The Evolution of 5G Communications within the Scope of the Fourth Industrial Revolution

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Resumo
A Quarta Revolução Industrial é uma consequência da última transformação digital e consiste na substituição de seres humanos por robôs. Está associada à utilização massiva de robôs, inteligência artificial, grandes dados, Internet das Coisas (IoT), computação quântica ou impressão 3D. A transformação digital e a transformação ambiental estão amplamente associadas, uma vez que a primeira permite uma utilização mais eficiente dos recursos, o que tende a reduzir a pegada de carbono, e permite a geração de energias renováveis. A Quinta Geração de Comunicações Celulares (5G) é disruptiva, uma vez que consiste numa mudança de paradigma relacionado com as gerações anteriores. As Comunicações 5G dão uma forte contribuição para a implementação da Quarta Revolução Industrial numa vasta gama de áreas, tais como em veículos autónomos, cidades inteligentes, indústrias e agricultura inteligentes, cirurgias remotas, etc. Enquanto as comunicações 5G visam implementar alguns dos requisitos da Quarta Revolução Industrial, a Sexta Geração de Comunicações Celulares (6G), prevista para 2030, visa complementar essa implementação de uma forma mais profunda.

Palavras-chave
4ª Revolução Industrial; 5G; Internet das Coisas; Automação.

Abstract
The Fourth Industrial Revolution is a consequence of the latest digital transformation and consists of the replacement of humans by robots. It is associated to the massive use of robots, artificial intelligence, big data, Internet of Things (IoT), quantum computing or 3D printing. Digital transformation and environmental transformation are widely associated as the former allows a more efficient use of the resources, which tends to reduce the carbon footprint, and allows the generation of renewable energies. The Fifth Generation of Cellular Communications (5G) is disruptive, as it consists of a change of paradigm relating to the previous generations. 5G Communications give a strong contribution to the implementation of the Fourth Industrial Revolution in a wide range of areas, such as in autonomous vehicles, smart cities, smart industries and agriculture, remote surgeries, etc. While 5G communications aim to implement some of the requirements of the Fourth Industrial Revolution, the Sixth Generation of Cellular Communications (6G), expected by 2030, aims to complement such implementation in a deeper manner.

Keywords
Fourth Industrial Revolution; 5G; Internet of Things; Automation.

Resumen
La Cuarta Revolución Industrial es una consecuencia de la última transformación digital y consiste en la sustitución de los humanos por robots. Está asociada al uso masivo de robots, inteligencia artificial, big data, Internet de las Cosas (IoT), computación cuántica o impresión 3D. La transformación digital y la transformación medioambiental están ampliamente asociadas ya que la primera permite un uso más eficiente de los recursos, lo que tiende a reducir la huella de carbono, y permite la generación de energías renovables. La Quinta Generación de Comunicaciones Celulares (5G) es disruptiva, ya que consiste en un cambio de paradigma respecto a las generaciones anteriores. Las comunicaciones 5G contribuyen fuertemente a la implementación de la Cuarta Revolución Industrial en una amplia gama de áreas, como en los vehículos autónomos, las ciudades inteligentes, las industrias y la agricultura inteligentes, las cirugías a distancia, etc. Mientras que las comunicaciones 5G pretenden implementar algunos de los requisitos de la Cuarta Revolución Industrial, la Sexta Generación de Comunicaciones Celulares (6G), prevista para 2030, pretende complementar dicha implementación de manera más profunda.

Palabras-clave
Cuarta Revolución Industrial; 5G; Internet de las Cosas; automatización.

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1. Introduction

Digital transformation is a term that has been widely heard nowadays. Along the last decades, different digital transformations have occurred. The base for the Third Industrial Revolution was the development of electronics, initially analog and, in the eighties, the digital electronics. The Third Industrial Revolution consisted of the massive utilization of electronics equipment, the media, and of Information Systems and Technologies. Rapidly, we experienced the convergence of telecommunications, where a single network infrastructure based on all-over-IP (Internet Protocol) was employed for the transport of different types of data, such as voice, telemetry, Internet, or even television. In this context, we observed the replacement of humans by information systems and technologies in the society and organizations, which allowed a more efficient use of resources, but demanding higher level of skills from humans, to develop new and higher level of tasks. This massive and rapid access of information by humans was denoted as "information age", having originated a deep modification of the job market.

