Agro 4.0: Enabling agriculture digital transformation through IoT

Agro 4.0: Habilitando a transformação digital da agricultura por meio da IoT

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ABSTRACT - A few years have passed since the emergence of the Internet of Things (IoT) technology and its massification. Then, we saw the rise of Industry 4.0 and Agro 4.0, making the digitization of rural areas a hot topic, especially in Brazil where agribusiness is very important for the economy. Nowadays, IoT is already a mature technology, evidenced by cases of successful large-scale implementation of this technology in agricultural production. However, the combination of this technology with others still opens many opportunities, thereby further enhancing the chance to add value to the agricultural production chain. That is, the opportunities within IoT technology are in the aggregation and integration of a set of other disruptive technologies. This article presents a reference review with concepts of IoT, the updated status of this technology, foreseen opportunities, aggregated technologies, the future of IoT, and the vision of practical agricultural implementation in the field in Brazil.

Key words: Internet of Things. IoT. Agro 4.0. disruptive technologies. Big Data. Blockchain. Artificial Intelligence. 5G.

RESUMO - Alguns anos se passaram desde o surgimento da tecnologia Internet of Things (IoT) e sua massificação. Depois vimos o surgimento da Indústria 4.0 e agora o Agro 4.0, tornando a digitalização de áreas rurais um tema relevante, especialmente no Brasil onde o agronegócio é muito importante para a economia. Hoje em dia, o IoT já é uma tecnologia madura, evidenciado por casos de sucesso de implementação em grande escala desta tecnologia na produção agrícola. No entanto, a combinação desta tecnologia com outras ainda abre muitas oportunidades, potencializando ainda mais as chances de agregar valor à cadeia de produção agrícola. Ou seja, as oportunidades dentro da tecnologia IoT estão na agregação e integração de um conjunto de outras tecnologias disruptivas. Este artigo apresenta uma revisão de literatura com os conceitos de IoT, o status atualizado dessa tecnologia, as oportunidades previstas, as tecnologias agregadas, o futuro do IoT, e a visão de implementação prática agrícola no campo no Brasil.

Palavras-chaves: Internet das Coisas. IoT. Agro 4.0. tecnologias disruptivas. Big data. Blockchain Inteligência Artificial. 5G.

INTRODUCTION

The massive rise of Internet of Things (IoT) technology is now a reality. IoT can be found in connected autonomous cars, automated homes, manufacture of consumer products, and so on. Up to the end of this year, Gartner (HUNG, 2020) estimated 20 billion internet-connected things, which is an impressive number. In the next decade, this value is expected to increase dramatically, reaching 35 billion devices in 2025, or 5 times the world population (MCTIC, 2016). IoT has become the major disruptive technology in these last years. In the enterprise sector (DAHLQVIST *et al.*, 2020), the number of known applications is approximately 200, boosting the emergence of applications in sectors as diverse as Industry 4.0, smart cities, smart homes, connected cars, and e-health, to name a few. Advances with IoT technology mean that these days, all impacted sectors can access functionalities that did not exist five years earlier. In this context, for rural field applications, the terms Agriculture 4.0, Farming 4.0, or Agri-food 4.0 appear, which were derived from the concept of Industry 4.0 and refer to the processes of digitalization of farm production. In Brazil, we have the terms Agro 4.0, Agricultura 4.0, or Digital Agriculture.

Especially in Brazil, the IoT plays a fundamental role in the development and innovation in agribusiness in different sectors, which have been the main sources of economic and social support for the country for decades, being one of the world's largest food exporters (MARTINS; BARBOSA, 2019). The application of IoT in rural areas brings numerous benefits, with different applications for the field like monitoring of climatic conditions, growth of the plantation, performance of agricultural machines, and detailed monitoring of animal's health. The country is also emerging as the main frontier of growth in agricultural production for the coming years, having one of the largest untapped agricultural lands available in the world (BNDES - BANCO NACIONAL DO DESENVOLVIMENTO, 2020). Bring connectivity to remote areas in Brazil is the main bottleneck in the diffusion of new technologies in the field. With the introduction of the new 5th Generation (5G) network technology, is expected to bring a profound impact of improvement to the agriculture sector, enabling connectivity in the remote rural areas, and thus the arrival of IoT technology in areas where it is not currently possible (OKUMURA, 2020).

The IoT technology that has advanced over the past five years has gained its maturity, but it still holds significant market growth opportunities. Taking advantage of this maturity and wave of opportunities is a strategy that must be harnessed (DAHLQVIST *et al.*, 2020).

This article proposes the presentation of the current state of the art of IoT technology, with a brief review of related topics. The remainder of the paper is organized as follows. Section II contains basic IoT fundamentals and concepts. Section III describes the maturity of the IoT technology and presets opportunities in the agro sector. Section IV describes the IoT ecosystem and its components, standard, architecture, and security. Section V contains information about IoT aggregated technologies that promise to be disruptive in the forthcoming years. Section VI presents a practical view of an IoT implementation in the rural area in Brazil. Section VII presents the 5G technology as the new IoT revolution in rural areas. Section VIII concludes this article.

IOT FUNDAMENTALS

The term Internet of Things (IoT) was first used in 1999, in the radio frequency identification (RFID) development scenario (PATEL; PATEL, 2016), however, it did not become of interest until 2010/2011 and reached popularity in early 2014 (LUETH, 2020). Wikipedia describes IoT as "the network of physical objects or "things" that are embedded with sensors, software, and other technologies for connecting and exchanging data with other devices and systems over the Internet" (INTERNET OF THINGS, 2020). This description with the term "Internet" refers to the use of the worldwide public Internet, but it is flawed as it is not necessarily a need the use of the public Internet. Private networks over the IP protocol can be used. A restriction exist in the case of public Internet in remote rural areas in Brazil because of long distance, which will be discussed further in Section VI.

Cisco System adopted the term Internet of Everything (IoE) (EVANS, 2020). Intel initially called it the "embedded Internet" (WHITE PAPER INTEL® EMBEDDED PROCESSOR, 2020). McKinsey's (CHUI; LOFFLER; ROBERTS, 2020) short definition of IoT seems to make more sense: "Sensors and actuators embedded in physical objects are linked through wired and wireless networks, often using the same Internet Protocol that connects the public Internet". Meanwhile, the International Telecommunication Union (ITU) defines IoT as "a global infrastructure for the information society, enabling advanced services by interconnecting (physical and virtual) things based on existing and evolving interoperable information and communication technologies (ICTs)" (ITU-T Y.4460, 2019). Moreover, according to Soma *et al.* (2019), "IoT is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment. IoT uses sensors that can record and provide multiplied and growing data volumes, connect multiple objects and devices in

production and value chains, and accordingly, make large amounts of new real-time data accessible. An IoT device can be any traditional device that becomes connected and therefore able to collect and transmit data. Along with Big Data, IoT can transform the agricultural sector, contributing to improved farm production processes by making a huge amount of useful data available".

Summarizing these presented definitions, we can suggest that "devices" are not only sensors but also something limitless. For example, in traditional industry, sensors and actuator devices are important part of controlling industrial automation locally. Meanwhile, in the new Industry 4.0, these are interconnected within the IoT technology directly, or with an existing industrial bus that can be interconnected to the IoT using gateways, expanding the local control. Examples in agriculture sector come from the use of sensors to monitor the weather conditions and actuators to control crop irrigation, and the use of gateways for interconnection with machines controller area network (CAN) buses, or more recently with drones.

Going further, "devices" nowadays can be smart devices that interact within the IoT system. Hence, we can consider that IoT is not only a technology, but it is a concept, a system, or an ecosystem that aggregate infinite set of devices, different set of connectivity devices, or network elements with different protocols, and different set of application technologies.

IOT OPPORTUNITIES

IoT has become a mature technology, but it is still in a relatively early stage. Thus, there are plenty of opportunities, especially in the agribusiness sector, due to the Brazilian potential on this area.

IoT as a Maturing Technology

As seen in Gartner Report, Hype Cycle for the Internet of Things (2020) and Hype Cycle (2020), IoT becomes a maturing technology, reaching the initial productivity stages. They describe that the Gartner Hype Cycle for supply chain strategy shows that the IoT has reached the bottom of the trough of disillusionment, and the market will begin to climb out of this trough as technology advances with the success of practitioners in defining unique opportunities brought about by this emerging technology. IoT is in the trough because we have seen that many companies are implementing the technology, but they are struggling to define the best options for using it. For example, its measurement and tracking capabilities for supply chain logistics and management transformation are not well explored yet. According to Gartner (2020), "We see further potential to grow its use over the next several years, estimating that installed IoT endpoints for manufacturing and natural resource industries are forecasted to grow to 1.9 billion units in 2028. That is five times from 331.5 million units in 2018". Figure 1 presents the Gartner Hype Cycle chart.

IoT has become absorbed into people's daily personal and working lives, as evidenced by fitness monitors, smart meters, controlling smart end devices, and working at smart office buildings or at home using voice assistants, such as Amazon's Alexa, Apple's Siri, Google Assistant, or Microsoft's Cortana. This is now the world's reality although people do not realize that these usages are part of the IoT system and that they are using a set of different applications, such as cloud computing and cloud apps in their smartphones. Thus, IoT is not an isolated technology. It depends on integration with other technologies, connectivity technologies, intelligent platforms, and applications. The more integrated these technologies are in a solution, the more businesses will be able to reap the benefits of gaining insights from this integration.

