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5G IoT Industry Verticals and Network Requirements

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ABSTRACT

The effective provisioning of industry verticals over the next-to-come 5G systems opens novel business opportunities for telco operators especially when considering the integration of Internet of Things (IoT) devices as enablers of business cases based on remote sensing and control. This chapter highlights the main features of IoT verticals with particular attention on healthcare, smart cities, industry automation and entertainment business cases. The aim of this Chapter is to derive the requirements such IoT verticals pose in terms of design features to be considered in the standardization of 5G systems. This chapter presents the state of the art on the contribution from the research community and standardization bodies to address the 5G design characteristics with particular attention to the features enabling a proper management of IoT-oriented business cases.

Keywords: 5G, IoT, Network slicing, SDN, NFV, MTC, HTC.

INTRODUCTION

Over the last decade, the Internet of Things (IoT) has gained an always growing importance in the mobile market scenario by opening new business opportunities coming from the availability of data collected from sensors (Palattella et al, 2016). The support of IoT traffic, as analyzed for instance by Atzori et al. (2010), thus introduces the idea of providing connectivity to machines and this poses additional challenges to mobile networks that has been traditionally designed in order to provide high transmission data rates for human-type communications (HTC). HTC traffic is characterized by the transmission of bursty-based traffic which usually deals with large packets with non-strict constraints in terms of access delay (i.e., the time between the generation of the packet and its effective transmission over the radio channel) and energy consumption. IoT pushes novel traffic features to be considered over mobile systems due to the set of unique characteristics of the so-called machine-type communications (MTC) traffic characterised by minimal human intervention, periodic or event-triggered small packets and short connection time (e.g., short access and data transmission delays) in order to keep low the energy consumption of battery-equipped devices. The main features of MTC traffic are analyzed by Laya et al. (2014), who also provide a comparison of MTC and HTC traffic types.

As briefly mentioned above, the current mobile technologies such as Long Term Evolution (LTE) and LTE-Advanced (LTE-A), a.k.a. fourth generation (4G) systems, are designed to deal mainly with HTC traffic. As a consequence, when considering the next-to-come fifth generation (5G) networks, IoT dictates to re-design the transmission procedures of mobile systems in order to natively handle the simultaneous presence of HTC and MTC traffic while guaranteeing to meet the requirements of these two very heterogeneous traffic types. Thus, the current standardization of 5G systems aims to enable the provisioning of a great number of business cases arisen due to the emergence of IoT. As a further step, the disruptive technologies enabling the deployment of 5G systems aiming at introducing flexibility, customization and re-configurability of the network in both radio and core segments, will enable the provisioning of enhanced IoT services interconnecting people and everything. Indeed, a natural evolution of connecting devices to the Internet, is to remotely control these devices through the Internet; machines are not only able to talk to each other, but 5G is also focusing on enabling novel industry-related IoT applications in both consumer and business environments, for instance to increase industry automation, remote control and tactile Internet applications (Simsek et al., 2016).

This Chapter will cover the main trends in the industry to use the IoT to tackle several problems or to improve outcomes: business-to-business (B2B) market, increase in automation and remote control/operation, cost reduction, efficiency improvement. This Chapter will present a detailed analysis of the main IoT industry use cases enabled by 5G systems. As the introduction of MTC has enabled a high number of applications that can be targeted to the consumer directly (i.e., smart homes, wearables) or to more specific business activities, the aim of this analysis is to recognize the role of MTC in 5G systems in generating an added value to the business activity or consumer end. The main industry use cases we will discuss are healthcare, smart cities, industry automation and entertainment.

According to the features of the use cases investigated in this Chapter, we will also discuss the main requirements that such use cases push on 5G systems. These requirements range from QoS (e.g., data rates, latency, jitter, and energy consumption) to more generic constraints from a network point of view. Indeed, 5G systems need to exploit disruptive technologies that can simultaneously provide critical and non-critical MTC, and this dictates requirements in terms of network flexibility and customization. In addition to the analysis of requirements of 5G use cases, we will also discuss several proposals to tackle the related challenges. We will summarize the contributions of the research community and standardization bodies to the development by focusing on the recent advances in terms of network slicing, virtualization and softwarisation, solution for supporting MTC traffic, device multi-connectivity and centralized/cloud radio access network (RAN).

To summarize, the main contributions of this Chapter are:

- Presenting 5G use cases highlighting the novel business opportunities for IoT in the next-to-come mobile systems;
- Highlighting the role of MTC in the effective provisioning of the above considered use cases;
- Deriving and classifying the requirements that the considered use cases push on 5G systems;
- Surveying the contribution from the research community and standardization bodies to satisfy the requirements of 5G IoT use cases.

IOT IN THE INDUSTRY: EXPLOITING THE INTERNET CAPABILITIES

Connecting devices to the Internet has enabled a wide range of industrial opportunities due to the availability of data collected from sensors (e.g., sensing devices that measure specific parameters to be sent to remote servers or other machines) as well as the opportunity to remotely send tasks or commands to actuators. As analyzed by Andrews et al. (2014), from an application of view, 5G systems are expected to natively support the traffic generated by devices without the human intervention. Indeed, with the boost of IoT, machines can be connected to provide advantages such as economic savings or safety improvements. At the same time, this opens massive challenges in the design of 5G.

One of the most notorious changes in the design of the new generation of mobile communications, studied for instance by Osseiran et al. (2014), is the inclusion of a variety of use cases and applications that provides more to the society than only enhancing the user broadband experience. Thus, 5G is intended to support a high number of *vertical industries* providing fast and reliable communications. In this Section, we will survey different uses case in order to highlight their unique features as well as the requirements they pose in the design of 5G networks. A summary of the features of the 5G IoT verticals discussed in this Section is given in Table 1.

Healthcare industry

The healthcare industry has received a lot of attention, as for instance highlighted by Istepanaian & Zhang (2012), during the past years and several applications were already carefully recognized for 4G mobile health. Two major applications are being considered in the 5G context:

1. Remote healthcare and precision medicine with the use of bio-connectivity.
2. Remote intervention with the use of remote robotic surgery.

5G-PPP (2015) has analyzed the bio-connectivity context by highlighting the trend for: *decentralization of hospitals*, where medical care can be provided at home or while moving; *predictive analysis*; electronic medical records; *the use of embedded systems to perform individual pharmaceutical analysis*. Moreover, in the remote surgery context, the physical aspects need to be virtualised to allow for reliable diagnostics and treatments. In the existing robotic surgery devices, there is currently no feedback for the stiffness or any haptic information and adding these capabilities would reduce the doctor's reliance on video and sound transmission. Above mentioned aspects are discussed by Simsek et al. (2016).

