5G Americas White Paper

5G NETWORK TRANSFORMATION

December 2017

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The evolution of the 5G New Radio and Next Generation Core is a major driver for innovation. By introducing three new improved characteristics - low latency, distribution, and through-put - new business opportunities are able to be addressed. 3GPP is the main standards body where 5G is being addressed with Release 15 with expected completion in May of 2018. As standards evolve, 5G technology will transform networks and operations in new ways. Network Function Virtualization Infrastructure (NFVI) is one area in which technology and operational models will change.

Automation and orchestration will transform how networks of the future are built and operated. Network transformation will happen through large scale adoption of Network Functions Virtualization (NFV), orchestration of network services, and automated network management. Artificial intelligence, machine learning, and adoption of new 5G technologies will transform network operation models and business economics leading to the creation of widely distributed, highly dense, high bandwidth mobile networks. Use cases like immersive Augmented Reality / Virtual Reality (AR/VR) and Autonomous Driving can change how humans consume and interact with technology. These new use cases and other emerging use cases will alter consumption patterns and lead to the creation of new services and new revenue opportunities for carriers.

In this paper, some of the emerging use cases, standardization, architecture and technology advancements with the fifth generation of mobile networks are explained.

1. INTRODUCTION

If a common sentiment from 5G can be distilled, it's that 5G will be an innovation engine, bringing disruptive change across industries and society. Worldwide mobile subscriptions now total around 7.4 billion; by 2021, the number will grow to 9 billion. IoT devices with cellular subscriptions will leap from 400 million today to 1.5 billion by 2021.[1] 5G will accelerate this transformation and create new use cases, new revenue streams, and new business models for industries and consumers. Industries will benefit from 5G by connecting physical world devices to the internet in order to create innovative products or services, provide a better customer experience, increase efficiency, and/or improve safety. With 5G, industries will have connectivity that is customized for their requirements and the agility to move quickly to meet customer needs.

5G, being the next generation mobile networking standard, brings several new components. Two of the most important features are low latency (< 10ms) and high through-put (Multi-Gbps). Using these new enhancements, operators will be able to address the market by addressing new use cases. 5G enhances the use cases that LTE is able to minimally address today, and brings new revenue streams to operators by leveraging new solutions that LTE was not able to serve. 3GPP Release 15 defines 5G and is expected to be completed by mid- 2018. In preparation for the launch of 5G over the years to come, operators have many tasks to accomplish for 5G technology transformation.

When reviewing the life cycle of the wireless telecommunications industry, technology leaps have occurred roughly every 5-10 years for the past three decades. Since LTE's first deployment in 2010, LTE has been the most rapidly deployed wireless technology. There have been many advancements in LTE (for example. LTE-Advanced) and yet the industry is striving for another leap to 5G by 2020. Because LTE is so widely adopted and successfully deployed, many features targeted for 5G will actually debut on LTE networks.

[1] Ericsson Mobility report. Nov 2016

The network architecture for 4G is connection-oriented and based on centralized mobility anchor points. With the exploding demand indicated in the Use Case Requirements section, it is clear that the LTE architecture will be unable to satisfy the scalability, latency, or overall experience required in future networks. Fortunately, there is momentum and innovation in the industry toward meeting the requirements of 5G use cases. The new 5G architecture brings improved radio units with a much faster air interface when compared to LTE and a new Service Based Architecture for the Core.

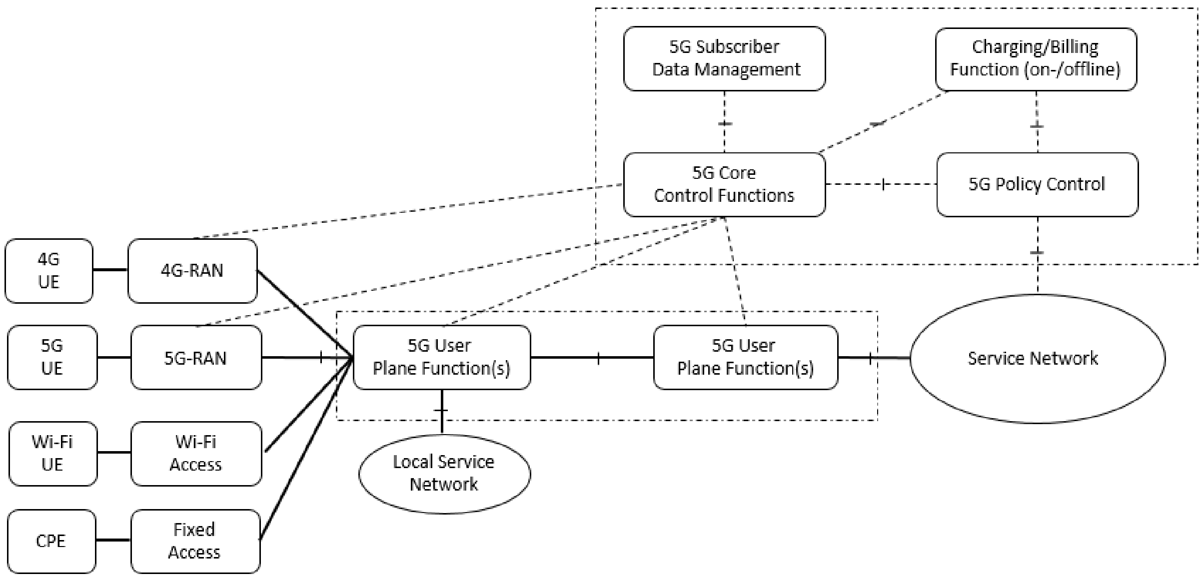

Figure 1. 5G Converged Architecture.

5G promises ubiquitous wireless coverage. Radios leveraging licensed and/or unlicensed spectrum, small cells, macro LTE eNodeBs, fiber, microwave, leased Ethernet, or satellite backhaul will be considered when offering services. Given the service performance requirements, it is possible that not all services will be available in all areas of ubiquitous coverage. It will be essential to maintain continuity, as devices change locations and move between different types of networks.

Figure 1 indicates how functions will be involved in providing network services. Each service will have certain characteristics, such as QoS or Mobility. These services can be assigned to dedicated and/or shared network slices. Each network slice will be realized by creating one or more virtual networks, each of them with certain performance characteristics. User-subscribed services will be mapped to the slices. With the potentially infinite number of network slices that will be needed, a strong Network Function Virtualization Infrastructure (NFVI) will be necessary. Orchestration, Analytics, and automation will play a key role in transforming a network to support and run the 5G network.

The revolution towards the 5G innovation engine is well underway. In following sections, the technology and transformation required to leverage 5G is explained.

2. USE CASES

With the prospect of universal availability of instantaneous communications, a high level of guaranteed QoS, and lower cost points, 5G is looking to pave the way for new use cases and new business opportunities. 5G architecture is expected to accommodate a wide range of use cases with requirements providing a wide range of capabilities in terms of latency, coverage, bandwidth and robustness.

5G is also expected to meet another important challenge; it will provide an end-to-end network and cloud infrastructure using network slicing making it possible to meet the various requirements of a diverse set of use cases.

Numerous use cases with a wide variety of applications are on the rise with a highly varied range of performance attributes such as mobility, data speed, latency and reliability. The supporting user data rates could range from a few kbps for some IoT devices where power consumption will be extremely low, to multiple Gigabits per second used by Augmented Reality and Virtual Reality (AR/VR) or high quality multi-media applications. Mobility supported by the use cases could range from fixed wireless high capacity, high data rate applications to high velocity trains or aircraft at speeds of 500 mph.

Ultra-low latency, in the order of 0.5 ms, is needed to enable real-time applications like industrial automation and is very different from smart home applications that may be more delay tolerant. Reliability is critical for remote surgery and health care monitoring, but may be less so for some remote sensors and meters in smart cities. A wide variety of use cases are considered and chronicled as part of forming the basic requirements for 5G in multiple studies.

1. *5G Use Case and Services,* White Paper by 5G Americas, 29 November 2017[2]
2. *NGMN 5G White Paper*, NGMN, 17 February 2015[3]
3. *The 5G Business Potential*, Ericsson, February 2017[4]
4. *5G Use Cases and Requirements* White Paper by Nokia, April 27[5]
5. *5G Use Cases*, presentation by Ericsson, 2015[6]

In the following sections, the emerging key use cases and categories that will be supported by 5G are summarized.

2.1 USE CASE CATEGORIES

The following is a general and well accepted grouping of use cases that will be supported by 5G:

1. Enhanced Mobile Broadband
2. Connected Vehicles
3. Enhanced Multi-Media
4. The Massive Internet of Things
5. Ultra-Reliable Low Latency Applications
6. Fixed Wireless Access (Early 5G Deployments)

[2] http://www.5gamericas.org/files/3215/1190/8811/5G_Services_and_Use_Cases.pdf
[3] https://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2015/NGMN_5G_White_Paper_V1_0.pdf
[4] https://www.ericsson.com/en/events/mwcs-2017/5g-business-potential
[5] https://resources.ext.nokia.com/asset/201152
[6] https://www.ericsson.com/assets/local/news/2015/7/5g-use-cases.pdf

2.1.1 ENHANCED MOBILE BROADBAND

Enhanced Mobile Broadband (eMBB) is characterized by broadband data access in specific locations such as crowded spaces or office areas, across a wide coverage area, or in a high-speed public transport system. It provides maximum user experience with connectivity both indoors and outdoors while delivering high QoS broadband even in challenging network conditions. Multi-user interaction, Augmented Reality and Context Recognition are essential features for this category of use cases. Several sub-use cases in this category are:

- **Hot Spots – Broadband Access in Dense Areas**
    - This use case relates to providing high enhanced broadband access in densely populated areas such as high-rise building complexes, urban city centers, crowded areas, and etcetera
- **General Broadband Everywhere**
    - This use case relates to providing a consistent user experience, guaranteeing improved user speeds of estimated 50+ Mbps everywhere towards a mobile and a connected society. The user data has to be delivered consistently across the coverage area
- **Public Transport**
    - Public transport is about providing broadband access in public transport systems such as high-speed trains. The use case consists of providing robust communication link and high quality mobile internet for information, entertainment, interaction or work
- **Smart Offices**
    - This use case in characterized by heavy data use in an Indoor Environment. Hundreds of users require ultra-high bandwidth to serve intense bandwidth applications. Low latency served by a distributed user plane could also be leveraged in this scenario
- **Specific Events**
    - This use case requires providing very high connection density in scenarios such as in Stadiums, concerts and Large Gatherings where several hundred thousand users are served at high data rates with low latency. This would bring the ability to serve content such as instant replays or 360 degrees viewing to all users

2.1.2 CONNECTED VEHICLES

The category of use cases for mobile communications related to Connected Vehicles is going to be an important driver for 5G. This category of use cases entails supporting advanced safety applications mitigating road accidents, improving traffic efficiency, smoother traffic for emergency vehicles. These applications require a concerted framework with features supporting ultra-low latency for warning signals, higher data rate to share video information between vehicles and infrastructure, high mobility, high reliability and scalability features. The following are the key communication framework and use cases that need to be established for Vehicle to Everything Communications (V2X):