Digital Agriculture and Transformation Opportunities

Digital and infrastructure transformation in the rural area can be witnessed with the farm production and connected farms encompassing the harvest area, new farm equipment, connected tractors, machines, and drones. This is a demand to increase efficiency, productivity, quality, and optimization in the farming supply chain. Also, it is an enabler for environmental protection, reducing global warming and limiting carbon emission, saving water, and conserving soil. For the Brazilian rural digitalization process, Agriculture 4.0, Magazine Pesquisa FAPESP (2020) reports "A high rate of digital adoption, with 1.5 million growers now accessing data using electronic devices, a figure 1,900% higher than 10 years ago". However, it cites a weak point to the expansion: "Process digitalization, however, requires rural telecommunications infrastructure that is still limited in Brazil. It's our Achilles' heel". The connectivity issues in rural areas can be reversed with the entry of 5G technology in Brazil, as presented in section VII.

Figure 2 provides a view of sensors and applications acting in different Smart Farm functions (FAROOQ *et al.*, 2019). The following are excerpt of potential IoT applications for Smart Farming: Chemical control (e.g., pesticides and fertilizers); Crop monitoring; Pest and disease prevention; Irrigation control; Soil management; Supply chain traceability; Vehicles and machinery control; Precision agriculture; Soil monitoring; Weather station; Livestock monitoring; Irrigation

management; and Water quality monitoring. Sundmaker *et al.* (2019) presents some results in the use of IoT in these applications:

- Better sensing of farming and food processing operations, including usage of inputs, crop growth, animal behavior, food spoilage, and resource utilization;

- Improving quality management and traceability by remotely monitoring the location and conditions of shipments and agricultural products, and improving product origin certification;

- Better understanding of specific production circumstances, such as climate conditions, animal welfare, microbiological quality, pest pressure, and optimal interventions;

- More advanced and remote control of operations enabled by actuators and robotics, for example, precise application of pesticides and fertilizers, autonomous harvesting, or adjusting ambient conditions;

- Food monitoring during transportation, minimizing waste, and cost decreasing;

- Increasing consumer awareness of sustainability and health issues by personalized nutrition advice and personalized food and wearables ordering.

Lezoche *et al.* (2020) presents the following IoT impacts: farm production; economic; environmental; social; business; and technological. With associated challenges: organizational; social; and technological. In Brazil, the Banco Nacional do Desenvolvimento (BNDES), in partnership with the Ministry of Science, Technology, Innovations and Communications, supported the realization of a study for the diagnosis and proposal a strategic action plan on the IoT for the country (ESTUDO "INTERNET DAS COISAS: UM PLANO DE AÇÃO PARA O BRASIL", 2020). The following is a citation of rural aspiration in IoT: "Increase Brazil's productivity and relevance in world trade in agricultural products, with high quality and socio-environmental

Figure 1 - Gartner Hype Cycle chart showing IoT as a maturing technology with plenty of opportunities, especially in Brazil's agribusiness (GARTNER REPORT, HYPE CYCLE FOR THE INTERNET OF THINGS, 2020)
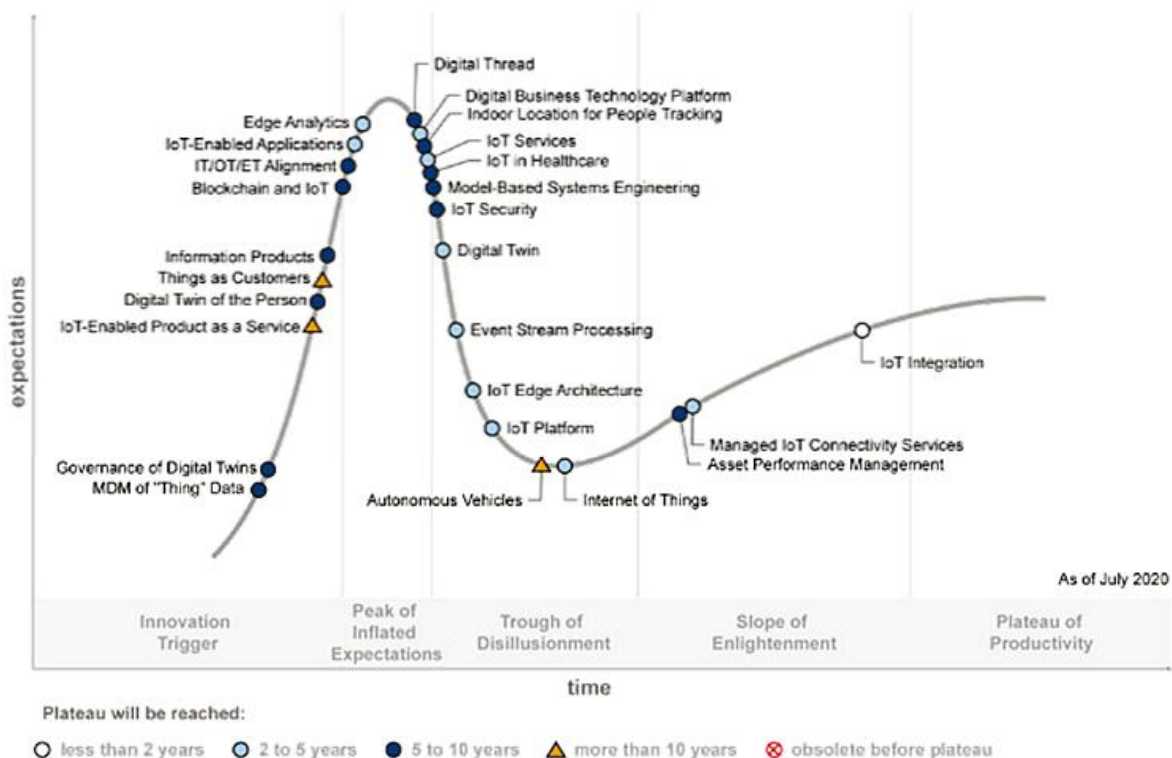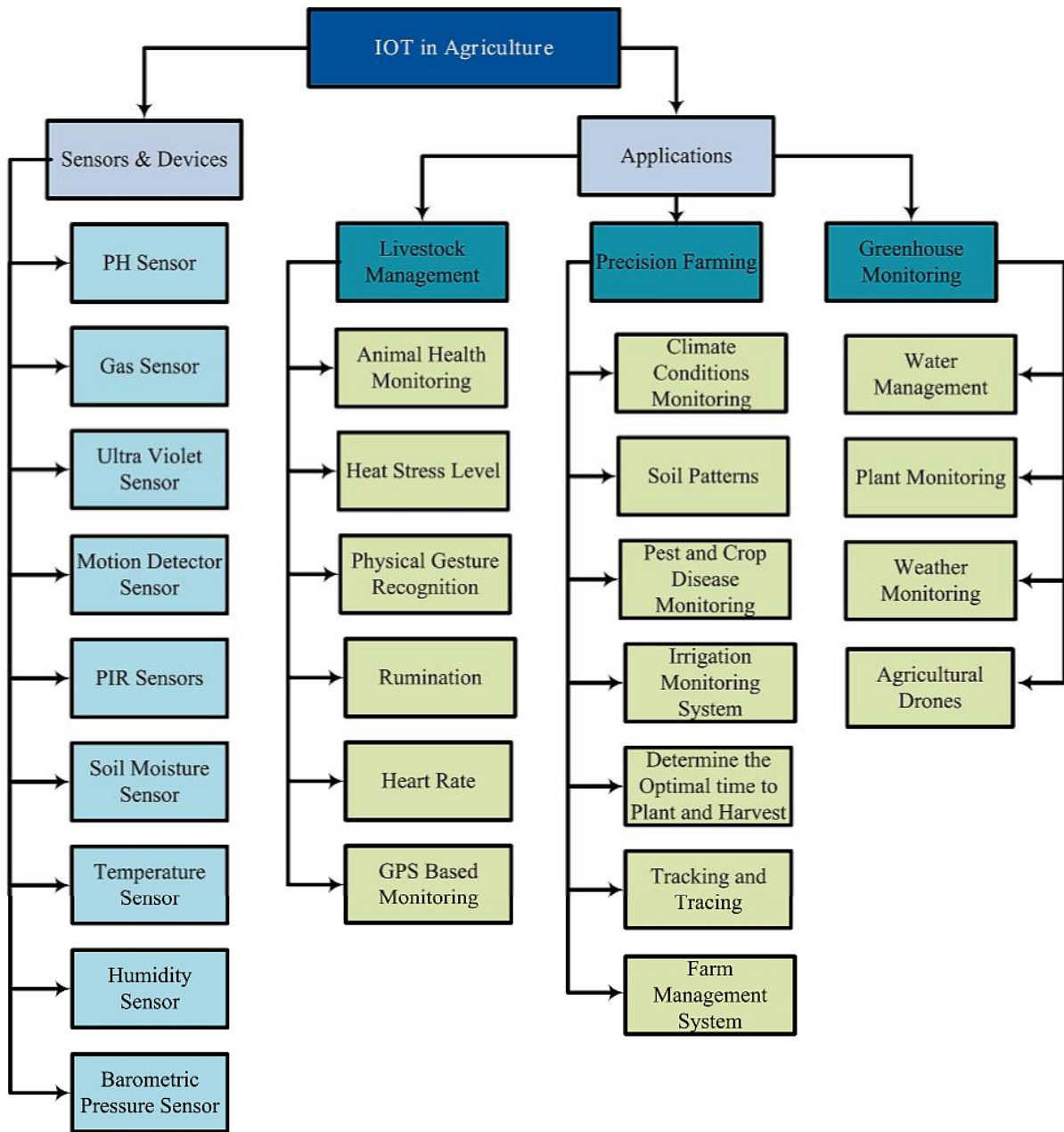
Figure 2 - IoT in agriculture depending on sensors and applications with different roles within the Smart Farm (FAROOQ *et al.*, 2019)

sustainability, and position it as the largest exporter of IoT solutions for tropical agriculture". According to this study, the applications of efficient use of natural resources, inputs, and machinery are those that have the greatest impact (BNDES - BANCO NACIONAL DO DESENVOLVIMENTO, 2020):

