculture becomes more widespread, the average

34 Link to report: https://www.mckinsey.com/industries/agriculture/our-insights/agricultures-connected-future-how-technology-can-yield-new-growth
35 Link to report: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.
36 Link to report: https://www3.weforum.org/docs/WEF_The_Impact_of_5G.pdf.
37 Link to report: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.
38 Link to report: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.

Precision Canola Farming[35,36]	
	Saskatchewan oilseed farmer could expect to realize up to $40,000 in annual savings.
5G capabilities used	▪ eMBB ▪ mIoT ▪ Power efficiency
CapEx requirements	▪ Unmanned drones, IoT devices and data analytics applications; other potential purchases include edge computing and private network infrastructure.
Maturity timeline	▪ Current state: Connectivity requirements of precision agriculture can be supported by existing 4G networks; however, the implementation of large-scale IoT sensor networks and real-time video analysis will require 5G's bandwidth and speed capabilities. ▪ Short-term: Fixed wireless access and network slicing will allow 5G networks to support additional IoT applications in rural areas. ▪ Long-term: autonomous machine learning and satellite, content-based analytics that further augment the benefits of precision agriculture.

Viticulture Disease Mitigation[39,40]	
Background	▪ In 2017, Canada's viticulture industry earned roughly $6.2 billion in revenue and employed over 37,000 individuals.[41] ▪ Grapevine Leafroll Disease (GLD) is one of the most common viruses impacting vineyards globally and can be difficult to identify from the ground. The disease is capable of reducing berry weight and delaying time to maturity by up to four weeks.[42] ▪ Halifax-based company VineView and its partner Global UAV Technologies initiated the "Digital Vineyard of the Future" pilot project, which involved flying a 4G-enabled drone over a Nova Scotia winery to conduct real-time analysis of vineyard health.
Improvement areas	▪ An automated approach to vineyard monitoring would enable the timely identification, isolation and treatment of infected or at-risk vines necessary to mitigate adverse outcomes from GLD. ▪ Unmanned aerial reconnaissance using 5G-enabled communications networks would allow for greater volumes of data and imagery to be transmitted in real-time so farmers can quickly take action to mitigate losses attributable to crop disease.

[39] Link to report: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.
[40] VineView. https://www.vineview.com/.
[41] Wine Growers Canada. Link to webpage: https://www.winegrowerscanada.ca/our-industry/economic-impact/.
[42] Link to report: https://brocku.ca/ccovi/wp-content/uploads/sites/125/2016-03-02.-CCOVI-Lecture-Series.-Urbez-Torres-Grapevine-viruses-in-BC.pdf.

Viticulture Disease Mitigation[39,40]	
Economic and societal impacts	▪ For an average 50-acre Okanagan vineyard, GLD can impact yields by as much as 30%. If left undetected and untreated via targeted vine replacement, this would result in an average annual loss of $18,000.[43] 5G-enabled unmanned aerial drone reconnaissance enables farmers to quickly detect and treat GLD such that crop yields are improved. [U.N. SDGs 2 & 12]
5G capabilities used	▪ eMBB
CapEx requirements	▪ Unmanned drones and data analytics applications; other potential CapEx purchases include edge computing and private network infrastructure.
Maturity timeline	▪ Current state: Connectivity requirements of aerial drone monitoring can be supported by existing 4G networks, however, real-time high-resolution video analysis will require 5G's bandwidth and speed capabilities. ▪ Long-term: autonomous machine learning that further augments the benefits of drone reconnaissance

[43] Link to report: https://www.cwta.ca/wp-content/uploads/2019/11/Accelerating-5G-in-Canada-V11-Web.pdf.