Next generations of mobile communications are the key enablers of the main targets and trends of the healthcare industry providing: cloud-based solutions that improve the accessibility of high-resolution medical data; increased capacity for real-time high-definition video transmission; robust mobility and low latency communications. Zain et al. (2012) and 5G-PPP (2015) describe some of major challenges and requirements in the healthcare industry:

- **QoS guarantee:** Examples are reliability, mobility, latency. Delay and its stability (i.e., jitter) are the major requirement for remote interventions. When a robot is operated remotely, and there is a force feedback information being transmitted, the stability of the feedback process can be seriously impaired in presence of substantial time delay. These aspects have been widely discussed as for instance by Anderson & Spong (1989).
- **Security and confidentiality:** These aspects comprise both identity management and privacy protection.
- **Network support:** In the form of location tacking (like position accuracy), seamless handovers between different RATs, routing protocols, MTC capacity.

Smart cities

According to the definitions provided by the International Telecommunication Union-Telecommunication (ITU-T) standardization sector, a smart sustainable city is an innovative city that uses information and communication technologies to improve quality of life, efficiency of urban operation and services, and competitiveness (ITU, 2014). The smart city concept extends the intelligent mobility (IM, a.k.a. intelligent transport systems, ITS) paradigm where cars are connected to each other to increase the level of security and to optimize traffic management by considering the availability of, e.g., enhanced public transportation and emergency services. Based on this, a smart city is a highly heterogeneous scenario, where MTC and HTC coexist in heterogeneous network deployments. From this point of view, MTC traffic can range from data gathered from road-side sensors (measuring traffic congestion, pollution, traffic light timing, parking availability, etc.) to car-embedded sensors (measuring the status of the car in terms of engine and brakes, for instance, as well as reporting information such as position, mobility speed, and acceleration) to public transport sensors (deployed to check the position of public buses as well as their status) to public authority sensors. MTC traffic can also be considered in terms of actuators, when commands are sent to, for instance, traffic lights to change light timing to react to a congestion or to provide a quicker path for first aid services in case of an emergency. On the contrary, HTC traffic can be considered in terms of request/data sent from/to users for instance for parking payment as well as in terms of data/voice traffic among public authority users. As each one of the above mentioned types of traffic could be potentially handled in a different way from an architectural point of view, a primary characteristic of a smart city is the integration of different communication infrastructures.

Zanella et al. (2014) discuss urban IoT technologies that are close to standardization, and agree that most of smart city services are based on a centralized architecture where data is delivered to a control centre in charge of subsequently processing and storing the received traffic. From a deployment point of view, such a centralized architecture can be either a centralized, distributed or cloud-based data center according to the needs of the specific scenario as well as the availability of network resources in a specific area. A logical centralized architecture is thus considered as an effective solution in order to gather all together the data collected from different services (traffic management, parking, public transportation, public authorities, etc.) and to globally optimize the smart city. Despite these general requirements, each smart city application may have different challenging key performance indicators (KPIs) to be simultaneously satisfied: city energy consumption, smart lighting, smart parking or smart transportation.

One of the most demanding services in a smart city is the IM, which aims at providing more efficient movement and seamless journeys for people in both public and private means of transportation. In general, to increase safety, reduce congestion and pollution, real-time ultra-high reliable communications are required. To this end, autonomous or assisted driving cars need to continuously monitor the situation outside and inside the car, there is a constant information exchange mainly between the different participants of the transport network, i.e., vehicle to vehicle (V2V) and vehicle to infrastructure (V2I) communications. Autonomous or assisted driving are very much related to connected cars, since the flow of information from the infrastructure and other surrounding cars is essential to provide a safe experience. Cellular communications such as LTE LTE-A provide a good access technology to support communications in the IM environment as analyzed for instance by Araniti et al. (2013). It is certain that 5G networks are a key enabler of a majority of the potential future automotive user applications, as discussed by Andrew et al. (2014) and Osseiran et al. (2014). However, one of the major challenges to be faced is the massive number of devices that are going to be constantly accessing the network. Given that mobility is the protagonist, enhanced mobility management solutions, in terms of handovers and device discovery for high capacity and low latency communications are required, as well as fast recovery processes after coverage loss.

According to what reported above, the main task of 5G in a smart city environment is thus to integrate the management of these very diverse services and devices in an efficient manner. The intrinsic heterogeneity in smart city environments requires quick reconfiguration of networks according to the current state of traffic, congestion or depending on the service being delivered. Based on the discussion given by Condoluci et al. (2015), general requirements of smart cities can be outlined as:

- **Scalability:** a large number of devices are expected to be connected simultaneously to the network. High loaded networks may impair some stringent QoS requirements, as for example low latency in mission critical MTC.
- **Easy integration and management:** this is necessary to provide seamless experience and efficient use of resources.
- **Overhead reduction in MTC.**
- **Security**: This comes from the fact that multiple tenants could share the same network and this could involve security threats.

Industry automation

Now that the Internet has arrived to everything, it is a natural evolution to remotely control the objects connected to the network. Remote control, as discussed by Simsek et al. (2016), is an application that can be particularized to many industries: remote control of heavy machineries, factory automation or real-time monitoring of industrial plants.

The IoT has provided powerful solutions to improve industrial systems and applications. In the past, industrial monitoring could be carried out with the use of wireless sensor networks (WSNs), which interconnected a number of intelligent sensors to perform sensing and monitoring. A comprehensive survey on WSNs is given by Al-Fuqaha et al. (2015). The evolution of WSNs has largely contributed to the development of IoT in mobile communications, and industrial applications nowadays include much more than monitoring and tracking. The main competitive trend in the manufacturing business is to evolve into intelligently connected production information systems that can operate beyond the factory premises, and in this context 5G communications represent the natural evolution to WSNs to support several applications enabling huge opportunities; this has been analyzed by Palattella et al. (2016) and 5G-PPP (2015a). The provisioning of these applications pushes the following requirements:

- **Time critical process optimization and control:** This requirements is necessary to support real-time optimization based on instantly received information from monitoring or interaction between different operators, and remote control of robotic operations.
- **Non-time critical communications:** This assures to provide applications such as non-critical localization of assets and goods, quality control and sensor data collection.
- **Remote control:** This is mainly required to support augmented reality applications to provide support in production and maintenance.
- **Seamless communications:** This is required to provide connectivity between different production sites and other parties inside the value chain.
- **Use of edge intelligence:** Integrate high processing in mobile edge computing clouds in order to cut delays and overhead.
- **Overhead reduction in MTC.**

Real-time cooperation and intervention requires a flexible and converged connectivity that provides seamless experience across multiple mediums, such as wired and fixed networks, multiple vendors, and multiple technologies. In this sense, 5G needs to provide a highly heterogeneous multi-connectivity scenario, where everything is capable of communicating, even in harsh industrial environments. Also it is necessary a fast, reliable and flexible reconfiguration of QoS and traffic demands, to enable fast adaptation to current needs. Examples can be the simultaneous management of applications involving high data transmission due to the use of wearable devices (for instance 3D video or augmented reality content) and applications involving low data transmitted by sensors. Many of these applications will involve massive MTC and mission critical MTC, being the latter more stringent in terms of network requirements: ultra-low latency and ultra-high reliability and availability are essential to provide these type of applications.

Entertainment: Content Delivery and Gaming

The media and entertainment business is experiencing the big changes, mainly because of the behavioral change of individuals, consumers now interact directly with the media and entertainment devices as presented by 5G-PPP (2016). On the other hand, the gaming industry with online games, with increased graphic resolution and simultaneous events happening among different active users involve high level of user real-time interaction, especially when considering the exploitation of enhanced gaming devices humans interact with (glasses, remote controllers, etc.). Gamers want as much realism as possible and also wish to have the most immersive experience while playing.

One of the main market drivers for enhancing both the entertainment and online digital game experience is the availability of high speed networks; both mobile and fixed internet, together with data centres and cloud computing, have contributed in large extend to the increase of more immersive experience demand. Also, the growing capabilities of the devices together with the innovative services provided by the different content generators have largely influenced in the user media and entertainment consumer behaviour.

The gaming industry's efforts are placed in enhancing gamer experience by adding virtual reality and the use of bio-sensing in order to allow the player to detect people in the game, in real or imaginary worlds. Also, motion capture is introduced to interact with objects surrounding, and realistic force feedback. Also, augmented reality, which is expected to revolutionize the gaming industry in general, because of the inherent realism, as it lets the gamer experience real world in tandem with the game played.

Some of the main technical challenges to deliver these new kind of entertaining services are centred in: data-rate, mobility, end to end latency, coverage and reliability. However, the main stringent requirements to provide full immersive experience are related to the augmented and virtual reality, which limits very much the allowed end to end. In general, 5G needs to provide the following features to content delivery and gaming use cases:

- **QoS guarantee:** Reliability, mobility, latency. Being the last a major requirement for augmented and virtual reality. For virtual reality and augmented reality 15ms to 7ms round trip time (RTT) is the threshold.
- **Security and confidentiality:** Identity management and identification of sources of content, to assure that only subscribers access the content.
- **Network support:** In the form of location tracking (like position accuracy), full integration with non-3GPP systems (radio and fixed), allow for network assisted direct device-to-device (D2D) communications.
- **Use of edge intelligence.**

Table 1. Features of 5G IoT verticals

	QoS guarantee	Security and Confidentiality	Network support	Scalability	Easy integration and management	Overhead reduction for MTC	Time critical communications	Non-time critical communications	Remote control	Seamless communications	Use of edge intelligence
Healthcare	✓	✓	✓								
Smart City				✓	✓	✓					
Industry automation						✓	✓	✓	✓	✓	✓
Entertainment	✓	✓	✓								✓

BUSINESS MODELS AND APPLICATIONS

The integration of healthcare, transport services or entertainment applications on one hand generate new business opportunities for network operators, and on the other hand pose strong requirements to the future 5G network. Making one single communications network, capable of delivering all services across multiple industries is challenging, since every use case or application will require different KPIs. On the other hand, the inclusion of these variety of services has enabled new business opportunities to telecom players, which are the ones in charge of providing added value to these new verticals. This Section provides an overview of the new market opportunities and business models for service providers.

Healthcare

Many mobile operators are active players in offering mobile health services and offer solutions beyond simple connectivity services: content-based wellness information services to consumers or sophisticated end-to-end solutions aimed at improving the efficiency of healthcare systems and workforce. Other players facilitate mobile telemedicine and health call-centres by enabling partnerships with healthcare providers; they also provide real-time connectivity for devices as well as managed services for monitoring vital body parameters of patients. According to the study done by GSMA (2012), mobile operators are expected to be the key beneficiaries of the expected growth in the mobile health market and command nearly 50% share of the overall market.

Other opportunities and business models in the healthcare industry are providing solutions in hospitals and at home, to deliver enhanced tele-healthcare services. According to the Office for Life Sciences (2015), the remote healthcare market has already started to merge with the mobile health apps market.

Disruptive changes could impact the current model of delivery for tele-care and tele-health, and tele-healthcare is likely to converge with mobile Health and connected home solutions. These models could go from mere connectivity provider to adding value by selling complete IoT solutions.

Automotive

The emerging technologies such as 5G and the evolution of complementary industries (such as digital players) have increased the number of potential services that can be offered as analyzed by GSMA (2012a). There has been a change of paradigm in the definition of the business roles between the different players of the automotive industry, but nearly all market analysts agree that there is a strong need for strategic partnerships, in particular cooperation between the telecom players and the car manufacturers. This cooperation enables to complement each other's needs: mobile technology is in great extent one of the main drivers of the change on the way people use cars nowadays and in the future.

Network operators in general play an instrumental role in the development of the connected car services in general. In particular, GSMA (2012a) presents a study on the opportunities of network operators in the connected car market, and highlights the core competencies the operators bring to the value chain:

- **Critical enablers:** billing is probably one of the big assets operators bring, and it is as well one critical enabler of the connected car services. Device management, controlling the upgrades or roaming information. Subscription management, added value such as information related to the location to enhance services.
- **Telematics Service Provider (TSP) platforms:** activate, maintain and upgrade services. TSPs are expected to gain 11.3% of the connected car market share, and many telecom companies are expanding their presence.
- **Data collection and analysis:** operators can handle big amounts of data that can be analysed to provide added value in services, such as traffic patterns based on mobile user position.
- **Cloud services for connected devices.**
- **Integration platforms for different service providers, content provision and access to infotainment services.**

In general, it is not only about the service but the added value it provides:

- **Infotainment services:** a number of operators around the globe are already offering content and storage services for in-car entertainment.
- **In-car wireless services:** provide wireless connectivity inside the car, and facilitate the M2M communication inside the car to collect data from sensors or allow to perform vehicle health records.
- **Connected car analytics:** meaning the collection of vehicle parameters, or driving coaching services for inexperienced drivers. This market opportunity requires collaboration agreements with the automotive industry.
- **Wearables:** such as safety switch for passenger.