The Fourth Industrial Revolution is a new change of paradigm in the way society and organizations are shaped, consisting of a massive replacement of humans by robots in a myriad of areas (Kunze et al., 2018) (Griffiths and Ooi, 2018). Figure 1 shows the important areas of the 4^{th} Industrial Revolution. Robots use sensors and IoT to communicate with the environment, generating large amount of data (big data). Such data is processed by Artificial Intelligence (AI) algorithms to generated knowledge, which will then be used by robots to make decisions. In addition to these key parameters mentioned in Figure 1, others such as 3D printing or quantum computing can also be considered to have important roles in the modification of the society. Moreover, the 4th Industrial Revolution also comprises the massive translation of communications between humans into machine-to-machine communications (i.e., IoT). Digital transformation and environmental transformation are widely associated as the former allows a more efficient use of the resources, which tends to reduce the carbon footprint, and allows the generation of renewable energies.

5G Communications are disruptive, introducing profound modifications relating to the previous generations. 5G Communications give a strong contribution to the implementation of the Fourth Industrial Revolution in a wide range of areas, such as in autonomous vehicles, smart cities, smart industries and agriculture, remote surgeries, etc. (Marques da Silva and Guerreiro, 2020). 5G Communications are substantially different from the previous generations, incorporating the new paradigms considered by the 4th Industrial Revolution, namely in terms of IoT (Marques da Silva, M., et. al., 2018). Besides the higher data rates and lower latencies, 5G allows direct device-to-device communications (without being through a base station), which is especially important in terms of IoT for the implementation of e.g., Smart Cities or Autonomous Vehicles.

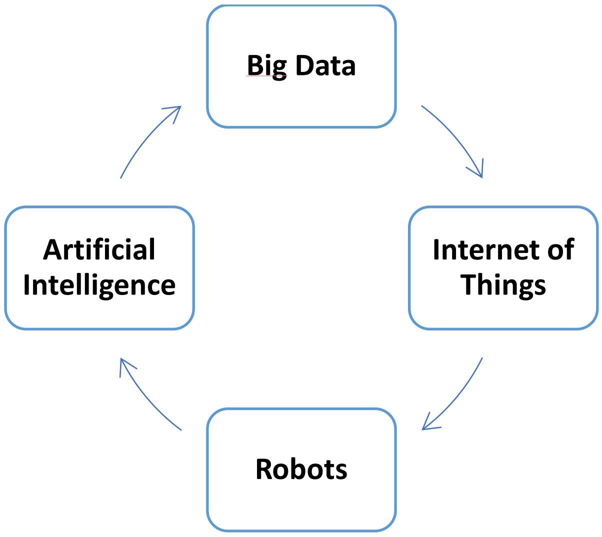

Figure 1. The important areas of the 4th Industrial Revolution and their Main Interconnection

This paper is organized as follows: section 2 describes the Fourth Industrial Revolution and its dependency from 5G communications, while section 3 describes the fifth generation of cellular communications. Finally, section 4 concludes this paper.

2. The Fourth Industrial Revolution and its dependency from 5G Communications

As a result of the Fourth Industrial Revolution, we are observing deep changes in the society, such as in agriculture, industry, cities, work, mobility, teaching, among others (Zhou et al., 2015). The pace of technological innovation is getting faster and faster, and the changes are so profound that there has never been a potentially more promising or dangerous moment in human history (Schwab, K., 2016).
While the Third Industrial Revolution consisted of the replacement of humans by information systems and technologies in the society and organizations, the Fourth Industrial Revolution comprises the replacement of humans by robots, originating a deep modification of the society and, consequently, of the job market, with the creation of some jobs and the extinction of others (FORD, M., 2015) (Rainai and Kocsis, 2017), while a wide number of jobs are suffering deep modifications on the way they are implemented. While repetitive tasks tend to be implemented by robots, higher level of skills are required by humans (AOUN, Joseph E., 2017), such as advanced scientific, technical and human skills, critical spirit, emotional intelligence, or abstract thinking. In this new context, higher level of skills became more important assets than tangible goods. According to a study developed by the Organization for Economic Co-operation and Development (OECD) the following impacts of the Fourth Industrial Revolution are expected on the labour market (OECD, 2018) (Cabeças and Marques da Silva, 2021):