A. Glossary of Key Terms

Terms	Definitions
3GPP	The focal point of development for 5G specifications and standards is the Third Generation Partnership Project (3GPP), a consortium made up of seven of the regional telecommunications standards development bodies. 3GPP has hundreds of technical specifications under development for mobile wireless communications, including the air interface/radio access (5G New Radio), the 5G core, and the IoT, among others. 3GPP is also developing standards for networks to interconnect and collaborate with one another. For example, 3GPP's non-public network support is intended to allow private networks optimized for a specific purpose (e.g., an automated manufacturing facility) to co-exist with public carrier networks.
Area traffic capacity	Total traffic throughput served per geographic area, measured as data rate per unit area. Area traffic capacity increases will enable better network performance in densely populated areas. *Category - Massive Internet of Things (Massive IoT).*
Artificial Intelligence	The ability of a computer or a robot controlled by a computer to do tasks that are usually done by humans because they require human intelligence and discernment.
Augmented Reality (AR)	An enhanced version of the real physical world that is achieved through the use of digital visual elements, sound, or other sensory stimuli delivered via technology.
Automation	Describes a wide range of technologies that reduce human intervention in processes. Human intervention is reduced by predetermining decision criteria, sub process relationships, and related actions — and embodying those predeterminations in machines. Automation includes the use of various equipment and control systems such as machinery, processes in factories, boilers, and heat-treating ovens, switching on telephone networks, steering, and stabilization of ships, aircraft, and other applications and vehicles with reduced human intervention. Automation has been achieved by various means including mechanical, hydraulic, pneumatic, electrical, electronic devices, and computers, usually in combination. Complicated systems, such as modern factories, airplanes, and ships typically use all these combined techniques. The benefit of automation includes labor savings, reducing waste, savings in electricity costs, savings in material costs, and improvements to quality, accuracy, and precision.
Backhaul	The portion of the network that comprises the intermediate links between the core network and the small subnetworks at the edge of the network. In the context of a mobile network, the backhaul connects a cell site toward the core network. The two main methods of mobile backhaul implementations are fibre-based backhaul and wireless point-to-point backhaul.
Bandwidth	Is the maximum aggregated system bandwidth. The bandwidth may be supported by single or multiple radio frequency (RF) carriers. The requirement for bandwidth is at least 100 MHz. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Big Data Analytics	The use of advanced analytic techniques against very large, diverse data sets that include structured, semi-structured and unstructured data, from different sources, and in different sizes from terabytes to zettabytes.
Connection density	Total number of connected and/or accessible devices that can be accommodated, measured in devices per unit area. Increased connection density will support customer use where there are a tremendous number of devices, such as in stadiums and warehouses. *Category - Massive Internet of Things (Massive IoT).*
Control plane latency	Control-plane latency refers to the transition time from a most "battery efficient" state (e.g., Idle state) to the start of continuous data transfer (e.g., Active state). The target for control plane latency should be 10ms. *Category - Enhanced Mobile Broadband (eMBB).*
Coverage	Is the uplink and downlink between device and Base Station site (antenna connector(s)) for a data rate of 160bps, where the data rate is observed at the egress/ingress point of the radio protocol stack in uplink and downlink. The target for coverage should be 164dB (decibel). Link budget and/or link level analysis are used as the evaluation methodology. *Category - Massive Internet of Things (Massive IoT).*
Cyber-physical system (CPS)	A computer system in which a mechanism is controlled or monitored by computer-based algorithms. In cyber-physical systems, physical and software components are deeply intertwined and are able to operate on different spatial and temporal scales, exhibit multiple and distinct behavioral modalities, and interact with each other in ways that change with context. CPS involves transdisciplinary approaches, merging theory of cybernetics, mechatronics, design and process science. CPS is also similar to the Internet of Things (IoT), sharing the same basic architecture; nevertheless, CPS presents a higher combination and coordination between physical and computational elements. Examples of CPS include smart grid, autonomous

