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Abstract

This deliverable is intended to keep track of the evolution of the 5G technologies since the TRIANGLE project proposal was submitted and the project started. Intention is to identify potential relevant candidates which can be included in the TRIANGLE test bed. The document includes the description of new 5G features released by the standardization bodies and the possible relevance for the project. This deliverable will be used as input in the WP4 activities for the identification of new 5G functionalities that could be included in the testing framework. The scope of this version covers evolutions until March 2018.

Keywords

5G, ITU-R, 3GPP, ETSI, LTE, LTE-A, Wi-Fi, Automotive, Internet of Things

Executive summary

TRIANGLE, as project started on January 2016. The original description of action, which is the core of the project, was developed and completed by the consortium during summer 2015. The content of the project was aligned to the known state of the art available during summer 2015 with anticipation of where 5G would be evolving towards in the next couple of years.

However, an interested reader and 5G enthusiast would recognise that 5G today is a highly dynamic research topic. Maturation of the technology is still an on-going international effort via e.g. H2020 projects in Europe but also private consortiums across the world. Full anticipation of the 5G evolutions is therefore not possible.

Based on this assumption, the consortium decided to, on a regular basis, look back at 5G evolutions and understands their potential impact on the TRIANGLE project. This document summarizes the important 5G evolutions known up to March 2018, 27 months after the start of the project. It is the 3rd revision after D2.3 (first edition, D2.4 (second revision).

Before entering the core of the topic, we need to refresh the project scope itself.

The focus of TRIANGLE is the development of a framework that facilitates the evaluation of the QoE of new mobile applications, services and devices designed to operate in the future 5G mobile broadband networks. The framework will exploit an existing FIRE facility, PerformNetworks, adding new facilities and/or components when necessary.

The project identifies reference deployment scenarios, defines new KPIs (Key Performance Indicators) and QoE (Quality of Experience) metrics, develop new testing methodologies and tools, and design a complete evaluation scheme. The project develops a framework to ensure users QoE in the new challenging situations, especially those due to heterogeneous networks and considering the role software will have in the new 5G ecosystem.

The framework as value added also provide the means to allow certification and quality mark for the applications, services and devices compliant to the requirements and test specifications developed in the project but also extensible to other FIRE test solutions. This will allow vendor differentiation, especially startups and SMEs, in the current globalized and competitive markets and further visibility of FIRE facilities.

The framework, methods and tools developed during the project will focus on providing the mechanisms to incorporate new wireless technologies and topologies envisaged in 5G and contribute to the new ecosystem.

Starting from the current project scope, the consortium has identified the following areas as being important to be monitored as of now: IoT (section 2), heterogeneous access networks (section 3), the evolution of the RAN and core network and it's virtualisation (section 4) to conclude with automotive (section 5) and the application requirements it brings.

Beside the specific technologies, the consortium also follows the standardisation movements in groups such as 3GPP, ITU (see section 7), and the evolution of test beds under development (Section 6). We have to note that in the meantime the TRIANGLE thinking and results are now integrated into the NGMN vision documents.

Further information and details can be found in the respective sections. We will here focus more on their potential impact on TRIANGLE.

Two technologies have been selected in 2016/2017 by the consortium to be evaluated on short-term basis. Other technologies will be further monitored.

The first one is Internet of Things (IoT). IoT, operating in licensed band will bring the need for a new kind of testing. The test ranges from R&D test (design and validation) up to conformance test. This kind of needs brings potentially an additional high value test to the TRIANGLE test

bed. For this reason, the decision was taken within the consortium to include NB-IoT (a specific licensed version of IoT) as an additional capability of the TRIANGLE test bed. This choice seems to be a right one as NB-IoT is gaining in momentum.

The second technology which is highly considered within TRIANGLE is the deployment of SDN / NFV capability on a virtualized network. These technologies, if deployed within Triangle, would open the door and increase potential interest for future 5G operators to understand the requirements on the network. The project has implemented and deployed SDN capability to understand the impact it can have on the backhaul network for QoS enforcing. NFV also got attention and first solution will be implemented.

In 2017, based on the previous 5G analysis, the testbed planned to support heterogeneous networking, including functionalities such as Wi-Fi offloading or dual. These actions were completed in Year 2 of the project in task 4.1. and launched in the tesbed release 3.

The automotive use cases, once being the core of potential 5G use cases have been slowed down by multiple standards. This led to the decision within the consortium not to focus on the creation of specific automotive test cases for now. However, the technology and scenarios developed within Triangle are highly leverageable for such industry.

This document is the last release of the 5G evolutions which will influence the testbed. Release 3 of the testbed has been rolled out and is now in use by experimenters. The new evolutions in 5G from April 2018 onwards if any will not be included anymore in the frame of the TRIANGLE EU project but rather be added to the testbed under commercial operation (2019 onwards).

Contents

List of Figures

List of Tables

N/A

List of Abbreviations

2G	Second generation wireless technology
3G	Third generation wireless technology
3GPP	3rd Generation Partnership Project
4G	Forth generation wireless technology
5G	Fifth generation wireless technology
AP	Access Point
BBU	Base Band Units
BS	Base Station
BSS	Business Support System
C-ITS	Cooperative ITS
C-RAN	Cloud RAN
CDMA	Code Division Multiple Access
CO	Confidential
CPRI	Common Public Radio Interface
CTTC	Centre Tecnologic de Telecomunicacions de Catalunya
D	Deliverables
D2D	Device-to-Device
DEN	Decentralized Environmental Notification
DL	Downlink
DRX	Discontinuous Reception
DTX	Discontinuous Transmission
EC-GSM	Extended Coverage GSM
EM	Element Manager
eNB	Evolved Node B
ETSI	European Telecommunications Standards Institute
E-UTRAN	Evolved UTRAN
EVM	Error Vector Magnitude
FCAPS	Fault, Configuration Accounting, Performance and Security
FDD	Frequency Division Duplex
FEC	Forward Error Correction

GCF	Global Certification Forum
GPRS	General Packet Radio Service
GSM	Global System for Mobile communications
HGi	Home Gateway Initiative
HTC	Human Type Communications
ICI	Inter-Carrrier Interference
ICT	Information and Communications Technology
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Communications
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Rights
IR	Internal report
ISG	Industry Specification Group
ITS	Intelligent Transport System
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union-Radio
IVI	In-Vehicle Infotainment
KPI	Key Performance Indicator
LAN	Local Area Network
LBT	Listen Before Talk
LPWAN	Low Power Wide Area Networks
LTE	Long Term Evolution
LTE-A	Long Term Evolution-Advanced
LTE-M	Long Term Evolution For Internet of Things
M	Milestones
Mbps	megabits per second
Mo	Month
MANO	Management and Orchestration
MCL	Maximum Coupling Loss
MEC	Mobile Edge Computing

MGT	Management
MIMO	Multiple-Input Multiple-Output
MMC	Massive Machine Communication
M2M	Machine to Machine
MTC	Machine Type Communications
NB-IoT	Narrow Band Internet of Things
NFV	Network Function Virtualization
NFVO	NFV Orchestrator
NR	New Radio (temporary denomination for new 5G radio)
OBSAI	Open Base Station Architecture Initiative
OCF	Open Connectivity Foundation
OEM	Original Equipment Manufacturer
OIC	Open Interconnect Consortium
OSS	Operation Support System
PC	Project Coordinator
ProSe	Proximity Services
PU	Public
QAM	Quadrature Amplitude Modulation
QMR	Quarterly Management reports
QoE	quality of experience
QoS	Quality of Service
RAN	Radio Access Network
RAT	Radio Access Technology
REC	'Radio Equipment Controllers'

RF	Radio Frequency
R&D	Research and Development
RRH	Remote Radio Heads
SC-PTM	Single Cell Point to Multipoint
SL	Side Link
T	Task
TDD	Time Division Duplex
TS	Technical Specficiation
TTA	Telecommunications Technology Association
UE	User Equipment
UL	Uplink
UMTS	Universal Mobile Telecommunications System
UTRAN	UMTS Terrestrial Radio Access Network
V2V	Vehicle-to-Vehicle
V2X	Vehicle-to-anything
VIM	Virtual Infrastructure Manager
VNF	Virtualized Network Function
VNFM	VNF Manager
WAN	Wide Area Network
WG	Working Group
WFA	Wi-Fi Alliance
WLAN	Wireless Local Area Network
WP	Work Package

1 Introduction to 5G Emerging Technologies

Triangle, being a pre-5G test bed is constantly monitoring the 5G evolution in order to ensure the testbed relevance. Focusing on a target without considering the 5G evolution would limit the chance of being successful from a test bed exploitation perspective.

In this report (finalized - March 2018), we describe the evolution states that took place between the project submission (summer 2015) and March 2018. At consortium level, we identified the following high-level technologies as being potentially relevant for the TRIANGLE project:

- Internet of things with their different flavors (licensed and unlicensed)
- Evolution on the radio interface and ability to integrate heterogeneous networks
- Evolution within the RAN and Core Network towards virtualization of the components
- The automotive impact on 5G applications

Each section elaborates on the technology itself, provides background reading, provides more detail around the state of the art together with a perspective on why this potentially matters for Triangle. When possible, the consortium will take these evolutions into account and upgrade the objectives to reflect this state of the art evolution.

If the technologies covered in this document are known to our readers, we recommend focusing on the sections ‘Impact on TRIANGLE’, which clarifies per technology how the consortium intends to take these evolutions into account.

Beside technology evolutions, the report also provides an overview of the main evolutions and development around other 5G test beds.

Whenever possible, links towards existing documentation are provided rather than copy pasting them into this document.

2 Internet of Things

Internet of Things (IoT) is the term that identifies the paradigm of interconnected systems, machines, and things that communicate and collaborate without human intervention. Contrary to mainstream services for Human Type Communications (HTC) such as web browsing, voice call, video streaming, where, in general, high data rates are essential, IoT (also known as Machine-Type-Communications – MTC) is based on mostly sporadic transmission/reception of small data packets, where the main requirement can be summarized in three main aspects [1]:

- Reliability: IoT devices controlling or monitoring critical services require high reliability, where 99.XX% of the time the information must reach its destination before a critical amount of time. It should be noted that even within the same application, different messages have different reliability requirements (e.g., periodic consumption report vs. alarm message).
- Massive device transmission: the number of IoT devices per cell is in the order of tens of thousands, therefore, scenarios with large number of simultaneous or near simultaneous devices becomes a possibility (e.g., an earthquake). This poses a new challenge for traditional wireless communication systems that were not designed for such cases.
- Ultra-low power consumption: IoT devices are expected to operate for more than 10 years without charging or replacing the battery.

To cope with the new set of requirements, a variety of new communication systems, protocols and message exchange formats are being developed in recent years. These can be organized in three main categories:

- Licenced spectrum: mainly lead by 3GPP with the standardization of LTE for machines (LTE-M) in release 12 and 13, and Narrow Band-IoT (NB-IoT), which are explained in the following sections. In addition, there is an ongoing effort to evolve GSM for IoT denoted as Extended Coverage GSM (EC-GSM).
- Unlicensed spectrum: the main initiatives are the Wi-Fi for IoT (IEEE 802.11ah), and proprietary networks for IoT such as SiGFox and LoRa.
- Interoperability: lead by ETSI and its oneM2M standard to ensure inter-operation between IoT devices from different manufacturers.

Also AllSeen Alliance and OCF are defining methods of communication among devices so that they can be recognized and information exchanged.

2.1 Licensed Spectrum

This section describes the main activities and protocols for MTC in the licensed spectrum. These new radio access systems are expected to occupy part of the spectrum that has, so far, been allocated to 2G networks (800-900MHz band) due to its better propagation properties.

Highlights from 3GPP release 14:

- Support for positioning. This feature is present in all 3GPP IoT protocols. The devices can measure the time difference between specific signals from several base stations and report the differences to the network. This feature will enable new position-aware services and will allow to easily track devices.

- Support for multicast SC-PTM (Single Cell Point to Multipoint). It supports broadcast/multicast services over particular areas in the cell. The area covered by the service can dynamically modified
- Support for VoLTE. LTE-M devices will be VoLTE capable.

NB-IoT Highlights from 3GPP release 15:

- Support for TDD mode.
- Further latency and power consumption optimizations.
- Improvements in device power measurement reports.

LTE-M Highlights from 3GPP release 15:

- Support for higher moving speeds (up to 200 kph)
- Support for lower power transmissions.
- Better spectral efficiency

2.1.1 Enhanced Machine Type Communications (eMTC) and LTE-M

3GPP has completed a study (TR 36.888) on optimizing LTE for MTC (Machine-Type Communications) to provide devices that are competitive with 2G, which in turn, will move MTC traffic from outdated 2G networks to the new and more efficient LTE networks [2] [3].

One important aspect for enhancing MTC is the intended coverage improvements of MCL 15-20dB which is higher when compared with traditional cellular networks, such as GSM or LTE. The main reason behind such effort is due to the challenging locations of some IoT devices, e.g., smart meters in the basement of houses [2].

In addition to the coverage improvements, one fundamental enhancement is the reduction of device complexity in order to reduce the cost of IoT devices. For that end, the requirements on UE bandwidth for devices in release 12, denoted as category ‘0’, were relaxed to 1.4MHz in the uplink, while maintaining the bandwidth for the downlink. Further improvements were done in release 13, denoted as LTE-M, where the downlink bandwidth is also reduced to 1.4MHz, with the aim of further reducing device complexity. The reduced downlink capacity imposes a series of major modifications on the network, as current control channel in LTE can spread over 20MHz.Therefore, LTE-M can be seen as spin-off of LTE, with a separated control channel and where multiple LTE-M cells could be expected within a single LTE cell. The main feature enhancements for release 14 are support for VoLTE, positioning and multicast. These changes will enable a new range of services for IoT that were not previously supported.

2.1.2 Narrowband Internet of Things (NB-IOT)

NB-IoT corresponds to a clean slate design of a radio access network specifically designed for MTC.It addresses the massive number of IoT devices per cell, low throughput and extended battery life. NB-IoT can be seen as an evolution of the LTE-M in respect to the optimization of the device complexity/cost with a bandwidth of only 200 kHz (i.e., the equivalent to one resource block in LTE). It is also seen as the ideal candidate to support legacy 2G devices [4]. NB-IoT was first introduced in release 13. The main feature enhancements for release 14 are support for positioning and multicast, further power consumption and latency reduction and potentially

new power classes (e.g., 14 dBm).NB-IoT is particularly suitable for the re-farming (repurposing)of the traditional GSM channels.

2.1.3 Extended Coverage GSM for Internet of Things (EC-GSM-IoT)

The idea of EC-GSM standardization track is to moderately change legacy GSM/GPRS in order to achieve extended coverage, while allowing co-existence with existing GSM deployments. In normal coverage conditions the same physical layer speeds as today can be achieved and legacy devices are supported. When a device is out of coverage in a legacy network, the extended coverage features are obtained via blind repetitions of the messages. Finally, it should be noted that like NB-IoT, EC-GSM also features a reduced level of signalling traffic, obtained through new simplified control messages [5]. EC-GSM was first introduced in release 13. The improvements for release 14 focus on the radio interface modifications that will allow transmissions for higher coverage classes and support for positioning.

2.2 Unlicensed Spectrum

The ISM band is considered an interesting option for massive deployment of devices, as no license to use the medium is necessary. Devices operating in this band should use techniques to avoid creating excessive interference to other devices in the same band. These included mainly LBT (Listen Before Talk) or low duty cycles. Devices that implement LBT are required to sense the channel before transmitting to avoid disturbing other devices using the band. Devices with very low duty cycles are not required to sense the medium before transmission, as they transmit at low power and use the band for a very brief period of time. The main advantage of these types of networks is also its main disadvantage, unregulated spectrum. This implies that at any time an existing network might be disrupted by a new deployment.

3GPP has not decided yet whether or not the new air interface (and LTE) should operate in unlicensed spectrum, and without the use of an anchor carrier in licensed spectrum.

2.2.1 SIGFOX

SIGFOX provides an end-to-end solution for the communication chain, from objects through to information systems, with low pricing models and low energy consumption.

As a network operator SIGFOX operates fixed-location transceivers (equivalent to base stations) and enables objects (equivalent to terminals) to be connected “out of the box”. The SIGFOX transceivers and the entire SIGFOX connectivity solution has been developed, built and deployed to only serve the low throughput M2M and IoT applications.

SIGFOX uses a UNB (Ultra Narrow Band) based radio technology to connect devices to its global network. The use of UNB is key to providing a scalable, high-capacity network, with very low energy consumption, while maintaining a simple and easy to rollout star-based cell infrastructure.

The network operates in the globally available ISM bands (license-free frequency bands) and co-exists in these frequencies with other radio technologies. SIGFOX currently uses the most popular European ISM band on 868MHz (as defined by ETSI and CEPT) as well as the 902MHz in the USA (as defined by the FCC), depending on specific regional regulations. In terms of compatibility, the network takes a similar approach to traditional GSM networks. Any device with integrated SIGFOX hardware can connect to the Internet, in regions where a SIGFOX network has been deployed, without any external hardware, like a Wi-Fi or Zigbee router. The SIGFOX network, however, is entirely different from traditional GSM networks, in that it can only transmit small amounts of data, at just 100 bits per second.

The SIGFOX Back-end provides a web application interface for device management and configuration of data integration, as well as standards based web APIs to automate device management and implement data integration. These APIs use HTTPS REST requests, as GET or POST and the payload format is JSON.

SIGFOX is collaborating with ETSI on the standardization of low throughput networks.

The SIGFOX Ready™ certification process aims to ensure the optimal radio capacity of their devices, and thus guide the customers in regards to the coverage that can be expected for the SIGFOX devices. Only certified devices can claim to be SIGFOX Ready™.

2.2.2 LoRa

The LoRa Alliance is an industrial association involved in the standardization of Low Power Wide Area Networks (LPWAN) to enable Internet of Things (IoT), machine-to-machine (M2M), smart city, and industrial applications.

LoRaWAN is a Low Power Wide Area Network (LPWAN) specification intended for wireless battery operated Things in regional, national or global networks. LoRaWAN targets key requirements of IoT such as secure bi-directional communication, mobility and localization services. This standard provides seamless interoperability among smart Things, without the need of complex local installations and gives back the freedom to the user, developer, and businesses enabling the role out of Internet of Things.

LoRaWAN networks layout typically follows a star-of-stars topology in which gateways relay messages between end-devices and a central network server at the backend. Gateways are connected to the network server via standard IP connections while end-devices use single-hop LoRa™ or FSK communication to one or many gateways. All communication is generally bi-directional, although uplink communication from an end-device to the network server is expected to be the predominant traffic.

A new specification covering Regional Parameters (EU, US, China, Australia...) has been released.

LoRa launched a Certification Program in November 2015 which will confirm that the end device meets the functional requirements of the LoRaWAN™ protocol specification, and includes a suite of tests that are specified in the LoRa® Alliance End Device Certification Requirements document. A device manufacturer must be a member of the LoRa® Alliance to be LoRa® Certified, and must use one of the accredited LoRa® Certification test houses to do the functional protocol testing.

The Certification Program includes a suite of regional tests:

- LoRa Alliance European EU 863-870MHz
- LoRa Alliance US + Canada US902-928MHz
- LoRa Alliance Asia AS 923MHz
- LoRa Alliance South Korea 920-923MHz

According to the LoRA web site [6], the number of LoRaWAN™ Certified Products sums more than 90 devices in March 2018.

2.2.3 Wi-Fi Alliance: HaLow

There is a Task Group in the Wi-Fi Alliance called “Wi-Fi HaLow Marketing Task Group” whose main focus is to extend Wi-Fi’s usefulness for new device categories and applications with very

constrained power requirements and need for long-range connectivity based on the IEEE 802.11ah standard [7].

Wi-Fi Alliance issued a press release publicly announcing the Wi-Fi HaLow brand on January 4th, 2016 According to the WFA, "*Wi-Fi HaLow extends Wi-Fi into the 900 MHz band, enabling the low power connectivity necessary for applications including sensor and wearables. Wi-Fi HaLow's range is nearly twice that of today's Wi-Fi, and will not only be capable of transmitting signals further, but also providing a more robust connection in challenging environments where the ability to more easily penetrate walls or other barriers is an important consideration. Wi-Fi HaLow will broadly adopt existing Wi-Fi protocols and deliver many of the benefits that consumers have come to expect from Wi-Fi today, including multi-vendor interoperability, strong government-grade security, and easy setup*" [8].

Wi-Fi HaLow™ is optimized for the following IoT use cases:

- Connected Home, Industrial Automation, Wearables. Longer range and superior wall penetration for whole house, factory, or farm coverage plus lower power facilitates coin-cell devices like door locks, water detectors, and sensors.
- Wearables and sensors: Lower power, shorter control packets, and longer standby times give wearables and sensors significantly longer battery life.
- Dense deployments, venues, and utilities are well served by 802.11ah that allows a large number of devices (1000s) per AP and requires lower power per node.

Wi-Fi HaLow™ is designed to provide the following features:

- Operates in available, existing unlicensed spectrum in the 900 MHz band with few geographic exceptions.
- Narrower bands optimized for low traffic load typical of IoT applications: 1, 2, and 4 MHz channel operation required.
- Narrow bandwidths and long sleep cycles yield much greater power efficiency than traditional Wi-Fi at similar range to 2.4/5GHz networks.
- Vendor estimates indicate comparable or better power performance than Bluetooth Low Energy or Zigbee sensors on a per-bit basis.
- Better signal propagation at the low end of the RF spectrum; easier transit through walls and other obstructions.
- Data rates range from 150 kbps – 18 Mbps at lower channel widths.

The main output of the Wi-Fi HaLow Marketing Task Group has been the document called "Marketing Requirements Document for Interoperability Testing of Certified ERah Devices" [8] to develop an interoperability certification test-plan for Wi-Fi Alliance Certified interoperability of ERah devices (Extended Range ah).

The WFA is aware of the fact that Wi-Fi is relatively late with a technology that addresses the low power consumption requirements for the IoT market compared to ZigBee, Bluetooth, or Z-Wave. WFA also acknowledges that Wi-Fi market entry into new bands has historically taken long time to worldwide adoption. In response to that context, WFA created in mid-2015 the "Wi-Fi HaLow Technical Group" to develop an interoperability certification test-plan for Wi-Fi Alliance Certified interoperability of 802.11ah devices.