- Automation affects mainly industry and agriculture, but trade and services are also vulnerable;
- Higher risk is associated to jobs with higher level of routines, lower skills and lower incomes;

- About 14% of existing jobs in OECD are highly automated, while 32% of jobs can suffer a main modification on the way they are performed;
- Younger people who enter the jobs markets are more vulnerable to automation than jobs developed by more experienced people;
- Lower risk is applicable to jobs related to creation, maintenance and administration of technologies, creative intelligence, organization manipulation, social intelligence;
- Not all the jobs technically automated will disappear. Moreover, other jobs will be created, predicting that employability will continue to rise.

While the 3rd Industrial Revolution was known as the “Information Age”, as it originated massive quantities of information being available to humans, the 4th Industrial Revolution is also denoted as “Knowledge Age”. Knowledge can be viewed as the right information provided to the right person (or object), at the right time, to make the right decision. While large quantities of information can be useless or can even represent noise, knowledge is the result of data processing (data consists of the encoding of information), which is carried out using AI algorithms (Mariani, 2017).

The use of artificial intelligence has been accelerated by the recent increase of processing speeds, as well as increase of data quantities (big data). It is worth noting that the new generation of artificial intelligence algorithms are not limited to learning from the past, but also considering the impacts of these decisions, taking into account factors such as empathy, ethics and altruism. It is also important noting that the emergence of quantum computing will accelerate exponentially the capabilities of the AI algorithms, as its processing power also increases exponentially, as compared to conventional computation. Since repetitive tasks are implemented by robots, the risk of accidents tends to reduce. Moreover, automation also represents an added value for disable and elderly people (Marques da Silva, 2019).

An autonomous vehicle can be viewed as a robot, which senses the environment and communicates with the other vehicles using sensors and IoT, generating massive quantities of data (big data). Big data is processed by AI algorithms to allow autonomous vehicles making decisions. We observe an increasing dependency from cybersecurity, which can be viewed as a vulnerability. On the other side, AI and big data allow for the devising of new cybersecurity solutions.

Autonomous driving will potentiate the sharing of vehicles, making the future of mobility rely on car sharing, instead of having a private car parked for 97% of the time. Consequently, the vehicles traffic is expected to decrease as well as the risk of accidents. 5G communications have special characteristics to support IoT autonomous vehicles (as well as smart cities, smart industries, smart agriculture, remote surgeries, etc.) In the scope of 5G, an autonomous vehicle needs to communicate with the other vehicles (Vehicle-to-Vehicle [V2V]), exchanging data related to point of origin and destination, position, traffic, etc. Moreover, it communicates with pedestrians (Vehicle-to-Pedestrian [V2P]), namely, to avoid accidents. It also needs to communicate with the network (Vehicle-to-Network [V2N]), as well as with the infrastructure (Vehicle-to-Infrastructure [V2I]), e.g., to change the traffic lights. All these types of communications are globally known as Vehicle-to-Everything (V2X). 5G communications comprises an important feature, entitled network slicing, which comprises the reservation of resources for achieving certain requirements. In the case of vehicle communications, in order to avoid accidents, two important requirements are: (1) high reliability and (2) low latency. These requirements are provided by one of the three groups of use cases of 5G communications depicted in Figure 2: Ultra Reliable Low Latency Communications (URLLC).

3. The Fifth Generation of Cellular Communications

In telecommunications, 5G is the acronym used to refer to the fifth generation of cellular communication technologies. This corresponds to the successor of the Fourth Generation of Cellular Communications (4G), which provides connectivity to most of today's mobile phones.

5G is designed to increase connection speed, peak data rate, reduce latency and exponentially increase the number of connected devices (GSMA, 2020). To achieve the goals outlined by the 3GPP (3rd Generation Partnership Project) and be able to adapt to the variety of services that must be supported, 5G is supported by technologies: 5GNR, Edge Computing, Network Slicing, Software Defined Networking and Network Function Virtualization. These concepts are discussed in the following subsections.