- Efficient use of natural resources and input with the following high impact considerations:

* Monitoring of the microclimate and natural resources by sensors or mini-stations; generating alerts about the possibility of pests, diseases, and rains; and supporting decision-making on planting, harvesting, time to return to the field, and the need for irrigation. The expected results of IoT are reduced use of crop protection products, better precision in planting decisions, and harvest irrigation optimization;

* Monitoring of physical, chemical, and biological properties of the soil, and generating information to guide agricultural practices such as irrigation and soil management. IoT expected results are increased fertility of ground, increased production, and optimization of the use of fertilizers.

* Efficient use of machinery: with high impact considering real-time monitoring of operations, generating big data that allow the monitoring of the quality of operations and the impact on culture, and providing the ideal time for machine maintenance. IoT expected results are reduced fuel costs, increased availability of machines, and increased agricultural productivity.

* Pest management: Monitoring the health of the plantation or pasture that captures images; identifying diseases, weeds, and pests; and emitting better phytosanitary control. IoT expected results are reduction in the use of pesticides through immediate application only in infected areas.

* Location and behavior monitoring: Monitoring the location and behavior of the animal, indicating disease or need for intervention when it exhibits abnormal behavior. IoT expected results are the reduction of losses due to theft.

* Monitoring of animal health and welfare: Monitoring the health and welfare of the animal, and helping in the detection of diseases and stress, in the prediction of calving dates, and in the optimization of livestock feed. IoT expected results are reduction of animal losses due to disease and quality improvement in animal protein.

* Production management by analytics: Collection of production data and generation of performance reports through advanced analytics, which indicates sources and causes of losses and offers tools for better planning and management of the next harvest. IoT expected results are increased agricultural productivity and reduced costs.

A combination of IoT technology with other technologies with a high impact on the agri-food value chain is an innovative solution that has had disruptive impacts on the sector. Examples of the other technologies are automation and robotization, Artificial Intelligence (AI), traceability and Big Data, and Blockchain (SOMA *et al.*, 2019).

IOT ECOSYSTEM IN AGRICULTURE

As aforementioned, digital transformation in the farm depends on different technologies, such as agricultural applications, connectivity technology, and

a set of sensors. IoT technology basement consists of architecture, technologies, and applications.

Characteristics

The following fundamental are the characteristics of the IoT (PATEL; PATEL, 2016):

* **Interconnectivity:** Anything can be interconnected with the global information and communication infrastructure.

* **Things-related services:** The IoT can provide thing-related services within the constraints of things, such as privacy protection and semantic consistency between physical things and their associated virtual things. To provide thing-related services within the constraints of things, both technologies in the physical and information world will change.

* **Heterogeneity:** The devices in the IoT are heterogeneous based on different hardware platforms and networks. They can interact with other devices or service platforms through different networks.

* **Dynamic changes:** The state of devices changes dynamically, e.g., sleeping and waking up, connected and disconnected, and the context of devices, including the location and speed. Moreover, the number of devices can change dynamically.

* **Enormous scale:** The number of devices that need to be managed and communicate with each other will be at least an order of magnitude larger than the devices connected to the current Internet. Even more critical will be the management of the data generated and their interpretation for the application. This relates to semantics of data and efficient data handling.

* **Safety:** As we gain benefits from the IoT, safety must be prioritized. Being both the creators and recipients of the IoT, we must design them for/with safety purposes. This includes the safety of personal data and physical well-being. Securing the endpoints, the networks, and the data moving across all of it means creating a security paradigm that will scale up.

* **Connectivity:** Connectivity enables network accessibility and compatibility. Accessibility is getting on a network, whereas compatibility provides the common ability to consume and produce data.

The following are cross-related terms with IoT that describe different technologies or applications, but they can be present in the same solution architecture with IoT:

Machine to machine (M2M): any data communications technology between devices without human intervention. This may be a data communication between devices and a server or device-to-device, either directly or through a network. M2M has been used for

more than a decade and is well-known in the industry or utility sectors. M2M communication had initially been a one-to-one connection, linking one machine to another. However, today's explosion of mobile connectivity means that data can now be more easily transmitted, via a system of IP networks, to a much wider range of devices.

Machine-type communication (MTC): the M2M concepts applied within mobile cellular network technology over long-term evolution (LTE) or 4G/5G networks. It enables ubiquitous connectivity among autonomous devices, and devices and application servers.

Narrow band IoT (NB-IoT): a new narrowband technology to address the requirements of the IoT applied within mobile cellular network technology, which provides improved outdoor and indoor coverage, support of a massive number of narrowband devices, with low delay sensitivity, ultra-low device cost, low device power consumption, and optimized network architecture.

Figure 3 presents a comparison of IoT, M2M, IoE, and industry 4.0 (LUETH, 2020). M2M has a field of use in industrial and utility sectors that supports critical operations. Thus, it demands more throughput, more reliability. Industry 4.0 has the largest scope of all the concepts, including connectivity in the industrial context, to drive to the next industrial revolution. However, it

goes further and includes real changes to the physical world around us such as 3D-printing technologies or the introduction of new augmented reality hardware. Industry 4.0, M2M, and MTC focus on the scope of machines, objects, and devices, whereas IoT is related to these scopes and with the things used by people daily life.

The great advantage of MTC and NB-IoT technologies is that they can be provided by the same network that supports 4G or 5G broadband networks, implying possible exploitation of these networks for different services, apart from the possibility of being shared or virtualized, as described in section VII.

Architecture Components

As an initial illustration, the Figure 4 presents the IoT system solution consisting of three basic stratifications layers: the device layer; communication or connectivity layer; and application layer. Device layer consit of measuring (sensors) or control (actuators) components. Common sensors are temperature sensors and thermostats, pressure and moisture sensors, humidity/moisture level and light intensity detectors, proximity detectors, RFID tags, and quick response (QR) code (MUANGPRATHUB *et al.*, 2019). End devices are sometimes designated as Node or Mote. Actuators control commonly electromechanical