The Wi-Fi HaLow Technical Group initially set the deadline for the Wi-Fi HaLow program launch to be in the second quarter of 2017. Even though some technology articles report that Wi-Fi

HaLow is expected in 2018 [9], the latest Wi-Fi Alliance Certification Program Roadmap [10] published in February 2018 has postponed again the program launch from mid-2019 to2020.

2.3 Interoperability

2.3.1 AllSeen

The AllJoyn, originally designed by Qualcomm, is now managed by the Linux Foundation and is a registered trademark of AllSeen. AllSeen who handles certification (AllJoyn certified) is probably the first industry consortium certifying IoT devices (October 2015). AllJoyn, the underlying technology, is an open-source framework that defines service interfaces that devices can implement to enable various features. AllJoyn does not specifically define device types, but rather services that devices can support or interact with. Although other technologies are supported, AllJoyn, which focuses on proximal connectivity, was developed with Wi-Fi in mind.

Since October 2016 Allseen has merged with OCF (Open Connectivity Foundation) under the OCF name and bylaws.

2.3.2 oneM2M

oneM2M was launched in 2012 as a global initiative to ensure the most efficient deployment of Machine-to-Machine(M2M) communications systems and the Internet of Things(IoT). The Partner Type 1 organizations in oneM2M as follows:

- ARIB: Association of Radio Industries and Businesses, Japan
- ATIS: Alliance for Telecommunications Industry Solutions, US
- CCSA: China Communications Standards Association
- ETSI: European Telecommunications Standards Institute
- TIA: Telecommunications Industry Association, US
- TSDSI: Telecommunications Standards Development Society, India
- TTA: Telecommunications Technology Association, Korea
- TTC: Telecommunication Technology Committee, Japan

The goal of oneM2M is to develop technical specifications which address the need for a common M2M Service Layer that can be embedded within various hardware and software to connect the wide range of devices worldwide with M2M application servers.

ETSI organized a M2M workshop in December 2015.

In August 2016, ETSI published oneM2M Release 2 specification [11].

ETSI is currently leading the development of the interoperability test specifications (TS-0013) thatis planned to be completed in 2017. The latest version was published in January 2017. The purpose of the test specification is to prove end-to-end functionality between Application Entities and Common Service Entities over the main reference points. The document includes 98 tests.

In 2017 oneM2M has defined a certified program which is "*intended to create an ecosystem of certified products that ensures interoperability between them*" [12]. TTA (Telecommunications Technology Association) is the only Certification Body and Authorized Test Laboratory for the oneM2M Certification.According to the oneM2M certification web site [12], the number of oneM2M Certified Products sums 15 devices in March 2018.

2.3.3 OCF

This organization has been one of the most important organizations in 2016 due to its impressive list of members as Intel, Qualcomm, Microsoft, Samsung, GE and Cisco.

The OCF specification defines OCF framework including standard model for IoT devices, apps & services to interact. OCF adopted RESTful APIs and CoAP protocol. It defines two logical roles: server (exposing hosted resources) and client (accessing resources on a server).

OCF sponsors the IoTivity Project, an open source reference implementation of the OCF framework to help easy industry adoption. These implementations are available on Android, Linux, Tizen and Windows Operating Systems.

They launched a certification program and designed 6 authorised test laboratories and have certified so far more than 2300 device implementations last year.

OCF promotes the goal of broad interoperability via collaboration with other organisations and standards as oneM2M.

2.4 Impact on TRIANGLE

Current and forecast market evaluations (such as Cisco's forecast of a 14.4T$ global IoT market by 2022 [13]) show that IoT has a huge revenue potential, to be shared between operators, service providers, hardware and testing solutions vendors. Thus, it is not surprising that IoT is currently one of the hottest topics in the telecommunications world, as endorsed by both industry and academia. Moreover, IoT is often considered as the road to 5G due to the new set of requirements that this use case imposes, for which traditional wireless communication systems were not originally designed.

TRIANGLE, focusing on the evolution towards 5G networks, considers IoT as a unique opportunity for learning and testing new requirements. The main focus of TRIANGLE will be on licensed spectrum solutions, where it is expected that developers will expend more efforts optimizing their solutions, due to the need for conformance and interoperability testing. Such needs come from the prevention of higher direct, and indirect costs,that are associated with eventual technology mismatches between devices when compared to unlicensed technologies.

Licensed bands are in fact stable use cases in terms of testing. The standards that operate in such bands have a solidified process that has been created and improved in the past decades, and is constantly being refined by standardization bodies such as 3GPP. For this reason, TRIANGLE, as a testing-oriented project, is focusing mostly on such standards.

The project has chosen to follow and implement NB-IoT 3GPP features as part of WP4, enabling the testability of pre-standard devices and applications. These implementations will be supported by the development of specific use cases and testing processes in WP2. They will be disseminated as marketable feature in the open calls in WP5, with the idea of attracting technology forerunners in using the test bed as a service.

However, it is noted that the procedures developed for the licensed solutions are expected to also be applicable in the other cases. The project will constantly monitor both the licensed and unlicensed bands standards in case major testing processes and needs will appear, justifying the use of a TRIANGLE test bed as a commercial solution.

The consortium has recently reached an agreement to receive one of the CommSolid devices for evaluation and testing. This device is one the first commercial IoT devices that supports Cat-NB1, also known as NB-IoT.

Release 15 (expected completion date June 2018) will not have a significant impact in TRIANGLE. Most of the new features defined in the standard are further optimizations of already existing procedures.

3 Heterogeneous Access Networks

To make the exponential growth of connections in the access network feasible, the heterogeneous networks (HetNets) concept has been included as part of the forthcoming 5G technologies. HetNets combine LTE cells of different sizes, non-3GPP access technologies, and the utilization of new frequencies, as well as carrier aggregation. Most of these technologies have already been included in the latest 3GPP releases as part of LTE-A, paving the path to 5G.

Getting all these technologies to work together presents a challenge, as seamless mobility between technologies or dynamic/fast switching between frequencies, cells and RATs need to be ensured.

3.1 3GPP

The TSG Radio Access Network (TSG RAN) is responsible for the definition of the functions, requirements and interfaces for the UTRAN, E-UTRAN and beyond. The “RAN 5G Workshop – The Start of Something (September 19, 2015)” [14] event covered the full range of requirements that will feed TSG RAN work items for the following five years. There was a consensus that there will be a new, non-backward compatible, RAT as part of 5G, supported by the need for LTE-Advanced evolution in parallel.

In June of 2016, 3GPP TSG RAN#72 agreed on a detailed workplan for Release 15 (this release would define the 5G system architecture). By the end of 2017, a first set of stage 2 level specifications was achieved in the context of Release 15, allowing the deployment of operational 5G system. The complete description is provided by the following specifications:

- TS 23.501 [15]
- TS 23.502 [16]
- TS 23.503 [17]

By June 2018, TSG#80 will execute Release 15 stage 3 freeze for NR and NexGen, including Standalone architecture.

3.1.1 Multi-RAT/multi-carrier Base Station

RAN WG4 (RAN4), in charge of the development of specifications regarding UTRA, E-UTRA and beyond on radio performance and protocol aspects, has published a technical report for the work item on Multi-Standard Radio (MSR) [18].This has the objective of identifying relevant scenarios and writing an RF requirements specification that is applicable to Multi-Standard Radio (MSR) Base Station with multiple carriers, and/or multiple 3GPP Radio Access Technologies (RAT).

3.1.2 Dual Connectivity

In the 3GPP dual connectivity scheme the UE can receive/transmit data from/to multiple eNBs simultaneously (also called inter-eNB carrier aggregation). There is a Master eNB (MeNB) and one or more Secondary eNBs (SeNB). Supporting dual connectivity requires changes in S1 and X2, and aggregation/splitting traffic at the backhaul and transport related protocols. LTE release 12 only considers one SeNB and defines the implementation by splitting control and user plane. Control plane at RRC level is only with the MeNB, while the data plane includes both MeNB and SeNB. The data plane can be implemented in several ways: splitting the traffic (bearers) at the S-GW or at the MeNB (requires X2).

3GPP 36 series include Dual Connectivity as standard functionality within E-UTRA architecture since release 12. The 3GPP Technical Documents involved in the specification process for Dual Connectivity are as follows:

- TS 36.300 (Evolved Universal Terrestrial Radio Access (E-UTRA)) [19].
- TS 36.875 (Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Extension of dual connectivity in E-UTRAN) [20].
- TS 36.331 (Evolved Universal Terrestrial Radio Access (E-UTRA); Radio Resource Control (RRC)) [21].
- TS 36.412 (Evolved Universal Terrestrial Radio Access Network (E-UTRAN); S1 Application Protocol (S1AP)) [22].
- TS 36.465 (Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Wireless LAN (WLAN);Xw interface user plane protocol) [23].

3GPP RAN2 has recently released a technical report called “Study on New Radio Access Technology” [24]. This report introduces some subjects regarding dual connectivity between LTE and NR, namely protocol functionality to be added and user and control plane protocol architecture.

3GPP Release 15 technical specifications on 5G system architecture (see [15] and [16]) includes Dual Connectivity as supported functionality. A deeper description of NR DC is shown in the technical specification TS 37.340 [25]. In this document, different DC scenarios are defined, for instance Multi-RAT DC for E-UTRA-NR, which enables dual connectivity by using concurrently 5G and 4G nodes.

3.1.3 FDD/TDD carrier aggregation

3GPP Release 12 will enable the use of FDD/TDD carrier aggregation for intra and inter-band cases, with either FDD or TDD as the Master Cell, providing more flexibility by using low band FDD for better coverage, and high band TDD for higher data rates.

A technical report called “Study on LTE Time Division Duplex (TDD) – Frequency Division Duplex (FDD) joint operation including Carrier Aggregation (CA)” [26] has been published. The main objectives of this are in identifying deployment scenarios of joint operation on FDD and TDD spectrum, identify possible solutions and consider whether such solutions, if any, need to be added to the Work Item which initiated this study or in separate Work Items. The outcome of this study is to support a solution that is not based on CA for TDD-FDD joint operation. Instead, it would be desirable that the dual connectivity feature would be designed to support TDD-FDD dual connectivity in the applicable scenarios, in addition to TDD-TDD and FDD-FDD dual connectivity.

The Work Item Document RP 131399 “LTE TDD – FDD Joint operation including CA” includes the list of relevant 3GPP TS to the specification process of FDD/TDD aggregation.

As a consequence, NR specification reports recently delivered do not include TDD-FDD Join Operation CA amongst 5G RAN functionalities. TR 37.865-01-01 “Intra-band (mDL/1UL) and Inter-band (nDL/1UL) NR Carrier Aggregation” [27] provides further information on NR carrier aggregation capabilities.

3.1.4 IP flow mobility between 3GPP and a WLAN (Wi-Fi offloading)

This functionality, conceived as a way to extend the existing cellular network capacity, allows 3GPP network users to access LTE networks through WLAN access points, performing seamless handover procedures between both radio access technologies. Wi-Fi offloading

reduces the data traffic that base stations have to support, freeing RF resources for other users. Wi-Fi is a suitable technology to extend LTE capacity, as it uses an unlicensed spectrum available worldwide and it is a widespread standard technology, especially in indoor environment, where most of the data traffic is generated.

The technical specification 3GPP TS 23.261 “IP flow mobility and seamless Wireless Local Area Network (WLAN) offload“ [28] depicts the system description for IP flow mobility and seamless WLAN offload. In March 2017, a new version of 3GPP TS 23.261 was published, adapting LTE WLAN offloading specification to Release 14.

Under Release 15, connectivity of the UE via non-3GPP access networks (e.g. WLAN) with 5G Core Networks is supported. However, in this release only untrusted non-3GPP access is defined, deployed outside the NG-RAN (referred to as “standalone” non-3GPP access, see [100]).

Non-3GPP access networks shall be connected to the 5G CN via a Non-3GPP InterWorking Function (N3IWF), which interfaces with control plane and user plane via N2 and N3 interfaces. The UE connected to the standalone non-3GPP access supports NAS signaling with NG-CN using the N1 reference point.

3.1.5 LTE – License Assisted Access

The use of LTE directly in unlicensed spectrum, instead of by means of Wi-Fi offloading, was motivated by the possibility of achieving higher spectrum efficiency and a more seamless method of offloading, while continuing to use the same radio core technology for both licensed and unlicensed spectrum. The coexistence of both Wi-Fi offloading and LTE directly in unlicensed spectrum has been widely studied by 3GPP. Its conclusion was that this coexistence is feasible. Thus, mobile operators will be able to use both technologies to offload data to unlicensed spectrum.

The use of unlicensed spectrum will be assisted by using the License Assisted Access (LAA). 3GPP has finished a study on the necessary modifications of LTE to operate in unlicensed spectrum called “Feasibility Study on Licensed-Assisted Access to Unlicensed Spectrum” [29]. Based on its conclusion, 3GPP RAN decided to move the project to the normative phase with the specification of LAA downlink operation in release 13 and is currently working on specifying LAA for uplink operation in Release 14. Although Docomo and Huawei announced in 2014 that their joint test successfully demonstrated that LTE can be deployed over the 5 GHz unlicensed spectrum in indoors, work on the development of a test plan to ensure fair coexistence continues (see section below).

While 3GPP is developing LAA specifications, there has been a request to conduct multi-node tests where two wireless systems share the same unlicensed spectrum and their system performance is to be ensured, e.g. between two LAA systems or between LAA and other wireless systems, e.g. Wi-Fi. Procedures for testing coexistence of LAA with other systems operating in the same band are described in 3GPP TR 36.789 [30]approved in June 2017 under version 1.0.0 in release 13 of the specifications. This Technical Report defines “Multi-node tests” to verify LAA coexistence, more specifically Throughput and Outage tests. The scope of these tests is to verify cross-technology coexistence, with emphasis on coexistence between LAA and IEEE 802.11 operating in the same spectrum.3GPP has no current work item for the development of pass/fail criteria for multi-node coexistence testing, no approved study item to extend 3GPP TR 36.789 to cover LAA Rel-14, and considers it beyond the scope of 3GPP to either mandate co-existence tests or specify pass/fail criteria for coexistence tests with technologies developed outside 3GPP.

3.2 WFA: Coexistence with LTE in unlicensed band

There is a Task Group in the Wi-Fi Alliance called “Coexistence” whose main focus is to study mechanisms for coexistence in the unlicensed bands, and to define baseline performance evaluations for coexisting systems [7].

Their major work in 2015 has been to develop the document “Coexistence Guidelines for LTE in Unlicensed Spectrum Studies” [31]. This document seeks to provide a common basis upon which future Wi-Fi / LTE coexistence studies may be conducted, and provides a strong foundation upon which to build an unlicensed LTE test plan.

The purpose of this coexistence analysis has been to determine whether an LTE network impacts a Wi-Fi network any more than a Wi-Fi network impacts another Wi-Fi network. According to the WFA, this document does not constitute a test plan by which conformance of LTE devices with Wi-Fi Alliance minimum requirements for coexistence can be assessed.

The document highlights three important aspects that should be the basis of coexistence studies:

- Identify the appropriate key performance indicators (KPIs) that characterize the performance of different types of traffic, and specify how the KPIs should be measured and presented.
- Specify the topologies of the Wi-Fi/LTE networks to be studied, which include the number of devices, their geographic spacing, and other physical characteristics of the setup.
- Define the type and mix of data traffic that loads the network under study.

The current version of the document “Coexistence Guidelines for LTE in Unlicensed Spectrum Studies” [31]is 2.0 and was released on January 8th, 2016.

They have also completed the work on a test plan document called “Coexistence Test Plan” [32]. This document seeks to verify the performance of coexistence algorithms such as LTE-U Forum CSAT, and to measure the impact of unlicensed LTE on a Wi-Fi network to determine the unlicensed LTE device coexistence behaviour in an unlicensed spectrum. The document details the required test equipment, configurations, procedures, expected results, and pass/fail criteria.

The current version of the document “Coexistence Test Plan” [32]is 1.1.10 and was released on January11th, 2018 As 3GPP has no plans to include pass/fail criteria in TR 36.789 (see 3.1.5) WFA is has revised its Coexistence Test Plan to include coverage of coexistence between Wi-Fi and LTE-LAA. In summary, the updated WFA test plan is now generic to downlink-only 5GHz unlicensed technologies, including LTE-U and LAA.

3.3 Mm-wave, NR – New radio access

The enormous amount of connections that are foreseen for the following years, the huge data rates demanded by users, and other extreme requirements included within 5G, are not sustainable using only the LTE-A radio access approach. Thus, a new radio (NR) access technology is imperative, and the use of high-frequency signals in the millimetrer-wave frequency bands is one of the most promising technologies.

In August of 2017 3GPP delivered a study, “Study on scenarios and requirements for next generation access technologies” [33], in which the utilization of mm-wave frequency bands was taken in consideration as one of the possible features to be included in the forthcoming next generation access technologies. The outcome of this study highlighted the relevance of supporting the potential use of frequency range up to 100 GHz.

Whereas the LTE evolution will focus on a more efficient use of the spectrum under 6 GHz, 5G will also introduce the use of new spectrum above 6 GHz, and in the millimeter-wave frequency bands. Such bands provide large bandwidths and are capable of multi-Gbps data rates, and extremely dense spatial reuse, resulting in a significant capacity increase. Millimeter waves imply high propagation losses and susceptibility to blockage from buildings and other elements. To solve this issue, the use of massive MIMO (feasible with relatively small antennas due to the size of millimeter wavelengths) has been proposed. This will enable highly directional transmissions (and reception), which will overcome the path loss, and thus, increase the achievable data rates. Additionally, it is necessary to develop efficient continuous beam searching and tracking algorithms to discover and switch to the dominant beam path, which is continuously been modified according to the channel conditions. Furthermore, multipoint connectivity is another functionality to be included in the new radio access, so that 5G mobile devices could concurrently connect to several cells, ensuring a more reliable high-quality connection.

Because of the characteristics of the higher frequencies, LTE bands will be used to provide wide-area coverage, while the new upper bands will allow leveraging of data rates in specific areas. Thus, the coexistence of both technologies and interworking of low and high frequency bands are needed, and will play an important role in the forthcoming 5G network design.

In December of 2017, 3GPP TSG Radio Access Network (TSG RAN) group completed the first implementable 5G NR specification for Non-Standalone (NSA) operation as part of Release 15, which enables global mobile industry to start full-scale trials and commercial deployments. 3GPP will continue the development of Release 15, including Standalone (SA) 5G NR operation design compatible with NSA operation in a unified way.

Relevant vendors have already developed several technology demonstrators of mmWave radio access solutions:

In February of 2018, Verizon, partnering with Nokia and Qualcomm, performed the first over-the-air call based on the recently defined 3GPP 5G NR NSA specification and using millimeter wave spectrum. The test utilized 28GHz spectrum and transmitted 4K video stream, and was completed over Nokia’s CloudRAN solution and Qualcomm’s 5G NR mmWave prototype device with an optimized mmWave RF front-end design.

The South Korean operator KT, along with Samsung and Qualcomm, is performing tests on 5G NR in the 3.5 GHz and 28 GHz bands. The latter band, millimeter wave frequencies, is planned to be used for massive, hot spot-type capacity. Those experiments, which are composed of KT’s spectrum, Samsung’s base stations and a Qualcomm’s prototype user equipment, yield multi GBps data throughput.

Several OEMs (for instance Fujitsu, Asus, OnePlus or Sony) have selected the Qualcomm’s X50 5G NR modem family for theirs standard-compliant 5G NR mobile devices, starting launches in early 2019. Those devices will make use of sub-6GHz and also millimeter wave spectrum bands.

3.4 Impact on TRIANGLE

The foreseen impact of Heterogeneous Access Networks technologies on TRIANGLE is significant for those technologies included as part of the project. Depending on the outcome of

the deliverable “Report on 5G evolution” D2.3 released in M3 (first edition) and D2.4 released in M15 (second revision), deciding which technologies will remain part of the TRIANGLE testbed will be necessary. The deadline for this should be the milestone M4.1 “Networking capabilities ready” [M21].

- Dual Connectivity functionality will enable users of the TRIANGLE portal to perform tests of devices and applications in a flexible radio access network. Devices will be connected to the network through more than one RAT simultaneously, performing control and data plane split. The inclusion of Dual Connectivity functionality in the TRIANGLE infrastructure is being tackled in the task T4.2 “Dual Connectivity”. This task provides the use of Wi-Fi technology on the data plane, whereas that control plane remains in LTE eNodeB.
- Wi-Fi offloading capability has been evaluated within the TRIANGLE testbed as part of the task T4.1 “Extending the eNodeB emulator of LTE-A to integrate with a Rel.12 core network”, by implementing the necessary modifications to support Wi-Fi seamless handover. The testbed core network was expanded to support the ANDSF and ePDG to provide non-3GPP untrusted access to the testbed and the data transport was tested with a client prototype. However, there is no commercial ePDG Android support yet in the marked, so TRIANGLE has decided to offer this feature only for researcher profile (no TAP automation).
- The use of FDD/TDD carrier aggregation within the same cell seems to have been discarded by the industry. The technical difficulties encountered to introduce the features in the device have made this feature unrealistic. While the loose architecture of Dual Connectivity could allow to have this blend of TDD and FDD technology coming from two independent cells, it is not likely to happen in contiguous bands, but rather in very different parts of the spectrum, e.g. cm and mm wave chunks. This is of course well within the scope of the 5G technology, but the integration within the mobile devices could take an amount of time well beyond the scope of the project. Not having any device needing the feature would make the development within the project not only untested but also unfruitful. For this reason, the TDD/FDD combinations would be down prioritized to a “nice to have” feature rather than a mandatory one.

Although other technologies highlighted in this section are beyond the scope of this project, they are very promising, and their developing process should be closely monitored by TRIANGLE as they are intended to become 5G technologies. In the case of WFA and LAA, it seems too early to include coexistence scenarios in the scope of TRIANGLE due to the early stage of the standards at the 3GPP side. In the case of mm-Wave, the technology is still too fragmented, with trials from different vendors. Regarding the adoption of the technology, TRIANGLE is tracking all the efforts to detect which will be the alternative finally adopted by the industry and/or standards.