- The V2X communication encompasses data exchange between vehicles and other infrastructure to improve road safety and increase traffic. V2X communications as defined in 3GPP consists of four types: V2V, V2I, V2N and V2P
- V2V and V2P communications are essentially between vehicles or between vehicles and vulnerable road users (for example, pedestrian, cyclist) to provide information about location, velocity and direction to avoid accidents
- V2I transmission is between a vehicle and a road side unit (RSU). V2N transmission is between a vehicle and a V2X application server. An RSU is used to extend the range of a

V2X message received from a vehicle by acting as a forwarding node. V2I includes communications between vehicles and traffic control devices in the road vicinity

2.1.3 ENHANCED MULTI-MEDIA

This category of use cases is targeted towards providing high quality media everywhere to meet the growing demands of consumer media consumption. The targeted users are regular consumers of media, pay TV operators, broadcasters, new content owners, aggregators, and OTT providers. These use cases aim to provide high quality video anywhere and meet all TV consumer demands. Recent developments of 4K, 8K 3D Videos, expanded use of HD TV, streaming audio and video services, and interactive video on the go over growing number of devices, are key driving factors for this family of use cases. The enhanced data capacity, the high data rates and the enhanced broadcast/multicast features will essentially serve these use cases aiming to provide TV for in-home screens and realize the media vision for mobile TV. Some of the Enhanced Multi-Media use cases are as follows:

Broadcast Services
These services distribute real time and non-real-time content, are typically heavy on the downlink, and provide a feedback channel for interactive services in wide distributed areas. Sub-use cases consist of:

- Delivering news and information in audio and video everywhere to customers in all geographic areas
- Delivering local services within 1 to 20 kms that includes scenarios such stadium events, advertisements, fairs, conventions and emergency services
- Delivering services in a larger distribution within 1 to 100 kms that includes scenarios such as communicating traffic jams, disaster emergency warnings, and jetcetera
- Delivering services at a national level, complimentary to broadcast radio or television, providing benefits for the automotive industry

On Demand and Live TV
This use case is based on scaled-up content delivery on live TV or on demand providing high quality video using enhanced data capacity and data rates.

Mobile TV
Entertainment and video streaming on smart phones, tablets and other devices in high mobility environments such as trains, cars and airplanes defines this use case.

2.1.4 MASSIVE INTERNET OF THINGS

The category of use cases in Massive Internet of Things essentially addresses the emerging Low Power Wide Area (LPWA) needs for low cost devices, extended coverage and long battery life. The use cases in the category of massive Internet of Things are expected to make up a large part of the new types of services and use cases that 5G systems will address. This category consists of growing use cases with a massive number of devices such as sensors, actuator, cameras, and etcetera.

This family of use cases are expected to be pervasive in urban, sub-urban and rural areas providing metering, city or building lights management, environment monitoring (pollution, temperature, noise, etcetera), and traffic control, among many other applications. The combined number of these services is expected to require supporting a very high density of devices with different characteristics in a common communication framework. Massive IoT covers a wide spectrum of use cases across many industries and societies, as shown in Figure 2.

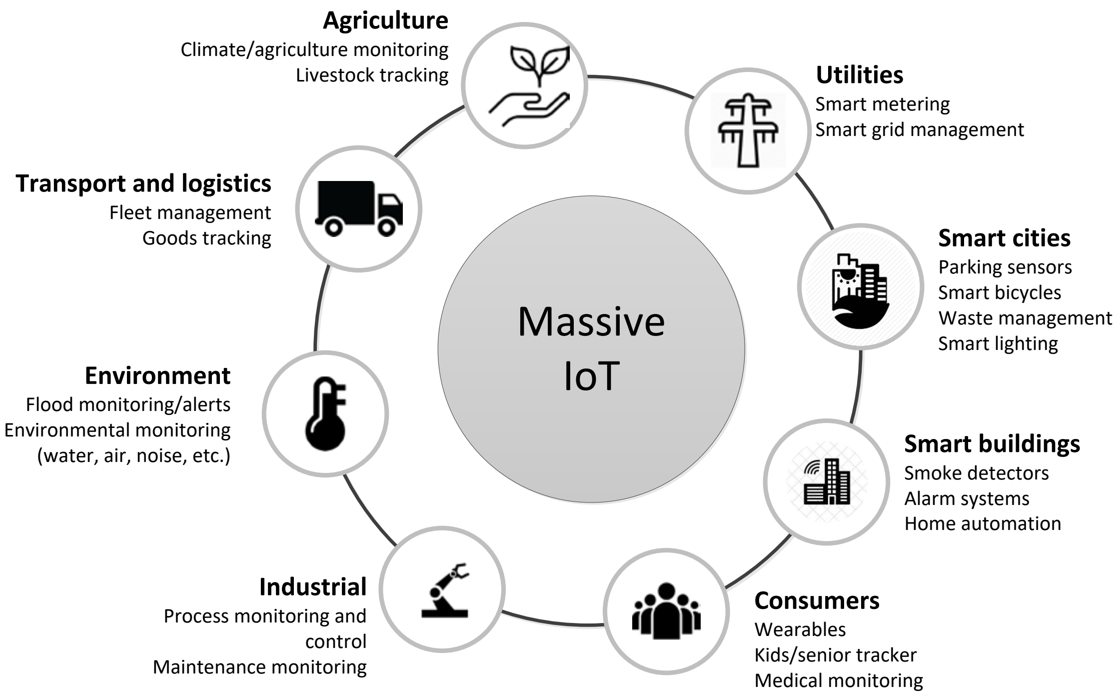

Figure 2: Massive IoT Verticals Enabled by 5G Technologies[7]

2.1.5 ULTRA RELIABLE LOW LATENCY APPLICATIONS

These set of use cases are the Critical IoT applications that will have very high demands on reliability, availability and extremely low latency where the volumes are typically much smaller, but the business value is significantly higher. As listed in table 1, the latency range for these type of use cases ranges from .5 milliseconds to 5 milliseconds. These use cases also fall into the category of mission-critical machine type communication use. The mission-critical MTC is envisioned to enable real-time control and automation of dynamic processes in various fields, such as industrial process automation and manufacturing, energy distribution, intelligent transport systems. These applications and use cases requires communication with very high reliability and availability, as well as very low end-to-end latency going down to millisecond level.

Process Automation

- These use cases are centered on information integration enabling process automation useful in oil and gas, chemicals, energy and water industries. The application here covers pumps, compressors, mixers, monitors of temperature, pressure, flow and etcetera.[8]

[7] https://www.ericsson.com/assets/local/publications/white-papers/wp_iot.pdf
[8] ARC Advisory Group

Automated Factories

- These use cases involve communication transfers enabling time-critical factory automation that are required in many industries across a wide spectrum that includes metals, semiconductor, pharmaceuticals, electrical assembly, food and beverage etc. Applications for these use cases fall into functions related to material handling, filing, labeling, palletizing, packaging, welding, stamping, cutting, metal forming, soldering, sorting, printing presses, web drawing, picking and placing, and etcetera.

Tactile Interaction

- These use cases involve interaction between humans and systems where humans wirelessly control real and virtual objects and the interactions require a tactile control signal, and audio or visual feedback. Robotic controls and interactions include several scenarios where most applications are found in manufacturing, remote medical care and autonomous cars. These tactile interactions require real-time reactions in the order of sub-milliseconds.

Emergency, Disasters and Public Safety

- These use cases require robust and reliable communications in case of natural disasters such as earthquakes, tsunamis, floods, hurricanes, etcetera. These use cases may require accurate location identification and quick communication exchanges between users and systems. Energy efficiency in user battery consumption and network communications are critical for these use cases. Public safety organizations require enhanced and secured communications. Public safety use cases include requirements like real time video and the ability to send high quality pictures.

Urgent Health Care/ Remote Surgery

- These use cases are envisioned around applications that will conduct remote treatment. Applications include monitoring and surveillance of patients remotely and communications with devices such as ECG, pulse, blood glucose, blood pressure, and temperature monitors. These critical remote patient treatments and heath care responses, based on monitored data, can be immediate, automatic, or semi-automatic. Remote surgery applications in a mobile scenario in ambulances, in disaster situations, and in remote areas require providing precise control and feedback communication mechanisms. Latency, reliability and security of these messages are critical for remote medical health professionals.

2.1.6 FIXED WIRELESS ACCESS

Fixed Wireless Access could be one of the first use cases to be addressed in early 5G deployments. The combination of fiber and 5G will be part of the same network in the future. This use case is an important application of the enhanced broadband features of 5G. Fixed networks with 5G are expected to complement fiber to provide very high-speed data rates. Fixed wireless use cases using 5G are geared towards mass-market distribution of on-demand high bandwidth content.

2.2 USE CASE REQUIREMENTS

The specific requirements for different use cases can be significant depending on the service being delivered. Listed in Table 1 are some early estimations on 5G use case requirements.

Table 1. Use Case Requirements.

Use Case	User Data Rate	Latency	Mobility
Hotspots: Broadband Access in Dense Areas	DL: 300 Mbps –500 Mbps UL: 50 Mbps – 100 Mbps	10 ms	0 – 120 km/h
Broadband Everywhere	DL: 25– 50 Mbps UL: 10 – 25 Mbps	10 ms	0 – 120 km/h
Homes and Offices	DL: 1 Gbps – 5 Gbps UL: 100 - 500 Mbps	10 ms	Pedestrian
Public Transport, MBB in Cars, High Speed Trains	DL: 25 – 50 Mbps UL: 10 – 25 Mbps	10 ms	Up to 500 kmph
Broadband Access in Events & Large Gatherings	DL: 10 - 25 Mbps UL: 25 - 50 Mbps	10 ms	Pedestrian
Connected Vehicles: V2V	DL: 1 - 5 Mbps UL: 1 - 5 Mbps	1 ms	0 – 160 km/h
Connected Vehicles: V2I	DL: 1 - 5 Mbps UL: 1 - 5 Mbps	5 ms	0 – 160 km/h
Connected Vehicles: V2P	DL: 1 - 5 Mbps UL: 100 kbps - 1 Mbps	1 ms	0 – 160 km/h
Moving Hotspots	DL: 10 - 50 Mbps UL: 5 - 25 Mbps	10 ms	0 – 160 km/h
Enhanced Multi-Media: Live TV	DL: 50 - 200 Mbps UL: 500 kbps	10-50 ms	0 – 8 km/h
Enhanced Multi-Media: On Demand	DL: 50 - 200 Mbps UL: 500 kbps	10-50 ms	0 – 80 km/h
Enhanced Multi-Media: Mobile TV	DL: 10 - 50 Mbps UL: 500 kbps	10-50 ms	250 – 500 km/h
Massive IoT: Sensor Networks (Connected	DL: 1 – 100 kbps	50 ms - hours	0 – 500 km/h

Roads, Railways, Buildings, Smart Cities, Parking, Lighting, Environment Monitoring)	UL: 1 – 100 kbps		
Massive IoT: Smart Grid/Utilities	DL: 1– 100 kbps UL: 1 – 100 kbps	50 ms - hours	Pedestrian
Massive IoT: Wearables	DL: 100 kbps - 5 Mbps UL: 100 kbps – 5 Mbps	1 - 5 ms	0 – 120 km/h
Massive IoT: Agriculture	DL: 1 – 100 kbps UL: 1 – 100 kbps	1 - 5 ms	Pedestrian
Industry Process Automation	DL: 100 kbps - 10 Mbps UL: 100 kbps – 10 Mbps	0.5 – 1 ms	Pedestrian
Automated Factories	DL: 100 kbps – 10 Mbps UL: 100 kbps – 10 Mbps	0.5 – 1 ms	Pedestrian
Tactile Interaction	DL: 100 kbps - 10 Mbps UL: 100 kbps – 10 Mbps	0.5 – 1 ms	Pedestrian
Emergency Services, Public Safety	DL: 100 kbps – 10 Mbps UL: 100 kbps – 10 Mbps	1 - 5 ms	0 – 120 km/h
Urgent Health Care	DL: 100 kbps – 10 Mbps UL: 100 kbps – 10 Mbps	1 - 5 ms	0 – 120 km/h
Fixed Wireless	DL: 100 kbps - 5 Mbps UL: 100 kbps – 1 Mbps	10 ms	Pedestrian

The business potential for 5G will be enabled by the use cases in Table 1. Although some scenarios may be addressed by LTE today, 5G will enhance them and/or make new use cases possible.