Figure 3 - Comparison of IoT, M2M, IoE, and Industry 4.0 (LUETH, 2020)
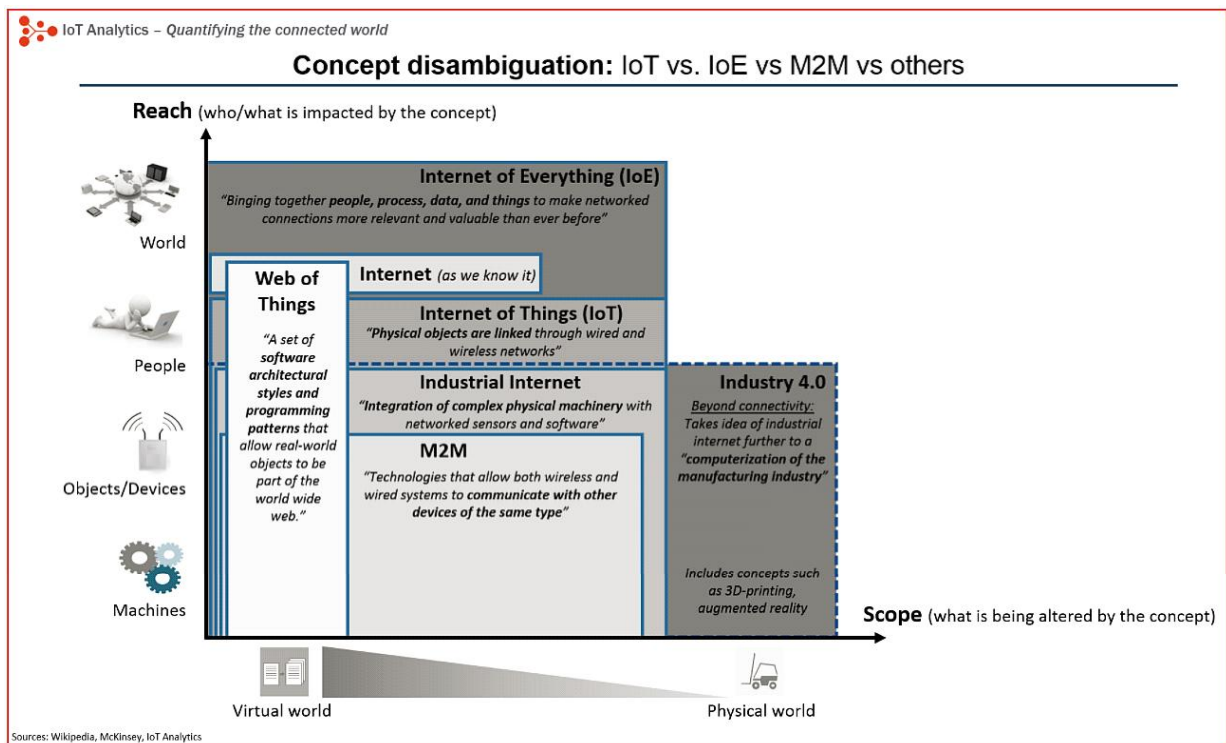
devices. The application layer consists of different farm control, and monitoring applications providing data as reports to be accessed, for example, in cellular applications. In the middle of these, communication layer provides connectivity between applications and devices. This can be in diverse and heterogeneous ways, as with the inclusion of solutions for long, medium and short range coverage. It can also include gateways to interconnect devices in diverse topologies and protocols, such as with the star or mesh topologies, or in local communication such as CAN or factory automation buses.
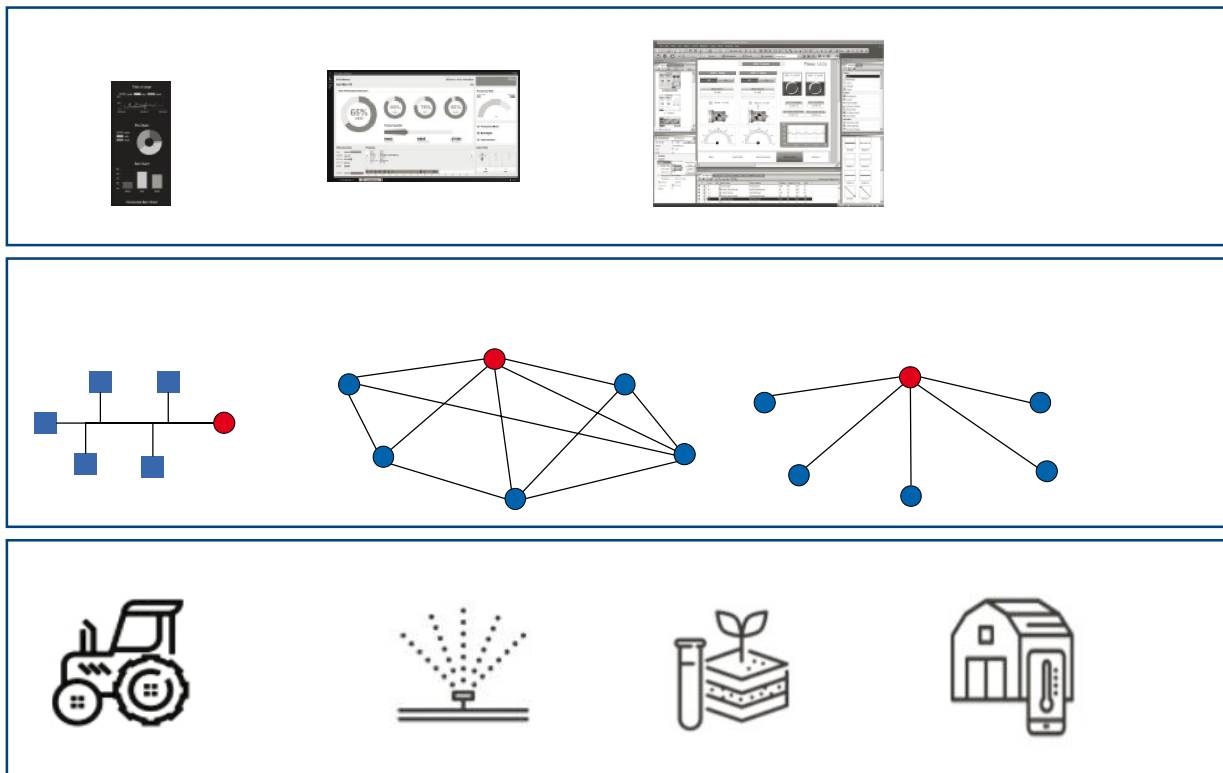
IoT Standards

As aforementioned, IoT is not only a technology but also a concept, system, or ecosystem with an aggregation of different technologies. To deploy an IoT solution, we have different vendors with different technical standards or specifications as solutions. From this comes the great problem that is related mainly to the communication or connectivity technologies. For example, connectivity technologies attending different coverages use different standards, or even proprietary standards. The existing consensus for the majority is the use of the IP protocol, allowing multi-vendor interoperability and thus cost reduction, but that is not enough. The presence of different standards for connectivity technology results in cost impact because this encompasses the access layer, that is, where an interconnection of a large number of end devices exists. IoT connectivity technology standardization arising from different groups. Without a standardization alliance, can jeopardize the expected cost reduction for the end devices, which is the driving force for future maintenance of massive IoT expansion.

The following are the existing IoT Standardization bodies (STANDARDIZATION BODIES, 2020; JIA, 2017):

* **Internet Engineering Task Force (IETF):** The mission of the IETF is to improve the Internet by producing high quality, relevant technical documents that influence the way people design, use, and manage the Internet.

* **The Internet Research Task Force:** promotes research of importance to the evolution of the Internet by creating focused, long-term research groups working on topics related to Internet protocols, applications, architecture, and technology.

* **World Wide Web Consortium (W3C):** The W3C mission is to lead the World Wide Web to its full potential by developing protocols and guidelines that ensure the long-term growth of the Web.

Figure 4 - The basic view of the IoT components and layers

* ITU-T: The Study Groups of ITU's Telecommunication Standardization Sector (ITU-T) assemble experts worldwide to develop international standards known as ITU-T recommendations, which act as defining elements in the global infrastructure of ICTs.

* European Committee for Standardization/European Committee for Electrotechnical Standardization: its mission is to fulfill the needs of business, industry and commerce, service providers, public authorities and regulators, gym and research centers, European trade associations and interest groups representing environmentalists, consumers, trade unions as well as small and medium enterprises, and other public and private institutions.

* European Telecommunications Standards Institute (ETSI): the recognized regional standards body–European Standards Organization–dealing with telecommunications, broadcasting, and other electronic communications networks and services. Special groups include ETSI Smart Cities and ETSI ISG CIM group, working with M2M technology.

* ISO: an independent, non-governmental international organization with 162 national standards bodies as members.

* International Electrotechnical Commission: the world's leading organization that prepares and publishes international standards for all electrical, electronic, and related technologies.

* Open Mobile Alliance (OMA): The OMA SpecWorks Application Programming Interfaces (API) program provides standardized interfaces to the service infrastructure residing within communication networks and on devices. Focused primarily between the service access layer and generic network capabilities, OMA SpecWorks API specifications allow telecommunication operators and other service providers to expose device capabilities and network resources in an open and programmable way–to any developer community independent of the development platform. By deploying APIs, we can expose fundamental capabilities such as SMS, MMS, location services, payment, and other core network assets in a standardized way. This reduces development cost and time-to-market for new applications and services, moreover, it simplifies wider deployment of existing applications and services.

* The 3rd Generation Partnership Project: unites seven telecommunications standard development organizations and works in the following cellular technologies specification: LTE; 4G; 5G; NB-IoT, and MTC.

* Electrical and Electronics Engineers (IEEE): standardization focusing on architectural framework, security, and sensor quality (IEEE STANDARDS ACTIVITIES IN THE INTERNET OF THINGS – IoT, 2020).

Other standard initiatives are listed in (WEYRICH; EBERT, 2016).

IoT Reference Architecture

Within the list of the different initiatives of the IoT standardization bodies previously presented, the main general architecture adopted is the ITU-T recommendation Y.2060 (JIA, 2017; WEYRICH; EBERT, 2016; RAY, 2018), as shown in Figure 5. ITU-T recommendation Y.2060 provides a reference model for IoT architecture, with the application layer containing IoT applications. The service support and application layer consist of generic and specific support capabilities. The network layer containts two types of capabilities: networking capabilities and transport capabilities. Meanwhile, the device layer contains two types of capabilities: device and gateway capabilities. Figure 5 layers description are (MCTIC, 2020):

Application Layer: contains IoT applications, for example, health monitoring, industrial automation control; or Smart Farm applications;

Services and Applications Layer: includes support for developing applications and services by providing functions that use cloud computing infrastructure, data storage and processing, providing interoperability between applications through APIs, or by using a broker, defined and intermediating communication with the network layers and devices;

Network Layer: addresses the communication protocols and technologies associated with the IoT connectivity between devices or elements of different technologies. Includes different network infrastructures, such as local network, a wide area network, long-range network, backhaul for long-distance connection, CAN bus, or different kinds of industrial automation networks;

Device or Perception Layer: includes different kinds of sensors, actuators, wireless sensor network composing a distributed sensor network, RFID, near field communications (NFC). Typically, a wireless sensor node consists of a processing module, usually a low-power microcontroller unit, one or more sensor modules (embedded or external analog or digital sensing devices) and a radio frequency (RF) module, supporting a low-power wireless technology, and network gateways;

Management Layer: in charge of the IoT infrastructure management, in all its layers, to guarantee the reliability of this structure through the commissioning, monitoring, provisioning and configuration of the sensor,

actuator, and other devices, network elements and computational infrastructure, supporting all the operation; and

Security Layer: permeates all other layers, mapping the main technologies used to meet information security requirements such as privacy, integrity, availability, and access control.