4 RAN and Core Virtualization

4.1 Introduction

Virtualization is a broad topic in 5G, covering many different aspects. This section currently covers Software Defined Networks (SDN), a general paradigm in which the control plane of the network is moved to a central entity (the network controller), and Network Function Virtualization (NFV), that consist of the virtualization of network functions by moving from dedicated equipment to common cloud infrastructure.

We also introduce recent advances in C-RAN (Centralized or Cloud RAN). C-RAN is a new RAN architecture that centralizes the baseband processing into a pool and virtualizes soft base–band units on demand so that they can be shared between remote radio heads. The fronthaul part of the network spans from the RRHs sites to the BBU Pool.

The motivations behind the C-RAN concept are to provide a higher spectral efficiency, to reduce power consumption, and to reduce deployment and operational cost of the radio access. The major challenge for C-RAN is the hard, real-time constraint for system performance.

4.2 Verizon 5G specifications

The Verizon 5G Technology Forum (V5GTF) formed in cooperation with Cisco, Ericsson, Intel, LG, Nokia, Qualcomm and Samsung, has created 5G technical specifications. The initial release includes the description of the physical layer, and also layer 2 and layer 3 (Medium Access Control, Radio Link Control, Packet Data Convergence Control and Radio Resource Control). Current specifications are available at http://www.5gtf.org/.

4.3 3GPP 5G New Radio (NR) standardization roadmap

After the completion of the study items on 5G NR in Release 14 by March 2017, the specification in Release 15 on NR will include support for non-standalone and standalone operation of this technology. Non-standalone operation implies using LTE as control plane anchor to assist 5G NR, likely to connect to “existing LTE core network”. Standalone implies full control plane capability for NR. Proposed architectures are shown in RP-161266.

The uses cases considered in Released 15 are Enhanced Mobile Broadband (eMBB), as well as Low Latency and High Reliability to enable some Ultra-Reliable and Low Latency Communications use cases. The frequency rages taken into account are frequencies below 6GHz and above 6GHz.

During the 3GPP RAN Technical Specification Group (TSG) plenary meeting celebrate in March 2017 the following roadmap for the 5G New Radio in Release 15 was agreed.

- In December 2017 was performed a Stage-3 freeze of L1/L2 specifications for common aspects of NonStandalone and Standalone NR. Furthermore, principles for Standalone specific L1/L2 components were agreed.
- In March 2018 the first implementable 3GPP 5G NR complaint specification was released, which will base the core of forthcoming 5G products.
- June 2018: Second 5G version targeted (eMBB, low latency)
  - Standalone 5G-NR Stage 3 completion
  - Overall 5G Core Network already agreed to be completed.

3GPP release 16 will consider other use cases. A third 5G version which will add the remaining functionality to meet full IMT-2020 requirements is expected by December 2019.

4.4 Organizations working on NFV

ETSI, 3GPP and TM Forum have reached an agreement for cooperation; the responsibilities are divided as follows:

- ETSI: Architecture, NFVO (NFV Orchestrator), VNFM (Virtual Network Function Manager, VIM (Virtual Infrastructure Manager), virtual resource lifecycle management and proof of concepts.
- 3GPP SA5 for the mobile side and TM Forum for the fixed part: EM, OSS (Operation Support System), BSS (Business Support System), network element FCAPS (Fault, Configuration Accounting, Performance and Security) management, service management, end to end management procedures.

4.4.1 ETSI NFV Industry Specification Group (NFV-ISG)

The working group is http://www.etsi.org/technologies-clusters/technologies/nfv. It has standardized the MANO (Management and Orchestration) architecture in the standard NFV-MAN-001 [34]. NFV MANO splits the architecture in three main functional blocks: the NFV orchestrator, the VNF Manager and the VIM.

3GPP has adopted this architecture [35] and in the technical report TR 32.842 [36]the impact of the architecture in the 3GPP standards is analyzed. The SA5 group [37] is including the following tasks in release 14: management concept [38], and lifecycle, configuration, fault and performance management.

4.4.2 ETSI Mobile Edge Computing Industry Specification Group (MEC ISG)

The technology is focused on services. It is an improvement of the cloud computing paradigm that locates the infrastructure at the edge of the core network, sometimes even in the base stations, in order to support ultra-low latency and real time services. ETSI has also a group to manage the development of the technology that has published a technical white paper covering the technology [39] and has already generated some specifications [40].

4.4.3 Broadband Forum (BBF)

This organization is mainly focused on broadband fixed access, as convergence between fixed and wireless networks is also expected in future 5G technologies. BBF has several work tracks that might be of interest for TRIANGLE, in particular:

- WT-317, which is focused on moving the functionality of the residential gateways to the operator network, to improve the maintenance and evolution of existing and/or new capabilities.
- WT-341, studying information models for AAA (Authentication, Authorization and Accounting) functions.
- WT-348, which studies the bonding between 3GPP access networks and broadband accesses to offer higher throughput and better WAN reliability.

4.5 Organizations working on SDN

This section provides insights of organizations working on general definitions of SDN technologies (that might be applied or not to wireless networks).

4.5.1 IRTF's SDNRG

The IRTF has the Software-Defined Networking Research Group (SDNRG) that investigates SDN from different perspectives and provides definitions, metrics and background on the technology [41]. The RFC 7426 [42]provides a good overview covering terminology, but also including references to different model and architectural views.

4.5.2 Open Networking Foundation (ONF)

It seems that OpenFlow is the accepted interface between the control layers and the infrastructure layer. Stanford originally developed OpenFlow and it is currently an open standard maintained by the Open Network Foundation. OpenFlow specifications are evolving to cover more functionality and cover the basic function of OpenFlow enabled switches and the OpenFlow protocol to manage it from a remote controller [43].

ONF has formed the WMWM (Wireless and Mobile Working Group) group that is devoted to collect use cases and determine architectural and protocol requirements. They have produced a white paper with some examples of use cases for mobile networks [44].

4.5.3 ITU-T

The ITU study group 13 (Future Networks including cloud computing, mobile and next generation networks) plans to include requirements for network virtualization frameworks and requirements for formal specification and verification methods for SDN [45]. There is a joint coordination activity on software defined networks that reports to SG-13 and others study groups and has published a roadmap of all the ongoing activities regarding SDN [46].

4.6 Organizations working on C-RAN

4.6.1 ETSI

Mobile operators typically deploy a base station architecture with functions distributed into 2 network elements: a BaseBand Unit (BBU) which performs the processing of the radio protocols (physical layer and higher layers), and the Remote Radio Head (RRH) or Integrated Active Antenna, which converts the digital baseband signal into the analogue signal for transmission/reception over the air.

The interface between the BBU and RRH can currently be provided in a "semi proprietary" nature, e.g. based on industry standards like CPRI (Common Public Radio Interface) or OBSAI (Open Base Station Architecture Initiative).

ETSI has established the Open Radio equipment Interface Industry Specification Group (ORI ISG) to develop an interface specification enabling interoperability between BBUs, more generically defined as 'Radio Equipment Controllers' (RECs), and Remote Radio Heads (RRHs), more generically defined as 'Radio Equipment' (RE), of base transceiver stations of cellular mobile network equipment. The ORI interface is built on top of the interface already defined by the CPRI (Common Public Radio Interface) group. However, options are removed and functions are added with the objective of making the interface fully interoperable.

ORI Release 4, published in October 2014, is based on CPRI version 6.0. Release 4 adds IQ data compression for LTE and supports a line bit rate up to 10.14 Gbit/s. This is particularly useful in C-RAN type network topologies.

4.6.2 NGMN

The ETSI ORI Industry Specification Group (ISG) is a direct result of requirements work undertaken by the NGMN Alliance, in their OBRI (Open BBU RRH Interface) project. The ISG is strongly supported by the NGMN Alliance, and leading mobile network operators and telecommunication equipment vendors are among the ISG's founding members.

In 2010 NGMN founded P-C-RAN, a dedicated C-RAN. As part of this project a need to identify a BBU-BBU interface supporting the physical level was identified, similarly to what is being done by ORI for the BBU-RRH interface. The functional interfaces defined by the 3GPP constitute the best choice in C-RAN to support all conventional mechanisms for mobility, management of radio resources, and interference coordination in LTE. However, it has to be noted that there are some limitations for multi-vendor deployment, since some interfaces (e.g., Iub) are not fully open. These limitations are also faced in conventional DRAN architectures, however, these interfaces do not support the physical level (e.g., I/Q data transfer between clouds or physical resource negotiation and allocation). To provide interoperability at this level the development of an additional interface (ODI) would be required, similarly to what has been done for the BBU-RRH interface. Additional study would be needed to determine if such an interface needs to be defined as stated in [47].

A new project funded by NGMN that is currently active is “C-RAN evolution” [48]. This project covers C-RAN architectures, CoMP support and performance and multi RAT joint radio optimization (MRJRO).

4.6.3 3GPP

3GPP is the organization responsible for developing cellular telecommunications network technologies, including radio access, the core transport network, and service capabilities - including work on codecs, security, quality of service - and, thus, provides complete system specifications.

C-RAN is an implementation approach that consists, basically, of a different way of grouping functions, and has therefore no direct relevance to the standardization work conducted in 3GPP. The 3GPP interfaces are defined at the functional level, and should naturally be exploited in C-RAN. However, it is useful to determine how the C-RAN architectures can be mapped to the reference models defined for 2G, 3G and 4G. This analysis helps in identifying the interfaces of the BBU-clouds with the external world, and the degree of interoperability offered. This work is done by the P-C-RAN project [47].

In [48] the 3GPP have also identified some features and studies that could indirectly facilitate evolved RAN implementations or make them more efficient.

- Carrier Aggregation (CA) and New Carrier Types (NCT) give the opportunity of switching off some carriers depending on the load, thus providing higher energy saving gains (note that NCT have also the virtue of higher energy efficiency thanks to a lower overhead), and possibly, additional pooling gains.
- eIMTA (DL-UL interference management and traffic adaptation) enables dynamic reconfiguration of the TDD frame. Energy saving gains can be obtained by choosing high UL/DL ratio during low traffic periods (this gain is actually not specific to C-RAN). Additionally, some additional pooling gains can be expected assuming a sufficient decorrelation of traffic patterns between cells clusters.

4.7 3GPP Architecture for Next Generation Systems

3GPP has mainly decided to use the results from the ETSI NFV group. There is a study focused on the use cases that could be applied to network management [36].

Based on the conclusions of the study [36], five new release 14 work items were approved in June and September 2015, which are to standardize the following features for mobile networks that include virtualized network functions:

- Concept and Architecture
- Performance Management
- Fault Management
- Configuration Management
- Lifecycle Management

In relation to the system architecture, a new study item to design a system architecture for the next generation mobile networks, was agreed at an SA2 meeting in Nov 2015.

The architecture should be developed with the following non-exhaustive list of operational efficiency and optimization characteristics:

- Ability to handle the rapid growth in mobile data traffic/device numbers in a scalable manner.
- Allow independent evolution of core and radio networks.
- Support techniques (e.g. Network Function Virtualization and Software Defined Networking) to reduce total cost of ownership, improve operational efficiency, energy efficiency, and simplicity in and flexibility for offering new services.

The study and the standardization of “Next Generation System Architecture” do not have a concrete schedule yet.

4.7.1 Control and User plane separation

Although Control and User plane separation functionalities are not part of the Next Generation study, it is assumed that both share the same motivation on coping with the data traffic challenges by separation of control and user plane functionalities. 3GPPTR 23.714 [49] provides a study and performs an evaluation of potential architecture enhancements for the separation of user plane functionality from control plane functionality in the EPC's S-GW, P-GW and TDF (Traffic Detection Function) to further enable flexible (i.e., distributed or centralized) network deployment and operation.

The aspects covered by the Feasibility study on control and user plane separation of EPC nodes (FS_CUPS) are the following:

- Functional separation of the S-GW, P-GW and TDF into control and user plane functions, while not affecting the overall functionality provided by these nodes.
- The needed reference points between the separated control and user plane functions of the S-GW, P-GW and TDF and the corresponding procedures.
- Impacts to other EPC entities and interfaces that are essential to support the separation of S-GW, P-GW and TDF into control plane and user plane functions, and to enable the

flexible placement of the separated control plane and user plane functions for supporting diverse deployment scenarios.

4.7.1 Dedicated Core Networks selection mechanism

The Feasibility Study on Enhancements of Dedicated Core Networks selection mechanism (eDecor) [50], aims to enhance the DECOR feature, which enables a PLMN to have multiple dedicated core networks to separately serve devices and/or customers with very different characteristics, such as machine type devices, MVNO, data usage, etc. Similar to the FS_CUPS, DECOR might be considered to bring some commonality with the next generation system by enabling something comparable to network slicing.

4.8 Impact on TRIANGLE

During the writing of the proposal the inclusion of SDN technologies as part of the project was considered as a marginal contribution on tasks 4.6 and 4.7. However, during the kick-off meeting the consortium discussed about a more extensive usage of SDN and NFV technologies. It is clear for the consortium that SDN and NFV are core technologies in the future 5G network architecture.

NTT Docomo has announced in 2014 that working on this separately with different vendors. It has completed proof of concept trials verifying feasibility of NFV. Nokia Networks also announced in 2014 what (they claim) is the first commercial NFV solution. And Huawei is launching what (they claim) will be China´s largest commercial SDN network. The consortium will, continue to monitor the advances in these technologies.

After the initial meeting, a specific action group on SDN and NFV was created inside the project. The target of this group is to decide on which SDN scenarios are more interesting for the final users of the testbed (app developers, devices makers and researchers), and if we can attract new users, such as mobile operators, or network equipment vendors with the inclusion of SDN/NFV technologies. Testing of SDN/NFV is a challenge for operators. Previously, in legacy networks, testing was based on electronic box functions and end to end trunk/aggregate paths for throughput and failure. There are some projects in the Phase 2 5G PPP group addressing fault managements as part of FCAPS for network slicing. How to test this new paradigms in current operator networks is still an open issue which we will be tracking in the long term.

SDN technologies has been deployed in TRIANGLE testbed to provide link performance control to experimenters, assuming a domain change (i.e. the backhaul network is controlled by a third party), while also leaving the possibility of enforcing QoS policies in radio links. The functionality is exposed to application developers via the VELOX VPS Engine, which provides an API to manage QoS demands to the LTE network (via the the standard Rx interface of the EPC). Thanks to these tools, Triangle users are able to modify backhaul network conditions during the execution of their experiments, simulating real situations as network congestion.

Regarding NFV, an extension (by TNO) regarding the use of orchestrators in the testbed has been selected in the first open call wave. This extension provides orchestration in the application servers.

The project will evaluate the use of the technologies in the testbed as well as it will keep track of the evolution of the testing methodologies in both paradigms.

Control and user plane separation was considered during the proposal and this functionality has been implemented as part of Task 4.2.

Regarding C-RAN and the 3GPP Architecture for Next Generation Systems, the project will continue exploring its evolution and analysing its potential impact on the final users of the testbed. The project will consider this in trying to determine the inclusion of new features related with these two topics on the testbed.

5 Automotive

5.1 3GPP

Starting from release 12, a feature known as Proximity Services (ProSe) has been specified within 3GPP (3GPP TS 23.303, July 2015). ProSe Direct Discovery and ProSe Direct Communication allow UEs (User Equipment) within communication range, regardless of whether they are in or out of E-UTRAN coverage, to discover and communicate with each other directly, i.e., without traversing the network infrastructure. This strategy is known in the research literature as Device-to-Device (D2D) communication [51].

In the automotive scenario, the underlying motivation is to grant availability of wireless services in wide deployment of ITS services where network coverage cannot be guaranteed.

ProSe Direct Discovery and Direct Communication are enabled by a new E-UTRA capability known as “sidelink” (SL) [52], which refers to the direct radio link between two (or more) UEs, as opposed to the conventional uplink and downlink radio links between UE and eNB.In terms of radio access, current sidelink release 12 specifications needed to be enhanced in several ways [53].

Figure 1shows some use cases using the “sidelink” interface.

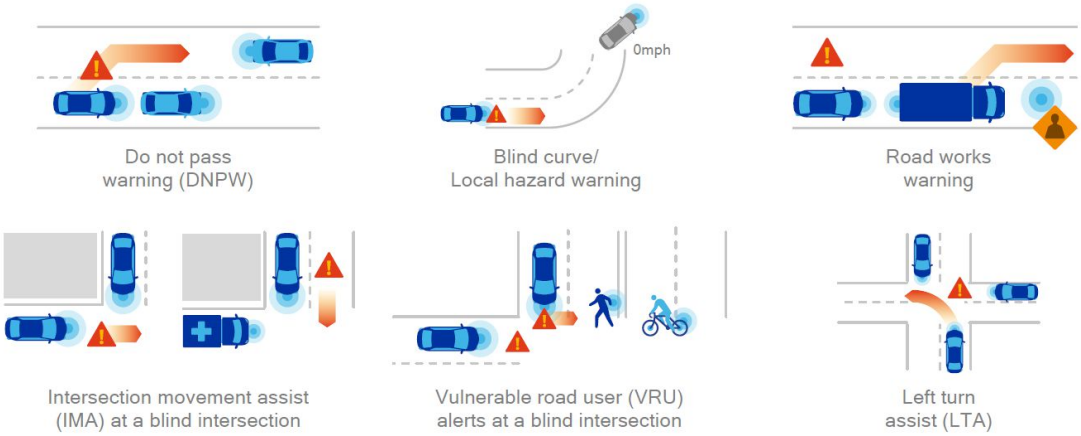


Figure 1–3GPP PC5 (sidelink) Use Cases

Within release 13, the work has been organized in a V2V(RP-161272) and a V2X (RP-161298) work items. The V2V work item specifies the details of a vehicle to vehicle communications, and has provided enhancements to earlier work on D2D ProSe and the PC5 interface while the V2X work item is focused on additional aspects of vehicular communications leveraging the cellular infrastructure.

In September 2016 the 3GPP concluded that the first version of the specification of the LTE V2V capability was completed [54], with further enhancements to support additional V2X operational scenarios to follow, in release 14, targeting completion during March 2017.

In 2017, 3GPP has officially introduced in release 14 C-V2X (Cellular-Vehicle to Everything) which embodies V2V (Vehicle-to-Vehicle), V2I (Vehicle-to-Infrastructure) and V2P (Vehicle-to-Pedestrian). PC5 interface has defined as the radio link, which enables short-range direct communication between vehicles. PC5was formerly known as “sidelink”.

In 2018, 3GPP is adding in the release 15 track some enhancements such as aggregation up to 8 carriers in PC5 interface,64QAM in PC5 interface, and transmission diversity.

5.2 ETSI

Currently, ETSI is working in the development of the release 2 of standards for Co-operative ITS (Intelligent Transport Systems) that, according to ETSI, offers enormous potential through vehicle-to-vehicle and vehicle-to-roadside communication.

In particular, it will include specifications to protect vulnerable road users such as cyclists and motorcycle riders, and for Co-operative Adaptive Cruise Control. It will also address platooning, a practice which is expected to save both fuel and space on the roads. ETSI is also working on the Co-operative Observation Service, whereby sensor information is shared between road users to, in effect, extend a driver's field of vision, and have initiated studies into relevant use cases. ETSI is addressing cross layer Decentralised Congestion Control for the management of Co-operative ITS.

ETSI is also developing conformance tests, which are crucial for the commercial deployment of Co-operative ITS.

Table 1summarizes the latest conformance test specification published by ETSI:

Table 1 – ETSI ITS Conformance Test Specifications

Title	Version	Release Date
Conformance test specifications for Cooperative Awareness Basic Service (CA); Part 2: Test Suite Structure and Test Purposes (TSS & TP) [55]	1.51	2017-03
Conformance test specifications for Decentralized Environmental Notification Basic Service (DEN); Part 2: Test Suite Structure and Test Purposes (TSS & TP) [56]	1.51	2017-03
Conformance test specifications for Geographical addressing and forwarding for point-to-point and point-to-multipoint communications; GeoNetworking validation report	1.2.1	2014-04
Conformance test specifications for Co-operative Awareness Messages (CAM); CAM validation report	1.2.1	2014-04
Conformance test specifications for Decentralized Environmental Notification basic service Messages (DENM); DENM validation report	1.2.1	2014-04

In March 2018 ETSI has organized a workshop on Intelligent Transport Systems (ITS). The German Federal Ministry of Economic Affairs and Energy have hosted this event.This workshop has provided a status of the ongoing activities to facilitate the deployment of Cooperative ITS, not only in Europe but also around the globe.Nineteen companies presented in this event.

Regarding the actual deployment, the European Commission in [57] has called upon all parties concerned, and in particular Member States and industry, to collaborate at all levels and across sectors to start deploying C-ITS successfully in 2019.

5.3 Wi-Fi Alliance

There is a Task Group in the Wi-Fi Alliance called “Automotive Market Segment Task Group”, whose key focus is, “*to identify automotive needs and use cases for current and upcoming Wi-Fi certification programs, to examine new standards to address automotive market needs and to act as the focal point for communications with other automotive-related industry organizations*” [7].

Their major work in 2015 has been to develop the document “Market Needs and Use Cases” (MN&UC) [7]. This document represents input and review from a broad cross section of the Wi-Fi and automotive industries, and is a comprehensive view of the expected market potential for Wi-Fi in automotive applications.

According to the WFA, in-car applications will be worth over $1.2 billion by 2017, due to advancements in automotive connectivity standards, such as MirrorLink and ever higher smartphone ownership.