3. STANDARDIZATION & INDUSTRY LANDSCAPE

Several industry associations have been researching 5G since 2013. The work has included identifying use cases for 5G, requirements for 5G, studying how to measure performance and researching technical concepts for 5G. 5G Americas published an excellent White Paper highlighting these pre-standards research efforts[9] that highlighted the dozens of 5G research projects worked across the globe. This early 5G research is allowing 5G to be rapidly standardized in organizations like 3GPP, ITU, ETSI, IETF and more. Some of the key Industry Standards Organizations (SDOs) involved in 5G are highlighted in the following section. It's important to note that 5G standardization is primarily driven through 3GPP. Many supporting technologies are needed such as Orchestration, Analytics, NFVI and more. These supporting technologies are driven by other organizations such as OPNFV, OpenStack, OpenDaylight and others.

3.1 INDUSTRY STANDARDS ORGANIZATIONS

5G standards are being reviewed and standardized in multiple SDOs and forums. This section will describe a few of the ongoing activities in some of those SDOs.

3.1.1 3GPP

3GPP is the primary driver for developing 5G standards; however, other organizations will develop standards that could supplement or be used by 3GPP (for example, ITU, IETF, ETSI, ATIS). 3GPP began their efforts on 5G with a RAN 5G workshop[10] in September 2015. The workshop preceded RAN Plenary #69 which approved a study item on channel modeling above 6 GHz. Since then, 3GPP has progressed from 5G study items, to now developing normative 5G implementable standards.

3GPP then began to study use cases for 5G and from the use cases developed requirements. This work was performed in the 3GPP Services work group (SA1). These requirements were then used to help guide in the selection of technical concepts by other work groups. One of their key documents is: 'Service and Markets Technology Enablers (SMARTER) for next generation telecommunications' with 4 approved Technical Reports (TR 22.861, 22.862, 22.863, 22.864) and the SA1 Service Requirements for the 5G system; Stage 1 (TS 22.261). Following is a diagram pictorially showing the four key groups for 5G services and markets.

[9] http://www.5gamericas.org/files/2114/0622/1680/2014_4GA_Summary_of_Global_5G_Initiatives__FINAL.pdf
[10] http://www.3gpp.org/ftp/workshop/2015-09-17_18_RAN_5G/

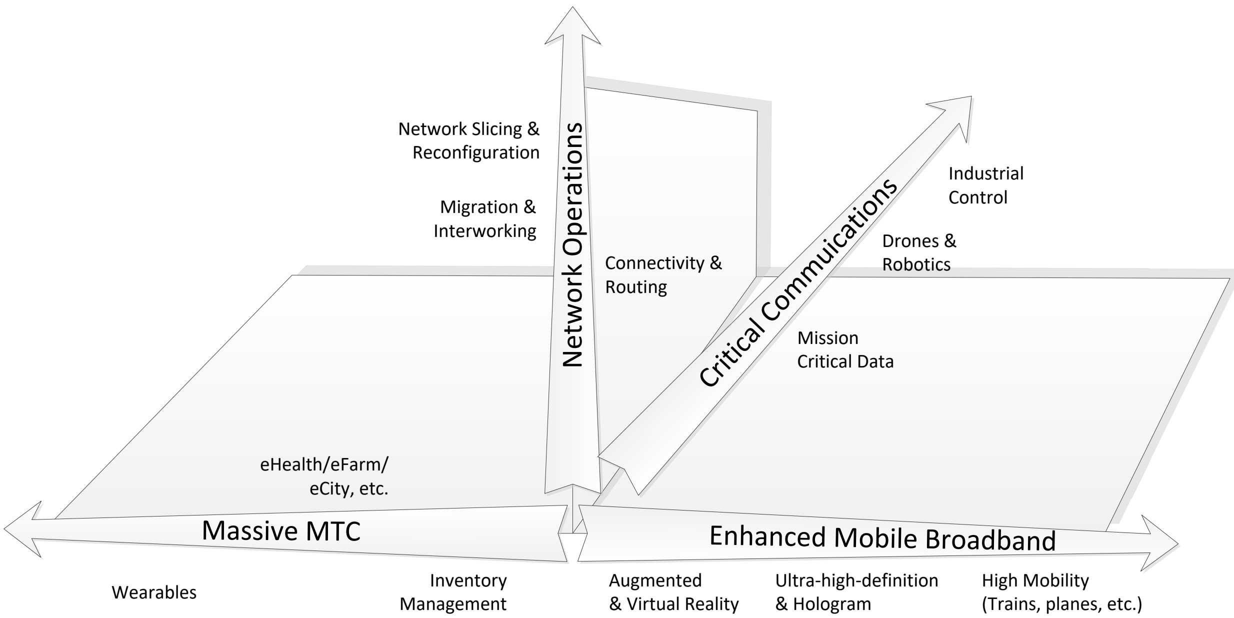

Figure 3. 3GPP Identified Key Use Cases for 5G Services & Requirements.[11]

In March 2017, 3GPP approved the work plan for the initial releases of 5G standards.[12]

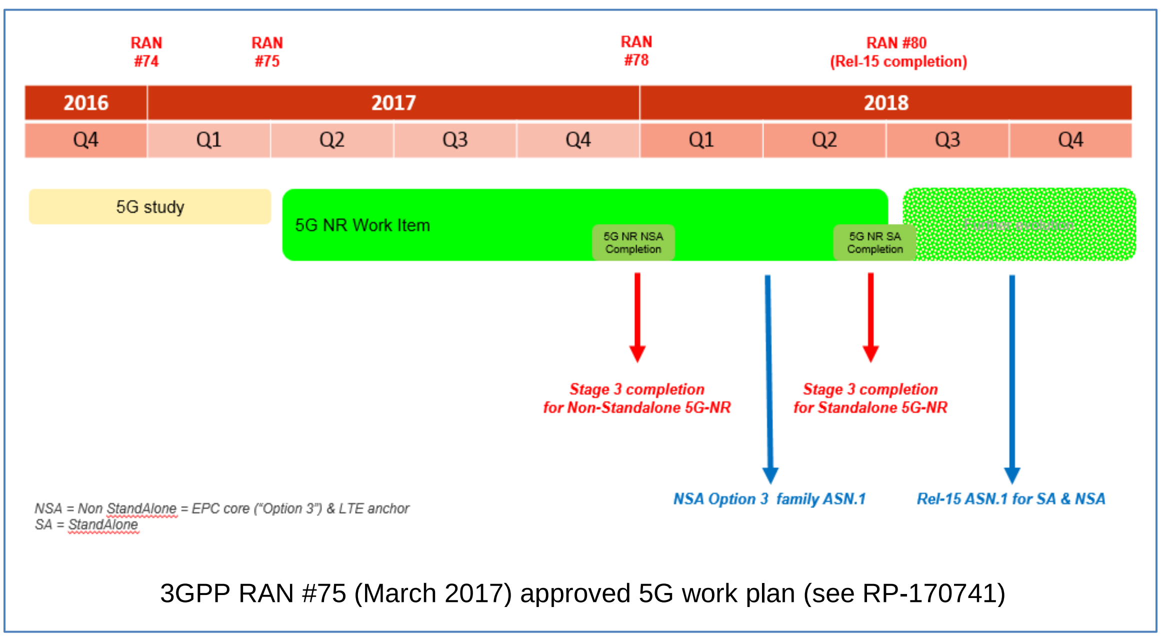

Figure 4. 3GPP 5G Standardization Milestones.

The first phase of 5G NR will focus on Fixed Wireless Access (FWA), enhanced Mobile Broadband (eMBB) and Ultra-Reliable and Low Latency Communications (URLCC) use cases with the introduction of extremely

11 http://www.3gpp.org/news-events/3gpp-news/1786-5g_reqs_sa1
12 http://www.3gpp.org/ftp/tsg_ran/TSG_RAN/TSGR_75/Docs/RP-170741.zip

short Transmission Time Internal (TTI), enabling basically 1 ms or less radio layer latency. The use case with massive Machine Type Communication (mMTC) is foreseen in a later phase due to the recently introduced NB-IoT and LTE-M solutions in Releases 12 and 13.

The 5G System architecture is being defined to support data connectivity and services enabling deployments to use techniques such as Network Function Virtualization and Software Defined Networking. The 5G System architecture shall leverage service-based interactions between Control Plane (CP) Network Functions where identified.

The 5G-RAN will include both a 5G New Radio (currently being called a gNB) and/or LTE Radios (eNBs) connected to the Next Generation 5G Core (NG Core). The gNBs and/or eNBs provide the user plane and control plane protocol terminations towards the UE. The architecture is illustrated in Figure 5. This architecture is being worked in 3GPP and will be finalized for Option 3 Non-Standalone in December of 2017 followed by the Standalone architecture middle of 2018. This can be seen in the timeline in Figure 4.