As can be seen from **Figure 2**, 5G comprises three groups of use cases (Marques da Silva and Dinis, 2021):

(1) Enhanced Mobile Broadband (eMBB), consisting of the traditional cellular communications when mobility is a requirement, through a base station, but providing higher speeds and some additional special features as compared to the previous generation of cellular system. This group of use cases is specific of services that require high mobility and high data rate.

(2) Massive Machine Type Communications (mMTC), being well suited for communications requiring low power and low duty cycle, typically for IoT devices used in smart cities, smart industries or smart logistics. This group of use cases is specific of services that require high capacity (high number of devices per square kilometer).

(3) URLLC relies on communications which are delay sensitive, and sensitive to corrupted data, such as in autonomous vehicles or remote surgeries.

It is worth noting that the network slicing also allows reserving 5G resources for use by Security Forces, as adopted by some countries, or for the provision of private networks.

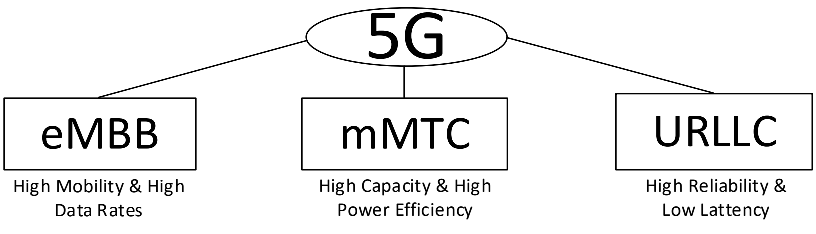

Figure 2 - The three groups of use cases of 5G

Table 1 lists some important requirement for each of the group of uses cases of 5G communications and compares them with the 4G. Note that the groups of use cases listed in Table 1 are only applicable to 5G. As can be seen, 5G communications achieve a peak data rate of 20 Gb/s in the downlink using eMBB (in the uplink this value is halved), while the latency is as low as 1 ms, as required for delay sensitive services, such as remote surgery or autonomous vehicles.

Table 1- Important requirements for each 5G group of use cases

Capabilities	5G		4G
Peak Data Rates	eMBB	20 Gb/s (downlink)	1 Gb/s (downlink)
Experienced Data Rates		100 Mb/s (downlink)	10 Mb/s(downlink)
Mobility Speed		500 km/h	350 Km/h
Connection Density	mMTC	1 million devices per Km^2	100,000 devices per Km^2
Latency	URLLC	1 ms	10 ms

Such high data rates are achieved with advanced signal processing and transmission techniques, such as Massive Multiple-Input Multiple-Output (MIMO), Orthogonal Frequency Division Multiple Access (OFDMA), or millimetre waves. While centimetre waves were used in previous generations of cellular communications (typically with carrier frequencies around 2 and 3 GHz), in addition to centimetre waves, 5G also uses carrier frequencies between 60 and 100 GHz (millimetre waves), supporting a much higher channel coherence bandwidth. This translates in higher transmission rates, but the ranges are highly reduced due to increased path losses (Rappaport, T.S. et. al., 2013).
While 5G aims to fulfil the initial requirements of the 4th Industrial Revolution, the Sixth Generation of Cellular Communication, expected by 2030, intends to complement and to improve the fulfil of such requirements. The digital transformation continues to increase the required number of IoT devices along the time, such as vehicles and drone's connectivity, smart cities and smart logistics sensors, etc. In this context, 6G communications aim to support emergent services such as holographic services, advanced autonomous vehicles, augmented and extended reality, increased mobility speeds, etc. 6G requirements are expected to be implemented using new frequency bands not yet considered, such as visible light communications and terahertz bands (100 GHz-10THz). The foreseen requirements for 6G include data rates up to 100 times higher than 5G, an energy efficiency 10 to 100 times better than 5G, and a spectral efficiency of up to 10 times better than 5G.