Agribusiness digital transformation depends on the emergence of different combined technologies in the application layer, such as Blockchain, AI, Cloud Computing, and Big Data. It is responsible for the transformation in agricultural practices, bringing significant benefits to the entire agribusiness value chain.

The following are network layer technologies segmented by their coverage or distance: (i) wireless personal area networks (WPAN) for short/medium distance; (ii) wireless local area network (WLAN) for medium distance; (iii) wireless neighborhood area network (WNAN) for neighborhood distance, and (iv) long range as (iv) low-power wide area network (LPWAN) for long distance, with narrowband low power consumption. Figure 6 shows common network or connectivity technologies that are commercially available, segmented by coverage (range) and data rate (Mbps or Kbps) (DIFFERENT WAYS TO CONNECT IOT DEVICES TO TRANSMIT AND RECEIVE DATA, 2020). For the specific Brazilian scenario with a large geographical dimension and with a lack of connection infrastructure, the most relevant technology is LPWAN. NB-IoT is a narrowband technology present in 4G and 5G networks. As described previously, 4G or 5G technologies are interesting because it can use the same infrastructure for all technologies, providing broadband and narrowband devices connectivity simultaneously, including other options, for instance, LTE-M device, which is part of the MTC solution (BARROS *et al.*, 2017). SigFox and LongRange WAN (LoRaWAN) are popular proprietary technologies for low data rates and long distances (CARRILLO; SEKI, 2017). Standards such as iBeacon and NFC are integrated with smartphones, and Bluetooth low energy (BLE) is also becoming common.

Wi-Fi 6 (or IEEE 802.11ax) is a new next-generation Wi-Fi promising short-range technology that operates with 2.4 GHz or 5 GHz frequency bands. In the future, this technology will also be available in the 6 GHz band. It can split the bandwidth into narrower sub-channels supporting different devices in the network (IEEE 802.11ax, 2020).

The use of frequency bands in these wireless technologies is an issue that causes many discussions because the frequency spectrum is an increasingly scarce resource. Unlicensed spectrum with higher bandwidth is available for use in short-range, WPAN, WLAN, and WNAN technologies. For long-range LPWAN technologies, licensed spectrum is an option, but this is acquired by the telecommunication operators due to the cost of the license, and the use of unlicensed spectrum is in the continuous discussion. These connectivity technologies are present in different network devices, access points, hot spots, mesh devices, gateways, and core devices. Moreover, they are part of the end devices, where the use of various of these technologies is impacting. One remarkable point is that the right choice of one or a set of these technologies, for the deployment of IoT system solution is part of the differential that will show up with the design and planning of the solution.

Figure 5 - IoT reference model (based on ITU-T Y.2060) for IoT architecture (PATEL; PATEL, 2016)
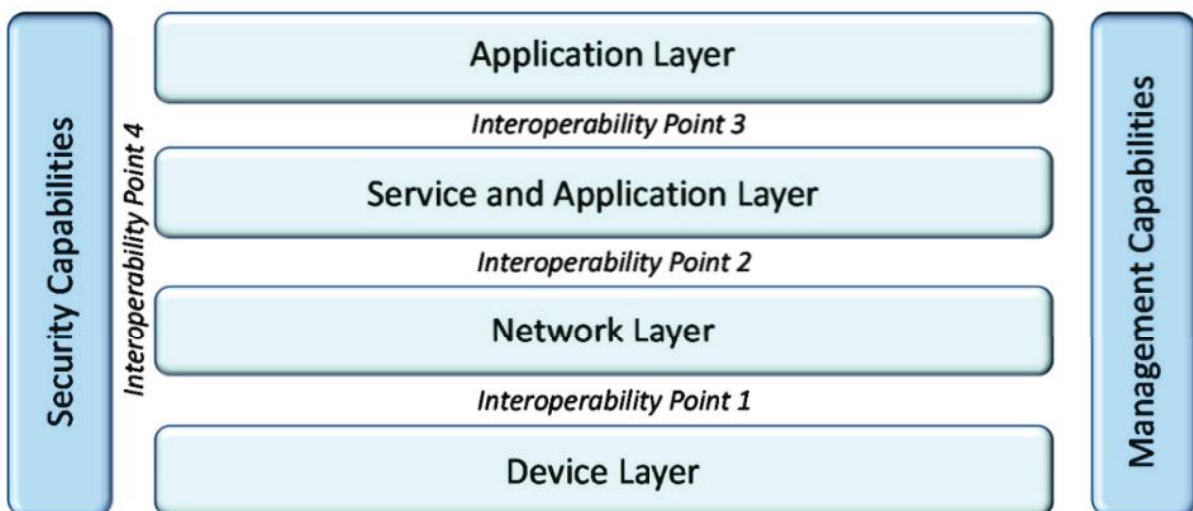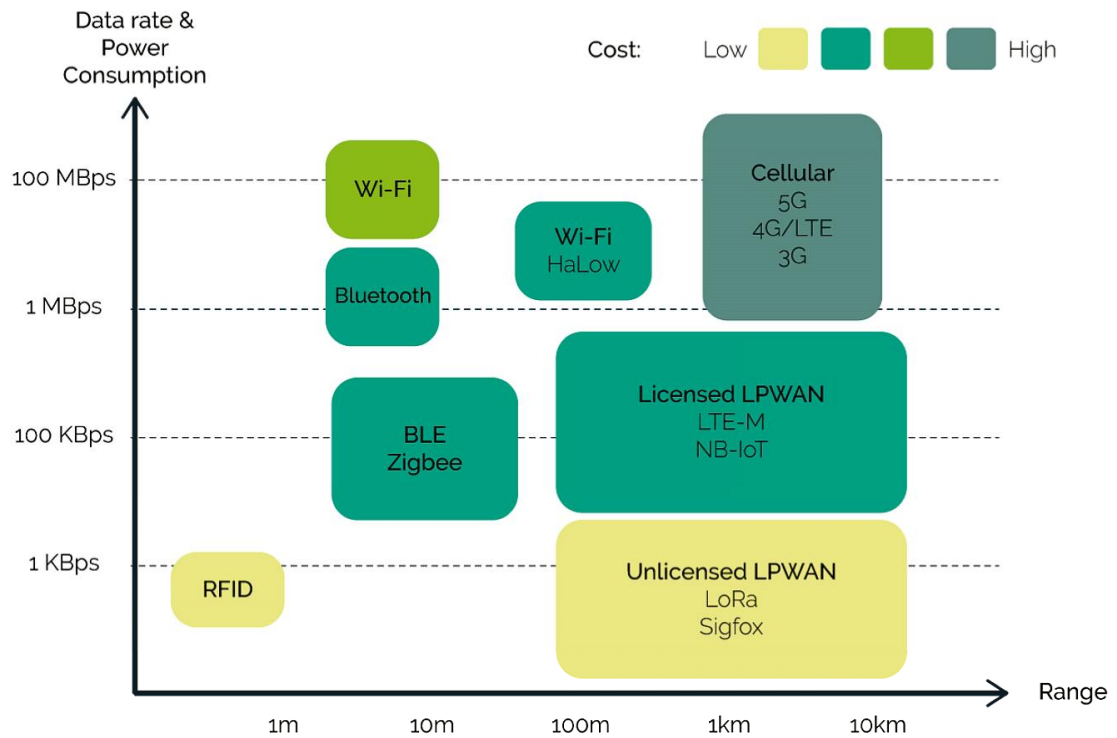
Figure 6 - Common network or connectivity technologies commercially available that are segmented by coverage and data rate (DIFFERENT WAYS TO CONNECT IOT DEVICES TO TRANSMIT AND RECEIVE DATA, 2020)


IoT Security

Modern IoT ecosystems are complex, the aggregation and integration of heterogeneous technologies present in different layers using a ubiquitous solution bring security concerns, especially as it scales and expands geographically and when they are dependent on the use of third-party networks or infrastructures. Moreover, adoption of public Internet network as a long-range connectivity solution and cloud computing solution brings concerns with cybersecurity attacks. Regarding the use of wireless network solution, there is special concern about non-intentional interferences in the RF signals, malicious attacks with interfering signals, or intentional blocking of RF signal. This last case is designated as Denial of Service attack or jamming attack where the communication in the network is completely blocked. However, considering wireless reliable solutions, they usually have protection or resiliency features on the air interface.

The forecasting of sensor devices within a corporation or industry, or even at home, in a large number, demands to be cheap. The heterogeneity of vendors and technologies is another point of security risk concern. With industries having traditional characteristics of being conservative when it comes to security in general, the agribusiness sector must also maintain this characteristic. The digital security risk could be present at every layer of the IoT architecture present in Figure 5. Moreover, due to the diversity and heterogeneity of solutions, deployment of an IoT system deserves strategic planning to mitigate digital security risks. Although security must be continuous within the process of operation, security risk assessment that examines vulnerabilities in devices and network systems, as well as in the user and customer backend systems, must be included (WEBNAR: (IN)SEGURANÇA EM IoT, 2020). Farooq *et al*. (2019) present a security service model in Figure 7 and describes that the model is illustrated with its three security systems: (1) the protection system, which is designed to mitigate the attack; (2) diagnosing system, which collects activity data from agricultural applications, networks, and nodes and analyzes detected agricultural data; and (3) reaction system, which is designed to help the agricultural entities survive all types of attacks.