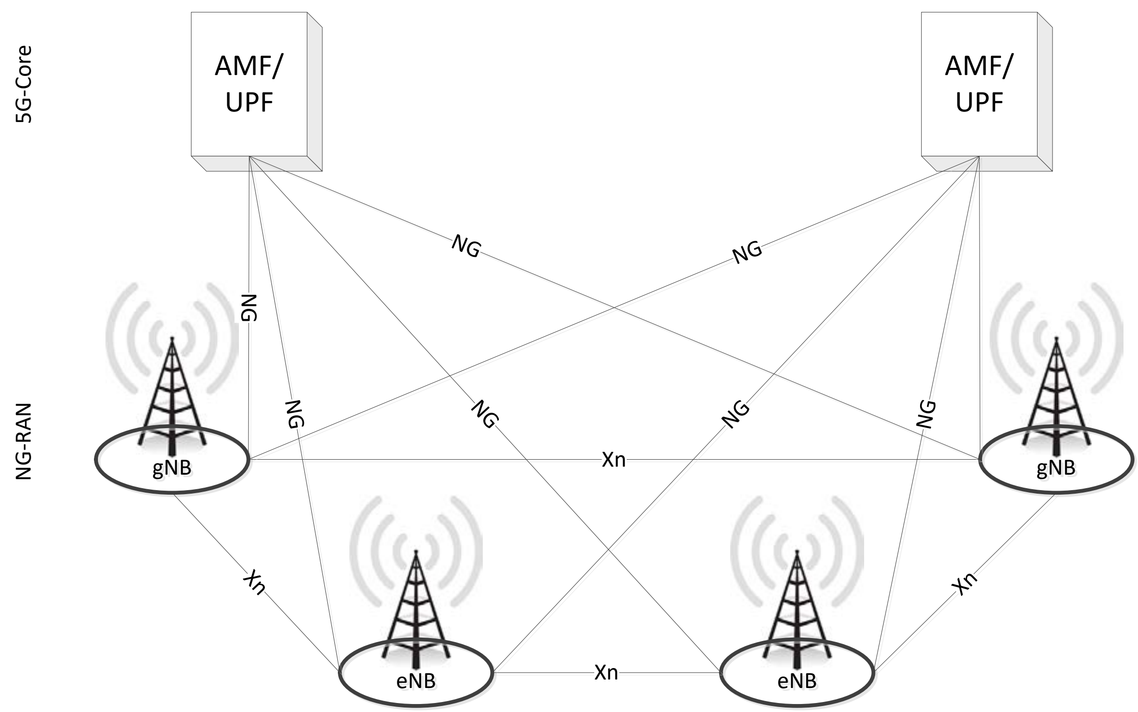

Figure 5. NG-RAN Architecture.

3.1.2 5GTF – 5G TECHNICAL FORUM

Some operators wanted to trial and possibly commercially deploy multi-vendor 5G equipment ahead of the 3GPP standards. These operators formed groups to develop essential specifications supporting early 5G systems. The two most high-profile groups include the KT 5G-SIG (5G Special Interest Group) and the Verizon 5G-TF (5G Technical Forum). The specifications and equipment deployed in these early 5G systems may be quite different from the vendor equipment compliant with the 3GPP 5G specifications.

The KT 5G-SIG has the goal to realize the world's first 5G trial service at the PyeongChang 2018 Winter Olympic Games. KT has published their 5G specifications.[13]

The Verizon 5G-TF was formed in late 2015 for fixed wireless deployments in the 28 GHz and 39 GHz bands. Verizon has also published their 5G specifications.[14]

3.1.3 ITU - INTERNATIONAL TELECOMMUNICATIONS UNION

The International Telecommunications Union (ITU) is a standardization group within the United Nations which has taken on a key role by defining 5G requirements and laying out their 5G timeline (which has mostly aligned with the 3GPP 5G plans). The ITU nomenclature for 5G is IMT-2020.

One of the key 5G documents is the ITU IMT-2020 5G Requirements ITU-R M [IMT-2020.TECH PERF REQ][15] to be approved November 2017. This document identifies the minimum performance requirements for IMT-2020, such as the peak data rates, throughput, latency, spectral efficiency, mobility and more.

As standards organizations (like 3GPP and 3GPP Organizational Partners) develop 5G standards, they will also need to perform simulations of their proposals to determine the system performance of their proposals and ensure the proposal meets the ITU IMT-2020 requirements. The detailed technical proposals along with performance data will be submitted to the ITU for evaluation. The final proposal along with necessary performance data is due into ITU-R by July 2019. The ITU will then evaluate proposals and approve IMT-2020 technologies.

3.1.4 IETF

IETF has been a key part of protocols used by 3GPP, including IPv4, IPv6, SIP, Radius, Diameter, WebRTC and many more. IETF will continue to play an integral role for developing protocols that will be leveraged by 3GPP for 5G technology.

3.1.5 ADDITIONAL SDOS & FORUMS

ETSI ISG NFV and ONF

As was noted in the introduction, 5G will fully leverage NFV (Network Function Virtualization) and SDN (Software Defined Networks) to provide more flexible networks and allow for new features to be rapidly developed and deployed. Work is progressing on NFV in the ETSI ISG NFV group and SDN is progressing in OpenDaylight (ODL) and the Open Network Foundation (ONF). To take full advantage of NFV and SDN, open source code will be needed and such work is proceeding in key industry groups such as: ONAP (Open Network Automation Platform), OPNFV (Open Platform for NFV), OpenStack and more. Each group is focused on different specific Open Source aspects.

5G Americas

5G Americas has been a key voice in the 5G effort. 5G Americas was one of the first organizations in the world to publish 5G recommendations well ahead of other efforts. 5G Americas has worked with operators across the Americas region to collect their 5G requirements, provide 5G technical and policy

13 https://www.kt.com/eng/biz/kt5g_02.jsp
14 http://www.5gtf.net/
15 https://www.itu.int/md/R15-SG05-C-0040/en

recommendations; file spectrum recommendations with governments and also has signed cooperative agreements with global 5G organizations; including: The 5G Infrastructure Association (Europe), the 5G Forum (Korea), IMT-2020 Promotion Group (China), the Fifth Generation Mobile Communication Forum (Japan) and TeleBrasil. 5G Americas has published several 5G papers[16] with relevant information that the reader may use as a useful resource. Some topics include: 5G Technical Recommendations, 5G Spectrum Recommendations, Understanding Information Centric Networking and Mobile Edge Computing, and more.

4. 5G CORE

To support and enable the known and unknown use cases previously mentioned, a new core network was defined. This new core network is called the 5G Next Generation Core (NG-Core or NGC) to go along with the 5G New Radio (NR). Two architectures were proposed in Release 15 - a full reference point representation and a service-based representation (Figure 6). As standards progressed, the new Service-Based Architecture (SBA) was selected for architecture going forward. The 5G NGC architecture is defined as service-based and the interaction between network functions are represented in two ways: Network functions within the 5G Control Plane (5GC); and Network Functions connecting to the 5G Control Plane from the RAN network. Network Functions within the 5G CP shall only use service-based interfaces for their interactions. This is different than LTE architecture where all of the core has a reference point representation. Reference point interfaces will continue to exist within the Radio and User Plane (UP). In addition to SBA, two other new concepts have been included: Control Plane / User Plane (CP/UP) split; and Network Slicing.

The 5G core standardization defines the functional architecture where implementation technologies can be evolved and replaced over time. A few key principles that guide this architecture are:

- Prioritize interfaces to support multi-vendor integration
- Scale UP and CP functionality independently
- Allow for a flexible deployment of UP separate from the CP
- Support authentication for both IMSI-based and non IMSI-based identities
- Allow for different network configurations in different network slices
- Abstract transport layer for 3GPP NFs

16 http://www.5gamericas.org/en/resources/white-papers/

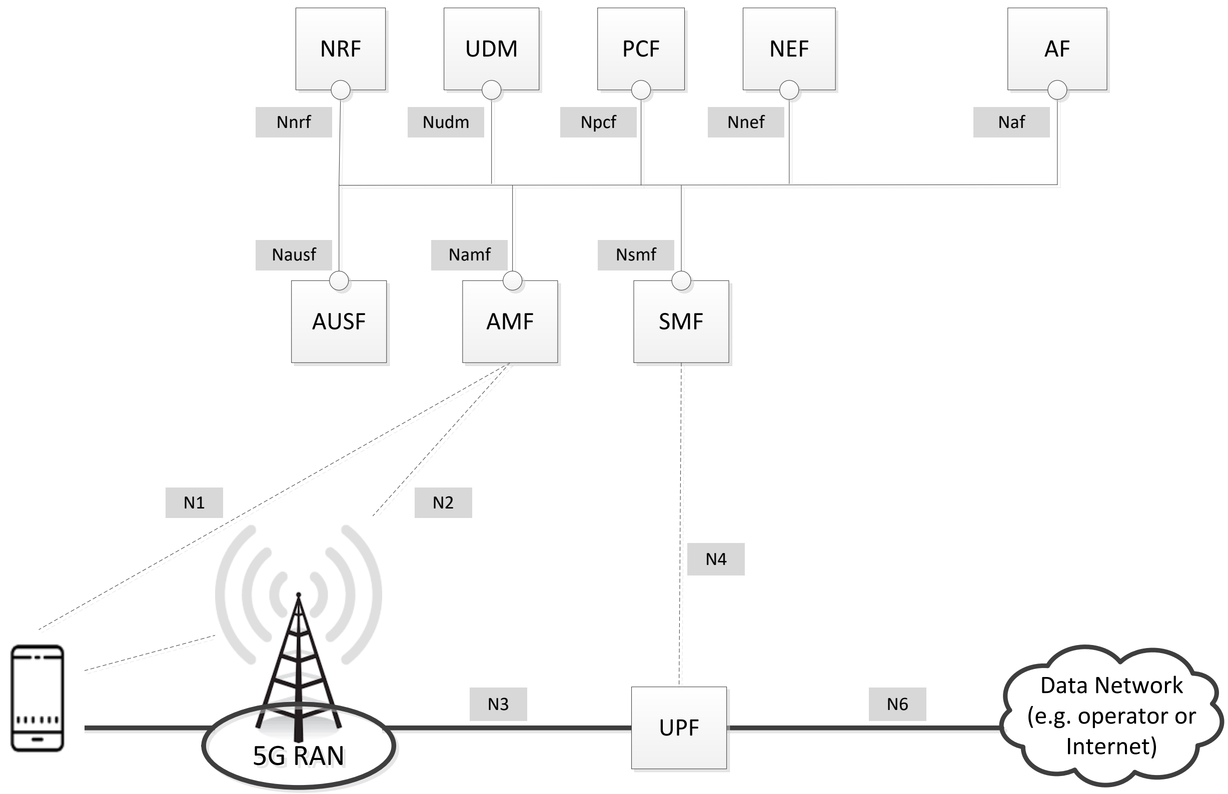

Figure 6. 3GPP 5G Core Service-based Architecture.