3.1 5G New Radio

The Radio Access Network (RAN) is part of the mobile cell phone network that supports users to connect to the internet without the need for a physical connection.
In 4G networks, the Radio Access Technology is called Evolved Universal Mobile Telecommunications System (UMTS) Terrestrial Radio Access - E-UTRA or also known as LTE (Long Term Evolution). In the case of 5G networks, the radio access technology is the New Radio (NR), known as 5G NR (SACHS, 2018). Therefore, this technology provides the infrastructure with the capabilities that makes possible having permanent connectivity to the 5G network from any 5G device that is part of the Fourth Industrial Revolution. The Standardization of 5G NR began in March 2017 with the release 15 of 3GPP (3GPP, 2017). In December 2020 3GPP published the release 16 (3GPP, 2020). The main content of this new release was:

- Enhancements of URLLC
- Improvement for Massive MIMO, especially for CoMP (Cooperative MultiPoint);
- V2X Phase 3 (Automated driving, remote driving);

- Industrial IoT;
- NR-based acess to unlicensed spectrum (NR-U);
- Interference Mitigation;
- eDual Connectivity;
- Device capabilities exchange;
- Mobility enhancements;
- Integrated Acess and Backhaul;
- Satellite Acess in 5G;
- Mobile Communications System for Railways (FRMCS Phase 2).

5G NR also addresses support for vehicular communications, making it critically important for V2X communication. 3GPP is working on the next generation of V2X technology with the proposed NR-V2X protocol (3GPP, 2021).
Several improvements of 5G system are presented in release 17. Figure 3 shows a new work schedule that was approved at the Technical Specification Groups meetings (TSG #90). The following are the priority contents that will be included in the launch of 3GPP release 17.

- NR multicast and broadcast services;
- NR support over non-terrestrial networks;
- RAN slicing for NR;
- Integrated access and backhaul (IAB);
- URLLC for industrial IoT over NR;
- MBS positioning;
- NR sidelink;
- Multi-RAT dual-connectivity;
- Support for multi-SIM devices for LTE/NR;
- NR small data transmissions in inactive state and multimedia priority service.

In turn, release 18's content, priorities, and schedule are moving into the discussion and decision-making phase. The process for defining release 18 features must be completed at the TSG#94 meetings, with the approval of the release 18 package.

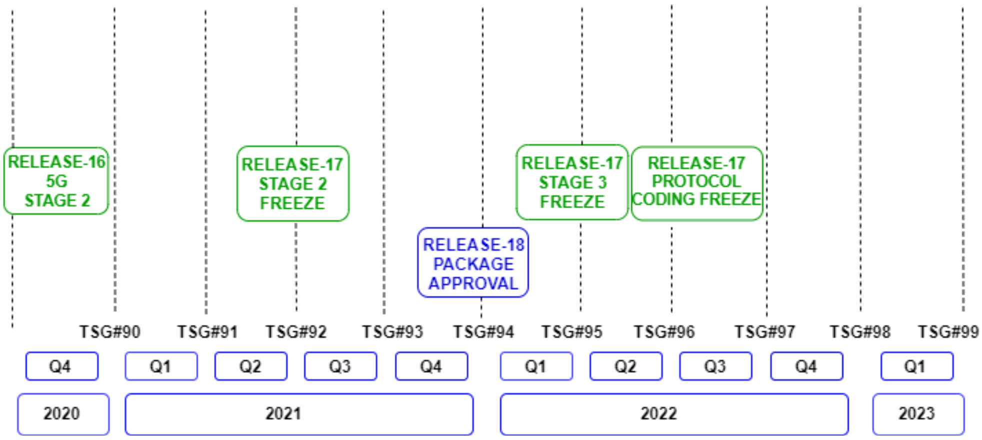

Figure 3 - 3GPP Release 17 Launch Calendar

3.2 Edge Computing

The concept of Edge Computing arose from the need to provide low latency services to some of the IoT devices. The implementation of 4th Industrial Revolution applications that need to run in real time leads to the need to process and analyze the information produced by the devices before being sent to the servers in the cloud. Latency cannot be too high for interactive virtual reality or collaborative applications such as autonomous driving. This type of solution needs a response time below 10 milliseconds to be reliable (GSMA, 2020). Edge Computing is a strategy to reduces latency, consisting of computing deployment (data processing) in Edge devices and network infrastructure (KEYAN, 2020). This paradigm is shown in figure 4.