Considering this proposed security model and given the fact that the adopted network connectivity solution is based on the transport over IP protocol, extending over the worldwide public Internet, the solutions to prevent or mitigate IoT security risks are the same for traditional network system based on IP protocol. These mitigation solutions can include:

Figure 7 - Proposed security model for Smart Farming (FAROOQ *et al.*, 2019)
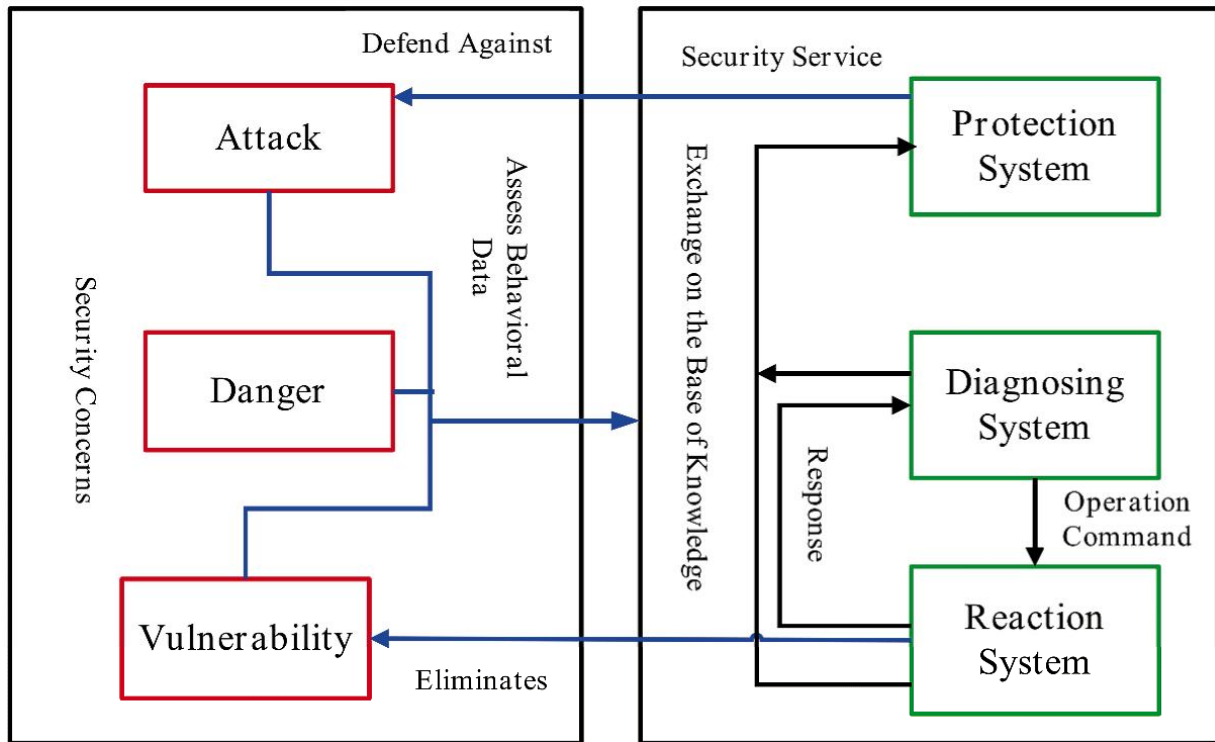
* Use of intrusion detection systems analyze network traffic for signatures that match known cyberattacks. Intrusion prevention systems also analyzes packets but can also stop the packet from being delivered based on what kind of attack it detects.

* Network segregation configuration, for example, using virtual local area network to isolate critical data information.

Other solutions are traditional in IP network, for example, use of firewall, end-device authentication, and transported data encryption and integrity check.

Use of these solutions is part of the best practices, but one cannot be negligent with the details. Moreover, the creation and use of a security policy must be considered, considering that the people who have access to the system are often the weakest point in the security issue. An additional solution adopted in the security in IoT ecosystem is the Blockchain.

Barriers in the expansion of IoT in rural areas

IoT application in agriculture is challenging, especially because of the business processes' high uncertainty (SUNDMAEKER *et al.*, 2019) and heterogeneity of the sector, with no single technological, business, or regulatory solution that will fit or accommodate the needs of all. Specifically for Brazil, the main themes of concerns are human capital, innovation and international insertion, connectivity and interoperability infrastructure, regulatory, and privacy and security (BNDES - BANCO NACIONAL DO DESENVOLVIMENTO, 2020). The future of IoT is ripe with potential. However, it depends on many moving parts, as it is an aggregation and integration of different technologies. Thus, there is a demand not only for technology but also for human capital in technological knowledge.

DISRUPTIVE TECHNOLOGIES IN SMART FARM

At this point in the escalation of the evolution of the IoT, a set of technologies, along with IoT technology, is considered disruptive, with high impact on agri-food value chain and possible greater impacts in future (SOMA *et al.*, 2019; DIVYASHREE; RANGARAJU, 2018):

Big Data: The Big Data aims to help people distinguish valuable data from junk data, which includes ways to find valuable insights. Deployment of IoT can produce large amounts of data where sensors are constantly sensing stimuli and provoke real-time functions. Thus,

data accumulation over time becomes comparatively easy. Big data platform or ecosystem process is easy for this large volume of data.

Traceability and Big Data: Big Data ensure traceability by increased data sharing and refers to data sets too large and complex for traditional data-processing software to adequately deal with them.

Cloud Computing: The emergence of cloud computing made storage of data and computing power easier and inexpensive in cloud to store and process data.

Automation and Robotization: The automation of a system or process by the use of robotic devices.

Artificial Intelligence (AI): Any device that perceives its environment and takes actions that maximize its chance of successfully achieving its goals.

Blockchain: is a growing list of records, called blocks, which are linked using cryptography. A block in a Blockchain contains a cryptographic hash of the previous block, a timestamp, and the transaction data.

In this section hereafter, we described some of these technologies in more detail.

Cloud Computing

Cloud computing is computational virtualization using a server located in the Internet cloud. Many companies provide this service, such as Amazon (as part of Amazon Web Services - AWS). You can rent virtual machines or storage services, and other web-computing services. Cloud computing is a paradigm, for the storage of big data and its analytics.

Big Data

Wikipedia describes Big Data (2020) as "A field that treats ways to analyze, systematically extract information from, or otherwise deal with data sets that are too large or complex to be dealt with by traditional data-processing software. Data with many cases (rows) offer greater statistical power, where as data with higher complexity (more attributes or columns) may lead to a higher false discovery rate. The challenges of Big Data include capturing data, data storage, data analysis, search, sharing, transfer, visualization, querying, updating, information privacy and data source. Big data often include data with sizes that exceed the capacity of traditional software to process within an acceptable time and value". The integration of Big Data technologies in agri-food projects, which is done through data semantics, analytics, or data-processing, plays an important role in the extension of farmers to create new knowledge, the creation of innovative services and processes, and bringing efficiency in production and cost reduction (LEZOCHE *et al.*, 2020).

Blockchain

All agricultural products go through the same path until they reach the consumer, production, processing, packaging, distribution, and retail sale. However, tracking the opposite path and identifying how the product's properties have been changing at each stage of the production chain are still a great challenge. To make traceability feasible along this chain, data and information from the various participants, namely, producers and suppliers of agricultural inputs, and from industry and transport to their commercialization must be collected. To integrate the actors of this production chain, establishing a layer of trust in each one's role, a strategy explored the most innovative companies in the sector is the creation of a blockchain-based application. In this way, the entire history of an asset produced in the field can be traced without exposing industry secrets, sharing information with consent, and only with those who are necessary. With blockchain technology, traceability in the field to guarantee the origin and quality of the product that arrives at the tables of Brazilians becomes much more transparent and easily verifiable. It is possible to confirm, for example, if a product offered at retail as an organic one is in fact produced on a farm with this type of manufacture and without the use of pesticides. Moreover, by knowing the origin and path the product took, those involved in its production chain gain agility and precision in the event of recalls, to collect and exchange only what is necessary.

The traceability of the products from the Carrefour Brasil Swine Sabor & Quality line is a successful case. They use a solution developed by SafeTrace in partnership with CPqD (Research and Development Center on Telecommunications, Campinas-Brazil) (CPQD, 2020). Through a QR Code, consumers can have access to detailed information on the stages of production and distribution of food, from the farm to the arrival at the store. In addition, the technology allows Carrefour to have control in cases of product recall (FIGUEIREDO *et al.*, 2020).

Artificial Intelligence

The constant search for technologies and solutions to improve the various processes of agricultural operation is an important factor for the digital transformation of the sector. In the case of agricultural machinery, maintenance processes represent relevant costs for producers and are fertile ground for the application of AI combined with IoT and edge computing, paving the way for the "connected maintenance" era. For many companies, maintenance has been conducted in the same way for decades. Almost every asset has a set of recommendations on how to maintain the equipment, based on data from the manufacturer's engineering area. With the adoption of IoT technologies, combined with AI approaches and techniques, the manager

responsible for the machinery can minimize losses, adjust processes, and maximize results. The early discovery of a machine failure, using predictive algorithms based on machine learning, for example, allows actions to be taken to avoid it and guarantee the reliability and availability of the equipment.