This new representation of the 5G Core Architecture network functions (for example, Access Management Function (AMF)) within the control plane enables other authorized network functions to access their services. Communications with these nodes will leverage HTTP based APIs, replacing protocols like Diameter. The overall design and other potential benefits include:

- NR standalone mode (SA) Option 2, without dependency on legacy networks
- Flexible and extensible architecture based on SBA
- Easier integration with third party software using Application Programming Interfaces (APIs)
- Multi-slice User Equipment (UE), single UE simultaneously connecting to multiple services over multiple slices with optimized access and mobility signalling.
- Improved QoS concepts
- Simultaneous access to local and centralized networks within the same data connection
- Mobility on Demand concepts
- Preparing for non-3GPP access integration

4.1 CORE NETWORK FUNCTIONS

When it comes to the network functions themselves, several new nodes have been defined. Many of the requirements for the functions described in the following text are still being discussed within 3GPP Release 15. The primary Network Functions (NFs) and their capabilities as they are defined in the standards process today are:

Authentication Server Function (AUSF)

- Contains mainly the EAP authentication server functionality
- Storage for Keys

Core Access and Mobility Management Function (AMF)

- Termination point for RAN CP interfaces (N2)
- UE Authentication & Access Security.
- Mobility Management (Reachability, Idle/Active Mode mobility state handling)
- Session Management Function (SMF) selection
- Non- Access Stratum (NAS) signalling including NAS Ciphering and Integrity protection, termination of MM NAS and forwarding of SM NAS (N1).
- N2 signalling for sending/receiving Mobility Management (MM) information to the RAN such as MM specific N2 information, and forwarding of N2 Session Management (SM) information such as QoS.
- Likely to include the Network Slice Selection Function (NSSF)

Data Network (DN)

- Services offered
  - Operator services
  - Internet access
  - 3rd party services

Network Exposure Function (NEF)

- Provides security when services or Application Functions (AF) access 5G Core nodes
- Can be thought of as a proxy, or API aggregation point, or translator into the Core Network

NF Repository Function (NRF)

- Provides profiles of Network Function (NF) instances and their supported services within the network

Policy Control Function (PCF)

- Expected to have similarities with the existing policy framework (Policy and Charging Rules Function - PCRF) in 4G
- Updates to include the addition of 5G standardized mobility based policies

Session Management Function (SMF)

- NAS handling for SM
- Sending QoS/policy N2 information to the Access Network (AN) via AMF
- Idle/Active aware
- UE IP address allocation & management
- Policy and Offline/Online charging interface termination
- Policy enforcement control part
- Lawful intercept (CP and interface to LI System)
- User Plane (UP) selection and termination of N4 interface

Unified Data Management (UDM)

- Expected to have similar functionality as the HSS in Release 14 for the Evolved Packet Core (EPC)

User Plane Function (UPF)

- Allows for numerous configurations which essential for reduction of latency in 5G
- Can be collocated in the core network, pushed all the way out the customer site, or anywhere in between
- Anchor point for Intra-/Inter-RAT mobility
- External IP point of interconnect
- Packet routing and forwarding
- QoS handling for User Plane
- Packet inspection and PCC rule enforcement
- Lawful intercept (UP Collection)
- Roaming interface (UP)
- Traffic counting and reporting

Application Functions (AF)

- Services considered to be trusted by the operator
- Can access Network Functions directly or via the NEF
- Un-trusted or third-party AFs would access the Network Functions through the NEF

4.2 5G CORE INTERACTIONS

Service and operations within the Next Generation Core have been defined using two different mechanisms: Request-Response and Subscribe-Notify. A given Control Plane Network Function can provide one or more NF Services. A NF Service consists of operations based on either a request-response or subscribe-notify model. Communications in these models use HTTP based APIs, replacing protocols like Diameter from 4G.

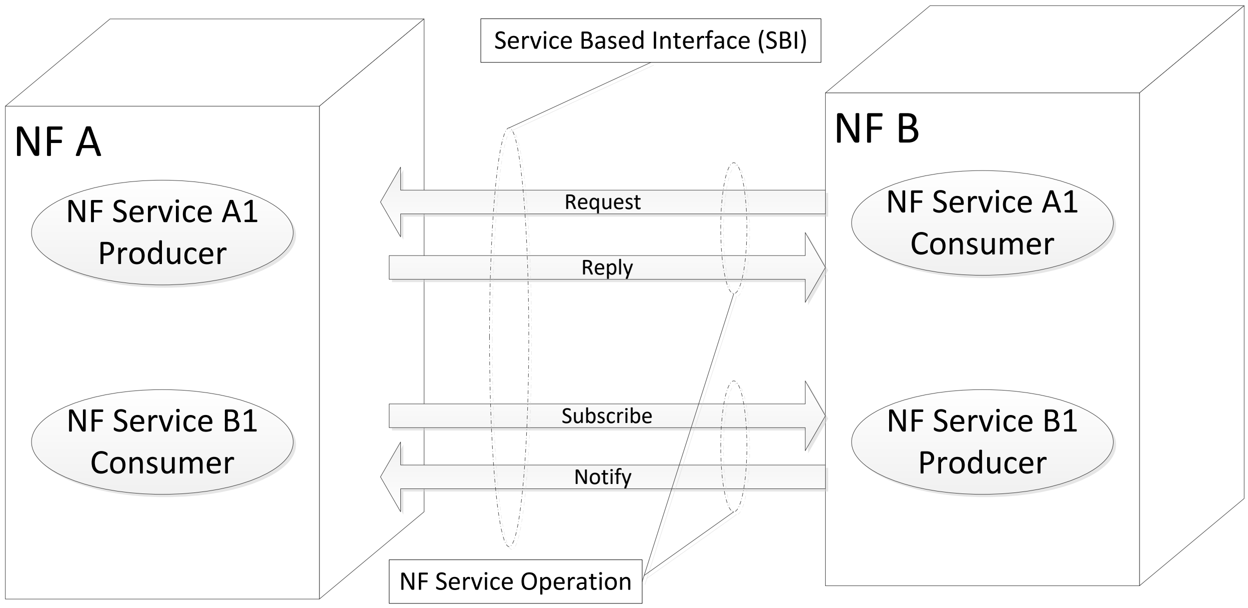

Figure 7. Network Function Service Models.

An NF service is a capability exposed by a NF (NF Service Producer) to other NFs (NF Service Consumer) through a service-based interface. Network Functions may expose one or more NF services.

There are two elementary operations provided by NFs through a service-based interface:

- **"Request-response":** A Control Plane NF A (NF Service Producer) is requested by another Control Plane NF B (NF Service Consumer) to provide a certain NF service, which can include performing an action and/or providing information. NF-A response provides NF service results based on the information provided by NF-B in its request. In order to fulfil the request, NF-A may in turn consume NF services from other NFs. In Request-response mechanism, communication is one-to-one between two NFs (consumer and producer) and a one-time response from producer to a request from consumer is expected within a certain timeframe.
- "**Subscribe-Notify":** A Control Plane NF-A (NF Service Consumer) subscribes to NF Service offered by another Control Plane NF-B (NF Service Producer). Multiple Control Plane NFs may subscribe to the same Control Plane NF Service. NF-B notifies the results of this NF service to the interested NF(s) that subscribed to this NF service. The subscription request from consumer may include notification requests for periodic updates or notification triggered through certain events (for example, the information requested gets changed, reaches certain threshold, etcetera). This mechanism also covers the case where NFs (NF-B) are subscribed to certain notifications implicitly without explicit subscription request (for example, due to successful registration procedure).

NF Service discovery, authorization and registration are framework mechanisms that enable the use of NF services.

4.3 5G CORE AND EPC INTERWORKING VARIANTS

When introducing a 5G Core Network, it is assumed that EPC/LTE networks need to support existing EPC/LTE handsets and inbound roamers. Different alternatives exist to enable support for mobility between 5GC and EPC (only MME and SGW in EPC):

- Re-attach without keeping IP address
  - VoLTE calls do not survive, New registration in IMS required
- Handover attach with loose interworking (keeping IP address) – in 3GPP "mobility without Nx"
  - Connecting SGW to SMF/PGW-C and H-UPF/PGW-U over S5, mimicking Wi-Fi interworking. Avoids new registration in IMS, but no seamless voice call continuity
  - "IRAT mobility" with tight CN-level interworking between EPC and 5GC (idle or active mode variants)
  - Required for VoLTE
  - Connecting SGW to SMF/PGW-C and H-UPF/PGW-U over S5, and MME to AMF over Nx(S10): potential for short voice interruption. Requires QoS translation between 5GC and EPC

A solution with common SMF/PGW-C, UPF/PGW-U, PCF/PCRF, and UDM/HSS is assumed to enable mobility support.

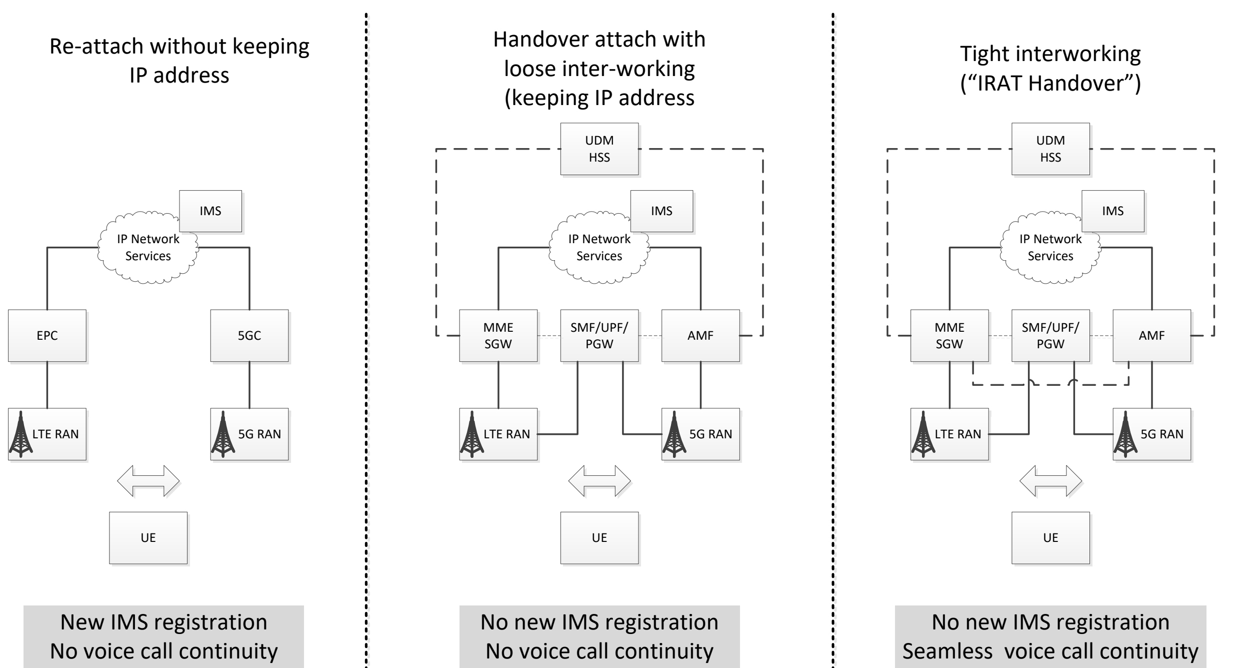

Figure 8. 5G Core and EPC Interworking Variants.

It is expected that service requirements regarding seamless mobility for services such as VoLTE need to be fulfilled when the user moves between 5G and 4G systems. For seamless mobility between LTE/NR and LTE, a solution is required where the UP anchor is not relocated to avoid a change of IP address.

4.4 NETWORK SLICING

Next-generation 5G networks will cater for a wide range of new business opportunities, some of which have yet to be conceptualized. They will provide support for advanced mobile broadband services such as massive media distribution. Applications like remote operation of machinery, tele-surgery, and smart metering all require connectivity, but with vastly different network service characteristics. The ability to provide customized connectivity will benefit many industries around the world, enabling them to bring new products and services to market rapidly, and adapt to fast-changing demands, all while continuing to offer and expand existing services. But how will future networks provide people and enterprises with the right platform, with just the right level of connectivity?

The answer: flexibility. The Information and Communication Technology (ICT) world has already started the journey to delivering elastic connectivity. Technologies like SON (Self-Organizing Networks) and virtualization are enabling a drastic change to take place in network architecture, allowing traditional structures to be broken down into customizable elements that can be chained together programmatically to provide just the right level of connectivity, with each element running on the architecture of its choice. This is the concept of network slicing that will enable core networks to be built in a way that maximizes flexibility.