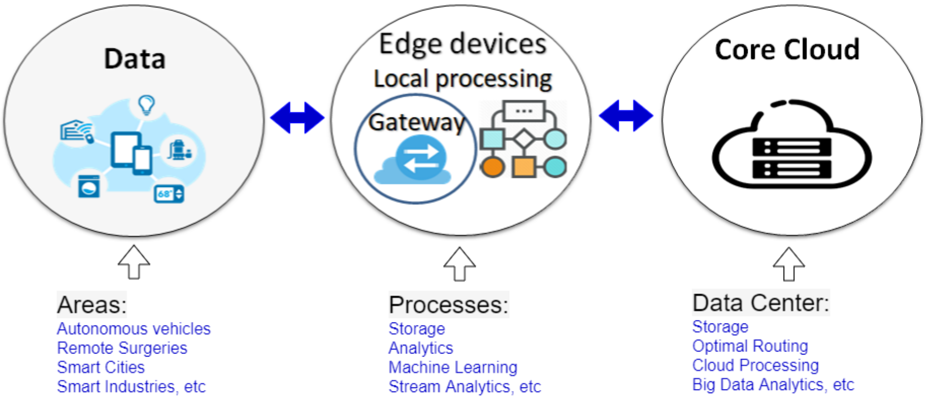

Figure 4 – Edge Computing

There are different variants of this principle, with different designations, such as the use of Micro Datacenters (SANDHYA, 2021) or Mobile Edge Computing (MEC) (THAVAVEL, 2021). Computing can be intelligently implemented with edge analytics, which refers to analytics deployment and machine learning at the network edge and in the cloud. Edge analytics uses statistical techniques and predictive modeling to find patterns and knowledge in data collected by devices. Edge Computing applications such as autonomous driving, remote surgeries, augmented reality and smart cities can benefit from edge analytics that provides processing and large-scale data aggregation (QUI, 2020).

It is worth pointing out that Edge Computing can also be leveraged with Streaming analytics since analytic computing can be performed in real time as the data is processed, with the advantage that it can be done both in the cloud and at the edge of the network, depending on the use case to be implemented (STIETENCRON, 2020).

3.3 Network Slicing

A network slice is a logical network that can provide specific features and characteristics for different types of traffic, allowing for more efficient distribution and use of network resources and greater flexibility for the implementation of diversified services (3GPP, 2021). This concept is materialized by the groups of use cases depicted in Figure 2 and described in Table 1.
Defined as an important feature of 5G, Network Slicing allows data processing and high connectivity for customers according to their needs (SHU, 2020). As shown in Figure 5, in network slicing the elements and network functions are easily configured and reused in each different slice.
An architecture based on 5G and MEC is ideal for supporting network slicing, allowing a URLLC network to function on the same physical infrastructure as other 5G services. This saves investment in infrastructure and network operation costs. For example, network slicing makes it possible to integrate a physical network infrastructure for autonomous driving along with other applications with different network service requirements, such as for eMBB or mMTC. Network slicing creates a flexible architecture for the efficient management of IoT devices, which opens up a much larger range of solutions for the Fourth Industrial Revolution. It is indispensable to integrate the different stages of an industrial process and stakeholders, such as customers, suppliers and partners.