Network operators have a key role as enablers of the fully immersive experience as explained by Pelletier (2016): to be able to support these innovations in the entertainment industry, connectivity providers need to ensure they can cope with the capacity and latency demands. Intelligent traffic management solutions, compression algorithms and investments in ultra low-latency, high-throughput networks will help networks to cope with the demands of VR content. Only such investments will enable most of the immersive applications to flourish, taking entertainment to a new level and opening up new revenue streams for content providers through cloud-based distribution on-demand.

Based on the findings by PwC (2014), entertainment companies have the largest opportunity for growth in the wearable technology market, there is a high number of applications available and very little companies have started to explore these applications. Overall, new business models for network operators need to be centred into adding value to the services provided, which means to collaborate closely with suppliers to ensure good end-to-end service quality that preserves a certain level of customer experience. In this line, the 5GPPP underlines that collaborative services imply the association of fixed and wireless as well as terrestrial and satellite network service providers to deliver services with common multiservice control layer and assured quality in contrast to competitive services that imply a form of competition between the involved network service providers as analyzed by 5G-PPP (2016).

Industry Automation

Changes in the new industry and business models will change the traditional manufacturing value chain. While traditional players: logistical partners, suppliers of parts, suppliers of sensors and actuators, and manufacturers themselves, are going to still be playing a major role in the industry business, new players that were not part of the traditional value chain will enter the scene: supplier of cyber-security, supplier of data storage and management, supplier of connectivity, supplier of specialized technology, and supplier of automation systems. Nowadays, as analyzed by McKinsey Digital (2015), the majority of players expect new competitors to enter the market: 84% of technology suppliers expect new competitors and 58% of manufacturers expect new competitors.

Telecommunications companies are going to have an instrumental role in this new industrial revolution. The study by McKinsey Digital (2015) recognizes that many of the disruptive technologies are driven by small, innovative companies that have specialized skills in a given field. Another important finding is that is likely to have an increasing emergence of highly specialized players especially in the telecoms area, providing solutions for data, connectivity and security. Furthermore, the study by McKinsey Digital (2015) shows that new business models are adding value around the whole connected items and collect, use and share data. Specifically, offering solutions around integration and new services, enabling manufacturing companies to capture this emerging value in the manufacturing industry. Business models particularly interesting for network operators are around providing technology platforms and data-driven business models.

From the discussions in this Section, it becomes clear the huge impact from a business point of view generated by the provisioning of IoT traffic in 5G systems. In the remainder of this Chapter, the focus will be on the network architecture of mobile systems, in order to investigate how it will possible to handle

IoT-related traffic. We will highlight the limitations of current systems in order to highlight why current mobile networks cannot handle the use cases reported above. Afterwards, we will introduce the key aspects to be considered in the design of 5G systems to handle IoT-oriented use cases and finally we will summarize the solutions currently under investigation to properly manage 5G IoT verticals.

OPPORTUNITIES FOR DELIVERY OF IOT THROUGH 5G

Currently deployed mobile architectures simply cannot handle the variety of requirements posed by 5G use cases. The 4G systems currently exploited, i.e., LTE and LTE-A, present several limitations to successfully implement the wide number of services being considered for the near future in the different industry verticals. In this Section, we briefly highlight the limitations of 4G mobile systems in order to better discuss later the requirements to be taken into account in the design of 5G systems when considering IoT-oriented verticals.

Deployment with 4G systems

Current mobile communications technologies do not offer the capabilities to easily incorporate a new variety use cases coming from the different industrial needs. From an architectural point of view, the design drivers of 4G systems (e.g., use of static deployment of vendor equipment, use of monolithic functionality at specific network locations) introduce different limitations to successfully support all the new verticals being considered for 5G.

The presence of proprietary black boxes limits the programmability of the network and thus its flexibility. An analysis of this limitation is given by Pentikousis et al. (2013). For instance, Bradai et al. (2015) highlight that elements in the 4G core network are controlled through standardized interfaces and cannot be controlled by APIs. The lack of programmability has a drawback in terms of the introduction of new services which are characterized by high deployment and operational costs (cellular operators have to replace existing equipment even if it is still sufficient for most purposes).

Another aspect underlined by Lee at al. (2013) is related to the configuration and the functionalities of control- and data-planes (C- and U-plane, respectively). In this case, the limitation is that some nodes are designed to provide both control- and data-plane functionalities; one example is the packet gateway (PGW) in 4Gsystems. This aspect introduces complexity and scalability issues as these nodes need to simultaneously manage both control- and data-plane messages. The scalability issue is exacerbated when considering that the PGW could represent the bottleneck of the mobile network. In more details, the PGW is in charge of establishing and managing the bearers that allow a device to be connected with the network: this means that all the traffic should pass through the PGW, even if the communication is between user equipments (UEs) attached to the same cell. This exposes the PGW to a huge amount of traffic to be managed and this could potentially cause overload and/or congestion.

Another issue is in terms of signaling traffic. According to Nokia Siemens Networks (2011), signaling is growing 50% faster than data traffic in LTE networks. The 4G core network, namely the evolved packet core (EPC), has a centralized control traffic management, i.e., the Mobility Management Entity (MME), which can reach a traffic volume in the C-plane of about 290,000 messages per second in networks with millions of users. As a consequence, scalability becomes an issue also when considering control-plane traffic. The aspect related to signaling needs to be further investigate when considering IoT-related traffic. Indeed, the maintenance of the user-plane in 4G networks may involve high signaling overhead and this limits the efficiency of the network. This also limits the support of IoT-related services which ask for low energy consumption (in order to save devices' battery) and signaling overhead (in order to cut the transmission/reception delays as well as to avoid unnecessary energy consumption).

Capabilities for 5G networks design

The capabilities to be considered in the design process of next-to-come 5G networks are derived according to the requirements of the verticals expected to be supported and by considering the limitation of 4G systems and should, potentially, be overcome with the deployment of 5G networks. This dictates for some disruptive architectural changes, which are summarized in the remained of this Section.