As we move deeper into the Networked Society, with billions of connected devices, lots of new application scenarios, and many more services, the business potential for service providers is expanding rapidly. And 5G technologies will provide the key to tap into this potential, ensuring that customized communication can be delivered to any industry.

Being able to deliver the wide variety of network performance characteristics that future services will demand is one of the primary technical challenges faced by service providers today. The performance requirements placed on the network will demand connectivity in terms of data rate, latency, QoS, security, availability, and many other parameters — all of which will vary from one service to the next. But future services also present a business challenge: average revenues will differ significantly from one service to the next, and so flexibility in balancing cost-optimized implementations with those that are performance-optimized will be crucial to profitability.

In addition to the complex performance and business challenges, the 5G environment presents new challenges in terms of timing and agility. The time it takes to get new features into the network, and time to put services into the hands of users' needs to be minimized, and so tools that enable fast feature introduction are a prerequisite.

Above all, overcoming the challenges requires a dynamic 5G core network.

Network slicing is one of the key capabilities that will enable this flexibility, as it allows multiple logical networks to be created on top of a common shared physical infrastructure. The greater elasticity brought about by network slicing will help to address the cost, efficiency, and flexibility requirements imposed by future services.

The concept of flexibility applies not only to the hardware and software parts of the network, but also to its management. For example, setting up a network instance that uses different network functions optimized to deliver a specific service needs to be automated. Flexible management will enable future networks to support new types of business offerings that previously would have made no technical or economic sense.

4.4.1 HIGH-LEVEL ARCHITECTURE

Network slicing allows networks to be logically separated, with each slice providing customized connectivity, and all slices running on the same, shared infrastructure. This is a much more flexible solution than a single physical network providing a maximum level of connectivity.

Virtualization and SDN are the key technologies that make network slicing possible. As shown in Figure 9, network slices are logically separated and isolated as systems that can be designed with different architectures, but can share functional components. One slice may be designed for evolved MBB services providing access to LTE, evolved LTE and NR devices; another may be designed for an industry application with an optimized core network control plane, different authentication schemes, and lightweight user plane handling. Together, the two slices can support a more comprehensive set of services and enable new offerings that are cost-effective to operate.

To support a specific set of services efficiently, a network slice should be assigned different types of resources, such as infrastructure — including VPNs, cloud services, and access — as well as resources for the core network in the form of VNFs.

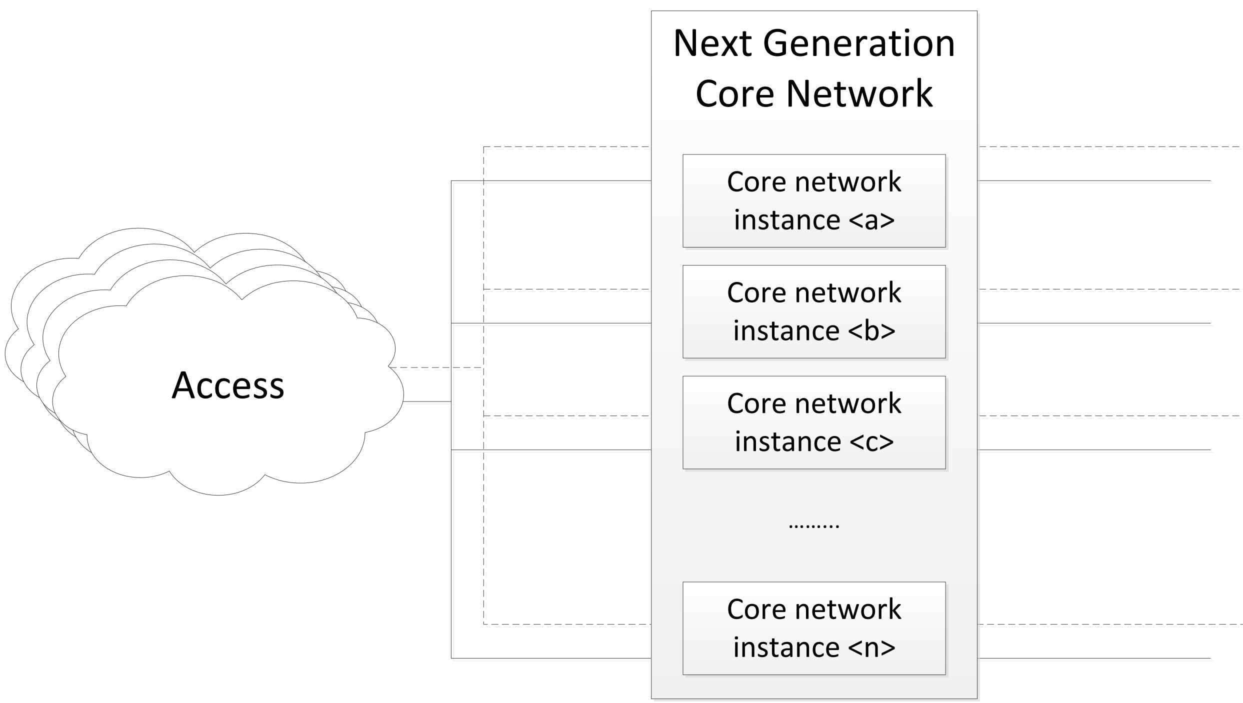

Figure 9. Next Generation Core with Network Slices.

As illustrated in Figure 10, network slicing supports business expansion since it lowers the risks associated with introducing and running new services — the isolated nature of slices protects existing services running on the same physical infrastructure from any impact. An additional benefit of network slicing is that it supports migration, as new technologies or architectures can be launched on isolated slices.

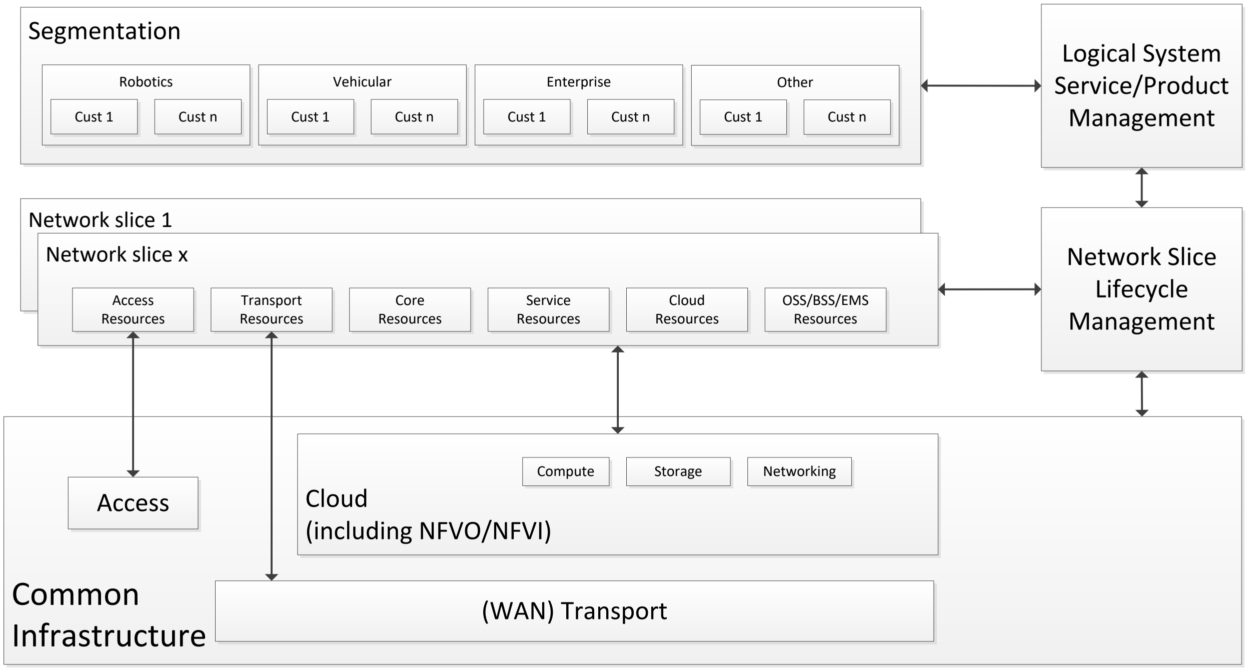

Figure 10. Network Slicing in Support of Business Expansion.

Evolving standards should allow network architecture to develop in a radical or revolutionary way. By steering away from a one-size-fits-all approach, evolving standards will allow for a whole palette of architectures from which different network slices can be designed. The introduction of a selection mechanism like Dedicated Core Network — which allows for multiple parallel architectures — is one step in the right direction as the industry continues to move forward towards rapid standardization.

5. RAN

5G includes radio equipment being called the 5G New Radio (NR) and the evolved LTE (eLTE) radio. Simulations will be required to demonstrate these technologies to meet the IMT-2020 requirements of the ITU along with ITU approval of these technologies. The base stations for the 5G-NR radios are anticipated to be called gNodeB.

The key requirements for the 5G radio (as noted previously) are to provide low latency (<5ms) with much higher through-put (Multi-Gbps) when compared to the eNB. Three of the primary use cases mentioned in Use Case Categories from the radio perspective are:

- Enhanced mobile broadband with higher data rates, higher density, higher user mobility, devices with highly variable user data rates, fixed mobile convergence and small-cell deployments
- Massive Internet of Things, which focuses on use cases with massive number of devices (for example, sensors and wearables). This group of use cases is particularly relevant to new verticals, such as smart home and city, smart utilities, e-Health, and smart wearables
- Critical communications, with lower latency, higher reliability and availability to enable, services like industrial control applications and tactile Internet. These requirements can be met with an improved radio interface, optimized architecture, dedicated core resources, and dedicated radio resources

3GPP is redesigning and optimizing the radio for 5G to meet these requirements. A few of the major changes are highlighted in sections 5.1 and 5.2.

5.1 LAYER 1

Since 5G is an evolutionary technology, 3GPP is taking an evolutionary approach and redesigning Layer 1. The design is based on extensive simulation work and many different proposals being considered from scientists and researchers. Some of the key physical layer changes for NR include:

- Support for new millimeter bands (Rel-15 will support frequencies up to 37-40 GHz with even higher frequencies expected in future releases). Note: existing LTE bands (sub 6 GHz) will also be supported by NR; however, not all bands will be supported initially as it will take time to work out the technical details
- Much wider channel bandwidths are supported. The maximum channel bandwidth per NR carrier is 400 MHz in Rel-15 (wider channel bandwidths are expected in future releases)
- Multiple subcarrier spacing options are allowed depending on the frequency of the channel being used. Subcarrier spacing can vary between 15 KHz and 240 KHz for below 6 GHz spectrum and 120 to 240 KHz for spectrum greater than 6GHz
- Subframes are fixed at 1ms and frame length is 10 ms
- Support for mini-slot transmissions with a duration shorter than a regular slot. Mini-slots can be beneficial for low-latency transmissions
- Will retain Orthogonal Frequency Division Multiplexing (OFDM) based waveforms
- 12 subcarriers per Physical Resource Block (PRB)
- Channel coding to use Low Density Parity-Check (LDPC, replacing Turbo coding used in LTE)
- Control channels to use Polar or repetition coding
- Support for gNB Beam management for UL and DL

This summarizes only the NR Physical Layer; for additional details, see 3GPP: TS 38.201, TS38.211, 38.212.