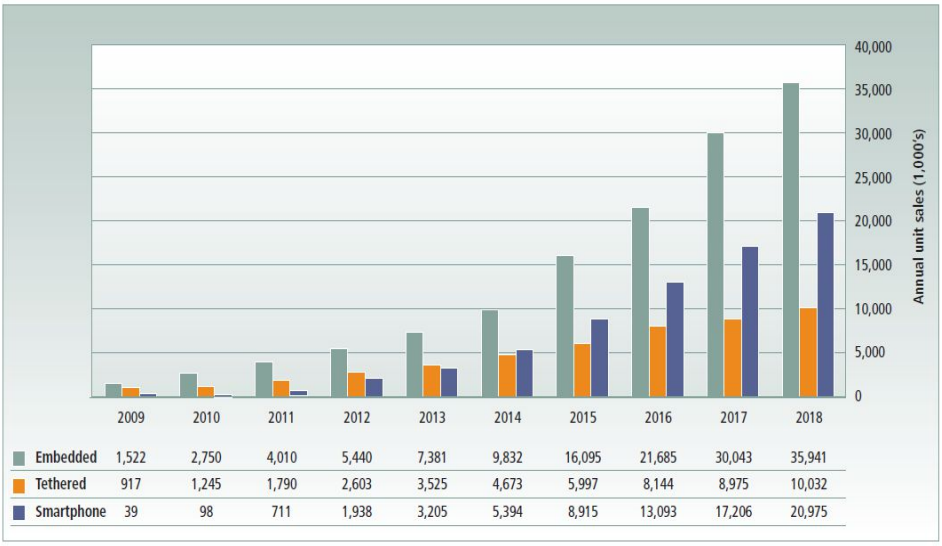


Figure 2 - In-Car Applications Unit Sales

In addition to a natural language description of the use cases, the WFA document concludes with sections on Wi-Fi certification programs relevant to automotive applications, and an analysis of gaps between existing certification programs and the requirements of Automotive Wi-Fi.

They have also continued the work on a recommended practices document called “Recommended Practices for Use of Wi-Fi in Automotive Applications” [58]which is in draft version 0.875. It defines recommended practices for all vehicles and recently incorporated an “Implementation Guidelines”.

Many of the use cases described so far are related to Internet connectivity; and it is foreseen that almost any vehicle thathas Wi-Fi will enable internet access, either from a cellular modem or from a hotspot tethered to the vehicle. However, Internet connectivity is only one aspect of Wi-Fi use in a vehicle; there are numerous use cases and features that can be enabled with Wi-Fi that will allow IVI (In-Vehicle Infotainment) and connectivity units to be differentiated within an OEM’s product line, as well as between OEM’s.

Their major work in 2016 has been to complete (MN&UC) document [7] which now includes background, market requirement and use cases.

The WFA also started in 2016 to develop the document Gap Analysis for Wi-Fi Automotive Applications [59] which identifies gaps between current certification programs and automotive needs/use cases, more specifically this document tackles with gaps related to co-existence, use cases, certification programs, and security.The major work in 2017 includes the release of the Gap Analysis document, the release of the Recommended Practices document, started work on Wi-Fi/Bluetooth coexistence use cases and Interaction with other WFA groups.

Their plans for 2018 includes completing the work on Wi-Fi/Bluetooth coexistence use cases (as complementary effort to IEEE 802.19.2 “Wireless Coexistence in Automotive Environments” – Recommended Practice), elaboration of recommended practices for Miracast in vehicles, use of Fi-Fi for controlling wireless chagrining for Electric Vehicles (based on JAE J2931/6, SAE J2954, ISO15118-8), and the identification of recommended features for 802.11ax in automotive.

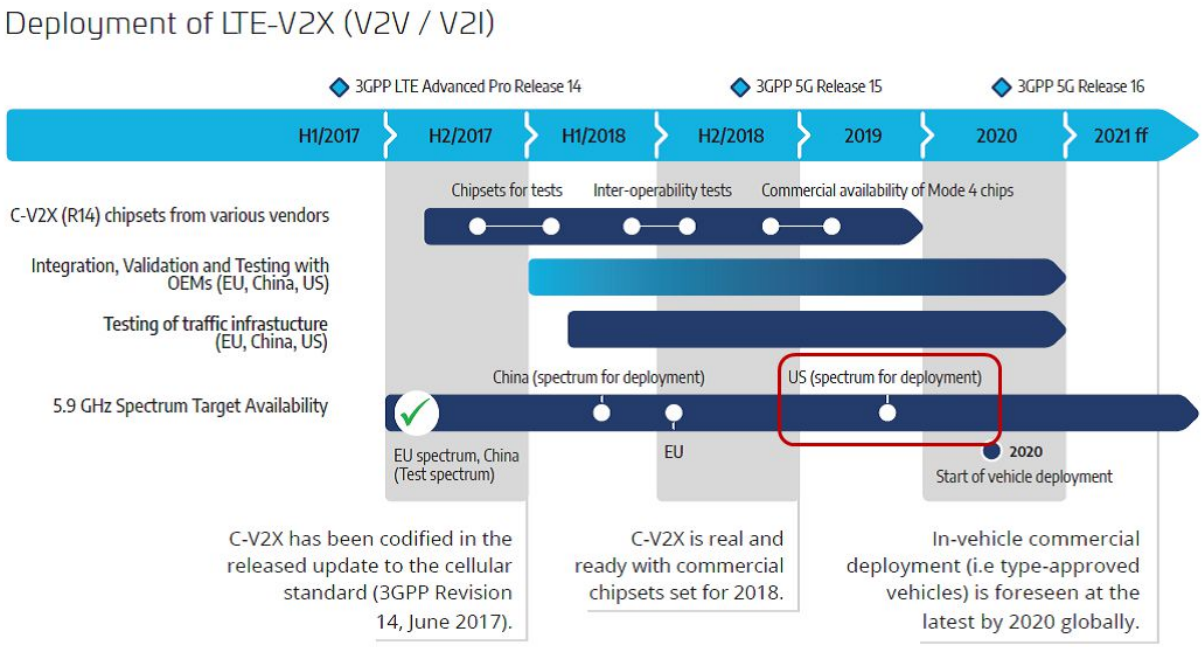
5.4 5GAA

The 5G Automotive Association (5GAA) is a global, cross-industry organisation of companies from the automotive, technology, and telecommunications industries (ICT), working together to develop end-to-end solutions for future mobility and transportation services. 5GAA was created on September 2016. The founding members are: AUDI AG, BMW Group, Daimler AG, Ericsson, Huawei, Intel, Nokia, and Qualcomm Incorporated.

The technologies associated with the concept of vehicles sharing information to make transportation safer, greener and more enjoyable are collectively known as Cooperative Intelligent Transportation Systems (C-ITS). A key enabling technology of C-ITS is wireless communication, covering vehicle-to-vehicle (V2V) communication, vehicle-to-infrastructure (V2I) communication, vehicle-to-network (V2N), and vehicle-to-pedestrian (V2P) communication, collectively, referred to as V2X communication (vehicle-to-everything).The 5GAA supports the idea that 5G will be the ultimate platform to enable C-ITS and the provision of V2X. 5G will be able to better carry mission-critical communications for safer driving and further support enhanced V2X communications and connected mobility solutions.

5GAA is structured in 5 working groups. WG1, Use cases and Technical Requirements; WG2, Standards and spectrum; WG2, System Architecture and Solution Development; WG3, Evaluation, Testbeds, and Pilots; WG4, Standards and Spectrum, and WG5, Business Models and Go-To-Market Strategies.

The work in WG1 has interest for TRIANGLE as they are defining, in waves, use cases (wave 1 has been completed and the work is actually working on wave 2). The work of WG3 is the most relevant for TRIANGLE, as the working group is defining general aspects and the strategy to assess system,performance, interoperability and conformance. By the end of 2017 the group was already working on a test specification document. 5GAA is also active in identifying and defining test methods to evaluate coexistence not only of devices but also of technologies. In this area the compatibility of Urban-Rail and Road ITS are under investigation. Within ETSI, the JTFIR is responsible for investigating the shared usage of 5GHz frequency band for Urban Rail and ITS; it is a joint group between ETSI TC RT (Railway) and ETSI TC ITS.



5.5 Impact on TRIANGLE

The TRIANGLE consortium members have been monitoring the definition of automotive applications which are candidate to be integrated in the scope of TRIANGLE WP3 – Application and Device testing framework, and also tracking the uprising of new QoE indicators for this kind of applications.

The TRIANGLE consortium members have been monitoring the evolution of the connected automotive industry to identify applications which can be candidate to be in the scope of WP3-Application and Device testing framework and also the potential QoE indicators for this kind of applications.

TRIANGLE has identified the key role OmniAir Consortium [60] is going to have in the US market in the area of connected car. This consortium is working towards developing a certification program for connected vehicles. OmniAir relies on Intelligent Transport Systems based on IEEE 802.11p as the lower layers technology supporting vehicle to vehicle communication and SAE/IEEE for the upper layers. In parallel, TRIANGLE is also following the testing and certification progress in Europe, work which is mainly taking place in ETSI relying for the lower layers also on IEEE 802.11p and on ETSI-ITS-G5 for the upper layers. 3GPP is, however, working on an alternative solution mostly backed by carriers. This alternative relies on the D2D (device to device) feature of the standards. As of today it is clear that technologies based on IEEE 802.11p have reach a more mature stated than those based on 3GPP standards, and there are some commercial modem implementations but not real interoperable products.

There is no clear worldwide agreement yet on the path ahead for the specification of the automotive technologies. Hence, the inclusion of automotive applications, devices and testing scenarios inside the scope of TRIANGLE has been as of now discarded.

From a technical perspective, the TRIANGLE testbed is going to provide functionality that could be exploited in these scenarios such as handover, high speed fading effects…

6 5G Test Beds and trials

6.1 Commercial "5G" Testbeds and technologies

Many claimed “5G” deployments have been announced, largely to coincide with large sporting events between now and the official scheduled rollout of “5G” in 2020. These scheduled events include:

- South Korea hosting the 2018 Winter Olympics (SKT)
- Russia hosting the 2018 World Cup (MegaFon)
- Japan hosting the 2020 Olympics (NTT Com)

In addition to these future intended countrywide rollouts, individual mobile operators worldwide have recently announced they are working on nearer term “5G” deployments of various types, some of these are described below.

6.2 South Korea

The 2018 Winter Olympics ran the world’s first outdoor real world use of 5G. The main Use case demonstrated was holograms, VR and Immersive broadcasting, using 5G-powered devices like cameras, communication equipment and sensors attached onto players, sports gear and arenas, so that viewers can experience the game on their mobile apps. However, since 5G UE was not available, spectators’ experience was limited to the test phones [61].

According to [62], Commercial rollout of 5G is claimed to take place in South Korea from Korea Telecom (KT) in March 2019.

6.3 Verizon 5G Technology Forum

The Verizon 5G Technology Forum [63] is a combination of Verizon and a number of technology partners who are conducting field tests of industrial and commercial technologies in indoor and outdoor environments. Some of these experiments include:

- Real world tests mimic scenarios using millimetre wave bandwidth with throughput of multiple gigabits per second.
- Latency measured in the millisecond range across varied distances, delivering superb video quality.
- Using robotic arms to investigate remote telemedicine through remote surgery
- Beamforming, beam tracking, massive MIMO (multiple input, multiple output), and wideband spectrum (200 MHz – 1 GHz swaths).
- Verizon started a ‘5G’service to pilot customers in 11 markets in the US in mid-2017 [64].
- This deployment is largely seen as pre-5G deployment.

6.4 AT&T

Following on from the launch of AT&T's "5G Evolution" trials [66], AT&T plans a rollout to twelve cities in the US [65]. This rollout will be aligned with standardised 5G 3GPP NR specifications. AT&T are also opening a new 5G lab in Austin, Texas, this will host their ANTS Advanced 5G NR Testbed.

6.5 NTT DoCoMo

NTT DoCoMo are planning a 5G trial to start in May in Tokyo that will use the 4.5 GHz and 28 GHz bands, with base station equipment said to support network speeds of more than 20 gigabits per second and devices supporting speeds in excess of 5 Gbps [66].

The carrier plans to develop a 5G commercial system this year, with the aim to launching commercial services by 2020. The company's trials are set to follow TSA specifications, with the plan to carry out new trials conforming to 3GPP 5G New Radio specifications this year.

NTT DOCOMO has also announced plans to collaborate with Intel and Nokia to to provide 5G technologies for the 2020 Olympics by supporting network infrastructure, connectivity and collaboration.

6.6 Intel 5G Mobile Trial Platform

Intel has developed an open design for a reference design for an open modular access point architecture.

The main Mobile Trial Platform components are:

- Baseband signal processor
- Radio frequency unit supporting operation in sub-6 GHz, cm-wave and mm-wave spectrum bands, as well as two-stream or four-stream MIMO capability
- Communications protocol stack

The platform allows testing multiple upload/download symmetric at multi-gigabit speeds on a wide range of frequencies and Wi-Fi/WiGig handover [67].

6.7 Ericsson and Nokia

The radio testbeds developed by Ericsson and Nokia (In particular after the recent acquisition [68]above. These solutions involve a combination of use of different radio frequencies and waveforms in addition to SDN, NFV and Edge-side computing. Both providers have some form of 5G testbed in development with a number of operators including:

- Involvent with AT&T's 5G Evolution rollout [69].
- China Mobile isplanning large–scale pre-commercial trials in 2019 [70].
- SK Telecomhas already made some demonstrations of "5G" network slicing [71]and opened a new 5G Innovation Centre with partnerships involving Nokia, Ericsson, Intel and Samsung.

6.8 Telecom Infra Project (TIP)

TIP is an Open Source wireless initiative lead by Facebook and supported by a number of companies including operators, infrastructure providers, and both chip and equipment

manufacturers [72]. The TIP project, announced at Mobile World Congress 2016, will focus on the areas of backhaul, core infrastructure and management. The project aims to develop new technologies to deploy in emerging and also developed markets.

Facebook has placed a strong emphasis on high-definition video and Virtual Reality as applications of future networks that will require low latency and high bandwidth.

There are some early technology experiments underway for TIP in remote areas of The Philippines and Scotland with millisecond range latency measured across varied distances.

The Open Cellular initiative [73]launched as part of TIP to provide Open Source reference implementation for Small Cells for 2G and LTE, however in the long term this technology is planned to upgrade to 5G NR [74].

6.9 5G Field Tests

The telecommunication operators who have claimed to have run 5G field test are [75]:

AT&T	Deutsche Telecom	KT
NTT DoComo	SK Telecom	Sprint
StartHub	Telia	Telstra
U.S. Cellular	Verizon	Vodafone

6.10 European Government backed 5G Initiatives

Several European governments have announced support for supporting 5G Testbeds and deployments. Examples of these include in the Netherlands [76] and Italy [77] and the UK. In the UK the government has published it is 5G strategy announcing the establishment of a number of testbeds for innovation. As part of the report [71]the government announced that one of these initiatives that was specifically mentioned in the report was the TRIANGLE project, mentioning specifically the benefits for application developers and device manufacturers for testing and benchmarking new mobile applications.

6.11 German 5G Testbeds

Germany is supporting initiatives in Berlin in conjunction with the Fraunhofer Institute through the Transfer Center 5G Testbed. This Testbed supports a number of H2020 projects including: Millimeter-Magic, Fantastic-5G, 5G-Crosshaul, Carisma, as well as in EU-Asian Projects MiWEBA, STRAUSS, 5G-MiEdge, 5G-Pagoda (EU-Japan) and 5G-CHAMPION (EU-Korea) [78].

6.12 Italian 5G Testbeds

According to [79] Italian operator Wind Tre is planning to build a pre-commercial 5G network in Italy across the 3.6-3.8GHz band. This involves a partnership with Open Fiber and Chinese vendor ZTE on the project, which will take place in the cities of Prato and L'Aquila. Wind have previously announced a testbed in the 3.7GHz band in Bari and Matera in southern Italy. These trials are set to begin from June 2018, aiming to provide 75 percent coverage in the areas by end of next year and full coverage by the start of 2020. Key areas are smart agriculture and automated vehicles with an IoT deployment in Rome.

Italian operator TIM are also planning a 5G trial using millimetre waves in San Marinon and Turin in 2018.

6.13 Belgian 5G Testbeds

According to [80] Ericsson are working with Corda Campus to create the first 5G Life Campus in Hasselt, Belgium. The 5G Life Campus will be located at Corda Campus, a technology park, and will be fully connected to Ericsson's R&D centre in Aachen, Germany

6.14 UK 5G Initiatives

Early in 2018 the UK government announced funding for six 5G testbeds as part of its Digital Strategy commitment. The selected testbeds from the initial round of funding are [81]:

5G Smart Tourism project: The project is led by the West of England Combined Authority. It is focused on delivering augmented and virtual reality (AR/VR) experiences to tourists in a number of key sites in Bath and Bristol. It will demonstrate self-provision of 5G and Wi-Fi as well as mmWave backhaul.

5GRIT (5G Rural Integrated Testbed): The project is led by Quickline Commnications. The project will focus primarily on innovative applications on agriculture and tourism and connecting rural communities using, among others shared spectrum in the TV bands. The aim is to ultimately make high quality connectivity available across Cumbria, Northumberland, North Yorkshire, Lincolnshire, Inverness-shire, Perthshire and Monmouthshire.

5G RuralFirst: The project is led by Cisco and the University of Strathclyde. Based primarily on the Orkney Islands, and in the farmlands of Shropshire and Somerset, the project will integrate spectrum sharing strategies for 5G; bringing connectivity to rural communities, enabling smart farming including drones, autonomous farm vehicles and remote veterinary inspections.

Liverpool 5G: The project is led by Sensor City. The project is focused on healthcare and wellbeing particularly of older residents in deprived urban areas. The project will use open source 5G networks, artificial intelligence, VR and IoT

AutoAir: The project is led by Airspan Networks. It aims to make 5G technologies available for the validation and development of Connected and Autonomous Vehicles (CAVs) at the UK's premiere vehicle proving ground at Millbrook. Fast travel speeds complicate cell-tower handoff, and autonomous vehicles will require more network bandwidth than is available currently. It will also investigate how these 5G connectivity solutions could be transferable to both road and rail transportation. It is based on the development of 5G small cells operating in both licensed sub-6GHz and mmWave bands on a shared 'neutral host' platform which allows multiple public and private 5G operators to simultaneously use the same infrastructure via network slicing.

Worcestershire 5G Consortium: The project will focus on ways to increase industrial productivity through preventative and assisted maintenance using robotics, big data analytics and AR over 5G and will also have a cyber security aspect. The project is addressing some of the challenges of Industry 4.0."

6.15 5GPPP Trials roadmap

5GIA (5G Infrastructure Association) has recently published the 5G Pan European Trials Roadmap (version 2.0). Most of the Roadmap implementation is and will be covered by the Industry on a private basis, with part of this implementation supported by the EC through the 5GAP, EC 5G Infrastructure PPP Phase 3, EC 5G Investment Fund, by Member States through specific National programmes as well as by Domains specific programmes (such as the one initiated by the European Space Agency (ESA)).

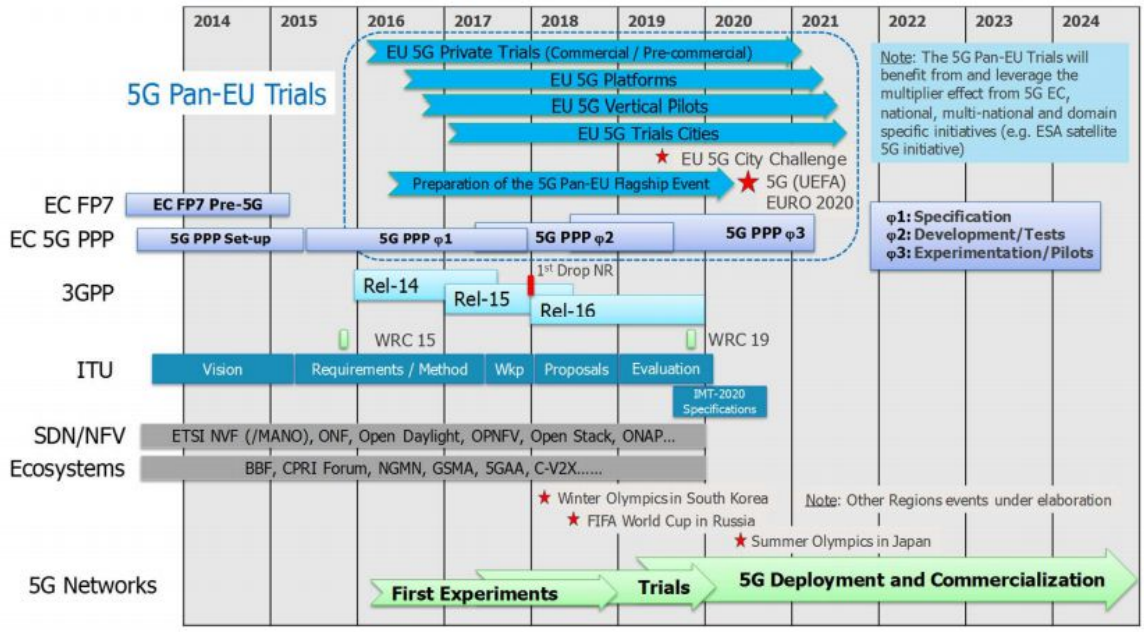


Figure 3 – 5GPP Trials Roadmap (Source 5GIA)

Trials in 2016-2017 have been focused on enabling technologies related to the radio interface (high throughput, millimetre-waves and other new large spectrum bands, antenna technologies, etc.), the network architecture (virtualization, cloudification, network slicing, edge computing, etc.) and the introduction of new technologies dedicated to specific use cases (technologies for IoT, for automotive, etc.). As 5G matures trials with vertical stakeholders will take place.

During and after 2018, European stakeholders will move to agree on detailed trials specifications (use-cases, scenarios, interfaces, agreement to transfer use-cases across trial networks) valid for Pan-European trials, largely based on standard-compliant systems. These trials will take advantage of the first 5G release of the 3GPP Standard (Rel-15 Stage 3 - December 2017). Most likely trials will initially be based on 3GPP Release 15 “early drop” (June 2018) compliant equipment, which will include a small set of 5G features and will be based on non-standalone LTE assisted NR, and to continue to full 5G System (5GS) trials, featuring standalone NR after June 2018. Trials will use some of the additional frequency spectrum proposed for identification in WRC 2019, enabling the full performance capabilities of 5G in terms of capacity and speed.