In Agro 4.0, prescriptive maintenance takes predictive maintenance a step further. Advanced analytical models support the identification of asset reliability risks that can impact the operation. Moreover, based on the recognition of predefined standards and rules, these models identify the actions and moments for acting on an asset, such as the exchange of an asset, electronic component, or the immediate cleaning of an air filter. This model can benefit from data analysis and AI to create a new dimension for the process of continuous improvement, correlating the agricultural machinery operation database with meteorological and corporate data. Despite connectivity difficulties in the field, detecting and making local decisions, without depending on centralized intelligence, are increasingly necessary. The advance there comes from the distribution of computational elements with low energy consumption and a high degree of processing, capable of executing the decision models obtained by machine learning techniques. This concept, called edge computing, opens the door to the so-called edge intelligence or edge AI. Coupled with agricultural machinery, this concept allows a high degree of automation in field decisions.

The advancement of AI integrated with IoT in the field tends to be accelerated in the coming years, with increasingly robust and accurate algorithms, bringing direct benefits to the business of producers in terms of cost reduction, productivity gains and environmental sustainability (FIGUEIREDO *et al.*, 2020).

VISION OF PRACTICAL IOT APPLICATION IN RURAL AREAS

This section presents the view of use cases of a private broadband wireless network to provide connectivity in wide geographic and remote areas as a solution for the Brazilian scenario with lack of long-range connection infrastructure.

Evolution of IoT in Brazil for Agriculture

The focus on innovation and the development of technologies for tropical agriculture has been a relevant factor for the exceptional performance of Brazilian agribusiness in recent decades. In the coming years, new challenges are expected to further accelerate digital transformation in the field, starting with sectors such as agricultural machinery, which represents an important part of investments and operating costs in crops with a high degree of mechanization.

Connectivity is an essential factor for the use of several of these technologies. Brazil has a substantial challenge to enable connectivity in rural and remote areas. The immense territorial extension, the diversity of scenarios, and the balance between supply and demand in the current business models of the internet service providers hinder the technical and economic feasibility of implementing and operating a connectivity infrastructure with the necessary scope and quality.

A first relevant factor that concerns the infrastructure for transporting high volume data traffic in the countryside is using links designated as "backhaul". In the case of wireless communications infrastructure, this challenging scenario is evident when looking at the coverage map of cellular networks in Brazil (Figure 8): about 70% of rural properties in the country do not have access to the internet. This is due to several aspects, such as economic barriers and diversity of morphoclimatic domains throughout the national territory (FIGUEIREDO *et al.*, 2020). The demand for ICTs in the field is expected to grow strongly on the global stage, particularly in Brazil. However, to increase the offer of technological solutions for the sector, connectivity in rural areas of the country must be expanded. Some initiatives in this regard have emerged recently using mainly access via 4G networks. The licensing of the 450 and 700 MHz frequency bands for all major operators is an example of public policy that contributes to connectivity in rural areas. However, the availability of broadband in these areas is still insufficient.

A relevant initiative to face the challenge of connectivity in the field is the recent deployment of private 4G network infrastructure based on LTE 250 MHz technology, developed by CPqD in partnership with São Martinho S.A. (SÃO MARTINHO, 2020), Trópico Sistemas e Telecomunicações da Amazônia Ltd. (TRÓPICO, 2020), and BNDES. Using the 250 MHz frequency band, destined to the Serviço Limitado Privado by ANATEL, allows the implantation of cells with a coverage radius of tens of kilometers, providing mobility with quality of service and high transmission rates.

Usina São Martinho, located in Pradópolis (SP), has an area of 135 thousand hectares, which was covered with quality for video transmission in real time. The 10 LTE 250 MHz radio base stations installed in 6 towers, with coverage over 40 km, are employed. This infrastructure is being used to collect data in real time in the agricultural operation of Usina São Martinho, through Terminal

Figure 8 - Geographical distribution of the coverage of the base stations of public mobile networks in Brazil in 2019 (FIGUEIREDO *et al*., 2020)

4.409.745,70 Km² (51,8%)
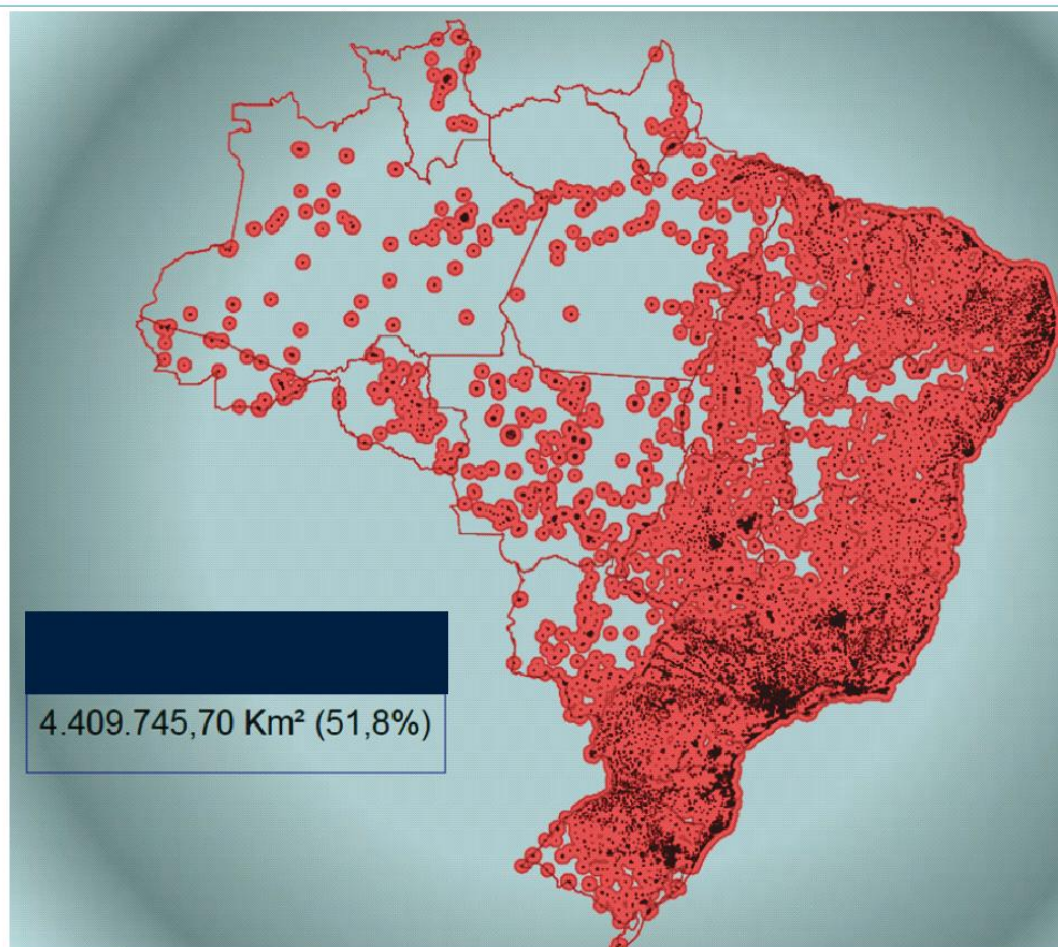
Inteligente Veicular installed in harvesters, tractors, and trucks that transport sugar cane. The system provided by Trópico is being implemented in several agricultural properties (and in other sectors, such as transport and utilities).

The initiatives such as ConectarAgro (2020), an association led by TIM telecom operator with a focus on LTE 700 MHz technology for rural production, and Sistema de Satélite Geoestacionário de Defesa e Comunicações Estratégicas (SGDCE), a national satellite that will support telemetry services throughout the Brazilian territory, are also worth mentioning.

IoT Connectivity Solution in Rural Areas

In agribusiness, the production process consists of several phases, each conducted at its own time: planning, soil preparation, nutrition, planting, cultural treatments, and harvesting. For each phase, IoT connectivity in the farm allows field data information to reach the Agricultural Operations Center in real time, where applications perform data analysis, thereby allowing the management of each of these phases. Without this connectivity, this field data information is collected locally using a USB memory, by extracting data from tractors, harvesters, and trucks accumulated by on-board computers during a period. These data are accumulated and processed at night, generating reports only the next day.

With the presence of connectivity in the field, a real-time monitoring is conducted, thus correcting any inefficiency avoiding losses or inefficiencies. An example would be the sugarcane harvest that involves many harvesters, two transshipment, transport trucks, and a fuel and lubricant truck. The operation needs to be coordinated so that an overflow is always available to the harvester

and a truck is always available to transfer cane from the overflows, maximizing the harvester's working time and ensuring a constant rate of truck arrival at the mill of the plant, not to mention that the stops to fuel machines and vehicles must be coordinated with the arrival of the fuel and lubricant truck.

The optimization of harvest logistics, essential for decreasing operating costs and maximizing working time, can only be done if the geographical position and data of each machine and vehicle are provided in real time to the Agricultural Operations Center. Because the sugar-energy sector involves an industrial area associated with the production process and the constant availability of sugarcane in the mill during the harvest period is paramount, it is a mission-critical operation, which implies the requirement for a highly reliable network with guaranteed quality of service. This requirement is not served by a telecom operator service that shares resources, and the focus is on providing broadband Internet access (BARBIERI; BIAZOTTO, 2018).