5.2 LAYER 2

Layer 2 is split into the following sublayers: Medium Access Control (MAC), Radio Link Control (RLC), Packet Data Convergence Protocol (PDCP) and SDAP (Service Data Adaptation Protocol). Figures 11 and 12 depict the Layer 2 architecture for downlink and uplink, where:

- The physical layer offers to the MAC sublayer transport channels
- The MAC sublayer offers to the RLC sublayer logical channels
- The RLC sublayer offers to the PDCP sublayer RLC channels
- The PDCP sublayer offers to the SDAP sublayer radio bearers
- The SDAP sublayer offers to 5GC QoS flows

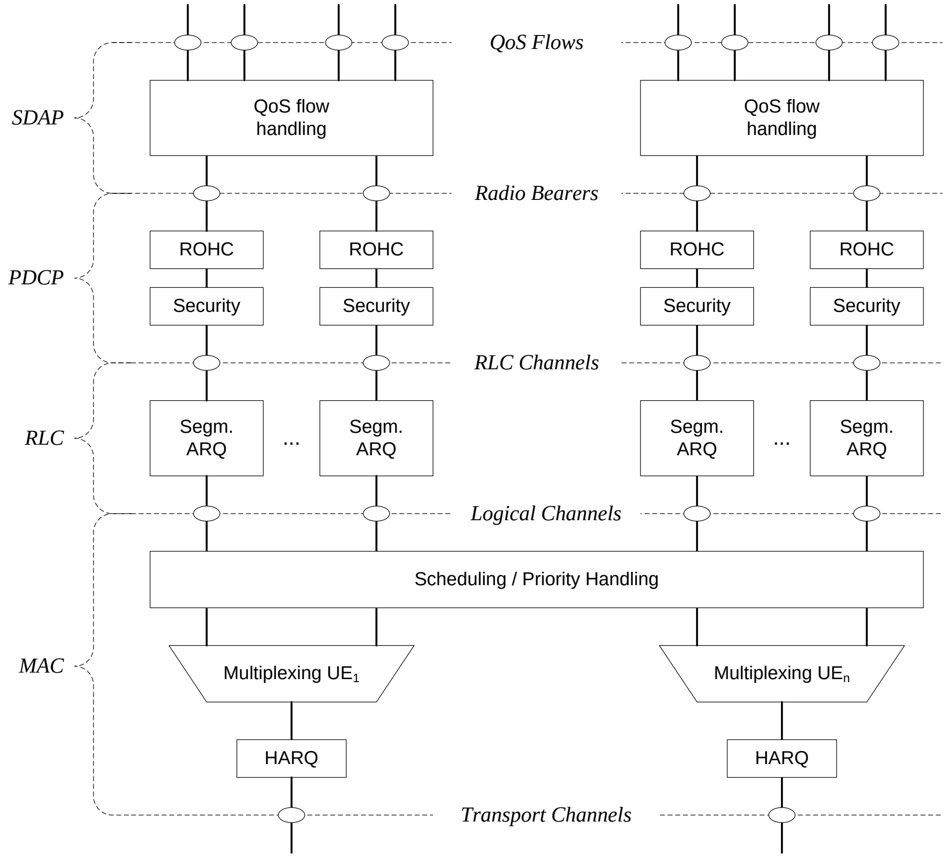

Figure 11. Downlink Layer 2 Structure.

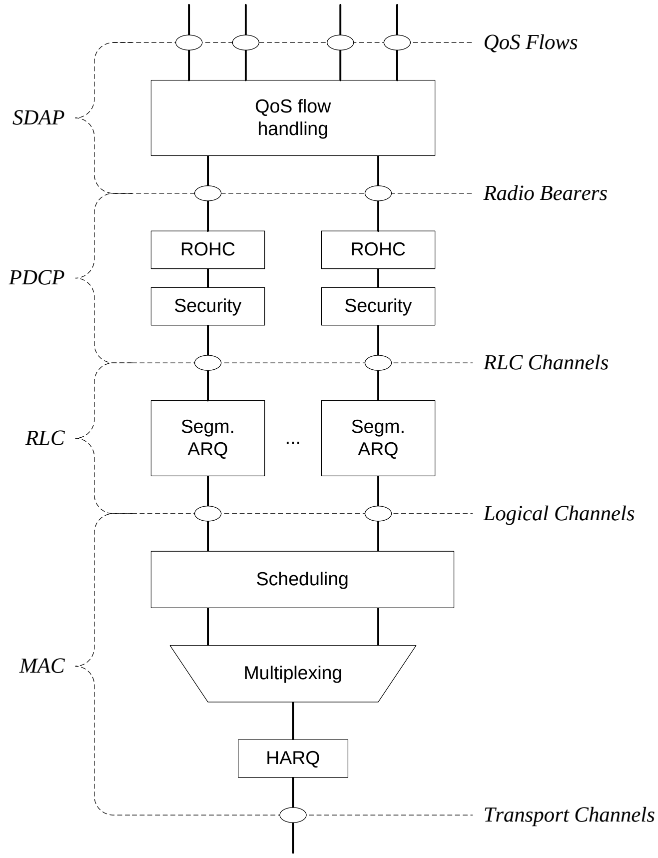

Figure 12. Uplink Layer 2 Structure.

5.2.1 RRC – RADIO RESOURCE CONTROL

The main services and functions of the RRC sublayer include:

- Broadcast of System Information related to AS (Access Stratum) and NAS (Non-Access Stratum)
- Paging initiated by 5GC or NG-RAN
- Establishment, maintenance and release of an RRC connection between the UE and NG-RAN
- Security functions including key management
- Establishment, configuration, maintenance and release of Signaling Radio Bearers and Data Radio Bearers
- Mobility functions
- QoS management functions
- UE measurement reporting and control of reporting
- Detection of and recovery from radio link failure
- NAS message transfer to/from NAS from/to UE

5.2.2 CLOUD RAN

Traditional radio equipment has been a rack of physical hardware located at the cell site. The hardware may be at the base of the tower with cables up to the antenna, or may include baseband processing hardware at the base of the tower with the RF components adjacent to the antenna. A Cloud RAN typically removes portions of the physical hardware handling baseband processing and moves that functionality into the cloud. The split of base station functionality between a Central Unit (CU) and Distributed Unit (DU) has a strong dependency on the transport layer that links the two (known as fronthaul). Figure 13 shows possible options for splitting the radio protocol stack. High performance transport enables lower layer functional split (for example, Option 6 or 7), while low performance transport can still enable functional split but only at higher layers (for example, Option 2 or 3).

Benefits of virtualization include:

- Automatically scale network capacity as demand changes
- Launch exciting new services in days or even hours, not months
- Run real-time services based on what's happening around your customers
- Manage and steer capacity from anywhere in the network to anywhere it's needed
- Ease to upgrade cloud based hardware lower cost and lower power base station equipment
- Dual connectivity between 5G and LTE with vRAN to mitigate trombone routing issues

In 3GPP Rel-15, one higher layer split will be standardized (Option 2) while lower layer split continues to be studied.

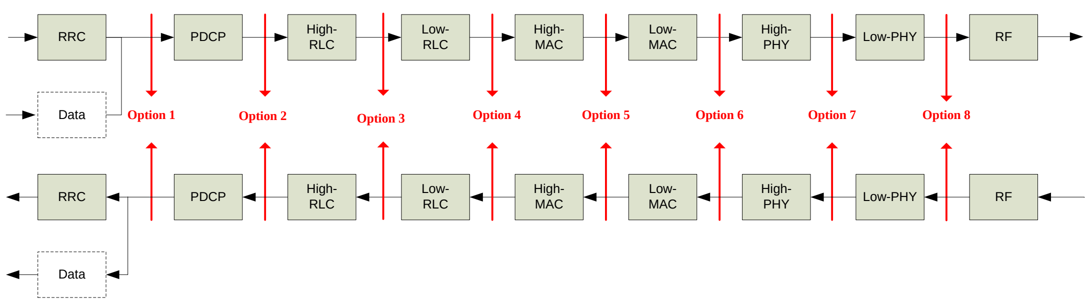

Figure 13. Possible Splitting Options for Radio Protocol Stack.

5.2.3 NETWORK SLICING IN RAN

Network Slicing will be supported within RAN to provide differentiated treatment of the bearer data depending on the type of data and user subscription. With RAN network slicing, it is possible for Mobile Network Operators (MNO) to consider customers as belonging to different tenant types with each having different service requirements that govern in terms of what slice types each tenant is eligible to use based on Service Level Agreement (SLA) and subscriptions. Following are some of the 3GPP RAN Network Slicing requirements:

- RAN shall support a differentiated handling of traffic for different network slices which have been pre-configured. How RAN supports the slice enabling in terms of RAN functions (i.e. the set of network functions that comprise each slice) is implementation dependent
- RAN shall support the selection of the RAN part of the network slice, by one or more slice ID(s) provided by the UE or the CN which unambiguously identifies one or more of the pre-configured network slices in the Public Land Mobile Network (PLMN). The Accepted Network Slice Selection Assistance Information (NSSAI) is sent by the Core Network (CN) to User Equipment (UE) and RAN after network slice selection

- RAN shall support policy enforcement between slices as per service level agreements. It should be possible for a single RAN node to support multiple slices. The RAN should be free to apply the best Radio Resource Management (RRM) policy for the SLA in place to each supported slice
- RAN shall support QoS differentiation within a slice
- RAN shall support resource isolation between slices. RAN resource isolation may be achieved by means of RRM policies and protection mechanisms. A shortage of shared resources in one slice should not break the service level agreement for another slice. It should be possible to fully dedicate RAN resources to a certain slice. How RAN supports resource isolation is implementation dependent
- The RAN and the CN are responsible to handle a service request for a slice that may or may not be available in a given area. Admission or rejection of access to a slice may depend on factors such as support for the slice, availability of resources, support of the requested service by other slices, etcetera

Architectural decisions for Network Slicing are still being worked in 3GPP RAN3 TS 38.301 section 17.3.