Nowadays the integration of new services or the change of network topology and architecture (i.e., distributed or centralized) requires the replacement or redistribution of hardware equipment as well as network functionalities. This aspect is particularly challenging for industrial-IoT environments, dictating the support of heterogeneous services to be provided on-demand and to be updated according to the needs of the deployment scenario. As a consequence, one key aspect for 5G systems in supporting IoT industry verticals is the introduction of *flexibility*, which can be achieved by means of the introduction of *programmability*, i.e., by allowing the network functionalities to be flexible. Programmability would directly facilitate the possibility to reconfigure the network. In addition, it would enable service-aware QoS (i.e., to dynamically provide QoS on demand according to the need of the supported verticals). Finally, programmability will allow the network to dynamically change the topology according to the network status (congestion, traffic demand) as well as the needs of the vertical to be provided. To this end, the new generation system architecture for mobile core needs to shift from the traditional hardware-based to software-based functions that can run in virtual environments. The introduction of softwarization (where network functions run on software instead of a dedicated hardware) and virtualization (where network functions run in virtual machines, VMs, and could be potentially moved across the network) in the core network allows to create and allocate dedicated functionalities depending on the application needs. This aspect will be treated in more details in the remainder of this Chapter.

As discussed above, complexity is one of the most limiting aspects of 4G systems. This becomes more evident when considering that, for instance, the role of the packet gateway (PGW) in 4G systems: this node represents the edge-node of 4G networks connecting 4G mobile users to external networks. The presence of the PGW as a data anchor point has the already discussed drawback of introducing *scalability* issues but it also reduces the possibility to deliver low-latency services. This underlines the fact that the complexity of 4G systems has a negative impact in the traffic across the network with consequent issues on the verticals that could be provided. When considering IoT-related verticals, many of these dictate the needs to support low latency services. This goal could be achieved by placing network entities or functions closer to the RAN. This has the following advantages: reduction of delays, reduction of the control overhead, higher scalability due to the presence of a higher number of anchor points closer to the devices instead of having one single (or few) anchor points for the whole network. An additional limitation for 4G systems is the centralized management of U/C-planes. This drastically affects the scalability of the network. As a consequence, a key capability to be added to 5G systems is related to the introduction of *distributed C/U-planes* which will allow the network to scale in a more effective way.

Another aspect to be considered is that the majority of the procedures in 4G systems are triggered by network entities rather than the user equipment (UE). This aspect is controversial when incorporating low-latency services (which are key services in the industrial IoT scenarios) as it adds a lot of complexity when performing active QoS management, based on instantaneous decision making (i.e., congestion, change of traffic prioritization, etc.). As the impossibility to provide instant QoS may seriously impair the ultra-high reliability requirement for 5G IoT verticals, *UE-triggered signaling* procedures should be designed in 5G systems. As seen in Section 2, not all the applications involve the same requirements. This feature could be used to the advantage of reducing the control-plane traffic in the design of 5G networks. For instance, mobility signalling can be dramatically reduced for devices considered to be stationary (this aspect is common to many IoT verticals, especially in industry automation and in remote surgery applications). By considering this aspect, the generation of signalling in the network could be optimized by considering the type of devices as well as the particular service needs. Hence, 5G needs to provide dedicated control signal procedures on a service basis.

In the remainder of this Chapter we will provide an insight on how the above mentioned capabilities are expected to be fulfilled in 5G systems.

SOLUTIONS ON THE ROAD TO 5G

The network solutions actually considered in the implementation of 5G systems are summarized in the remainder of this Section. Such solutions range from solutions to be applied to both core network and RAN segments from solutions to be considered only in one of these segments.

The core network represents the segment of the network which runs most of the functionalities of a cellular systems. The core network allows the devices to have a bi-directional connectivity towards other devices in the same or in external networks. From a core network point of view, 5G systems are expected to introduce disruptive changes aiming at overcoming the limitations in terms of scalability of 4G systems. In addition, such changes are expected to increase the level of flexibility of the network, which thus means having a flexible network able to support different vertical with heterogeneous features.

The RAN provides access points to the UEs by means of access procedures to allow devices to be synchronized with the network and to perform a connection request. In addition, the RAN handles the procedures relevant to the radio channel exploitation (resource assignment, power management, etc.).

From a RAN point of view, 5G systems are expected to introduce flexibility by means of having ad-hoc RAN functionalities designed to handle the specific requirements of the verticals to be supported.

In the remained of this Chapter, we will discuss from a technical point of view the novelties that are currently discussed to be introduced in 5G systems, with particular attention to those relevant to 5G IoT verticals.

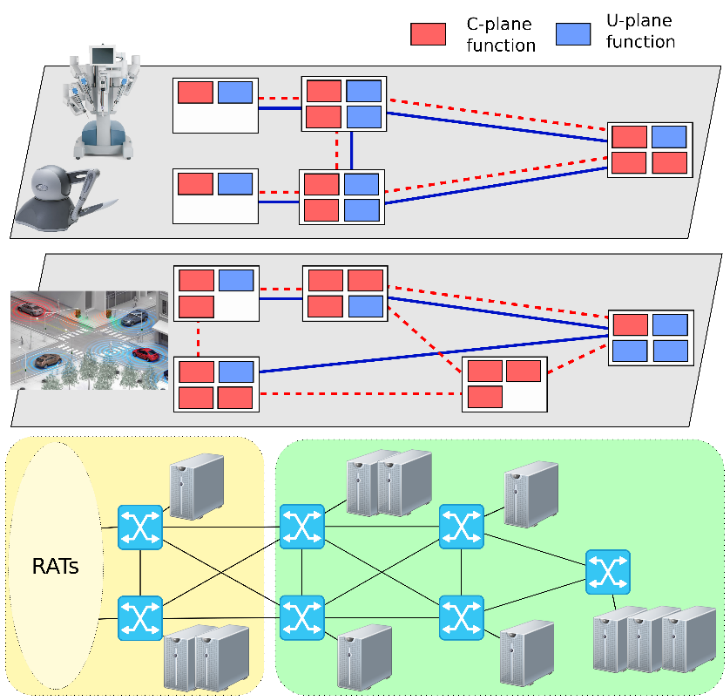

Figure 1. Example of 5G network slicing where two slices have a different configuration in terms of control and data paths and functionalities

Network slicing

In order to handle the requirements of different and heterogeneous verticals in a robust way, there is a need to isolate the different use cases from each other. These means that 5G systems need to handle in a different way different verticals, and this leads to the concept of network slicing. According to the Next Generation Mobile Networks (NGMN) alliance, network slicing primarily targets a partition of the core network, and it is the collection of 5G network functions that are efficiently combined to satisfy one specific business use case, and avoid all unnecessary functionalities. This brings a novel concept in the mobile core, i.e., having a different core network for each network slice to be supported as depicted in Fig. 1. Different examples of network slices tailored for different business cases can be in found in NGMN (2015).