Existing European platforms include: 5GBarcelona (www.5gbarcelona.cat/) in Barcelona, 5GTNF (5gtnf.fi/) in Espoo and Oulu, 5SECC mainly in France, 5TONIC (https://www.5tonic.org/) in Madrid, ATHENS5GLINK (www.athens5glink.eu/) in Athens, 5G-Ready-Trial-Platform and the 5G Berlin Testbed (http://5g-ready.org/ and http://www.5g-berlin.org) in Berlin, FlexibleNetLab in France, LUCY in France, SATis5

(https://artes.esa.int/projects/satis5) in Germany and TRIANGLE (http://www.triangle-project.eu) in Malaga.

6.16 Impact on TRIANGLE

Since 5G are still in development, the consortium views these efforts as quite vendor-specific deployments that are not an official implementation of the standard. Some of the technologies used in these experiments and deployments may well go on to become part of a standard. However, it is still too early to consider these a valid “5G” rollout.

These deployments are not really testbeds but are technology. These deployments may be useful to experiment with different technologies that may contribute to the 5G standard, but they are not useful for accurate measurements or running any conformance tests leading to certification. As these deployments are proprietary, closed platforms that only involve selected partners, and as a result they are unlikely to be open to external parties for use, unlike the TRIANGLE testbed.

The TRIANGLE consortium members are monitoring the developments of the new testbeds and the technologies and approaches that they use. As the TRIANGLE project evolves, some of the enabling technology and outputs from these testbeds and deployments, may be worth a closer examination and may be adopted if the 5G standards evolve in the same direction.

7 Initiatives towards 5G Standardization

7.1 ITU-R

The ITU Radiocommunication Sector(ITU-R) is one of the three sectors (divisions or units) of the International Telecommunication Union (ITU) and is responsible for radiocommunication.

In early 2012, ITU-R embarked on a program to develop “IMT for 2020 and beyond”, setting the stage for “5G” research activities that are emerging around the world and created the WP (Working Party) 5D, which is responsible for the overall radio system aspects of International Mobile Telecommunications (IMT) systems, comprising the IMT-2000, IMT-Advanced and IMT for 2020 and beyond. Work towards IMT-2020 was therefore initiated in 2012 with ‘foundation’ deliverables completed over the period from 2013 through 2016 [82].

7.1.1 Timeline and Process

Work on the next phases of IMT-2020 has ramped up in 2016 and early aspects on the work have been initiated towards the radio interface technology or sets of radio interface technologies. Actually, 400+ contributions have been uploaded since 2016 in the ITU-R WP5D document repository.

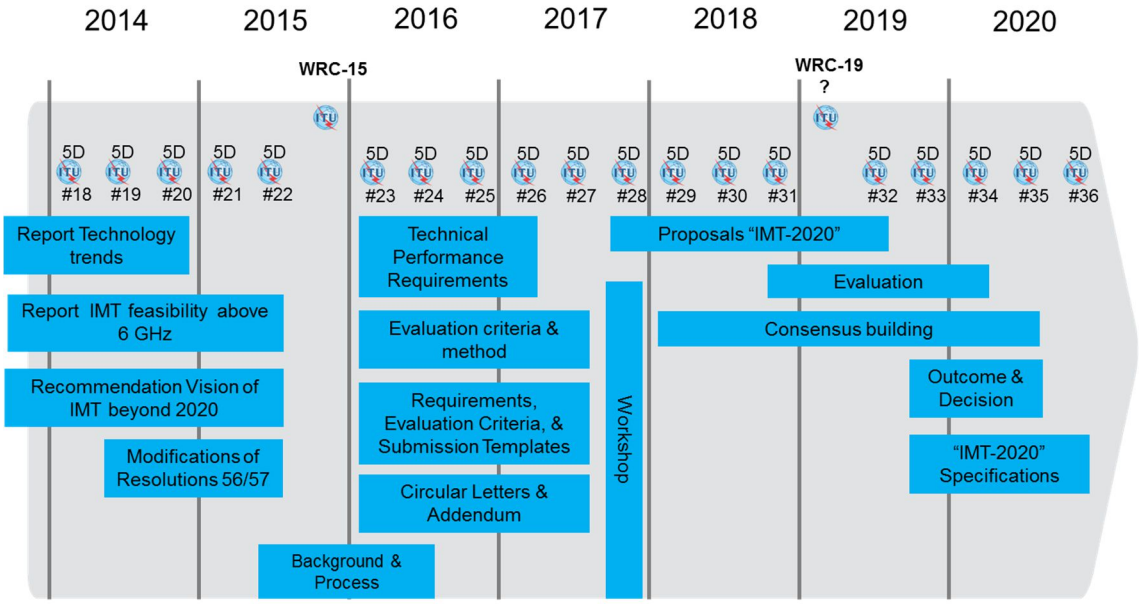


Figure 4 - Detailed Timeline & Process For IMT-2020 in ITU-R [83]

The key aspects of IMT-2020 timeline are summarized below:

- In the 2016-2017 timeframe, WP 5D has defined, in detail, the performance requirements and evaluation criteria and methodology for the assessment of new IMT terrestrial radio interface.
- WP 5D has organized a full-day workshop in October 2017 with around 200 participants. The WP 5D experts on the standardisation of IMT-2020 gave an overview of the IMT-2020 development process and provided a synopsis of the key deliverables underpinning the IMT-2020/5G work both in ITU-R and in the external organizations. There were also four potential technology proponent presentations (3GPP 5G, ETSI

DECT Forum/ETSI DECT, IMT-2020 Korea, IMT-2020 China). The conclusions of the workshop has been published in [84]. .

- The timeframe for proposals will be focused at 2018 (window spans late 2017 to mid-2019).
- The evaluation by independent external evaluation groups and definition of the new radio interfaces to be included in “IMT-2020” will take place from 2018 to 2020.
- The finalization of the complete Draft New Recommendation ITU-R M.[IMT-2020.SPECS] for the initial release of “IMT-2020” would be at WP 5D Meeting #36 (October 2020).

By 2015, ITU-R WP 5D has completed a detailed time line and action plan for IMT for 2020 to energize and focus the industry “5G” activities through year 2020, and a detailed deliverables table on the mapping of the work by meeting of WP 5D through year 2020.

In 2015 ITU-R WP 5D has released the following deliverables aiming at setting the ground for the later planned developments.

- Revision of Resolution ITU R 56-1: Naming for International Mobile Telecommunications
- New Resolution ITU-R [IMT.PRINCIPLES]: Principles for the process of future development of IMT for 2020 and beyond
- Recommendation ITU-R M.[IMT VISION]: Framework and overall objectives of the future development of IMT for 2020 and beyond
- Revision of Recommendation ITU-R M.2012-1: Detailed specifications of the terrestrial radio interfaces of (IMT-Advanced)
- Report ITU-R M.2370: IMT Traffic estimates beyond year 2020
- Report ITU-R M.2373: Interactive unicast and multicast audio-visual capabilities and applications provided over terrestrial IMT systems.
- Report ITU-R M.2376: The technical feasibility of IMT in the bands above 6 GHz
- Report ITU-R M.2375: Architecture and topology of IMT networks.

In 2016 ITU-R WP 5D completed the following deliverables:

- IMT-2020/001: Background on IMT-2020.
- IMT-2020/002: The Submission and evaluation process and consensus building for IMT-2020 as well as the “timeline” for IMT-2020.

In 2016 ITU-R WP 5D started the following deliverables (to be completed in 2017):

- Report ITU-R M. [IMT-2020. TECH PERF REQ]: General Technical Performance Requirements expected of a technology to satisfy IMT-2020.
- Report ITU-R M.[IMT-2020. EVAL]: Evaluation Criteria and Evaluation Methods for IMT-2020 technologies.
- Report ITU-R M.[IMT-2020. SUBMISSION]: Specific Requirements of the candidate technology related to submissions, the evaluation criteria and submission templates.
- Circular Letter IMT-2020: The official ITU-R announcement of the IMT-2020 process and the invitation for candidate technology submissions.

In 2017 ITU-R WP 5D has started the following deliverables (to be completed in 2019):

- IMT-2020/YYY Input Submissions Summary: Capturing in ITU-R documentation, the inputs documents and the initial view of suitability as a valid submission.

In late 2017ITU-R WP 5D has completed the requirements, evaluation criteria and submission templates for the development of IMT-2020:

- Report ITU-R M.2410 [85]: See 7.1.2.
- Report ITU-R M.2411 [86]: This Report deals with the requirements, evaluation criteria and submission templates for the development of Recommendations and Reports on IMT-2020, such as the detailed specifications of IMT 2020. It provides the service, spectrum and technical performance requirements for candidate Radio Interface Technologies (RITs)/Set of Radio Interface Technologies (SRITs) for IMT 2020.
- Report ITU-R M.2412 [87]: This Report provides guidelines for the procedure, the methodology and the criteria (technical, spectrum and service) to be used in evaluating the candidate IMT-2020 radio interface technologies (RITs) or Set of RITs (SRITs) for a number of test environments.

In February 2018, ITU-R acknowledged the “submission for proposal of candidate radio interface technologies” from China, Korea and 3GPP [https://www.itu.int/md/R15-IMT.2020-C].

7.1.2 Performance Requirements

ITU-R WP 5D has completed the report Minimum requirements related to technical performance for IMT-2020 radio interface(s) (ITU-R M.2410). This Report describes key requirements related to the minimum technical performance of IMT-2020 candidate radio interface technologies. It also provides the necessary background information about the individual requirements and the justification for the items and values chosen.

A call for inputs was initiated at ITU-R WP 5D #23 in February 2016 to announce the process of developing the requirements and the immediate next steps. ITU-T will request External Organizations (3GPP, IEEE, TIA, etc.) for their understanding of the key characteristics so that ITU-T can harmonize a consensus driven process to set the actual values, or range of values of the requirements. This started a discussion process between the ITU-T and the External Organizations , which ended as planned in November 2017 by approving the requirements.

Before starting the formal process ITU-R WP 5D shared their vision in the IMT-2020 Vision Recommendation deliverable [88].

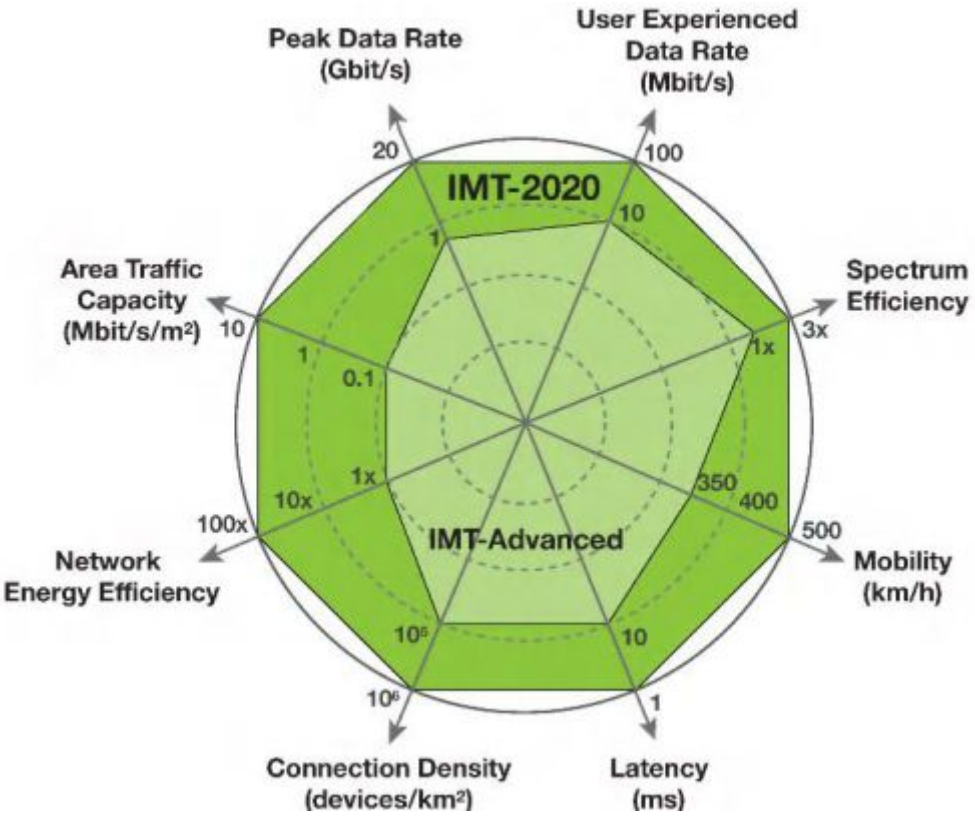


Figure 5 - Enhancement of key capabilities form IMT-Advanced to IMT-2020 [82]

ITU-R WP 5D stated that the values in the figure above are targets for research and investigation for IMT-2020 and may be further developed in other ITU-R recommendations, as it has been consolidated in ITU-R M.2410 .

Table summarizes the approved minimum performance requirements by ITU-R for IMT-2020:

Table 2–Minimum Performance Requirements for IMT-2020

KPI		**Value**
Peak Data Rate	Downlink	20 Gbit/s
	Uplink	10 Gbit/s
Peak Spectral Efficiency	Downlink	30 bits/s/Hz
	Uplink	15 bits/s/Hz
5th percentile user spectral efficiency	Indoor Hotspot – eMBB	Downlink: 0.315 bits/s/Hz Uplink: 0.21bits/s/Hz
	Dense Urban – eMBB	Downlink: 0.225 bits/s/Hz Uplink: 0.15 bits/s/Hz
	Rural - eMBB	Downlink: 0.12 bits/s/Hz Uplink: 0.045 bits/s/Hz

Average Spectral Efficiency	Indoor Hotspot – eMBB	Downlink: 9 bits/s/Hz/TRxP Uplink: 6.75 bits/s/Hz/TRxP
	Dense Urban – eMBB	Downlink: 7.8 bits/s/Hz/TRxP Uplink: 5.4 bits/s/Hz/TRxP
	Rural - eMBB	Downlink: 3.3 bits/s/Hz/TRxP Uplink: 1.6 bits/s/Hz/TRxP
Area Traffic Capacity	Indoor Hotspot – eMBB	10 Mbps/m^2
User Plane Latency	eMBB	4 ms
	URLLC	1 ms
Control Plane Latency	Minimum Req.	20 ms
	Recommended Req.	10 ms
Connection Density	mMTC	1 000 000 devices per km2
Energy Efficiency	"High sleep ratio and long sleep duration"	
Reliability	Urban Macro-URLLC	1-10^{-5} success probability of transmitting a layer 2 PDU
Mobility	Indoor Hotspot – eMBB	10 km/h at 1.5 bit/s/Hz
	Dense Urban – eMBB	30 km/hat 30 bit/s/Hz
	Rural - eMBB	120 km/h at 0.8 bit/s/Hz
		500 km/hat 0.45 bit/s/Hz
Mobility Interruption Time	eMBB and URLLC	0 ms
Bandwidth	<6 GHz	100 MHz
	>6 GHz	1 GHz

7.2 3GPP

ITU-R finally agreed the work plan for IMT 2020. Like for past generations, 3GPP will submit a candidate technology for IMT 2020.

3GPP is the organization developing, among others, the LTE specifications. The first incarnation of LTE was in release 8, and from there, the specifications have been regularly updated, with new features that boost performance and address new use cases.

Release 14 marked the start of 5G work in 3GPP. In addition to the continued LTE evolution, a new radio access technology will be standardized, and these two technologies together will form the 5G radio access. As clarified by the ITU-R, 3GPP should submit the final specs at the 5D meeting in Feb 2020, based on functionally frozen specifications by Dec 2019.

The "5G" timeline presented by 3GPP in March 2015 [89] is depicted below.

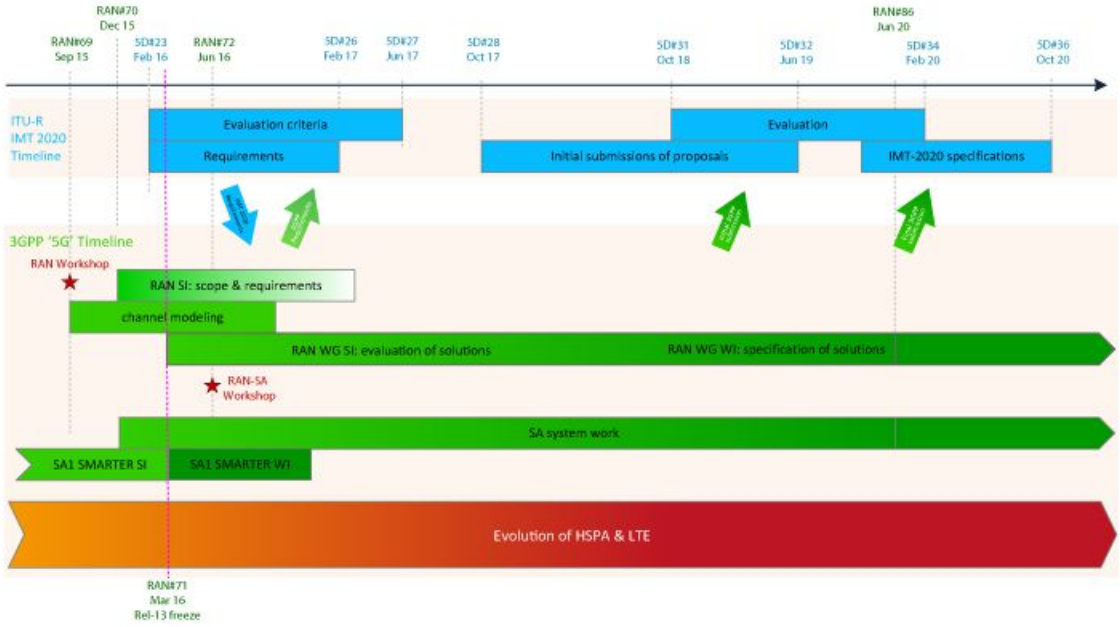


Figure 6 - Tentative 3GPP timeline for 5G [90]

3GPP RAN kicked off its development of the next generation 3GPP cellular technology with the 5G Workshop in September 2015 [91]. There were 550 participates from 159 organisations and 90 contributed documents.

In that event 3GPP highlighted three use cases for 5G: Enhanced Mobile Broadband, Massive Machine Type Communications, and Ultra-Reliable and Low Latency Communications. 3GPP also identified the scope of the new services such Automotive, Health, Energy and Manufacturing under the umbrella of the Study Item called SMARTER SI.

They presented and discussed three joint documents elaborated by forty five companies in three groups:

- Industry Vision and Schedule for the New Radio Part of the Next Generation Radio Technology [92][1]

RWS-150036 – Summary

- 3GPP needs to define the next generation mobile communication system meeting the needs of the next decade – and beyond
- The more imminent deployment needs are a subset of the overall next generation system capabilities
- 3GPP should phase its work and thus ensure that both the short term and long term needs can be met efficiently
- The time allocated to LTE work in RAN WGs should continue and parallel sessions for dealing with the new studies are needed.

[1] All the referred documentation is public and it is available in the 3GPP ftp url: ftp://ftp.3gpp.org/workshop/2015-09-17_18_RAN_5G/Docs/

- Views on 5G New RAT in 3GPP [93]

RWS-150085 – Summary

- A highly flexible and capable 5G system is required to fulfill all diverse requirements for usage scenarios envisaged for 2020 and beyond.
- A new RAT needs to be specified in 3GPP to fulfill all IMT-2020 requirements.
- Study item to target all IMT-2020 requirements.
- 5G new RAT shall apply at both low and high frequency bands. However low frequency has higher priority.
- Phased WIs will be accomplished in Rel-15 and 16, respectively.
  - Rel-15 (to 2018.09): Phase 1 specification, fundamental features of new RAT, both eMBB and IoT at sub 6GHz, with priorities to be set at launch of WI.
  - Rel-16 (to 2019.12): Phase 2 specification, covering all scenarios and bands, fulfilling all IMT-2020 requirements.

- Group of operators' common vision and priorities for Next Generation Radio Technology [94]

RWS-150090 – Summary

5G design recommendations: 5G key design principles include:

- Forward compatibility with radio protocol L1/2/3 structures and functionalities required for future services (including phase 2 and beyond)
- Energy efficiency should be a fundamental design principle
- Enhanced security and privacy design
- Cost efficiency
- Tight interworking with LTE (including e.g. bandwidth aggregation, seamless mobility)
- Fixed Mobile Convergence with seamless user experience

There was a basic consensus that:

- There will be radios both below 6 GHz and above 6 GHz
- There will be a backwards compatible RAT – LTE Evolution
- There will be a non-Backwards compatible RAT – 5G New RAT
- Dynamic/flexible duplex: FDD and TDD modes
- 5G will do everything for everyone

3GPP will use a phased multi release plan to achieve 5G as depicted in the diagram below, as presented in June 2016.