Some examples of RAN network slices may include:

- MTC - Machine Type Communication
- Real-time local video (possibly handled by Mobile Edge Computing)
- Public Safety
- Mobile Health

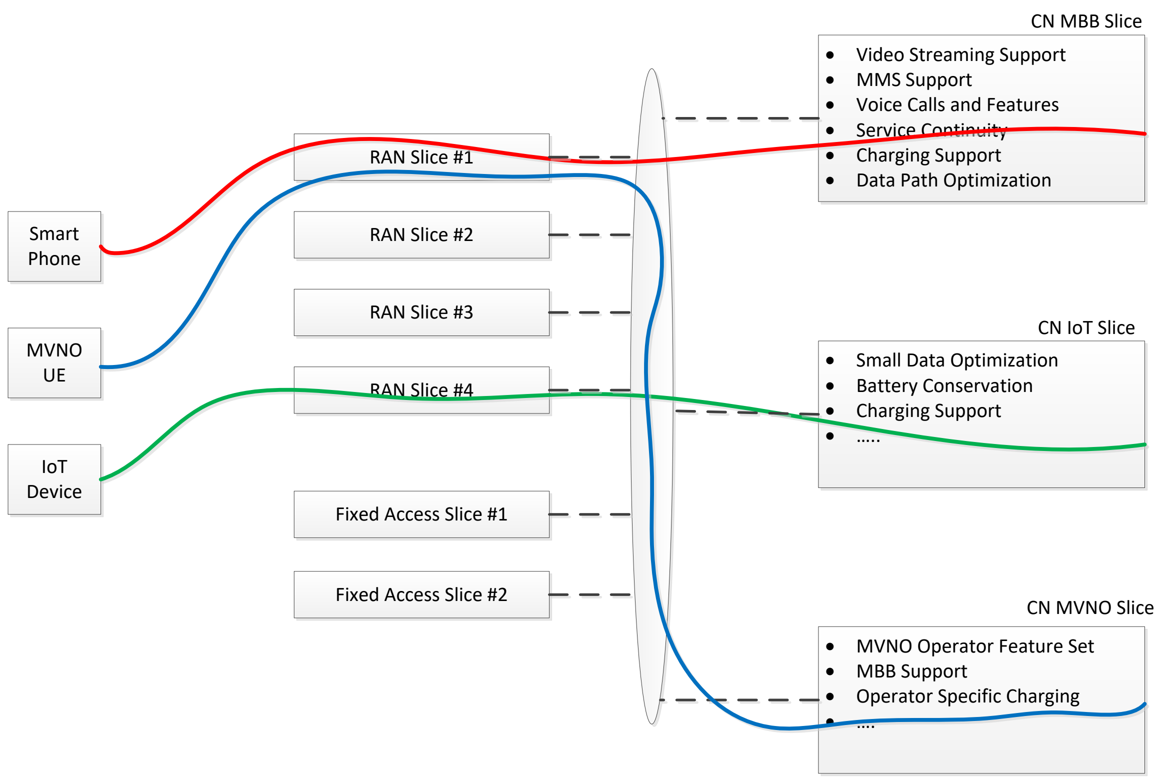

Figure 14. Network Slice Example.

6. WIRELESS SELF-BACKHAUL

The increased density of access nodes needed to meet performance objectives poses considerable deployment challenges (for example, backhaul availability, backhaul capacity and scalability). The use of wireless backhaul for such access nodes addresses some of these challenges. Wireless backhaul has been used in the past, using proprietary technologies.

Several groups are looking to address these new distribution needs, including 3GPP, CPRI, and IEEE to name a few. Another key question relates to splitting the fronthaul between the Lower Layer (RF) and Higher Layer (digital processing) which will help with Cloud RAN deployments.

Similar to 4G, 5G will leverage multiple backhaul technologies depending upon the product type (indoor femtocell vs. outdoor macro cell) along with the available resources (urban environment with fiber available vs. rural environment with ample spectrum available for wireless backhaul).

Wireless self-backhauling in the radio access network can enable simple deployment and incremental rollout by reducing reliance on the availability of wired backhaul at each access node location. Network planning and installation efforts can be reduced by leveraging plug and play type features including self-configuration, self-organization, and self-optimization.

Self-backhauling can leverage the advantages of mmWave RAT, which provides wide bandwidth and high spectral reuse due to narrow beams supported on both link end points.

Based on the deployment scenario, access and backhauling can share the same frequency resources – referred to as Integrated Access and Backhaul (IAB) – or operate in different bands, for example, mmWave RAT for backhaul and sub-6/LTE for access.

3GPP SA1 has defined requirements for wireless self-backhauling, including:

- Leveraging of NR and E-UTRA for self-backhaul links
- Operation in indoor and outdoor scenarios
- Flexible partitioning of radio resources between access and self-backhaul
- Autonomous configuration of access and self-backhaul functions
- Multi-hop transport to enable flexible extension of range and coverage area
- Autonomous topology adaptation to minimize service disruptions
- Topological redundancy to enhance reliability and capacity, and reduce latency.

3GPP RAN Plenary has approved IAB/self-backhauling as an NR project starting at the end of calendar year 2017.

7. CONCLUSION

5G system architecture has to be highly adaptable to meet the performance expectations to serve new and legacy use cases, services, business models, infrastructure usage approaches and radio access needs that will emerge with 5G.

Separation of the user plane from the control plane is one of the key technological changes in the path to 5G evolution. Considering that 5G use cases and deployment architectures may lead to significant wireless bandwidth densities, it's clear that distribution of the traffic towards the edge is imperative for 5G networks.

While it can be argued that 4G cores can be distributed further out to address the need, the connection oriented architecture makes distribution cumbersome. Thus, with separate user plane functions distributed along with edge-computing solutions and Distributed Mobility Management (DMM), allowing the breakout of the traffic closer to the edge, it will be possible to push out data-heavy application processing (such as enhanced video services, immersive user experience, virtual reality, and vehicle-to-vehicle/infrastructure communications). This shift avoids backhaul costs and bottlenecks, and meets 5G latency requirements.

Technology enhancements in the 4G Core will be used to inform and guide the development of 5G standards and technologies. Most of the technology is in place, and key projects are under way. The path will require continued 4G development for legacy device support and 5G development as specifications become available. The result will be a core that is small but supports the numerous use cases posed by 5G through configuration and the support of numerous underlying technologies.

GLOSSARY

3GPP	3rd Generation Partnership Project
4G	Fourth Generation Mobile Networks
5G	Fifth Generation Mobile Networks
AF	Application Function
AMF	Access and Mobility Management Function
APs	Access Points
ARPF	Authentication Credential Repository and Processing Function
AUSF	Authentication Server Function
BF	Beamforming
BL	Bandwidth Reduced Low Complexity
BS	Base Station
CDMA	Code Division Multiple Access
CIOT	Cellular IoT
CN	Core Network
C-U	Control/ User Plane
C Plane	Control Plane
CU	Central Unit
CUPS	Control and User Plane Separation
D2D	Device-to-Device
DCN	Dedicated Core Network
DCF	Distributed Coordination Function
DCI	Downlink Control Indicator
DCN/DECOR	Dedicated Core Network
DÉCOR	Dedicated Core Networks
DL	Downlink
DMRS	Demodulation Reference Signal
DN	Data Network
DRB	Data Radio Bearer
DTLS	Datagram Transport Layer Security

DU	Distributed Unit
EBF	Elevation Beam Forming
eLAA	Enhanced LAA
eLWA	Enhanced LWA
eMBB	Enhanced Mobile Broadband
eMBMS	Evolved Multimedia Broadcast Multicast Service
EMTC	Enhanced Machine Type Communication
eNodeB	Evolved NodeB
EPC	Evolved Packet Core also known as System Architecture Evolution (SAE)
EPC/SAE	Evolved Packet Core/System Architecture Evolutions
EPS	Evolved Packet System
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
FD	Frequency Division
FD	Full Dimension as in FD-MIMO
FDD	Frequency Division Duplex
GBR	Guaranteed Bit Rate
GHz	Gigahertz
GTP	General Packet Radio Service Tunneling Protocol
GTP-C	GPRS Tunneling Protocol - Control
GTP-U	GPRS Tunneling Protocol User Plane
HLCom	High Latency Communications
HLR	Home Location Register
HPLMNs	Home Public Land Mobile Networks
HSPA	High Speed Packet Access
HSPA+	High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA)
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
ICT	Information and Communication Technology

IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IoT	Internet of Things
ISG	Information Services Group
ISO	International Standards Organization
ITU	International Telecommunications Union
ITU-T	ITU-Telecommunication Standardization Bureau
KPIs	Key Performance Indicators
LAA	Licensed Assisted Access
LCM	Life Cycle Management
LDPC	Low Density Parity-Check
LI	Lawful Intercept
LSA	Licensed Shared Access
LTE	Long Term Evolution
LTE-U	LTE for Unlicensed Spectrum
4G LTE	Fourth-Generation Long Term Evolution
LWA	LTE Wireless Local Area Network Aggregation
M2M	Machine-to-Machine
MANO	Management Nodes
MBMS	Multimedia Broadcast Multicast Services
MBMS-GW	Multimedia Broadcast Multicast Services – Gateway
MGCF	Media Gateway Control Function
MEC	Mobile Edge Computing
MIMO	Multiple-Input Multiple-Output
MIOT	Massive Internet of Things
MME	Mobility Management Entity
mMTC	Massive Machine Type Communications
mmWave	Millimeter Wave
MNO	Mobile Network Operator
MOCN	Multi-Operator Core Network
MRO	Mobility Robustness Optimization

MSC-S/MGW	Mobile Switching Center – Server/Media Getaway
MTC	Machine Type Communications
MTC-M2M	Machine Type Communications/Machine-to-Machine
MTC_SIB	Machine Type Communication System Information Block
MU-MIMO	Multi-User Multiple-Input Multiple-Output
MWC	Mobile World Congress
NAS	Non-Access Stratum
NB-IoT	Narrowband IoT
NFC	Near Field Communications
NG	Next Generation
NGC	Next Generation Core
NGMN	Next Generation Mobile Networks Alliance
NFV	Network Function Virtualization
NSD	Network Service Descriptors
NSSAI	Network Slice Selection Assistance Information
NR	New Radio
OEMs	Original Equipment Manufacturers
OTA	Over-The-Air
OTT	Over-the-Top
PCC	Policy and Charging Control
PCEF	Policy and Charging Enforcement Function
PCF	Policy Control Function
PDN	Public Data Network
PDSCH	Physical Downlink Shared Channel
PDU	Packet Data Unit
P-GW	Public Data Network Gateway
PLMN	Public Land Mobile Network
PS	Packet Switched
PSM	Power Saving Mode
QCI	QoS Class Identifier
QoE	Quality of Experience

QoS	Quality of Service
RAN	Radio Access Network
REST	Representation State Transfer
RESTful	Representation State Transfer based
RLC	Radio Link Control Layer
RRC	Radio Resource Control
RRM	Radio Resource Management
RTP	Real-time Transport Protocol
SA	System Architecture
SCG	Secondary Cell Group
SDN	Software-Defined Networking
SDOs	Standards Development Organization
SEA	Security Anchor Function
SeGW	Security Gateway
SGW	Serving Gateway
SIM	Subscriber Identity Module
SMARTER	Services and Markets Technology Enablers
SMF	Session Management Control Function
SON	Self-Optimizing or Self-Organizing Network
TDD	Time Division Duplex
TD-LTE	Time Division LTE
ToS	Type of Service
TDD	Time Division Duplex
UDM	Unified Data Management
UE	User Equipment
UIC	International Union of Railways
UMTS	Universal Mobile Telecommunication System (also known as WCDMA)
U Plane	User Plane
UPGW	User Plane Gateway
UPF	User-Plane Function

URLCC	Ultra-Reliable Low Latency Communication
UTRAN	Universal Terrestrial Radio Access Network
V2X	Vehicle-to-Everything
VCC	Voice Call Continuity
VNF	Virtualization of Network Functions
VoLTE	Voice-over-LTE
ViLTE	Video over LTE
WI	Work Item

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