Private Network Solution in Rural Areas

The demands for IoT connectivity previous described characterize the network requirements for these sectors of the economy, remote area coverage, with no presence of a public Internet service provider or a telecom operator network infrastructure. In addition, it is ineffective when it exists. Thus, a private network providing IoT connectivity attending these sectors is the most feasible solution. The covering area is a challenge, which can be tens of thousands of square kilometers, and transport routes can be thousands of kilometers long. For the implementation of a private network to be feasible in meeting these businesses' needs, the network solution must be based on wireless technology with throughput to attend the needs for IoT narrowband connectivity. Moreover, the needs for farm operations and support must be met, which require voice and video services, meaning a broadband connectivity requirement.

In this scenario, LTE, 4G, and 5G in the future, best meet those requirements. Moreover, these technologies base station coverage area can be long range, thus minimizing the number of communication towers to be deployed, with the possibility of using existing towers in the farm. Network deployment planning is important in this case to have the size of the Base Station cell according to the number of users and the total required bandwidth in the cell.

Obtaining a large coverage area is another consideration. The use of lower frequencies is the best, since the attenuation of the free space varies directly with the frequency. For the same base station transmitter power and antenna gain, and end-user receiver sensitivity and antenna gain, the lower the frequency, the lower the attenuation of free space, and thus, the higher the communication range. Alternatively, the lower the frequency, the lower the availability of channel frequency bandwidth for the system to have a capacity compatible with the coverage area. These two antagonistic requirements need to be reconciled with the choice of the operating band of the system. A bandwidth must be available for an operation that reconciles these two requirements: low frequency in the VHF band and high channel frequency bandwidth.

Spectrum regulation is a sensitive issue because low-frequency spectrum must be allowed in the remote rural area and that spectrum must be regulated and licensed for private use. The licensing of frequency bands for private use for long periods (more than ten years) is also essential for this scenario, because legal certainty is necessary for the company's investment. In addition, the spectrum reserve must be guaranteed in its area of interest during depreciation of assets or the planned time for return on investment.

The company Trópico Telecomunicações developed a complete private broadband network solution based on LTE technology, present in 4G and 5G networks. The solution is made up of base stations, specialized terminals, antennas, network management software, network control software, SIM Cards, power supply for the towers, point-to-point radios to build the backhaul within the farm field areas, and professional services for planning, design, deployment, configuration, training, operation, and post-sale support. The Vectura eNodeB - Compact 250 Base Station (VeNB-C 250) and the Vectura Smart Access terminals are self-developed and manufactured, as well as the Vectura Access Manager network element management software. The other components of the solution are products from Trópico's commercial partners that have been properly tested and approved to be part of the solution.

5G TECHNOLOGY AS A NEW IOT REVOLUTION IN RURAL AREAS

The 5G networks (5th generation of mobile communications networks), whose commercial implementation began in 2019, promise to revolutionize not only the telecommunications sector but also several other sectors of the economy, called vertical markets, including agribusiness. The main characteristics of this network includes the ability to aggregate and integrate various services. The revolutionary potential of 5G is its offer of other usage scenarios, such as massive IoTs,

tactile internet applications in ultra-reliable networks, and low latency, and the scenario focused to remote areas. This offer is in addition to the scenario of higher transmission rates, which is common to the evolution of previous generations (REDES 5G - TRANSFORMANDO A SOCIEDADE, 2020).

The scenario to offer higher transmission rate is designated enhanced mobile broadband, establishing the requirement of data flow experienced by a user of 100 Mbps, urban and suburban areas, and 1 Gbps in hotspots with a peak rate of 20 Gbps (20 times higher than that offered on 4G networks). This high transmission rates will allow operators to offer several new applications such as transmission of 3D images and holograms, high-resolution video streaming, augmented reality, virtual reality, virtual presence, collaborative robots, and cloud robotics.

The scenario focused on IoT applications is massive, it is designated as massive MTC (mMTC) with requirements of a high density of connections (106 devices/km^2, 10 times greater than the defined for 4G networks) and an energy efficiency 100 times better than that offered in current mobile networks.

The scenario focused on critical applications, is designated as ultra-reliable and low latency communications, which is associated with applications that require low latency and high network reliability, such as tactile Internet applications. The latency and reliability requirements usually specified for tactile Internet applications are a maximum end-to-end latency of 1 ms and a probability of unavailability less than or equal to 10–7 (also called a system with seven 9s reliability). For comparison, the end-to-end latency of 4G networks is approximately 20 ms.

Finally, the scenario designated as enhanced remote area communications (eRAC) offers the benefits of 5G networks not only to densely populated urban areas but also to remote and rural areas. The main performance requirement for this scenario is to have a cell with a coverage area with a radius of 50 km, offering a rate of 100 Mbps at the edge of the cell.

The potentials of 5G technology in agribusiness are promising, and the availability of higher data transmission rates will increase the communication capacity of high-resolution images. An example is enabling the use of computer vision technologies and cloud analytics, for the application of pesticides and fertilizers with greater precision, reducing costs and environmental impact. Low latency and high-reliability network, with the use of AI algorithms, will make drones and autonomous agricultural machines application a reality. The massive IoT connection of the 5G will allow monitoring a much larger number of end devices such as a sensor for monitoring microclimate,

soil, crop, and animals, with the same infrastructure of other previous technologies. Besides the fact that this new technology can provide various new services, as previously mentioned, the same network infrastructure can provide connectivity for narrowband and wideband users or end devices, and we can include the option for sharing the network using the network slicing functionality. In this way, a telecom operator or a mobile network operator (MNO) can rent a slicing of their network as a service. Offering private networks can be a great opportunity for MNO operators, as they have a competitive advantage as a licensed spectrum provider, based on economies of scale.

There are three critical success factors for 5G, that is the infrastructure for the access network, virtualization and digital transformation, and ecosystem and innovation. In the case of access network infrastructure, the RF spectrum is the most important factor. The lower frequency bands (<1 GHz) offer better propagation conditions and, consequently, better coverage, in addition to greater communication reliability. However, the possible transmission rates are lower, due to the lower bandwidth. These ranges are suitable for applications related to the mMTC and eRAC scenarios, which require coverage of large areas. New models should be considered in the licensing of spectrum bands for applications that use 5G networks, and specific spectrum should be considered for use by different private networks. Regulators are willing to understand the demand, and several countries, have published regulatory tools for allocating spectrum with local grants to private network operators. New operators present network solutions that are allowing their customers to have networks appropriate to their specific needs, which include, among others, coverage for the areas of interest of their business.

According to the decree establishing the National IoT Plan, the Ministry of Science, Technology and Innovations will highlight the priority areas for applications of IoT solutions including, at least, health verticals, smart cities, industries, and agribusiness (ESTUDO "INTERNET DAS COISAS: UM PLANO DE AÇÃO PARA O BRASIL", 2020). The entry into force of the new Brazilian telecommunications regulatory framework, Law 13,879/19, brought an important concept to the development of private networks by introducing the concept of a secondary spectrum market. This should be further developed by sectoral regulation, as a mechanism to encourage the efficient use of the spectrum and to foster new business models among RF use holders and new operators, which could be important leverage for developing private networks by new operators, especially in scenarios in which part of the network is implemented by a company, or in rural and remote areas. The participation of satellite systems in the 5G ecosystem

will bring connectivity to rural and remote areas, allowing the development of the so-called Agriculture 4.0, which is extremely important for Brazil's agribusiness (20+% of GDP). Satellite networks can also be used in urban regions, with high population density, for example, to drain traffic in situations of congestion or failure of the terrestrial network.

In March 2017, the 5G Project was created within the scope of Telebrasil, called "Fórum 5G Brasil," (5G BRASIL, 2020).The 5G Brasil project established verticals (in alphabetical order) as priorities for its actions: agribusiness; education; basic industries and advanced manufacturing (mining, oil, and gas, industry 4.0); logistics (cargo logistics, including storage at origin and destination, transport and distribution); health (including health logistics, remote medical care and public health); and public security (urban and land, air and water borders).

CONCLUSIONS

1. Agriculture plays a great role in providing human food, maintaining production sustainability, and meeting this ever-increasing global food demand (FAROOQ *et al.*, 2019). Agriculture is predicted to be further optimized by the IoT technology, as farmlands and greenhouses move from precision to a micro-precision model of agricultural production. Distributed cloud computing will enable precise monitoring of the facilities and will provide the optimal growing or living conditions for both vegetables and animals. The sustainability of agricultural systems that is paramount for the survival and well-being of humans can be aided by the adoption of IoT technology globally;

2. The introduction of AI technology will control the production under the market situation, thereby maximizing the profit and minimizing the costs. Moreover, adopting the blockchain technology in food supply chains can allow monitoring of each stage in the product's life cycle, automatically identifying any cause in a faulty product, and increasing consumers' satisfaction and feeling of safety, through transparent product lifecycle information;

3. These predictions are feasible today but depend on investments (SOMA *et al.*, 2019). Moreover, some barriers need to be overcome as described in this article. Especially in Brazil, the connectivity gap is the biggest barrier to advancing Agro 4.0. In addition, Agriculture 4.0, Magazine Pesquisa FAPESP (2020) presents the following figures about this investment: "Brazil is sorely lacking in connection infrastructure, and the cost of building that infrastructure will need to be supported by telecommunications companies, governments, or farmers. Expanding coverage to around 90% will require some 16,000 new transmission towers, says Luis Claudio Rodrigues de França, director of the Department of Agricultural Innovation Support at the Ministry of Agriculture and Food Supply. The investment required would be more than R$8 billion".

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