Terms	Definitions
	automobile systems, medical monitoring, industrial control systems, robotics systems, and automatic pilot avionics.
Digital Twin	A virtual representation that serves as the real-time digital counterpart of a physical object or process. Data collected from sensors connected to a physical device can be used to update the digital twin copy to reflect any changes to the device's current state.
Digitalization	The use of digital technologies to change a business model and provide new revenue and value-producing opportunities; it is the process of moving to a digital business.
Digitization	the process of converting information into a digital (i.e., computer-readable) format. The result is the representation of an object, image, sound, document, or signal (usually an analog signal) obtained by generating a series of numbers that describe a discrete set of points or samples. The result is called digital representation or, more specifically, a digital image, for the object, and digital form, for the signal. Digitization is of crucial importance to data processing, storage, and transmission, because it "allows information of all kinds in all formats to be carried with the same efficiency and also intermingled".
Energy efficiency	On the device side, the number of bits transmitted or received per unit of energy consumption. On the network side, energy efficiency refers to the quantity of information bits transmitted to or received from users, per unit of energy consumption of the radio access network (RAN), measured in bits per joule. Energy efficiency improvements are critical due to the expected massive increase in data use over time. Category - Massive Internet of Things (Massive IoT).
GSMA	Global System for Mobile Communications, originally Groupe Spécial Mobile, is an industry association representing the interests of mobile operators worldwide, including more than 750 operators and almost 400 companies in the broader mobile ecosystem. GSMA has published hundreds of security guidelines, recommendations, and requirements over the years regarding best practices in mobile security that support real world deployments related to security of devices, networks, interconnect protocols, and services. GSMA's Fraud and Security Group is particularly active, working on 5G security in the context of other interdependent topics such as IoT and roaming.
IEC	International Electrotechnical Commission is an international standards organization that prepares and publishes international standards for all electrical, electronic, and related technologies – collectively known as "electrotechnology". IEC standards cover a vast range of technologies from power generation, transmission and distribution to home appliances and office equipment, semiconductors, fibre optics, batteries, solar energy, nanotechnology, and marine energy as well as many others. The IEC also manages four global conformity assessment systems that certify whether equipment, systems, or components conform to its international standards. All electro-technologies are covered by IEC Standards, including energy production and distribution, electronics, magnetics and electromagnetics, electroacoustics, multimedia, telecommunication, and medical technology, as well as associated general disciplines such as terminology and symbols, electromagnetic compatibility, measurement and performance, dependability, design and development, safety, and the environment.
IEEE	Institute for Electrical and Electronics Engineers is involved in the creation of many standards, including WiFi and WiMAX standards, as well as other machine communications standards that will change with 5G.
IETF	Internet Engineering Task Force covers specifications related to 5G non-radio network segments.

Terms	Definitions
Industry 4.0	The Fourth Industrial Revolution, 4IR, or Industry 4.0, conceptualizes the current rapid change to technology, industries, and societal patterns and processes due to increasing interconnectivity and smart automation. The term has been used widely in scientific literature, and was popularized by Klaus Schwab in 2015, the World Economic Forum Founder and Executive Chairman. Schwab asserts that the changes seen are more than just improvements to efficiency, but express a significant shift in industrial capitalism. A part of this phase of industrial change is the joining of technologies like artificial intelligence, gene editing, to advanced robotics that blur the lines between the physical, digital, and biological worlds. Throughout this, fundamental shifts are taking place in how the global production and supply network operates through ongoing automation of traditional manufacturing and industrial practices, using modern smart technology, large-scale machine-to-machine communication (M2M), and the internet of things (IoT). This integration results in increasing automation, improving communication and self-monitoring, and the use of smart machines that can analyze and diagnose issues without the need for human intervention. It also represents a social, political, and economic shift from the digital age of the late 1990s and early 2000s to an era of embedded connectivity distinguished by the omni-use and commonness of technological use throughout society (e.g., a metaverse) that changes the ways we experience and know the world around us. It posits that we have created and are entering an augmented social reality compared to just the natural senses and industrial ability of humans alone.
Internet of Everything (IoE)	The networked connection of people, process, data, and things. The benefit of IoE is derived from the compound impact of connecting people, process, data, and things, and the value this increased connectedness creates as “everything” comes online.
ISO	International Standards Organization is an international non-governmental organization made up of national standards bodies that develops and publishes a wide range of proprietary, industrial, and commercial standards. In addition to producing standards, ISO also publishes technical reports, technical specifications, publicly available specifications, technical corrigenda, and guides. The ISO plays an important role in facilitating world trade by providing common standards among different countries. ISO standards cover all fields, from healthcare to technology to manufacturing to security to the environment.
ITU	The International Telecommunications Union is in the process of developing ITU-R Recommendations for the terrestrial components of the IMT-2020 radio interface(s) based upon specifications from external, industry-led standards development organizations.
Latency	Time it takes from when the source sends a packet of data to when the destination receives it, usually measured in milliseconds. More precisely, latency for 5G is the contribution by the radio network to this time. Low latency is especially important for applications, such as industrial automation or remote medicine, where delays in data transfers could be disastrous. *Category - Mission Critical Control (MCC).*
Machine Learning	The use and development of computer systems that are able to learn and adapt without following explicit instructions, by using algorithms and statistical models to analyze and draw inferences from patterns in data.
Mobility	Maximum speed a device can be traveling and still experience a defined quality of service. Mobility is important for applications that require reliable connection when moving, such as in transportation safety. The target for mobility should be 500km/h. *Category - Enhanced Mobile Broadband (eMBB).*
Mobility interruption	Mobility interruption time means the shortest time duration supported by the system during which a user terminal cannot exchange user plane packets with any base station during transitions. The target for mobility interruption time should be 0ms. This KPI is for both intra-frequency and inter-frequency mobility for intra-New Radio (NR) mobility. *Category - Mission Critical Control (MCC).*
Network energy efficiency	The capability is to minimize the RAN energy consumption while providing a much better area traffic capacity. Both qualitative and quantitative KPIs are proposed. Network energy efficiency shall be considered as a basic principle in the New Radio (NR) design. The target is a design with: (1) the ability to efficiently deliver data; (2) the ability to provide sufficiently granular network discontinuous transmission when there is no data to transmit and network availability is maintained; (3) the ability to provide operator flexibility to adapt sleep durations of base stations depending on load, services, and area. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Operational lifetime	Operation time per stored energy capacity, which is particularly important for Internet of Things (IoT) devices requiring a very long battery life whose regular maintenance is difficult for physical or economic reasons. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*