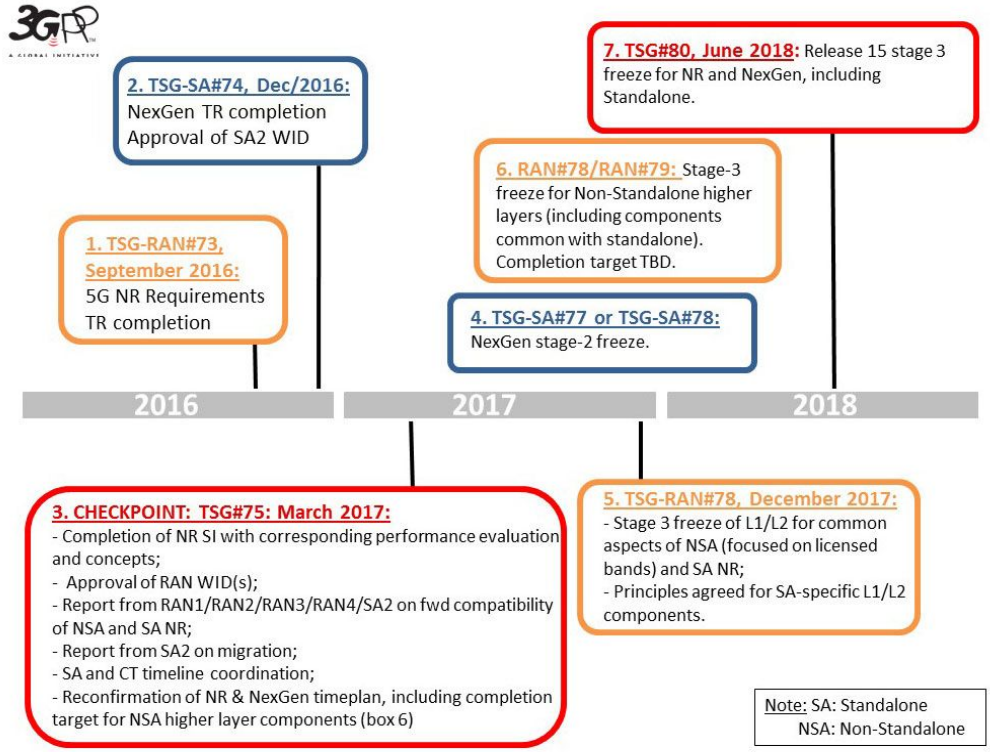


Figure 7 - 3GPP Planned Released within TRIANGLE timeline

Nevertheless, after presenting the standard Release plan, there have been several discussions on the feasibility and the opportunity of providing all the foreseen feature at once. During the RAN plenary meeting in November 2016 a hard decision has been made to cut down the expectations for the system capabilities. 3GPP has in fact decided to focus on the most prominent use cases, i.e. the eMBB with some partial ultra-low latency and ultra-reliability features [95]. Specifically, the features that have been left out represent quite a body:

- non-OFDMA waveforms for frequencies beyond 40 GHz
- mMTC, mostly due to the recent release of NB-IoT (Cat.M2) in LTE
- Interworking with non-3GPP systems such as Wi-Fi and unlicensed/shared spectrum operations
- Wireless relay and other sidelink communications (i.e. D2D)
- V2V and V2X due to current overlapping with LTE-Pro
- Multimedia Broadcast/Multicast Service

As it is understandable, 3GPP had to make this cut in order to ensure the finalization of the specifications within the very tight deadline of mid'2018. This would anyway conclude only the Phase 1 of the 5G standardization. During the next two years the new NexGen will be also standardized. NexGen is the disruptive evolution of the EPC that should be at the backbone of

the 5G network. With the new core in place, the Phase 2 of standardization will naturally be able to introduce the most disruptive feature and enable the more far-fetched use cases.

In March 2017, the 3GPP standardization body decided to speed up the development of the specificaitons for eMBB; where dual connectivity plays an important role. The latest specifications for 5G in December 2017 include the following reports:

Working group	RAN#78 Tdoc	Specification Title/Version
RAN1	RP-172530	TS 38.201 v2.0.0 on NR; Physical layer; General description
RAN1	RP-172630	TS 38.202 v2.0.0 on NR; Physical layer services provided by the physical layer
RAN1	RP-172284	TS 38.211 v2.0.0 on NR; Physical channels and modulation
RAN1	RP-172668	TS 38.212 v2.0.0 on NR; Multiplexing and channel coding
RAN1	RP-172703	TS 38.213 on NR; Physical layer procedures for control
RAN1	RP-172416	TS 38.214 v2.0.0 on NR; Physical layer procedures for data
RAN1	RP-172296	TS 38.215 v.2.0.0 on NR; Physical layer measurements

First public specifications for 5G (Layer 1)

Working group	RAN#78 Tdoc	Specification Title/Version
RAN2	RP-172496	TS 38.300 v2.0.0 on NR; NR and NG-RAN Overall Description; Stage 2
RAN2	RP-172521	TS 38.306 v1.0.0 on NR; User Equipment (UE) radio access capabilities
RAN2	RP-172419	TS 38.321 v2.0.0 on NR; Medium Access Control (MAC) protocol specification; for approval
RAN2	RP-172322	TS 38.322 v2.0.0 on NR; Radio Link Control (RLC) protocol specification; for approval
RAN2	RP-172335	TS 38.323 v2.0.0 on NR; Packet Data Convergence Protocol (PDCP) specification
RAN2	RP-172570	TS 38.331 v1.0.0 on NR; Radio Resource Control (RRC) Protocol specification
RAN2	RP-172464	TS 37.340 v2.0.0 on NR; Multi-connectivity; Overall description; Stage 2

First public specifications for 5G (Layer 2 and Layer 3)

Working group	RAN#78 Tdoc	Specification Title/Version
RAN3	RP-172545	TS 38.401 v1.0.0 on NG-RAN; Architecture description
RAN3	RP-172426	TS 38.425 v1.0.0 on NG-RAN; NR user plane protocol; for approval

RAN3	RP-172286	TS 38.470 v1.0.0 on NG-RAN; F1 general aspects and principles
RAN3	RP-172493	TS 38.471 v1.0.0 on NG-RAN; F1 layer 1
RAN3	RP-172261	TS 38.472 v1.0.0 on NG-RAN F1 Signalling Transport
RAN3	RP-172287	TS 38.473 v1.0.0 on NG-RAN; F1 Application Protocol (F1AP)
RAN3	RP-172671	TS 38.474 v1.0.0 on NG-RAN; F1 data transport

First public specifications for 5G (Core network interfaces)

Working group	RAN#78 Tdoc	Specification Title/Version
RAN4	RP-172475	TS 38.101-1 v1.0.0 on NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone
RAN4	RP-172476	TS 38.101-2 v1.0.0 on NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone
RAN4	RP-172477	TS 38.101-3 v1.0.0 on NR; User Equipment (UE) radio transmission and reception; Part 3: Range 1 and Range 2 Interworking operation with other radios
RAN4	RP-172268	TS 38.104 v1.0.0 on NR; Base Station (BS) radio transmission and reception; for approval
RAN4	RP-172420	TS 38.113 v1.0.0 on NR; Base Station (BS) ElectroMagnetic Compatibility (EMC)
RAN4	RP-172499	TS 38.124 v1.0.0 on NR; Electromagnetic compatibility (EMC) requirements for mobile terminals and ancillary equipment
RAN4	RP-172407	TS 38.133 v1.0.0 on NR; Requirements for support of radio resource management

First public specifications for 5G (Mobile Devices and Base station)

7.3 ETSI

ETSI, the European Telecommunications Standards Institute, produces globally applicable standards for Information and Communications Technologies (ICT), including fixed, mobile, radio, converged, broadcast and Internet technologies.

ETSI's Industry Specification Groups (ISGs) produces specifications in many technological areas. Recognizing that Horizon 2020 is a potential source of new technologies which could be standardized in ETSI, they are an Associate Member of the 5G Infrastructure Public Private Partnership (5G PPP).

ETSI also leads workshops events. In 2015 they have organized workshops on Telecommunication Quality beyond 2015, Open Source software and standardisation, M2M communications and the IoT, as well as the ETSI International User Conference on Advanced Automated Testing (UCAAT). In 2016 ETSI organized the "IoT/M2M Workshop 2016 featuring the Smart World" which focused on oneM2M release 2, published shortly before the event, and the 8th workshop on C-ITS was organized in order to bring together the activities related to the European Commission C-ITS platform [96].

In 2017 ETSI has organized a workshop on "Multimedia Quality in Virtual, Augmented or other Realities" which covered the latest developments in this area especially under QoS and QoE aspects. DEKRA has attended this workshop and used the concepts exposed there to design the testing for VR use case inside the scope of the work package 3 of the project.

ETSI has organized in April 2017 a summit on 5G Network Infrastructure to tackle the many open questions relating to the 5G network infrastructure and the multiple technological developments that will be necessary to meet the requirements of 5G. ETSI, 3GPP, IETF and operators presented in this event.

The following topics were discussed in that summit: What needs to be done in the Core Infrastructure Today to Support Tomorrow's 5G Services, European Commission view in 5G architecture, 3GPP work in 5G infrastructure, operator priorities for 5G core, NFV as a 5G infrastructure enabler, intent-driven and cognitive network operations, policy based management for network slicing, service management, next generation Internet protocols (IETF), ITU-T activities on architecture of 5G protocol, and DevOps in service chain and 5G network slices.

The following issues were raised for the development of the 5G infrastructure and service management: still need to engage vertical industries, need to consolidate balance between improved UX and sustainable cost base for operators, practical issues about how to allocate slices and services and what should be the regulation around it, still need an agreed definition of network slicing, how service management automation is arranged, need to address where policies best placed in the networks. ETSI will organize in June 2018 the 3rd NFV Plugtest which will concentrate on building complex Network Services that combine virtual network functions from different providers, while testing interoperability with MANO solutions across platforms and sites.

7.4 5G PPP

The 5G Infrastructure Public Private Partnership was initiated in 2013 by the EU Commission and industry manufacturers, telecommunications operators, service providers, SMEs and researchers to deliver solutions, architectures, technologies and standards for the ubiquitous next generation communication infrastructures of the coming decade [97].

One of the main goals of the 5G-PPP is for new H2020 projects to work efficiently and coordinate an open discussion on how interfaces, overlaps and cross-issues are handled efficiently between projects.

On December 2017, 5GPP issued a new release of the white paper "View on 5G Architecture" [98] .

7.5 NGMN

The Next Generation Mobile Networks Alliance is a global partnership “global alignment, harmonisation and convergence of technology standards and industry initiatives with the objective to avoid fragmentation and to guarantee industry scale” [99].

NGMN has developed end-to-end operator requirements to satisfy the needs of customers and markets in 2020+, published in the NGMN 5G White Paper [100].

NGNM has recently published a deliverable “Definition of the testing framework for the NGMN 5G pre-commercial network trials” [101] which includes several ideas of the TRIANGLE project. More specifically, the document has the following scope:

- Developing a testing framework for 5G New Radio (NR), as developed by 3GPP, allowing the harmonization of the testing methodologies between the different parties conducting trials.
- Devising a strategy for the trials activities to guarantee efficiency and success of the different trials activities.
- Testing 5G capabilities in realistic conditions with pre-commercial equipment.

For the definition of the network scenarios, the service classification and the KPI definition for High Speed Internet and Social Networking QoE, this document cites Triangle deliverables. The framework outlines an extensive list of pre-commercial test case definitions for 5G NR including deployment scenarios, KPIs, testing procedures and success criteria and is jointly developed by more than 20 of the leading operators and vendors globally. The 5G testing framework should serve as a baseline for global trial activities and will enable to benchmark the implementation of 5G NR against the targets set by 3GPP and NGMN. It will also enable the comparison of different trial results in an efficient way.

7.6 Wi-Fi Alliance

Wi-Fi Alliance® (WFA) is a global non-profit industry association whose members are the worldwide network of companies that develops Wi-Fi®, as a "wireless local area network" (WLAN) product based on the Institute of Electrical and Electronics Engineers’ (IEEE)802.11 standards.

WFA is also targeting some of the key use cases of 5G such as Automotive and IoT and also coexistence in the unlicensed band of LTE that has been brought up in 3GPP Release 13.

7.7 GCF

GCF was originally established as a certification scheme for mobile phones based on GSM technology. The GCF Certification has continued to evolve in parallel with the mobile telecommunications industry to include advances in 3GPP technologies including GPRS, EDGE, 3G UMTS, HSDPA, HSPA+, LTE and LTE-Advanced.

GCF has claimed its ability to accommodate new bands and the evolution of the technology toward 5G [102] and therefore its role will be key for the adoption of the 5G technologies by the industry players (manufacturers, operators and laboratories).

7.8 European 5G Observatory

The European Commission is launching a call for tenders for a service contract with the purpose to provide accurate and up-to-date market information that is relevant for the purposes of the EU policy makers, as the importance of dynamic policy making is increasing in the rapidly changing political and technological environment of today's global economy. As part of the contract an online platform providing access to information on a European and global status of 5G developments will be made available.

7.9 Impact on TRIANGLE

Various members of TRIANGLE are members of WFA, NGMN, ETSI, 3GPP, GCF and they are and will follow closely the standardization activities and the impact on TRIANGLE.

It is worth of remark the importance of GCF in the 5G ecosystem, as they determine what the industry is committed to adopt.

Two meetings took place with the GCF at their membership meetings where TRIANGLE has established a link. The first membership meeting in which TRIANGLE took part was on June 2016 in UK and the second on the December 2016 in Dubai where discussions and presentations on TRIANGLE took place. Further meetings and interaction took place in 2017 continuing to make the TRIANGLE approach more visible to leading edge operators.

TRIANGLE will continue establishing an outward link with the GCF. TRIANGLE will keep GCF informed about the progress of the testing framework under development with the goal of enriching the GCF certification process which now includes Conformance testing, Interoperability testing, Field trials and optionally Performance testing.

NGMN documents are now including the contribution and vision from TRIANGLE with respect to the automatic QoE computation.

8 Conclusions

In this document several new applications and technologies have been considered which are relevant for the project in line with the original project Description of Action (dated from summer 2015). This update is of course due to the high dynamicity that 5G as a research topic has at the present moment. For this reason, it is a good practice to look back at the research and industry community in order to provide the project and the test bed with the most up-to-date technology overview.

The different topics touched on in this document will have a greater or smaller impact on the project due first of all to their technological maturity, and then to the on-going discussion within the project partners to identify if such a specific topic will bring substantial benefits given the quantity of resources that will have to be allocated for its realization. Such will of course be susceptible of changes during the next project year.

In particular, summarizing the impact per topic:

- **Internet of Things**: given the importance of the topic for industry and academia, the project partners decided to continuously monitor the available technologies but focus mostly on the ones using licensed bands. This is choice is due to the greater importance of testing for such technologies. Finally the decision of implementing the NB-IoT has been already made and partners are already working on it. In fact, the consortium has reached an agreement to receive one of the CommSolid devices for testing.
- **HetNet and cellular technologies**: the following decisions have been taken in the scope of the heterogeneous networks: Wi-Fi offloading capability will be included within the TRIANGLE testbed and has been integrated release 3. Use of FDD/TDD carrier aggregation within the same cell has been discarded. Due to the immaturity of the related 3GPP specifications at this stage of the project, the coexistence scenarios (LTE in in unlicensed band) will not be considered in the test scenarios being specified in WP2.
- **Networking**: an overview of the ongoing standardization bodies working on the different technologies have been presented. While C-RAN has a developmental and network architecture importance, it does not represent a main disruptor. The project partners agreed instead that SDN and NFV will have stronger impact on future 5G networks. For this reason, SDN has been already deployed in TRIANGLE. Regarding NFV, an extension regarding the use of orchestrators in the testbed has been selected in the first open call wave and the partners will evaluate the use of these technologies in the testbed.
- **Automotive**: while the project recognizes the importance of the topic for future 5G applications, the technology is still unstable and fragmented. For this reason the inclusion of automotive applications, devices and testing scenarios inside the scope of TRIANGLE has been discarded.
- **5G Initiatives and Test Beds**: the project is continuously monitor the 5G community in order to capture the main evolutions of the standardization process and technology experimentation. The consortium has already established a link with GCF by attending meetings in 2016 and 2017. The consortium has also influenced the perspective of NGMN around testbed, KPI and QoE measurement.

Given the TRIANGLE project timeline, the remaining months will be used by the consortium to bring the testbed to the level of capability as defined in Release 4. This means that any new

future evolution after April 2018 will most probably not be implemented in the testbed during the EU project. Such features if critical will be added potentially in a commercial release of the testbed.

9 References

[1] Č. S. a. P. P. G. C. Madueño, “How many smart meters can be deployed in a GSM cell?,” Budapest, 2013.

[2] 3GPP, “Study on provision of low-cost Machine-Type Communications (MTC) User Equipments (UEs) based on LTE,” 2013.

[3] 3GPP, “Overview of 3GPP release 13,” 2015. [Online]. Available: http://www.3gpp.org/release-13.

[4] 3GPP, “Narrowband IOT,” 2015.

[5] 3GPP, “EC-GSM Concept Description,” 2015.

[6] L. Alliance, “LoRaWAN™ Certified Products,” [Online]. Available: https://www.lora-alliance.org/certified-products. [Accessed 09 March 2018].

[7] Wi-Fi Alliance, [Online]. Available: https://www.wi-fi.org/members/task-groups#Automotive Market Segment.

[8] Wi-Fi Alliance, January 2016. [Online]. Available: http://www.wi-fi.org/news-events/newsroom/wi-fi-alliance-introduces-low-power-long-range-wi-fi-halow#sthash.bOlidRpi.dpuf.

[9] E. Cunningham, January 2017. [Online]. Available: http://www.statetechmagazine.com/article/2017/01/wifi-halow-iot-implementations.

[10] W.-F. Alliance, October 2016. [Online]. Available: https://www.wi-fi.org/file-member/certification-roadmap.

[11] oneM2M, [Online]. Available: http://www.onem2m.org/.

[12] TTA, “TTA oneM2M Standard Certified,” [Online]. Available: http://www.onem2mcert.com/main/main.php. [Accessed 09 03 2018].

[13] L. Columbus, December 2015. [Online]. Available: http://www.forbes.com/sites/louiscolumbus/2015/12/27/roundup-of-internet-of-things-forecasts-and-market-estimates-2015.

[14] 3. R. 5G, September 2015. [Online]. Available: http://www.3gpp.org/news-events/3gpp-news/1734-ran_5g.

[15] 3GPP, “TS 27.501 System Architecture for the 5G System,” 2017.

[16] 3GPP, “TS 27.502 Procedures for the 5G System,” 2017.

[17] 3GPP, “TS 23.503 Policy and Charging Control Framework for the 5G System; Stage 2,” 2017.

[18 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/37900.htm.
]

[19 3GPP. [Online]. Available: http://www.3gpp.org/dynareport/36300.htm.
]

[20 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36875.htm.
]

[21 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36331.htm.
]

[22 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36413.htm.
]

[23 3GPP, 2015 December. [Online]. Available: http://www.3gpp.org/dynareport/36465.htm.
]

[24 3. RAN2, “Study on New Radio Access Technology. 38.804, v1.0.0,” 2017-03.
]

[25 3GPP, “TR 37.340 NR; Multi-connectivity; Overall description; Stage-2,” 2017.
]

[26 3GPP. [Online]. Available: http://www.3gpp.org/dynareport/36847.htm.
]

[27 3GPP, “TR 37.865 Intra-band (mDL/1UL) and Inter-band (nDL/1UL) NR Carrier
] Aggregation,” 2017.

[28 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/23261.htm.
]

[29 3GPP. [Online]. Available: http://www.3gpp.org/dynareport/36889.htm.
]

[30 3. G. P. Project, “Multi-node tests for Licensed-Assisted Access (LAA),” 2017.
]

[31 Wi-Fi Alliance, “Coexistence Guidelines for LTE in Unlicensed Spectrum Studies Version
] 2.0,” 2016.

[32 Wi-Fi Alliance, “Coexistence Test Plan Version 0.8,” 2016.
]

[33 3GPP, 2016. [Online]. Available: http://www.3gpp.org/DynaReport/38913.htm.
]

[34 ETSI, December 2014. [Online]. Available: http://www.etsi.org/deliver/etsi_gs/NFV-
] MAN/001_099/001/01.01.01_60/gs_nfv-man001v010101p.pdf.

[35 3GPP, October 2015. [Online]. Available: http://www.3gpp.org/news-events/3gpp-
] news/1738-sa5_nfv_study.

[36 3GPP, September 2015. [Online]. Available: http://www.3gpp.org/DynaReport/32842.htm.
]

[37] 3GPP, August 2015. [Online]. Available: http://www.3gpp.org/specifications-groups/sa-plenary/sa5-telecom-management.

[38] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/28500.htm.

[39] ETSI, September 2014. [Online]. Available: https://portal.etsi.org/portals/0/tbpages/mec/docs/mobile-edge_computing_-_introductory_technical_white_paper_v1%2018-09-14.pdf.

[40] ETSI. [Online]. Available: http://www.etsi.org/technologies-clusters/technologies/mobile-edge-computing.

[41] IRTF. [Online]. Available: https://irtf.org/sdnrg.

[42] IETF, January 2015. [Online]. Available: https://tools.ietf.org/html/rfc7426.

[43] B. Forum. [Online]. Available: https://www.broadband-forum.org/technical/technicalwip.php.

[44] O. N. Foundation. [Online]. Available: https://www.opennetworking.org/images/stories/downloads/working-groups/charter-wireless-mobile.pdf.

[45] ITU-T. [Online]. Available: http://www.itu.int/en/ITU-T/about/groups/Pages/sg13.aspx.

[46] ITU, “SDN standardization activity roadmap,” Geneva, 2015.

[47] NGMN, “Liaisons, contributions to 3gpp etsi on collaborative radio/mimo, ori interface, etc. Version 1.0,” January.

[48] NGMN, “Further study on critical C-RAN technologies,” 2015.

[49] 3GPP, February 2016. [Online]. Available: http://www.3gpp.org/DynaReport/23714.htm.

[50] 3GPP, February 2016. [Online]. Available: http://www.3gpp.org/DynaReport/23711.htm.

[51] X. A. J. G. G. A. &. R. R. Lin, “An Overview of 3GPP Device-to Device Proximity Services,” *IEEE Communications Magazine,* April 2014.

[52] 3GPP, “Evolved Universal Terrestrial Radio Access (E-UTRA); LTE physical layer; General description,” 2015.

[53] 5G-PPP, October 2015. [Online]. Available: https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-White-Paper-on-Automotive-Vertical-Sectors.pdf.

[54] 3GPP, “RP-161788 V2V Work Item Completion,” 2016.

[55] ETSI, “TS 102 868-2 Intelligent Transport Systems (ITS);Testing; Conformance test specifications for Cooperative Awareness Basic Service (CA);Part 2: Test Suite Structure and Test Purposes (TSS & TP),” 2017.

[56] ETSI, “Intelligent Transport Systems (ITS);Conformance test specifications for Decentralized Environmental Notification Basic Service (DEN);,” 2015.

[57] E. Commission, “A European strategy on Cooperative Intelligent Transport Systems, a milestone towards cooperative, connected and automated mobility,” Brussels, 2016.

[58] W.-F. Alliance, “Recommended Practices for Use of Wi-Fi in Automotive Applications,” 2016.

[59] W.-F. A. A. M. S. T. Group, “Gap Analysis for Automotive Applications Version 0.10,” 2017.