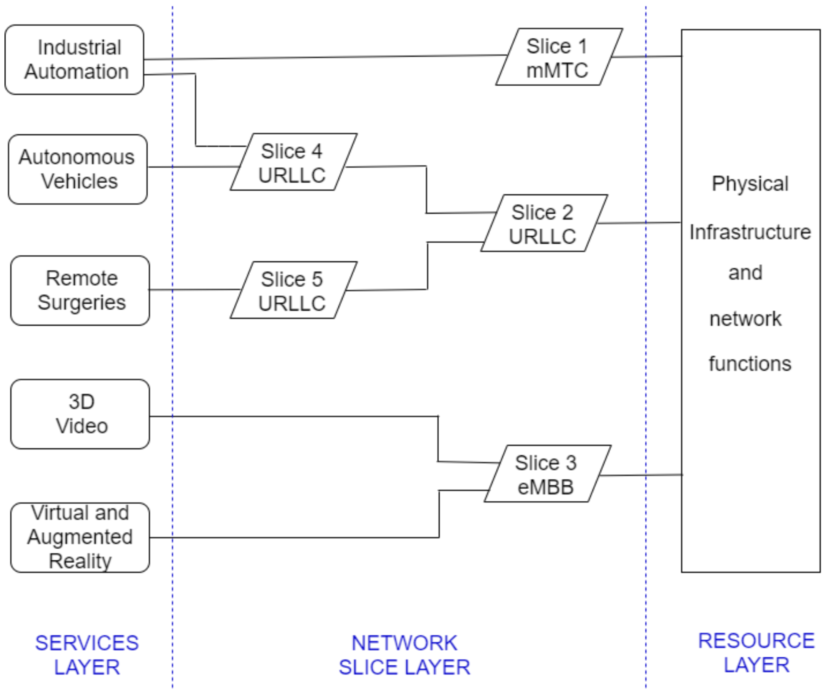

Figure 5 - Network Slicing architecture in 5G

3.4 Software Defined Networking / Network Function Virtualization

Software Defined Networking (SDN) and Network Function Virtualization (NFV) are two essential pillars of 5G networks. SDN refers to the ability of software to program an individual network of devices dynamically, and therefore control and manage the behavior of the network as a whole (IETF, 2015). For 5G, SDN represents a paradigm shift from "classic" networks. At 5G, SDN divides the network concept into 2 parts:

- Control plane → Software → Overlay Network
- Data plane→ Hardware → Underlying Network

NFV consists of creating an architecture aimed at decoupling network functions from proprietary hardware devices and executing them as software functions in virtual machines installed on high availability servers (ETSI, 2012).
In 5G networks these two technologies are closely related, although they are two distinct concepts. While SDN's main function is to make a programmable network that separates control and data plans and creates applications for Information Technology eXtended (ITX) using software to implement SDN Orchestrators/Controllers, at NFV its main function is to transform hardware into software applications that can run in virtualized environments. This is carried out with the use of software to implement Virtualization, Management and Administration, NFV Mgmt & Orchestration (MANO) and Virtual Network Functions (VNFs) (FAQUIR, 2018). In Figure 6 we can see the NFV/SDN interrelation for open systems.

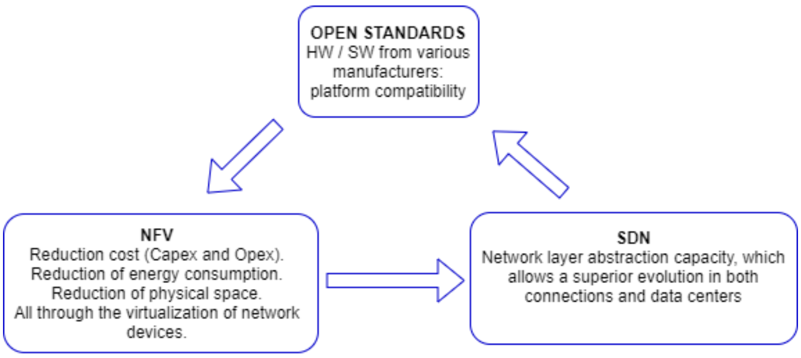

Figure 6. SDN/VFN Interrelation

Service providers and other vertical sectors can leverage SDN/NFV joining to deliver secure, low-cost, flexible services without compromising end-user Quality-of-Service (QoS). Currently, some network functions have already started to be implemented, as well as several access network and core elements, such as virtualized IP Multimedia Services (vIMS), Virtualized Firewalls, Virtualized Evolved Packet Core (vEPC), Virtualized Residential Gateway etc.

4. Conclusions

The Fourth Industrial Revolution comprises a change of paradigm on the way organizations and society is organized, comprising the replacement of humans by robots, as well as the massive use of AI, big data and IoT. The labour market is suffering deep modifications with the extinction of some jobs and with the creation of others, while certain jobs suffer a deep modification on the way they are implemented. Higher levels of skills are demanded from humans, such as advanced scientific, technical and human skills, critical thinking, emotional intelligence, or abstract thinking. While previous industrial revolutions harnessed the power of electricity and information technology, the Fourth Industrial Revolution, along with the creation of 5G, integrates advanced technologies with high wireless connectivity to contributes to all science areas. The resulting impact on our systems will transform the way we produce, manage, and govern our world.

The introduction of 5G is a high-impact development. 5G creates an underlying platform that allows existing technologies to be implemented in better ways, such as massive IoT. Therefore, 5G and its associated technologies provides a hardware and software infrastructure to support the fourth industrial revolution.

Acknowledgments

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