Terms	Definitions
O-RAN Alliance	Is working to build specifications and standards for 5G networks, focused on open and interoperable interfaces for radio access networks.
Peak data rate	Peak data rate is the highest theoretical data rate, which is the received data bits assuming error-free conditions, assignable to a single mobile station when all assignable radio resources for the corresponding link direction are utilised (i.e., excluding radio resources that are used for physical layer synchronisation, reference signals or pilots, guard bands and guard times). The target for peak data rate should be 20Gbps for downlink (DL) and 10Gbps for uplink (UL). *Category - Enhanced Mobile Broadband (eMBB).*
Peak spectral efficiency	Maximum achievable data rate under ideal conditions, usually measured in gigabits per second (Gbps), that can be transmitted over a given bandwidth in a specific communication system. It is a measure of how efficiently a limited frequency spectrum is utilized by the physical layer protocol, and sometimes by the medium access control (the channel access protocol). The target for peak spectral efficiency should be 30bps/Hz for downlink (DL) and 15bps/Hz for uplink (UL). Higher frequency bands could have higher bandwidth, but lower spectral efficiency and lower frequency bands could have lower bandwidth but higher spectral efficiency. Thus, peak data rate cannot be directly derived from peak spectral efficiency and bandwidth multiplication. *Category - Enhanced Mobile Broadband (eMBB).*
Price per MHz per unit population	A commonly used metric for expressing prices paid for spectrum during government auctions. Price per MHz per unit population first takes the total price paid by a network provider for a range of spectrum and divides it by the number of MHz purchased. This price per MHz is then divided again by the provider's number of people covered to obtain the final price per MHz per unit population. This metric allows for more accurate comparisons of spectrum prices across different auctions to be made since it accounts for market size.
Reliability	Capability to provide a given service with a very high level of availability. Reliability is compromised if too much data is lost, late, or has errors. Improving the reliability of the network is critical for time-sensitive, mission-critical applications like automation and healthcare. Category - Mission Critical Control (MCC).
Resilience	Ability of the network to continue operating correctly during and after a natural or man-made disturbance, such as the loss of power. Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).
Robotics	An interdisciplinary branch of computer science and engineering. Robotics involves design, construction, operation, and use of robots. The goal of robotics is to design machines that can help and assist humans. Robotics integrates fields of mechanical engineering, electrical engineering, information engineering, mechatronics, electronics, bioengineering, computer engineering, control engineering, software engineering, mathematics, etc. Robotics develops machines that can substitute for humans and replicate human actions. Robots can be used in many situations for many purposes, but today many are used in dangerous environments (including inspection of radioactive materials, bomb detection and deactivation), manufacturing processes, or where humans cannot survive (e.g., in space, underwater, in high heat, and clean up and containment of hazardous materials and radiation).
Security and privacy	Ability to encrypt and protect user data and signaling, and enhance network security against cyberattacks, such as unauthorized user tracking, hacking, fraud, sabotaging, and denial of service, which can be detrimental to national security and the safeguarding and privacy of users' data. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
Sensor	A device that produces an output signal for the purpose of sensing of a physical phenomenon. In the broadest definition, a sensor is a device, module, machine, or subsystem that detects events or changes in its environment and sends the information to other electronics, frequently a computer processor. Sensors are always used with other electronics. Sensors are used in everyday objects such as touch-sensitive elevator buttons (tactile sensor) and lamps which dim or brighten by touching the base, and in innumerable applications of which most people are never aware. With advances in micromachinery and easy-to-use microcontroller platforms, the uses of sensors have expanded beyond the traditional fields of temperature, pressure, and flow measurement, for example into MARG sensors. Analog sensors such as potentiometers and force-sensing resistors are still widely used. Their applications include manufacturing and machinery, airplanes and aerospace, cars, medicine, robotics, and many other aspects of our day-to-day life. There is a wide range of other sensors that measure chemical and physical properties of materials, including optical sensors for refractive index measurement, vibrational sensors for fluid viscosity measurement, and electro-chemical sensors for monitoring pH of fluids.