All network slices would be different and independently configured. This basically means that a 5G IoT industry automation slices will have its own set of functionalities which could be potentially different from those required to handle a healthcare slice. One of the key elements of slicing is thus the isolation among the different services, which requires reservation of resources (in terms of link bandwidth as well as storage, memory and computation resources of data centers) in order to fulfill the QoS needs of the vertical to be supported. This involves the concept that 5G systems will dedicate separate resources to serve industry automation and healthcare slices. The isolation concept implements the philosophy of network slicing, i.e., having multiple independent core networks according to the number of different verticals to be provided.

Network slicing also means that that RAN functionalities could be different for each network slice. As a consequence, a network slice tailored for ultra-low latency IoT verticals will implement RAN functionalities allowing to cut delay on the radio interface (for instance, a shorter random access procedure) while a network slice tailored for ultra-reliable IoT verticals will implement RAN functionalities to increase the reliability of data/control packets transmissions (for instance, by pushing the base stations and the devices to exploit more robust modulation and coding schemes).

Virtualization and softwarization

The need of bringing the network slicing concept into 5G involves a novel concept in the mobile network ecosystem, i.e., the underlay network (i.e., links among network entities) needs to be re-configured and network functions need to be enabled on an on-demand basis according to the slices to be deployed. This has driven the use of virtualization and softwarization in 5G systems. As mentioned above, each vertical would have a different dedicated core network slice created for its own use; this underlines that network functions need to be configured in a way that ensures the QoS accomplishment of the slice/vertical to be provided. This has a set of impacts on the core network functions:

- **Network functions should be programmable:** The same function (e.g., mobility management) could be implemented in a different way according to the needs of the vertical (i.e., basic functionalities for a slice handling industry automation while very complex functionalities for a slice handling a smart city with IM services).
- **Network functions should be modular:** The network should offer a set of functions and, accordingly, different subsets of these functions can satisfy the needs of different verticals.
- **Network functions should be moved in the network according to the slices to be deployed:** This means that new network functions could be installed to deploy a novel slice to support a novel vertical. The slice needs (e.g., one network function could be moved from one data center to another of the core network if this would increase the QoS experienced by the users of the slice) should be further taken into account when moving network functions.

In order to handle the above mentioned features, slicing brings the concept of virtualization into the mobile core. This means that some of the 5G network functions could run in a virtual environment (i.e., virtual machines, VMs) instead of dedicated hardware, and this introduces the possibility to move functionalities across the mobile core. Network function virtualization (NFV) is thus a paradigm at the basis in the design of 5G core, as it will allow the dynamic deployment of virtual network functions (VNFs) or service function chains (SFCs, i.e., a set of VNFs to be executed in a specific order). As a network slice can be seen as one or multiple SFCs, NFV will introduce the possibility to handle the creation of networks slices as well as to manage their deployment in the physical infrastructure. A survey on the features and capabilities of NFV is given by Li, Y., & Chen, M. (2015), while the role of NFV in 5G systems is analyzed by Abdelwahab et al. (2015).

Altogether with virtualization, softwarization is another key concept to introduce network slicing in 5G systems. An example of softwarization is Software Defined Networking (SDN), a paradigm where network functions (such as path computation) run in software and a managed in a logical central authority referred to as SDN controller. With SDN, the controller is in charge of managing the network entities (i.e., switches) and the related links by defining paths and rules in order to adapt the network topology and the link capabilities according to the need of the provider. SDN thus introduces flexibility in the network management and allows a monitoring and reconfiguration of the network itself. As a consequence, SDN increases the level of flexibility of 5G networks by providing an effective way of installing the paths requested by NFV for the SFCs of a specific slice. In addition, SDN can provide isolation for network slices by means of path separation or traffic isolation (with meters and/or queues) to avoid that the traffic of one slice would affect the performance of another slice. A survey on SDN is given by Kreutz et al. (2015), while the role of SDN in mobile systems is analyzed by Chen et al. (2015). An example which highlights the flexibility of 5G network architecture based on virtualization and softwarisation is depicted in Fig. 2.

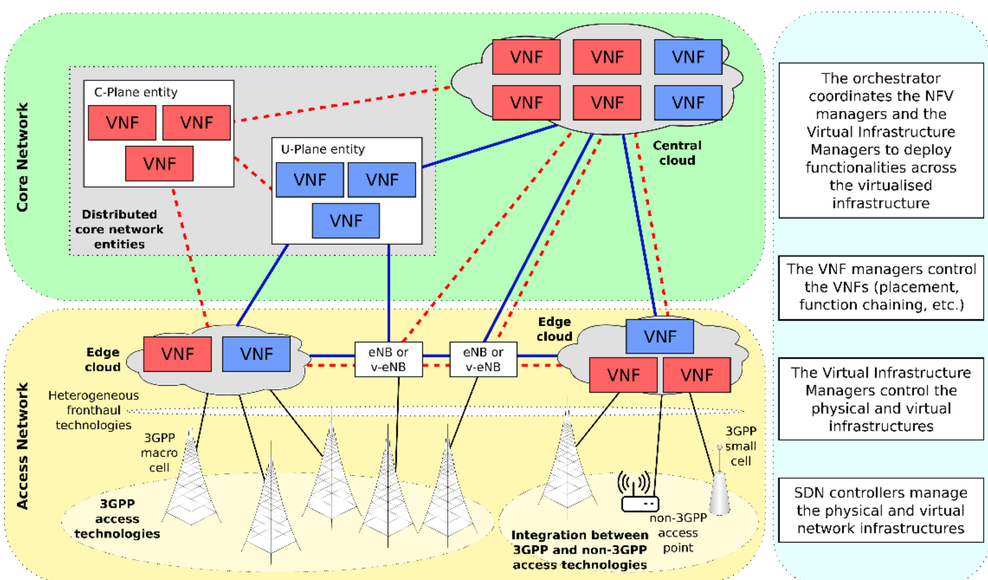

Figure 2. 5G network architecture enhanced by virtualization and softwarization

Device multi-connectivity

The wide range of services being provided is changing the paradigm of cellular networks, and concepts as common as cells are no longer relevant. In fact, 5G is evolving to a multi-connectivity approach. In a 3GPP perspective, multi-connectivity can be seen as a device sharing resources or more than one BS. 3GPP has been already introduced in Rel. 12 (please, refer to 3GPP, 2012) the concept of dual connectivity, where one UE will receive information from two separate BSs. In the 4G architecture, the management of this dual connectivity is carried through non ideal backhaul links; in this sense, virtual RANs that coordinate a cluster of antennas can reduce the reliance on this backhaul interface.