[60] O. Consortium, “OmniAir,” [Online]. Available: http://omniair.org/work-spaces/connected-vehicles/.

[61] Forbes, “In The Race For 5G, South Korea Shows Off Its Tech Prowess At The Winter Olympics,” 23 February 2018. [Online]. Available: https://www.forbes.com/sites/elaineramirez/2018/02/23/in-the-race-for-5g-south-korea-shows-off-its-tech-prowess-at-the-winter-olympics/#77c53b262853.

[62] N. A. Review, “South Korea's KT to launch 5G service for businesses next March,” 23 March 2018. [Online]. Available: https://asia.nikkei.com/Tech-Science/Tech/South-Korea-s-KT-to-launch-5G-service-for-businesses-next-March.

[63] M. Tracey, February 2016. [Online]. Available: http://www.verizon.com/about/news/verizon-5g-trials-driving-ecosystem-towards-rapid-commercialization.

[64] V. t. d. 5. s. t. p. c. i. 1. m. a. U. b. M. 2017, “Verizon,” 22 2 2017. [Online]. Available: http://www.verizon.com/about/news/verizon-deliver-5g-service-pilot-customers-11-markets-across-us-mid-2017.

[65] AT&T, “AT&T Drives Path to Nationwide Mobile 5G With Multi-Gigabit Speeds,” 20 February 2018. [Online]. Available: http://about.att.com/story/multigigabit_mobile_5g.html.

[66] RCRWireless, “NTT DoCoMo confirms plans to launch 5G trials in Tokyo in May,” 27 02 2017. [Online]. Available: http://www.rcrwireless.com/20170227/asia-pacific/ntt-docomo-confirms-plans-to-launch-5g-trials-in-tokyo-in-may-tag23 .

[67] Intel, February 2016. [Online]. Available: http://blogs.intel.com/technology/2016/02/paving-the-road-to-5g-mobile-services/.

[68] T. TV, “Ericsson expands its 5G portfolio following successful end-to-end operator demos,” 02 2017. [Online]. Available: http://www.telecomtv.com/articles/5g/ericsson-expands-its-5g-portfolio-following-successful-end-to-end-operator-demos-14382/.

[69] T. Verge, “AT&T is starting its 5G rollout with Austin and Indianapolis later this year,” 01 02 2017. [Online]. Available: http://www.theverge.com/2017/2/1/14474434/att-5g-network-launch-austin-indianapolis-markets.

[70] RCRWireless, “China Mobile to launch broader 5G field trials this year,” 28 02 2017. [Online]. Available: http://www.rcrwireless.com/20170228/asia-pacific/china-mobile-to-launch-broader-5g-field-trials-this-year-tag23.

[71] D. f. C. M. &. Sport, “Next Generation Mobile Technologies: A 5G Strategy for the UK,” March 2017. [Online]. Available: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/597421/07.03.17_5G_strategy_-_for_publication.pdf.

[72] [Online]. Available: http://telecominfraproject.com.

[73] K. Ali, “Introducing OpenCellular: An open source wireless access platform,” 06 07 2016. [Online]. Available: https://code.facebook.com/posts/1754757044806180/introducing-opencellular-an-open-source-wireless-access-platform.

[74] a. T. UK, “Facebook launches project to open source hardware, designs for cell networks,” 22 02 2016. [Online]. Available: https://arstechnica.co.uk/information-technology/2016/02/facebook-launches-project-to-open-source-hardware-designs-for-cell-networks/.

[75] Viavi, “Lighting the Path to 5G,” 2017. [Online]. Available: http://www.viavisolutions.com/en-us/5G.

[76] Huawei, “5Groningen: new 5G test network launched in the Netherlands,” [Online]. Available: http://www.huawei.com/en/news/2016/6/5Groningen.

[77] T. Italia, “TIM: Turin is the first 5G city in Italy,” [Online]. Available: http://www.telecomitalia.com/tit/en/archivio/media/comunicati-stampa/telecom-italia/mercato/business/2017/10-03-17CS-TIM-Comune-di-Torino-5G.html.

[78] Fraunhofer, “Transfer Center 5G Testbed,” 03 2018. [Online]. Available: https://www.digitale-vernetzung.org/en/dv/transfer_centers/5g_testbed.

[79] M. Europe, “Wind Tre joins Italian 5G party with new testbed,” 25 October 2017. [Online]. Available: https://www.mobileeurope.co.uk/press-wire/wind-tre-joins-italian-5g-party-with-new-testbed.

[80] Ericsson, “First 5G Life campus to open in Belgium,” 29 November 2017. [Online]. Available: https://www.ericsson.com/en/press-releases/2017/11/first-5g-life-campus-to-open-in-belgium.

[81] www.gov.uk, “£25m for 5G projects on the anniversary of the UK’s Digital Strategy,” 10 March 2018. [Online]. Available: https://www.gov.uk/government/news/25m-for-5g-projects-on-the-anniversary-of-the-uks-digital-strategy.

[82] ITU-R, 2015. [Online]. Available: http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Pages/default.aspx.

[83] ITU-R, “Workplan, timeline, process and deliverables,” 2015.

[84] ITU-T, “Summary of ITU-R Working Party 5D workshop on "IMT-2020" terrestial radio interfaces,” [Online]. Available: https://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/Workshop_conclusions.pdf. [Accessed October 2017].

[85] ITU-R, “Minimum requirements related to technical performance for IMT-2020 radio interface(s),” Novemember 2017. [Online]. Available: https://www.itu.int/pub/R-REP-M.2410.

[86] ITU-R, “Requirements, evaluation criteria and submission templates for the development of IMT-2020,” November 2017. [Online]. Available: https://www.itu.int/pub/R-REP-M.2411.

[87] ITU-R, “Guidelines for evaluation of radio interface technologies for IMT-2020,” November 2017. [Online]. Available: https://www.itu.int/pub/R-REP-M.2412.

[88] ITU-R M.2083-0, “IMT Vision – Framework and overall objectives of the future development of IMT for 2020 and beyond,” 09/2015.

[89] 3GPP, ““5G” timeline in 3GPP,” 2015.

[90] 3GPP, March 2015. [Online]. Available: http://www.3gpp.org/news-events/3gpp-news/1674-timeline_5g.

[91] 3GPP, “Report of 3GPP RAN workshop on "5G",” September, 2015.

[92] E. Q. N. D. S. S.-T. S. I. K. P. V. S. K. M. S. E. H. F. S. E. S. P. C. K. I. Nokia Networks, “Industry Vision and Schedule for the New Radio Part of the Next Generation Radio Technology,” Phoenix, AZ, USA, September, 2015.

[93] C. C. C. T. C. U. C. H. H. O. P. Z. A.-I. A.-I. S. B. CATR, “Views on 5G New RAT in 3GPP,” Phoenix, AZ, USA, September, 2015.

[94] D. T. T. T. I. K. T. T. S. T. S. D. N. Orange, “Group of operators’ common vision and priorities for Next Generation Radio Technology,” Phoenix, AZ, USA, September 2015 .

[95] A. Scrase, “The why, when, where, what and how of 5G Standards,” IEEE, Lisbon, 2017.

[96] E. Commission, January 2016. [Online]. Available: http://ec.europa.eu/transport/sites/transport/files/themes/its/doc/c-its-platform-final-report-january-2016.pdf.

[97] 5G-PPP, [Online]. Available: https://5g-ppp.eu.

[98] 5GPP, “View on 5G Architecture,” https://5g-ppp.eu/wp-content/uploads/2014/02/5G-PPP-5G-Architecture-WP-For-public-consultation.pdf.

[99] NGMN, September 2015. [Online]. Available: http://www.ngmn.org/fileadmin/ngmn/content/documents/pdf/about_us/150917_NGMN_Alliance_Overview.pdf.

[100] NGMN, February 2015. [Online]. Available: http://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2015/NGMN_5G_White_Paper_V1_0.pdf.

[101] NGMN, “DEFINITION OF THE TESTING FRAMEWORK FOR THE NGMN 5G PRE-COMMERCIAL NETWORKS TRIALS,”

https://www.ngmn.org/fileadmin/ngmn/content/downloads/Technical/2018/180220_NGMN_PreCommTrials_Framework_definition_v1_0.pdf.

[102] GCF, 2016. [Online]. Available: http://www.globalcertificationforum.org/news-events.

[103] ETSI, [Online]. Available: http://www.etsi.org/news-events/events/1045-onem2m-interop-2.

[104] N. C. Corporation, 2016 March. [Online]. Available: http://www.ntt.com/aboutus_e/news/data/20160308.html.

[105] 3GPP. [Online]. Available: https://portal.3gpp.org/desktopmodules/WorkItem/WorkItemDetails.aspx?workitemId=660174.

[106] 3GPP. [Online]. Available: http://www.3gpp.org/DynaReport/36331.htm.

[107] Qualcomm, November 2015. [Online]. Available: https://www.qualcomm.com/news/onq/2015/11/19/qualcomm-research-demonstrates-robust-mmwave-design-5g.

[108] Samsung, 2016 Februar. [Online]. Available: https://news.samsung.com/global/wp-content/themes/sw_newsroom/download.php?post_id=69506&id=69891&meta_type=file.

[109] O. N. Foundation. [Online]. Available: https://www.opennetworking.org/sdn-resources/openflow/57-sdn-resources/onf-specifications/openflow?layout=blog.

[110] FCC, “Notice of Inquiry 14-154,” 2014.

[111] FCC, “GN Docket No. 14-177”.

[112] R. M. e. al, “The CTTC 5G end-to-end experimental platform,” *IEEE Veh. Tech. Mag.,* vol. 11, no. 1, pp. 50-63, March 2016.

[113] 3GPP, “RP-141664 Study on Licensed-Assisted Access using LTE”.

10 Annex 1. 3GPP Release 13 Status

Source: Work Plan 3GPP version March 7th 2018.

Release 13 Features	100%
Mission Critical Push To Talk over LTE (MCPTT)	95%
MBMS Extensions and Profiling	100%
Isolated E-UTRAN Operation for Public Safety	100%
Service Requirements Maintenance for Group Communication System Enablers for LTE	100%
Enhanced Calling Information Presentation	100%
Flexible Mobile Service Steering	100%
GERAN UTRAN Sharing Enhancements	100%
Application specific Congestion control for Data Communication	100%
User Plane Congestion management	100%
Media Handling Aspects of IMS-based Telepresence	79%
RAN Sharing Enhancements	100%
Enhancements to WEBRTC interoperability	95%
Improvements to CS/PS coordination in UTRAN/GERAN Shared Networks	100%
Enhancements to Proximity-based Services	100%
Voice over E-UTRAN Paging Policy Differentiation	100%
IP Flow Mobility support for S2a and S2b Interfaces	100%
Double Resource Reuse for Multiple Media Sessions	100%
Lawful Interception in the 3GPP Rel-13	100%
STOPPED - Study on Lawful Interception Service Evolution	100%
Video enhancements by Region-Of-Interest information signalling	100%
TV video profile	100%
Enhanced LTE UE Delay test methods and requirements	100%
HTML5 Presentation Layer	100%
Support of EVS in 3G Circuit-Switched networks	100%
Enhanced DASH (Dynamic Adaptive Streaming over HTTP in 3GPP)	100%
QoS End-to-end Multimedia Telephony Service for IMS (MTSI) extensions (Stage 3)	100%
MTSI Extension on Multi-stream Multiparty	83%
Video Telephony Robustness Improvements Extensions	70%
Acoustic Test methods and Performance Objectives for Speakerphone Performance in Noisy Environments	100%
Rel-13 Operations, Administration, Maintenance and Provisioning (OAM&P)	100%
Rel-13 Charging	100%
Support of Real-time Transport Protocol (RTP) / Real-time Transport Control Protocol (RTCP) multiplexing (signalling) in IMS	100%
LTE in the 1670-1675 MHz Band for US (on hold till 12/2014)	8%
Enhanced Signalling for Inter-eNB Coordinated Multi-Point (CoMP) for LTE	100%
2GHz FDD LTE in Region 1 (1980-2010MHz and 2170-2200MHz Bands)	100%

Self Organizing Networks (SON) for Active Antenna System (AAS) based deployments	100%
Usage Monitoring Control PCC Extension	100%
Enhanced P-CSCF discovery using signalling for access to EPC via WLAN	100%
P-CSCF Restoration Enhancements with WLAN	100%
Mobile Equipment Identity signalling over WLAN	100%
Authentication Signalling Improvements for WLAN	100%
Stage-3 SAE Protocol Development - Phase 4	100%
Interworking solution for Called IN number and original called IN number ISUP parameters	74%
Warning Status Report in EPS	100%
Shared Data Update for Multiple Subscriber	100%
IMS Stage-3 IETF Protocol Alignment	70%
Retry restriction for Improving System Efficiency	100%
H.248 Aspects of WebRTC Data Channel on IMS Access Gateway	100%
Continuation of the Overload Control for PCC based Diameter applications	100%
Review of dedicated 3GPP UICC features	100%
Controlling IMS Media Plane with SDP Capability	100%
(SA66: on hold) Co-ordinated packet data network gateway (P-GW) change for SIPTO	100%
Enhanced CS Fallback (CSFB)	100%
SRVCC Enhancements for Transcoding Avoidance	100%
Base Station (BS) RF requirements for Active Antenna System (AAS)	100%
Enhanced LTE Device to Device Proximity Services	100%
Radiated requirements for the verification of multi-antenna reception performance of UEs	100%
UE core requirements for uplink 64 QAM	100%
UE Conformance Test Aspects - Core Requirements for Uplink 64QAM for E-UTRA	100%
Performance requirements of MMSE-IRC receiver for LTE BS	100%
CRS Interference Mitigation for LTE Homogenous Deployments	100%
Dual Connectivity enhancements for LTE	100%
Multicarrier Load Distribution of UEs in LTE	100%
LTE-WLAN Radio Level Integration and Interworking Enhancement	73%
RAN aspects for improvements to CS/PS coordination in UTRAN Shared Network	100%
LTE DL 4 Rx antenna ports	99%
AWS-Extension Band for LTE	100%
Additional bandwidth combination set for LTE Advanced inter-band Carrier Aggregation of Band 5 and Band 7	100%
Additional bandwidth combination set for LTE Advanced inter-band Carrier Aggregation of Band 3 and Band 5	100%
Multiflow Enhancements for UTRA	100%
Message interworking during PS to CS SRVCC	100%
Support of Emergency services over WLAN – phase 1	100%
MBMS Enhancements	100%

EPC Signalling Improvements for race scenarios	100%
Diameter Message Priority	100%
Downlink TPC Enhancements for UMTS	100%
Licensed-Assisted Access using LTE	99%
Elevation Beamforming/Full-Dimension (FD) MIMO for LTE	72%
L2/L3 Downlink enhancements for UMTS	100%
Support of single-cell point-to-multipoint transmission in LTE	100%
Extension of Dual Connectivity in E-UTRAN	100%
RAN sharing enhancements for UMTS	100%
Interference mitigation for downlink control channels of LTE	83%
Network-Assisted Interference Cancellation and Suppression for UMTS	100%
Dual Carrier HSUPA Enhancements for UTRAN CS	100%
Further Enhancements of Minimization of Drive Tests for E-UTRAN	100%
LTE-WLAN RAN Level Integration supporting legacy WLAN	100%
Indoor Positioning enhancements for UTRA and LTE	100%
Power saving enhancements for UMTS	100%
700MHz E-UTRA FDD Band for Arab Region	100%
European 700 Supplemental Downlink band (738-758 MHz) in E-UTRA and LTE Carrier Aggregation (2DL/1UL) with Band 20	100%
Release 13 Features on Internet of Things (IoT)	100%
Service Requirements Maintenance for Machine-Type Communications (MTC)	100%
Cellular (Narrowband) Internet of Things	100%
Extended Coverage GSM (EC-GSM) for support of Cellular Internet of Things	69%
Extended DRX cycle for Power Consumption	93%
Optimizations to Support High Latency Communications	100%
Further LTE Physical Layer Enhancements for MTC	99%
EGPRS Access Security Enhancements in relation to Cellular IoT	100%
Group based Enhancements	100%
Monitoring Enhancements	100%
Dedicated Core Networks	100%
Service Exposure and Enablement Support	100%
Architecture Enhancements for Service capability Exposure	100%
Rel-13 LTE Carrier Aggregation	94%
(Small) Technical Enhancements and Improvements for Rel-13	100%
(Small) Test Technical Enhancements and Improvements for Rel-13	100%
Awaiting formal work item	100%
(Small) Security Enhancements and Improvements for Rel-13	100%
Release 13 IoT related Studies	100%
Study on Power saving for Machine-Type Communications (MTC) devices	100%
Study on Cellular system support for ultra Low Complexity and low throughput Internet of Things	100%

Study on architecture enhancements of cellular systems for ultra low complexity and low throughput Internet of Things	100%
Study on Battery Efficient Security for very low Throughput Machine Type Communication Devices	100%
Study on Small data transmission enhancements for UMTS	100%
Study on Application specific Congestion control for Data Communication	100%
Study on enhancements for Infrastructure based data Communication Between Devices	100%
Release 13 other Studies	100%
Study on Isolated E-UTRAN Operation for Public Safety	100%
Study on architecture enhancements for Public Safety	100%
Study on Security Aspects of Isolated E-UTRAN Operation for Public Safety	100%
(SA66: on hold) Study on Co-ordinated packet data network gateway (P-GW) change for SIPTO	100%
Study on Flexible Mobile Service Steering	100%
Study on Enhanced Calling Information Presentation	100%
Study on RAN Sharing Enhancements on GERAN and UTRAN	100%
Study on Usage Monitoring Enhancements for Service, Application and Subscriber Group	100%
Study on Security aspects of Integration of Single Sign-On (SSO) frameworks with 3GPP networks	100%
Study on Subscriber Privacy Impact in 3GPP	100%
Study on Enhancements of OAM aspects of Distributed Mobility Load Balancing (MLB) SON function	100%
Study on Application and Partitioning of Itf-N	100%
Study on Charging aspects on Roaming End-to-end scenarios with VoLTE IMS and interconnecting networks	100%
Study on Network Management of Virtualized Networks	100%
Study on Review of dedicated 3GPP UICC features	100%
Study on Solutions for GSM/EDGE BTS Energy Saving	100%
Study on Downlink MIMO	100%
Study on MIMO OTA antenna test function for LTE	100%
Stopped at 20% - Study on UpLink MultiUser Multiple-Input Multiple-Output (UL MU-MIMO)	100%
Study on LTE FDD in the bands 1980-2010 MHz and 2170-2200 MHz	100%
Study on Positioning enhancements for E-UTRA	100%
Study on Multi-RAT joint coordination	100%
Study on Advanced Wireless Services (AWS) - Extension band for LTE	100%
Study on Indoor Positioning Enhancements for UTRA and LTE	100%
Study on Downlink enhancements for UMTS	100%
Study on Elevation Beamforming/Full-Dimension (FD) MIMO for LTE	100%
Study on Licensed-Assisted Access using LTE	100%
Study on EPC Signalling Improvement for Race Scenarios	100%
Study on Video Enhancements in 3GPP Multimedia Services	100%
Study on possible additional configuration for LTE TDD	100%

Study on Network-Assisted Interference Cancellation and Suppression for UMTS	100%
Study on Enhanced Multiuser Transmissions and Network Assisted Interference Cancellation for LTE	0%
Study on Support of single-cell point-to-multipoint transmission in LTE	100%
Study on Extension of Dual Connectivity in E-UTRAN	100%
Study on further enhancements of small cell higher layer aspects for LTE	100%
Study on RAN sharing enhancements for UMTS	100%
Study on LTE DL 4 Rx antenna ports	100%
Study on performance enhancements for high speed scenario in LTE	100%
Study on Enhanced Multiuser Transmissions and Network	0%
Study on regulatory aspects for flexible duplex for E-UTRAN	100%
Study on Downlink Multiuser Superposition Transmission for LTE	100%
Study on Measurement gap enhancement for LTE	100%
Study on Phase 1 of the Support of Emergency services over WLAN	100%
Study on EGPRS Access Security Enhancements with relation to cellular IoT	100%
Study on SCC AS Restoration	100%
Study on S6a/S6d Shared Data Update	100%
Study onLTE Advanced inter-band Carrier Aggregation of Band 20 and Band 28	100%
Study on Impacts of the Diameter Base Protocol Specification Update	100%
Study on new AWS-3/4 Band for LTE	100%
Study on multi-node testing for LAA	100%
Stopped - Study on Compliance of 3GPP SA5 specifications to the NGMN NGCOR	100%
Study on Expansion of LTE_FDD_1670_US to include 1670-1680MHz Band for LTE in the US	100%

11 Annex 2. 3GPP Release 14 Status

Source: Work Plan 3GPP version March 07th 2018.