Terms	Definitions
Spectrum	The ranges of frequencies (or airwaves) on the electromagnetic spectrum that are allocated to the mobile industry and other sectors for wireless communication. Spectrum is a sovereign asset, which implies that the use of such airwaves is overseen by the government or national regulator, who manages and issues licenses to permit usage.
Spectrum and bandwidth flexibility	Flexibility of the network design to handle 5G Wireless different scenarios, such as the capability to operate at different frequency ranges. *Category - Enhanced Mobile Broadband (eMBB), Mission Critical Control (MCC) and Massive Internet of Things (Massive IoT).*
UE energy efficiency	Is the capability of a UE to sustain much better mobile broadband data rate while minimizing the UE modem energy consumption. *Category - Massive Internet of Things (Massive IoT).*
User Equipment (UE) battery life	Is the battery life of the UE without recharge. For mMTC, UE battery life in extreme coverage shall be based on the activity of mobile originated data transfer consisting of 200bytes UL per day followed by 20bytes DL from MaxCL of 164dB, assuming a stored energy capacity of 5Wh. *Category - Massive Internet of Things (Massive IoT).*
User plane latency	Is also known as the radio segment latency. It is the one-way latency for successful reception of a packet and includes the time for one or more retransmissions if packet reception fails. The target for user plane latency should be 0.5ms for upload (UL), and 0.5ms for download (DL). Furthermore, if possible, the latency should also be low enough to support the use of the next generation access technologies as a wireless transport technology that can be used within the next generation access architecture. For eMBB, the target for user plane latency should be 4ms for UL, and 4ms for DL. *Category - Enhanced Mobile Broadband (eMBB).*
User-experienced data rate	User experienced data rate is the 5% point of the cumulative distribution function (CDF) of the user throughput. User throughput (during active time) is defined as the number of correctly received bits, i.e., the number of bits contained in the service data units (SDUs) delivered to Layer 3, over a certain period of time. The target values for the user experienced data rate are as follows in the Dense Urban – eMBB test environment: (1) Downlink user experienced data rate is 100 Mbit/s; (2) Uplink user experienced data rate is 50 Mbit/s. *Category - Enhanced Mobile Broadband (eMBB)*
Virtual Reality	The use of computer technology to create a simulated environment which can be explored in 360 degrees. Unlike traditional interfaces, VR places the user inside the virtual environment to give an immersive experience.