Inside the umbrella of multi-connectivity, it is also possible to add full flexibility in the cell association process. Having separate cell associations for UL and DL, a.k.a. downlink and uplink decoupling (DUDe), is a topic that has been covered by the literature lately by Boccardi et al. (2016). This concept, depicted in Fig. 3, brings also to the possibility of having a multi-connectivity feature for the device in terms of U/C-planes, as analyzed by Mohamed et al. (2016).

Supporting this solution while maximizing the capacity in 5G systems would require at least a shared medium access control (MAC) layer among both serving cells, since Layer 2 control information needs to be forwarded from one serving cell to another (i.e., hybrid automatic repeat request, i.e., HARQ, protocol acknowledgements). 4G systems actually rely on a logical interface, namely the X2 interface, which directly inter-connects the base stations. The current X2 interface among serving cells is not able to provide the required round trip time figures due to the fact that this is a logical interface and most of the times a direct physical interconnection among cells is not available. As well, Layer 3 RRC ought to be centralised and shared among both serving cells, since parallel radio resource control (RRC) connections would add too much complexity in the UE side. Further analysis are provided by ZTE Corporation (2013). Virtualization and softwarization could help to migrate MAC/RRC entities among the cells involved in the DUDe communications.

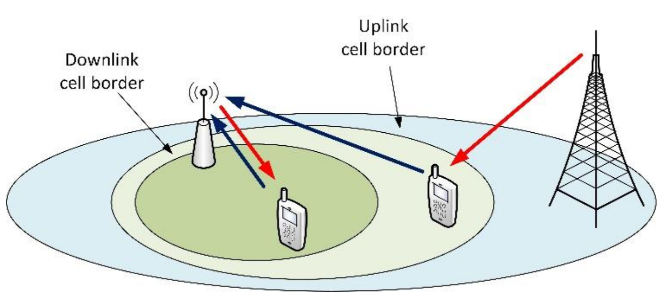

Figure 3. System model for uplink/downlink decoupling

Solutions for supporting MTC traffic

MTC traffic is characterized by the infrequent/frequent transmission of small data packets sent/received by devices which should save as much as possible energy. The effective support of MTC traffic is thus demanding new solutions in RAN to increase the efficiency of data transmissions from this particular type of terminals in order to reduce power consumption and latency. The following solutions are considered to achieve this goal:

- **Ad-hoc network access procedure for transmission of small amount of data.** An example is to dedicate a portion of radio resources in the uplink to a group of MTC devices to transmit their data in a contention manner without establishing a link in advance. The small data bursts can be carried either by implementing predetermined preambles dedicated to this purpose, or by sending the data load in the initial uplink resource allocated for RRC connection requests. However, sending the data along with RRC connection requests has security implications.
- **Data aggregation to improve the efficiency of data transmissions.** Data or signaling message aggregation may occur at different locations in the network (e.g. MTC device, MTC gateway, base station, or serving gateway, SGW). Intuitively, this incurs some additional delays and is only applicable to non delay-sensitive MTC applications.

In addition to the above mentioned solutions, there is a consensus in the need for a new radio access interface designed ad-hoc by considering the features of MTC traffic. In this direction, Narrow-Band IOT (NB-IoT) is a technology being standardized by the 3GPP standards body. This technology is a narrowband radio technology specially designed for IoT devices, with particular attention in handling massive MTC access of devices with delay tolerant requirements (e.g., metering, non-critical sensing). The features of this technology are discussed by Gozalvez (2016), and are here summarized:

- **Indoor coverage:** Enhanced coverage is important in many IoT applications. Simple examples are smart meters, which are often in basements of buildings behind concrete walls. Industrial applications such as elevators or conveyor belts can also be located deep indoors. NB-IoT provides 20dB additional link budget enabling about ten times better area coverage. The coverage enhancement can be achieved using a combination of techniques including power boosting of data and reference signals, repetition/retransmission and relaxing performance requirements (e.g. by allowing longer acquisition time or higher error rate).
- **Low cost:** The current industry target is for a module cost of less than 5 USD. To enable a positive business case for cellular IoT the total cost of ownership (TCO) including the device must be extremely low. To this aim, NB-IoT is designed to operate with a reduced bandwidth of 200 kHz in downlink and uplink. This, together with low-level modulation and coding schemes, means a reduced throughput based on single resource block operation with consequent lower processing and less memory on the modules compared to other cellular technologies. In addition, by considering that NB-IoT can be deployed in both GSM and LTE frequencies, this lowers the cost of deploying the NB-IoT technology by cutting the spectrum cost from an operator point of view.
- **Long battery life.** The industry target is a minimum of 10 years of battery operation for simple daily connectivity of small packages. NB-IoT implements a device power saving mode (PSM) to significantly improve device battery life. A device that supports PSM will request a network for a certain active timer value during the attach or tracking area update (TAU) procedure. The active

timer value during the attach or tracking area update (TAU) procedure. The active timer determines how long the device remains reachable (by checking for paging according to the regular discontinuous reception, DRX, cycle) for mobile terminated transaction upon transition from connected to idle mode. The device starts the active timer when it moves from connected to idle mode. When the active timer expires, the device moves to power saving mode. In power saving mode, the device is not reachable as it does not check for paging, but it is still registered with the network. The device remains in PSM until a mobile originated transaction (e.g. periodic TAU, uplink data transmission) requires it to initiate any procedure towards the network. By exploiting the above mentioned features, NB-IoT aims to achieve up to 36 years of battery with a daily update of 200 bytes. In reality, taking into account leakage current and battery self discharge, a battery option of 10 years is more realistic.