Release 14 Features	100%
Release 14 Features on Mission Critical	100%
Mission Critical Improvements	100%
Protocol enhancements for MCPTT over LTE	100%
Release 14 Features on V2X	100%
LTE support for V2X services	93%
Support for V2V services based on LTE sidelink	87%
Release 14 Features on CIoT	100%
Non-IP for Cellular Internet of Things (CIoT) for 2G/3G-GPRS(EC-EGPRS)	100%
Further enhanced MTC for LTE	78%
Enhancements of NB-IoT	68%
AT Commands for CIoT	100%
Extended architecture support for Cellular Internet of Things	100%
Radio Interface Enhancements for Extended Coverage GSM for support of Cellular Internet of Things	100%
New band support for Rel-14 Narrowband Internet of Things (NB-IOT)	99%
Enhancements of Dedicated Core Networks selection mechanism	99%
Addition of band 25 and 26 to LTE MTC cat.0	100%
Addition of bands 25 and 40 to LTE MTC cat.1	100%
Release 14 Features on WLAN	100%
EIR check for WLAN access to EPC	100%
Support of EAP Re-authentication Protocol for WLAN Interworking	100%
Phase 2 of the Support of Emergency services over WLAN	100%
T-ADS supporting WLAN Access	100%
Enhanced LTE-WLAN Aggregation (LWA)	100%
Release 14 Features on IMS	100%
Evolution to and Interworking with eCall in IMS	95%
Password based service activation for IMS Multimedia Telephony service	100%
IMS Signalling Activated Trace	75%
Other Release 14 Features	100%
User Controlled Spoofed Call Treatment	27%
Enhancement for TV service	100%
MBMS Transport Protocol and APIs	100%
Multimedia Priority Service Modifications	100%
Lawful Interception Rel-14	100%
SIP Reason header extension	75%
Enhancements to User Location Reporting Support	100%
Diameter Load Control Mechanism	98%

Diameter Base Protocol Specification Update	100%
Enhancements to Multi-stream Multiparty Conferencing Media Handling	99%
Deleted - CT aspects of (or "Enhancements of") MTSI Extension on Multi-stream	100%
Control and User Plane Separation of EPC nodes	100%
OAM14 Rel-14 Operations, Administration, Maintenance and Provisioning (OAM&P)	100%
Development of super-wideband and fullband P.835	100%
Enhancing Location Capabilities for Indoor and Outdoor Emergency Communications	100%
Enhancements to Domain Selection between VoLTE and CDMA CS	100%
Control of Applications when Third party Servers encounter difficulties	100%
PS Data Off Services	100%
SCC AS Restoration	100%
Paging Policy Enhancements and Procedure	100%
Enhancement to Flexible Mobile Service Steering	100%
Media Handling Extensions of IMS-based Telepresence	50%
Improved Streaming QoE Reporting in 3GPP	100%
New GPRS algorithms for EASE	100%
S8 Home Routing Architecture for VoLTE	100%
Improvements of awareness of user location change	100%
Service Domain Centralization	100%
Sponsored data connectivity improvements	100%
Stage-3 SAE Protocol Development - Phase 5	100%
Group based enhancements in the network capability exposure functions	100%
Robust Call Setup for VoLTE subscriber in LTE	90%
Extension of UE Delay test methods and requirements	100%
Improved operator control using new UE configuration parameters	100%
Shared Subscription Data Update	100%
Rel-14 Charging	100%
Determination of Completeness of Charging Information in IMS	100%
Enhanced LAA for LTE	78%
RRC optimization for UMTS	100%
DTX/DRX enhancements in CELL_FACH	100%
AWS-3/4 Band for LTE	100%
LTE FDD in the Bands 1980-2010 MHz and 2170-2200MHz for Region 3	0%
Addition of 1.4 and 3 MHz Channel Bandwidth to E-UTRA operating band 65 for CGC (Complementary Ground Component) operations in Region 1	99%
LTE 2.6 GHz FDD Supplemental DL band (2570-2620 MHz) and LTE Carrier Aggregation (2DL/1UL) with Band 3 for region 1	99%
Multi-Band Base Station testing with three or more bands	100%
Performance enhancements for high speed scenario in LTE	83%
Further Indoor Positioning Enhancements for UTRA and LTE	99%

Radiated performance requirements for the verification of multi-antenna reception of UEs in LTE	99%
Enhancements on Full-Dimension (FD) MIMO for LTE	99%
Further mobility enhancements in LTE	100%
Uplink Capacity Enhancements for LTE	72%
L2 latency reduction techniques for LTE	51%
eMBMS enhancements for LTE	99%
SRS (sounding reference signal) switching between LTE component carriers	72%
Downlink Multiuser Superposition Transmission for LTE	100%
IMS Stage-3 IETF Protocol Alignment	100%
Multi-Carrier Enhancements for UMTS	100%
Citizens Broadband Radio Service (CBRS) 3.5GHz band for LTE in the United States	100%
LTE Band 41 UE power class 2 operation	100%
Dedicated Core Networks for GERAN	100%
Positioning Enhancements for GERAN	100%
Quality of Experience (QoE) Measurement Collection for streaming services in UTRAN	93%
Flexible eNB-ID and Cell-ID in E-UTRAN	100%
4 receiver (4Rx) antenna ports with Carrier Aggregation (CA) for LTE downlink (DL)	78%
Requirements for a new UE category with single receiver based on Category 1 for LTE	84%
Enhanced LTE WLAN Radio Level Integration with IPsec Tunnel (eLWIP)	100%
LTE Measurement Gap Enhancement	100%
Enhanced CRS and SU-MIMO Interference Mitigation Performance Requirements for LTE	100%
Miscellaneous IETF dependencies	44%
(Small) Technical Enhancements and Improvements for Rel-14	100%
(Small) Test Technical Enhancements and Improvements for Rel-14	100%
Rel-14 LTE Carrier Aggregation	90%
Rel-14LTE Advanced inter-band Carrier Aggregation	79%
Release 14 Studies	100%
Study on channel model for frequency spectrum above 6 GHz	100%
Study on Scenarios and Requirements for Next Generation Access Technologies	100%
Study on NB-IoT RF requirement for coexistence with CDMA	100%
Study on need for Multiple Access Point Names	100%
Study on Multimedia Broadcast Supplement for Public Warning System	100%
Study on service aspects for dealing with User Control over spoofed calls	100%
Study on User Location Reporting Support enhancements	100%
Study on Control of Applications when Third party Servers encounter difficulties	100%
Study on Paging Policy Enhancements and Procedure Optimizations in LTE	100%
Study on Latency reduction techniques for LTE	100%
Study on High Power LTE UE for Band 41	100%
Study on Media and Quality Aspects of SRVCC Enhancements	100%
Deleted - Study on SON for eCoMP for LTE	100%

Study on UICC power optimization for MTC	100%
Study on Server and Network Assisted DASH for 3GPP	100%
Study on MBMS usage for mission critical communication services	100%
Study on enhancement of VoLTE	100%
Study on HSPA and LTE Joint Operation	100%
Study on LTE Advanced Carrier Aggregation of Band 3 and Band 39	100%
Study on Context Aware Service Delivery in RAN for LTE	100%
Study on further enhancements to Coordinated Multi-Point (CoMP) Operation for LTE	100%
Study on Determination of Completeness of Charging Information in IMS	100%
Study on Interactivity Support for 3GPP-based Streaming and Download Services	100%
Study on MBMS usage and codecs for MCPTT call and MC Video Service	100%
Study on MBMS Extensions for Provisioning and Content Ingestion	100%
Study on global application of LTE Band 11 and of LTE Band 21 UEs	100%
Study on Downlink MIMO for GERAN	100%
Release 14 studies on 5G MObile Network for Advanced communications	100%
Study on Stage 1 for New Services and Markets Technology Enablers	100%
SA2 aspects on Study on Architecture and Security for next Generation System	100%
Study on New Radio (NR) Access Technology	100%
Study on Network Assistance for Network Synchronization in LTE	100%

12 Annex 3. 3GPP Release 15 Status

Source: Work Plan 3GPP version March 07th 2018.

Release 15 Features	
Release 15 5G Features	
5G System - Phase 1	62%
Study on Charging Aspects of 5G System Architecture Phase 1	100%
Security aspects of 5G System - Phase 1	65%
Studies on CT1 aspects of 5G System - Phase 1	95%
Study on 5G Network selection	80%
Study on 5G Mobility management	100%
Study on 5G Session management	100%
Study on 5G Non-3GPP access networks	100%
Study on 5G Interworking with EPC	100%
Study on 5G System core network impact on services, network functions and capabilities	85%
Study on 5G Network slicing	100%
IMS impact due to 5GS IP-CAN	22%
Data Charging in 5G System Architecture Phase 1	0%
EPC enhancements to support 5G New Radio via Dual Connectivity	82%
New Radio Access Technology	29%
LTE connectivity to 5G-CN	20%
UE Conformance Test Aspects - 5G system with NR and LTE	5%
Release 15 Features on V2X	
Enhancement of 3GPP support for V2X scenarios	100%
V2X new band combinations for LTE	50%
Enhancements on LTE-based V2X Services	23%
Study on security aspects for LTE support of V2X services	90%
Study on V2X Media Handling and Interaction	30%
Release 15 Features on Ultra/Highly Reliable Low Latency Communication	
EPC support for E-UTRAN Ultra Reliable Low Latency Communication	15%
Highly Reliable Low Latency Communication for LTE	4%
Release 15 Features on improvements of Mission Critical (MC)	
Study on MC system migration and interconnect between MCPTT systems	100%
Study on MC Communication Interworking between LTE and non-LTE Systems	100%
Study on MC Security Enhancements	90%
Removal of 'over LTE' limitation from Mission Critical Specifications	100%
Enhancements to MCPTT functional architecture and information flows	55%
Enhancements to MC Data Functional architecture and information flows	50%
Enhancements to MC Video Functional architecture and information flows	25%
MBMS usage for MC communication services	95%
MC system migration and interconnection	80%

MC Communication Interworking between LTE and non-LTE Systems	87%
Protocol enhancements for Mission Critical Services	40%
Release 15 Features on MTC-IoT	
Battery Efficient Security for very low Throughput MTC Devices	95%
AT Commands for CIoT-Ext	0%
Even further enhanced MTC for LTE	17%
Further NB-IoT enhancements	26%
Release 15 Features related to WLAN	
Inclusion of WLAN direct discovery technologies as an alternative for ProSe direct discovery	91%
Complementary Features for Voice services over WLAN	48%
Release 15 Features on Virtual Reality (VR)	
Study on Virtual Reality	100%
Study on QoE metrics for VR	10%
Study on 3GPP codecs for VR audio	100%
Test Methodologies for the Evaluation of Perceived Listening Quality in Immersive Audio Systems	15%
Addition of HDR to TV Video Profiles	100%
Virtual Reality Profiles for Streaming Media	25%
Release 15 other Features	
Increasing the number of EPS bearers	0%
Increased number of E-UTRAN data bearers	0%
Remote UE access via relay UE	90%
Enhanced VoLTE performance	49%
Unlicensed Spectrum Offloading System	85%
Mobile Communication System for Railways	100%
PS Data Off Phase 2	47%
Northbound APIs for SCEF – SCS/AS Interworking	69%
Common API Framework for 3GPP Northbound APIs	60%
Management and orchestration of 5G networks and network slicing	33%
Framework for Live Uplink Streaming	85%
Self-Organizing Networks (SON) for Active Antenna System (AAS) deployment management	80%
Service Interactivity	10%
Server and Network Assisted DASH for 3GPP Multimedia Services	100%
SAND for MBMS	50%
Management Enhancement for EPC CUPS	0%
Provision of Access to Restricted Local Operator Services by Unauthenticated UEs	53%
Enhanced QoE Reporting for MTSI	80%
Enhanced Calling Name Service	51%
Enhancement of background data transfer	100%
Stage-3 SAE Protocol Development - Phase 6	55%

Security Assurance Specification for eNB network product class	100%
Security Assurance Specification for PGW network product class	100%
Security Assurance Specification for 3GPP network products	95%
HPLMN Radio Access Technology deployment Optimisation in Network Selection	100%
IMS Stage-3 IETF Protocol Alignment	3%
Lawful Interception Rel-15	10%
DL interference mitigation for UMTS	100%
Control and monitoring of Power, Energy and Environmental (PEE) parameters in Radio Access Networks (RAN)	80%
Management of QoE measurement collection	15%
Simplified HS-SCCH for UMTS	100%
Charging for enhancement to Flexible Mobile Service Steering (eFMSS)	100%
Receive acoustic output test in the presence of background noise	0%
Speech quality in the presence of ambient noise for super-wideband and fullband modes	0%
REST Solution Sets	71%
(Small) Technical Enhancements and Improvements for Rel-15	100%
(Small) Test Technical Enhancements and Improvements for Rel-15	100%
Release 15 Features on LTE improvements	
UL data compression in LTE	70%
LTE Advanced inter-band Carrier Aggregation (4DL/4UL) of Band 41C and Band 42C	40%
Additional LTE bands for UE category M1 and/or NB1 in Rel-15	37%
Additional LTE bands for UE category M2 and/or NB2 in Rel-15	59%
Extended-Band12 new E-UTRA Band	13%
Signalling reduction to enable light connection for LTE	66%
Enhancements of Base Station (BS) RF and EMC requirements for Active Antenna System (AAS)	55%
Shortened TTI and processing time for LTE	53%
680073450MHz E-UTRA FDD Band for LTE PPDR and PMR/PAMR in Europe	94%
E-UTRA 700MHz in Europe for Broadband-PPDR (Public Protection and Disaster Relief)	71%
FDD operating band in the L-band for LTE	75%
LTE Extended 1.5 GHz SDL band (1427 – 1518 MHz) and LTE Carrier Aggregation (2DL/1UL) with Band 20	100%
Add UE Power Class 2 to band 41 intra-band contiguous LTE Carrier Aggregation	67%
Addition of Power Class 1 UE to bands B3/B20/B28 for LTE	100%
TDD operating band in the L-band for LTE	100%
Further enhancements to Coordinated Multi-Point (CoMP) Operation for LTE	76%
UE Positioning Accuracy Enhancements for LTE	35%
Enhancements for high capacity stationary wireless link and introduction of 1024 QAM for LTE DL	35%
Enhancements to LTE operation in unlicensed spectrum	36%
Further video enhancements for LTE	99%

Quality of Experience (QoE) Measurement Collection for streaming services in E-UTRAN	99%
Enhancing LTE CA Utilization	15%
450 MHz Band for LTE in Region 3	100%
US 600 MHz Band for LTE	99%
LAA/eLAA for the CBRS 3.5GHz band in the United States	100%
Introduction new band support for 4Rx antenna ports for LTE for REL-15	50%
Addition of band 28 and 40 to LTE MTC cat.0	100%
LTE Advanced high power TDD UE (power class 2) for Rel-15	40%
New LTE band for 3.3-3.4 GHz for Africa	35%
UE requirements for network-based CRS interference mitigation for LTE	20%
Bluetooth/WLAN measurement collection in LTE Minimization of Drive Tests (MDT)	0%
Enhanced LTE Support for Aerial Vehicles	0%
Separation of CP and UP for Split Option 2 of NR	0%
UE requirements for LTE DL 8Rx antenna ports	0%
ProSe Support for Band 72 in LTE	0%
LTE Advanced inter-band Carrier Aggregation Rel-15 for xDL/1UL with x>5	0%
Performance requirements of interference cancellation receiver for LTE BS	100%
LTE CRS-Interference Mitigation performance requirements for single RX chain UEs	60%
LTE Advanced intra-band Carrier Aggregation Rel-15 for xDL/yUL including contiguous and non-contiguous spectrum	70%
LTE Advanced inter-band Carrier Aggregation Rel-15 for 2DL/1UL	30%
LTE Advanced inter-band Carrier Aggregation Rel-15 for 3DL/1UL	40%
LTE Advanced inter-band Carrier Aggregation Rel-15 for 4DL/1UL	65%
LTE Advanced inter-band Carrier Aggregation Rel-15 for 5DL/1UL	50%
LTE Advanced inter-band Carrier Aggregation Rel-15 for 2DL/2UL	40%
LTE Advanced inter-band Carrier Aggregation Rel-15 for xDL/2UL with x=3,4,5	50%
UE Conformance Test Aspects – Rel-15 CA configurations	7%
LTE UE Total Radiated Power (TRP) and Total Radiated Sensitivity (TRS) and UTRA Hand Phantom related UE TRP and TRS Requirements	82%
Release 15 Studies	100%
Release 15 Studies on 5G	100%
Study on management aspects of virtualized network functions that are part of the NR	100%
Study on 5G enhanced Mobile Broadband Media Distribution	25%
Study on Media Handling Aspects of Conversational Services in 5G Systems	35%
Study on CU-DU lower layer split for New Radio	95%
Study of test methods for New Radio	20%
Study on NR-based access to unlicensed spectrum	0%
Study on Non-Orthogonal Multiple Access (NOMA) for NR	0%
Study on integrated access and backhaul for NR	0%
Study on NR to support non-terrestrial networks	40%

STOPPED AT SA#77 - SA3 aspects on Study on Architecture and Security for Next Generation System	100%
Study on separation of CP and UP for split option 2 of NR	100%
Release 15 Studies on 4G/LTE	100%
Stopped - Study on LTE bandwidth flexibility enhancements	100%
Study on interference cancellation receiver for LTE BS	100%
Study on uplink data compression in LTE	100%
Study on LTE DL 8Rx antenna ports	100%
Other Release 15 Studies	0%
Study on EVS Float Conformance Non Bit-Exact	50%
Study on Update to fixed-point basic operators	80%
Study on further enhancements to LTE Device to Device (D2D), UE to network relays for IoT (Internet of Things) and wearables	100%
Study on Energy Efficiency Aspects of 3GPP Standards	100%
Study on system and functional aspects of Energy Efficiency in 5G networks	40%
Study on OAM support for assessment of energy efficiency in mobile access networks	100%
Study on Long Term Key Update Procedures	70%
Study on evaluation methodology of new V2X use cases for LTE and NR	10%
Study on MBMS User Services for IoT	30%
Study on FEC for MC Services	60%
Study on Enhanced Isolated E-UTRAN Operation for Public Safety	100%
Study on Management Enhancement of CUPS of EPC Nodes	100%
Study on Policy and Charging for Volume Based Charging	100%
Study on Technical Requirements for a new secure platform for 3GPP applications	100%
Study on technical requirements for a new secure platform for 3GPP applications	100%
Study on scheduling enhancements with carrier aggregation for UMTS	100%
Study on enhanced LTE Support for Aerial Vehicles	100%
Study on Architecture Evolution for E-UTRAN	85%
Study on Enhanced Acoustic Test Specifications	100%
Study on User Services Enhancements in 3GPP for TV Services	100%
Study on Management aspects of selected IoT-related features	45%
Study on Overload Control for Diameter Charging Applications	100%
Study on forward compatibility for 3GPP Diameter Charging Applications	100%
Study on OAM aspects of SON for AAS-based deployments	100%
Study on Implementation for the Partitioning of Itf-N	100%
Study on Management Aspects of Next Generation Network architecture and features	100%
Study on Management and Orchestration Architecture of Next Generation Network and Service	100%
Study on SON for eCoMP for LTE	100%
Stopped - Study on IMS Enhanced Spoofed Call Prevention and Detection	100%
Study on OAM aspects of LTE and WLAN integration	50%

Study on network policy management for mobile networks based on NFV scenarios	30%
Study on Volume Based Charging Aspects for VoLTE	35%
STOPPED - Study on UE characteristics and performance for Video	100%
Study on self-evaluation towards IMT-2020 submission	15%
Study on 6 GHz for LTE and NR	0%
Study on UE Application Layer Data Throughput Performance Expansion for Carrier Aggregation	0%

13 Annex 3. 3GPP Release 16 Status

Source: Work Plan 3GPP version March 07th 2018.

Release 16 Features	100%
Mobile Communication System for Railways 2	43%
Enhancements of Public Warning System	0%
5G Voice Service Continuity	0%
(Small) Technical Enhancements and Improvements for Rel-16	100%
Release 16 Studies	100%
Study on Enhancing Topology of SMF and UPF in 5G Networks	0%
Study on a Layer for User Centric Identifiers and Authentication	0%
Study on Multimedia Priority Service (MPS) Phase 2	0%
Study on application layer support for V2X services	0%
Study on Enhanced IMS to 5GC Integration	0%
Study on using Satellite Access in 5G	30%
Study on 5G message service for MIoT	25%
Study on LAN Support in 5G	65%
Study on the Wireless and Wireline Convergence for the 5G system architecture	15%
Study on positioning use cases	50%
Study on Enhancement to the 5GC Location Services	0%
Study on Communication for Automation in Vertical Domains	85%
Study of enablers for Network Automation for 5G	0%
Study on integration of ONAP DCAE and 3GPP management architecture	0%
Study on supporting 256-bit algorithms for 5G	0%
Study on Cellular IoT support and evolution for the 5G System	0%
Study on Enhancement of LTE for Efficient delivery of Streaming Service	75%
Study on enhancements to IMS for new real time communication services	75%
Study on Business Role Models for Network Slicing	10%
Study on Access Traffic Steering, Switch and Splitting support in the 5G system architecture	10%
Study on enhancements of Public Warning System	100%
Study on Maritime Communication Services over 3GPP system	55%
Study on MBMS APIs for Mission Critical Services	20%
Study on encrypted traffic detection and verification	0%
Study on architecture enhancements for 3GPP support of advanced V2X services	20%
Study on Media Handling Aspects of RAN Delay Budget Reporting in MTSI	0%
Study on EPC support for Mobility with Low Latency Communication	0%
Study on User Plane Protocol in 5GC	0%

14 Annex 4. OTA Measurements

It is commonly agreed by telecom operators that radiated test will be one of the key points related to 5G handset tests.

Research into radiated techniques to measure the radiated (over the air – OTA) performance of MIMO-enabled handsets is still on going in 3GPP and CTIA. This work is very important to the industry since despite it being 8 years since the original LTE specification was launched, there are still no radiated performance requirements for MIMO-enabled devices. This means designers have no targets to aim for other than single antenna isotropic efficiency. The potential benefits of MIMO therefore remain unknown in real networks.

The work to define MIMO OTA test methods has proven to be both difficult and time-consuming, however, progress is being made towards the definition and validation of equivalent test methods for measuring radiated MIMO performance. Triangle, when creating the project was taking the assumption this work would be completed by the start of the project. The key areas still open for research relate to the validation of the accuracy and equivalence of different test methods. Considerable experimental data has been gathered over the last 18 months which indicates the potential of different test methods to show equivalence, but also has highlighted unexplained differences within and between test methods for which no traceable explanation has been found.

During the last 6 months, AT4 Wireless, who are equipped with one of the MIMO OTA test systems (multi-probe anechoic chamber – MPAC), has in the frame of the Triangle project facilitated the ongoing research in 3GPP and CTIA by making measurements on devices known to show discrepancies between test systems. These result have been submitted to CTIA and 3GPP as part of the root cause analysis of test system accuracy. In addition to the analysis with the MPAC test method, AT4 has the potential working with Keysight to also implement a second test methods, called radiated two-stage (RTS) which is theoretically equivalent to MPAC. It is believed that having a lab with both test methods will accelerate research into the as yet unexplained differences between test systems with certain types of devices.

For this reason, it is proposed to continue the analysis of MPAC test system performance augmented by an implementation of the RTS test method within the scope of the TRIANGLE project and extend the Task 4.4 beyond its original timeline.