- **Large number of devices.** IoT connectivity is growing significantly faster than normal mobile broadband connections and by 2025 there will be seven billion connected devices over cellular IoT networks. This is equivalent to the current number of global cellular subscriptions. The target for NB-IoT is to handle up to 200,000 devices per cell.

Centralized/cloud RAN

The centralized/cloud RAN (C-RAN) is a new architecture for mobile access networks where all the processing of the base station is transferred to a central location. The C-RAN has been conceived to split the base station in two different components: the radio function unit, namely the remote radio head (RRH) which performs the physical transmission/reception of the signals over the radio interface, is separated from the digital function unit, a.k.a. base band unit (BBU). The link between the RRHs and the relevant BBU is the generic named as fronthaul, which can be either an optical fibre or a wireless link carrying digitized representations of the baseband data ready for transmission in the RAN. As multiple RRHs can be controlled by one single BBU, this entity has a global overview of the status of all the controlled RRHs and can therefore optimize the radio spectrum exploitation by means of reducing the radio interference and maximizing the spectral efficiency. The C-RAN features are analyzed for instance by Checko et al. (2015).

When considering C-RAN deployments in 5G systems enhanced by virtualization and softwarization, this will therefore involve that the BS's functionalities are softwarized in VMs. Thus, the virtualization enables elastic resource utilization in the cloud that allows a more efficient balancing of processing resources under the fluctuation of capacity demands. The role of virtualization and softwarization is discussed in more details by Dawson et al. (2014) and Pompili et al. (2016). An example of a C-RAN with enhanced functionalities can be found in Fig. 4. Advantages of the C-RAN with virtualization of BS functions can be summarized in terms of:

- Add potential for neutral host solutions (i.e., RAN sharing).
- Co-location of CN and RAN functionalities, which could enable low latency interconnection between RAN and core.
- Integrate a RAN service manager that can dynamically switch between RRHs and BBUs based on QoS and instantaneous network states.
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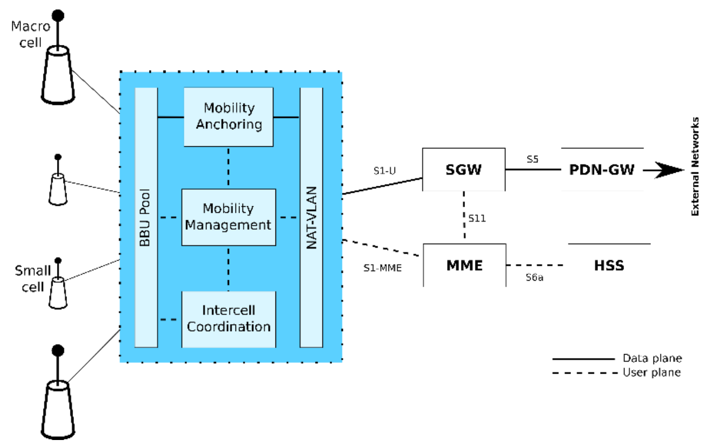

Figure 4. Example of a C-RAN enhanced by softwarisation and virtualization as proposed by Dawson et al. (2014)

The design and the deployment of a software-based virtualized C-RAN architecture are still under investigation. The related challenges have been investigated in by Arslan et al. (2015), and are now summarized here:

- **Latency:** The main task of the fronthaul network is to deliver highly delay-sensitive signals to the RRHs. If we consider the LTE frame, novel signals need to be delivered to the RRHs every 1ms (i.e., the LTE's subframe duration); this becomes more challenging in 5G deployments expected to operate also with shorter subframes. This introduces latency challenges in the fronthaul network, especially in terms of switching procedures.
- **Communication protocol:** C-RANs are still evolving and there is no consensus on open APIs to send\receive data to\from the RRHs. An admissible trend should be the exploitation of protocols such as the Common Public Radio Interface (CPRI), commonly used to carry signals between the indoor and outdoor units of traditional base stations and tailored to be extended for the fronthaul network. However, integrating such protocols with switch operations and catering to low latencies is still a big challenge to be adequately investigated.
- **Heterogeneity**: This challenge is due to the fact that the fronthaul interfaces may be composed of a mix of fiber, wireless, and copper links. This thus introduces the need of efficient integration strategies using the bandwidth from the available forms of physical fronthaul to support the logical configurations made by the controller.
- **Reliability and stability**: Reliability is an important requirement for network operators as they need to guarantee the service reliability and service level agreements; this should not be affected when considering SND/NFV deployments. The challenges deal with the fact that the flexibility of service provisioning may require the consolidation and migration of VNFs according to the traffic load as well as the user demand and this may involve reliability degradations.

CONCLUSION

This Chapter focused on the support of industry verticals over the next-to-come 5G systems by analyzing the business opportunities that the provisioning of IoT applications opens for telco operators. This Chapter highlighted the main features of IoT verticals with particular attention on healthcare, smart cities, industry automation and entertainment business cases. As the proper management of these IoT verticals pushes additional requirements to be considered in the design of 5G systems, this Chapter analyzed the capabilities to be introduced in 5G networks from an architectural and a procedural point of view. Finally, this Chapter presented the recent advances to handle the requirements that IoT vertical push on 5G systems by considering the enhancements currently under investigation from both a core network and a RAN point of view.

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KEY TERMS AND DEFINITIONS

5G: The next-to-come fifth generation of mobile networks expected to be standardized by 2020.

HTC: The human-type communications (HTC) traffic is the traffic that humans exchange over mobile networks characterized by asynchronous large packets with non-critical delay constraints.

IoT: The Internet of Things (IoT) is the network composed of devices with sensing or actuators capabilities which are connected to each other to enable these objects to collect and exchange data.

MTC: The machine-type communications (MTC) traffic is the traffic that machines send/receive to/from mobile networks characterized by periodic/a-periodic small packets with both critical or non-critical time constraints.

Network slicing: It is a design paradigm of 5G systems based on the concept of having multiple logically independent network designed and deployed in order to satisfy the requirements of the service to be provided.

NFV: Network Function Virtualization (NFV) is a paradigm where network functions run in software in a virtual environment instead of running on a physical machine.

SDN: Software Defined Networking (SDN) is a paradigm where network entities (such as switches) are instructed by a central controller which runs in software network functionalities such as path computation and link configuration.

QoS: The Quality of Service (QoS) describes the set of features that a specific traffic flow should receive in terms of data rates, delay, packet losses, priority, etc.